GREATER LONDON AUTHORITY

LONDON SUSTAINABLE DEVELOPMENT COMMISSION

Construction Scope 3 (Embodied)

Greenhouse Gas Accounting and Reporting Guidance

March 2013

March 2013

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This report has been led by Best Foot Forward Ltd working in collaboration with the Greater London Authority and the London Sustainable Development Commission.

The London Sustainable Development Commission (LSDC) comprises experts from business, social enterprise, charity, and the public sectors. It was established in 2002 to advise the Mayor on making London an exemplary sustainable world city. In June 2011, a Carbon Measurement, Modelling and Monitoring event was held at City Hall, hosted by the LSDC, the GLA Group, and the National Physical Laboratory. Subsequent to that event, the LSDC convened the Carbon Measurement Steering Group consisting of experts in the field to support and advise on the research and development of this publication.

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Glossary

Carbon emissions/ CO_2e emissions / CO_2e equivalent / Greenhouse gas emissions

Shorthand for emissions of any of the basket of greenhouse gases (GHG) that affect climate change. Carbon emissions are usually expressed as CO_2e (i.e. CO_2 equivalent), which is a unit of measurement that is based on the relative impact of a given gas on global warming (the so called global warming potential). For example, if methane has a global warming potential of 25, it means that 1 kg of methane has the same impact on climate change as 25 kg of carbon dioxide and thus 1 kg of methane would count as 25 kg of CO_2 equivalent. Global warming potential of greenhouse gases are presented in table below (taken from *IPCC Fourth Assessment Report: Climate Change 2007*):

Greenhouse gas	**GWP over 100 years**	**Typical sources**
Carbon dioxide	1	Energy combustion, biochemical reactions
Methane	25	Decomposition
Nitrous oxide	298	Fertilizers, car emissions, manufacturing
Sulfur hexafluoride (SF_6)	22,800	Switch gears, substations
Perfluorocarbon (PFC)	7,390 – 12,200	Aluminium smelting
Hydrofluorocarbon (HFC)	124 – 14,800	Refrigerants, industrial gases

Carbon hotspot

Carbon significant aspect of a project which should be targeted for reduction. Carbon hotspots represent not only carbon-intense elements but also quick wins where measurement data is more easily available and where carbon reductions are possible.

Cradle-to-cradle emissions

Carbon emissions assessment that includes the carbon benefits of displacing the use of virgin materials.

Cradle-to-gate carbon emissions

Carbon emissions between the confines of the 'cradle' (earth) up to the factory gate of the final processing operation. This includes mining, raw materials extraction, processing and manufacturing.

Cradle-to-site carbon emissions

Cradle-to-gate emissions plus delivery to the site of use (construction/installation site).

Cradle-to-end of construction

Cradle-to-site plus construction and assembly on site.

Cradle-to-grave carbon emissions

Cradle-to-end of construction plus maintenance, refurbishments, demolition, waste treatment and disposals ('grave').

Cradle-to-cradle

The process of making a component or product and then, at the end of its life, converting it into a new component of a) the same quality (e.g. recycling of

	aluminium cans) or b) a lesser quality (downcycling of a computer plastic case into a plastic container, which then is turned into a building insulation board, eventually becoming waste).
Ecological footprint	The measurement of an object's (be that product, individual, region or organisation) impact on ecosystems. It should take into consideration; built land, biodiversity, energy land, bioproductive land and bioproductive sea. The result should be quantified in hectares of land.
Embodied carbon	Carbon emissions associated with energy consumption (embodied energy) and chemical processes during the manufacture, transportation, assembly, replacements and deconstruction of construction materials or products. Embodied carbon can be measured from cradle-to-gate, cradle-to-site, cradle-to-end of construction, cradle-to-grave, or even cradle-to-cradle. The typical embodied carbon datasets are cradle-to-gate. Embodied carbon is usually expressed in kilograms of CO_2e per kilogram of product or material.
GHG Protocol	A standard that provides a step-by-step guide to quantifying and reporting the greenhouse gas emissions of an organisation.
Life cycle carbon	Another term for cradle-to-grave carbon emissions
Materiality threshold	Often used to determine whether an error or omission is a material discrepancy or not.
Operational carbon	Carbon emissions' association with energy consumption (operational energy) while the building is occupied. This includes the so-called regulated load (e.g. heating, cooling, ventilation, lighting) and unregulated/plug load (e.g. ICT equipment, cooking and refrigeration appliances).
Global Warming Potential (GWP)	A relative measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is measured against CO_2e which has a GWP of 1 (see table above).
Recycled content	The portion of a product that contains materials that have been recovered or otherwise diverted from the solid waste stream.
Scope 1	All direct GHG emissions (sourced and controlled by the reporting body)
Scope 2	Indirect GHG emissions from consumption of purchased electricity, heat or steam.
Scope 3	Other indirect GHG emissions such as the extraction and production of purchased materials and fuels, business travel, electricity-related activities not covered in Scope 2, waste disposal etc.

Executive summary

To limit further climate change in London and globally, the Mayor has set a target to reduce London's Scope 1 and Scope 2 CO_2 emissions by 60 per cent of 1990 levels by 2025.

In October 2011, the GLA published *Delivering London's Energy Future: The Mayor's climate change mitigation and energy strategy*. This details the Mayor's strategic approach to meeting his CO_2 target and securing a low carbon energy supply for London.

As nearly 80 per cent of CO_2 emissions produced in London are from buildings, construction works, and particularly refurbishment, is a central focus of this strategy.

Retrofitting London's existing buildings is not only crucial to tackling London's CO_2 emissions, it also reduces energy and water use, delivers new jobs and skills, as well as saving London businesses and homes money on energy bills. Almost 80 per cent of the 14,000 low carbon jobs that could be created per year from delivering the Mayor's CO_2 target and two thirds of the £721 million of annual low carbon economic activity would come from retrofitting.

Construction works, however, also generate indirect, 'embodied' CO_2 emissions. The extraction of raw materials and manufacture of the products used in new build and refurbishments can lead to significant emissions which need to be minimised.

Yet the accounting and reporting of these embodied emissions is poorly understood. 90% of construction industry professionals responded to a survey stating that they would benefit from better guidance and support. In response, this Guidance is framed as a series of recommendations, accompanied by supporting information. If followed, these will improve the ease and consistency of the accounting and reporting of embodied emissions within the construction sector.

1 Aim and scope

1.1 Aim

Management of greenhouse gas (GHG) emissions is seen as increasingly important to the delivery of high quality construction projects.

This guidance document (the Guidance) is aimed at helping professionals working within the construction industry to better understand and account for the embodied greenhouse gas emissions associated with construction; for example, those emissions relating to the raw materials and manufacturer of products used in a development . This Guidance shall use the term 'embodied emissions' throughout.

It is designed to support the assessment of the environmental performance of construction works including new and existing buildings and refurbishment projects.

It covers the six main GHGs; the most abundant being carbon dioxide (CO_2). For this reason, a measure of the greenhouse gas emissions associated with an activity, product or service is often referred to as its 'carbon footprint'.

A survey conducted to inform the development of this Guidance found no consistency in the data sources, tools or methodologies used to calculate embodied emissions. Furthermore, whether respondees had experience of undertaking embodied emissions assessments or not, they almost universally welcomed further guidance on the matter.

This Guidance is framed as a series of recommendations, accompanied by supporting information. If followed, these will improve the ease and consistency of the accounting and reporting of embodied emissions within the construction sector.

1.2 Scope

Whereas the estimation and measurement of a building's energy in-use, and the associated GHG emissions, is commonplace (for example, to comply with Building Regulations and for the purpose of generating Energy Performance Certificates), the calculation of the impact from other building life cycle stages is less frequently undertaken as such studies can be time-consuming and costly, requiring specialist expertise[1].

Embodied emissions are associated with the extraction, refining, manufacture and supply of project raw materials and products, the construction process itself, maintenance, repair, replacement and refurbishment of the building during its operational life and, finally, those activities linked to end of life.

Figure 1.1 illustrates those emissions that may be included within an embodied emissions assessment contrasting these with the more limited, direct, emission sources (often referred to as scope 1 and scope 2 emissions) usually included when calculating buildings in-use emissions (highlighted).

[1] [A survey undertaken by Best Foot Forward on behalf of the GLA showed that the main barriers to performing a scope 3 assessment were 'cost/resource' (72% of respondees), 'time' (62%) and 'expertise' (52%).]

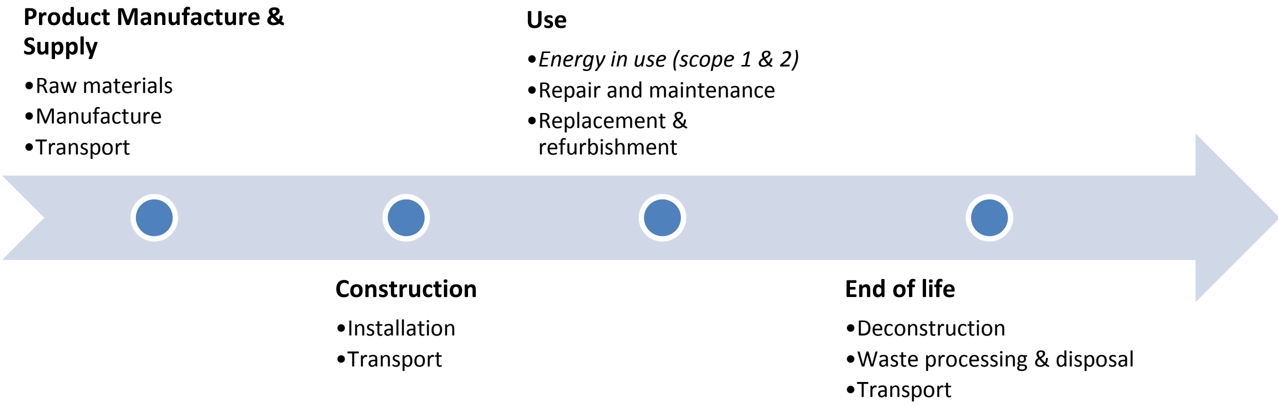

Figure 1.1: Building life cycle stages. All are considered as embodied emissions except the highlighted 'Energy in use' emissions. Source: Adapted from BS EN 15643-2:2011.

Analyses which only include consideration of product supply and manufacturer are typically referred to as 'Cradle to Gate' assessments. Where transport to site is also included, the term 'Cradle to Site' is commonly used.

Studies which consider the entire life cycle (to end of life) are often called 'Cradle-to-Grave' assessments. Such analyses are rare for long-lived items, such as buildings (and their constituent products), where the future use and end of life are uncertain.

Architect William McDonough's utopian vision goes one step further. His design philosophy is that every element of a building should be considered 'Cradle to Cradle'[2]. That is, the use of energy and materials should be considered to sit within a 'closed loop' economy.

Recommendations are made later in this Guidance for which life cycle stages to include – and how to deal with additional, discretionary elements.

[2] (Braungart and McDonough, Undated)

2 Policy Drivers

2.1 National carbon reduction agenda

The Climate Change Act 2008 commits the Government to a 26% reduction in GHG emissions by 2020, and at least an 80% reduction by 2050 (compared with the 1990 baseline). The Act has resulted in a series of carbon plans that the Government needs to adhere to if it is to achieve these ambitious reductions.

The Government's latest Carbon Plan[3] (published in December 2011) recognises that the construction sector has an important role to play in delivering a resource-efficient, low carbon economy. This fact was also recognised by the influential Low Carbon Construction Innovation and Growth Team (IGT) report[4] (November 2010) that further emphasised the importance of embodied emissions, and the need to bring the appraisal of embodied emissions into the early stages of the design process.

Two of their key recommendations are relevant to this Guidance:

> *Recommendation 2.1: That as soon as a sufficiently rigorous assessment system is in place, the Treasury should introduce into the Green Book a requirement to conduct a whole-life (embodied + operational) carbon appraisal and that this is factored into feasibility studies on the basis of a realistic price for carbon.*
>
> *Recommendation 2.2: That the industry should agree with Government a standard method of measuring embodied carbon for use as a design tool and (as Recommendation 2.1 above) for the purposes of scheme appraisal.*

This Guidance is one of a number of efforts underway to help deliver against the above recommendations and draws upon the consensus view expressed within the IGT report on the ways and means of accounting embodied emissions.

It also draws heavily on new European standards, BS EN 15978 and 15643-2, both published in 2011 which set out a framework and calculation method for assessing the environmental performance of construction works.

2.2 The size of the challenge

Estimates vary, but according to Department for Business Innovation and Skills (BIS), buildings (construction, refurbishment and use) are responsible for more than half of the UK's GHG emissions (see Figure 2.1)[5]. Most of these are currently associated with the in-use emissions from residential and non-residential buildings (scopes 1 and 2). However, a significant proportion (10% of the UK's overall total) relates to embodied emissions.

Due to successive Building Regulations, our buildings are becoming more efficient users of energy. This, coupled with the de-carbonisation of our energy supply systems is increasing the relative importance of embodied emissions.

Despite this, there is little evidence that embodied emissions assessments are being routinely used to inform the design of buildings.

[3] (HM Government, 2011)
[4] (HM Government, 2010)
[5] (HM Government, 2010)

A recent survey of more than 50 industry professionals, conducted by Best Foot Forward on behalf of the GLA, found that although more than half of respondents had undertaken an embodied emissions assessment, less than one-third of these had 'influenced' or 'modified' the project design as a result of the assessment. This means that less than one in five projects has given serious consideration to embodied emissions.

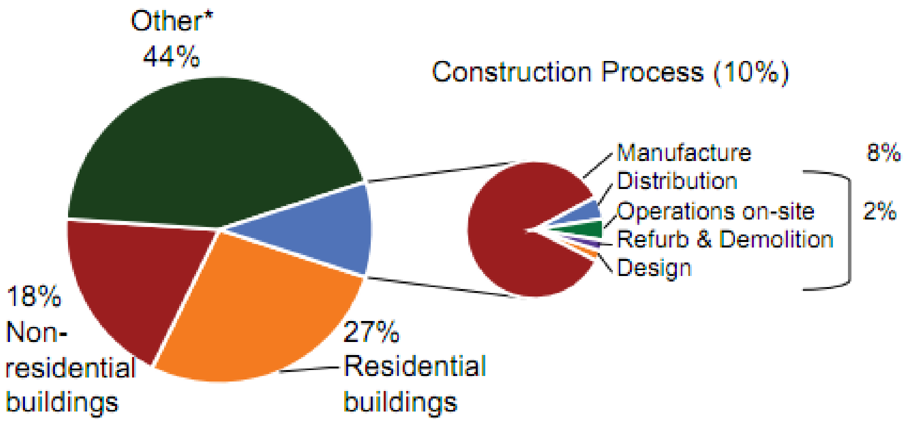

Figure 2.1: Proportion of total UK CO_2 emissions that construction can influence (split into in-use emissions for residential and non-residential buildings and construction-related emissions) Source: Department for Business Innovation and Skills.

2.3 Other drivers

What the IGT report, and many other commentators, are keen to emphasise is that while the urgent need to tackle climate change is the predominant policy driver, it is not the only one. Nor are GHG emissions the only sustainability metric of importance[6]. Waste and resource scarcity are two related issues worth further consideration due to their complex inter-relation with GHG emissions.

According to Defra, the UK construction sector is responsible for around one third of all waste arisings[7]. Although waste is closely associated with GHG emissions, there are other environmental impacts which are also significant when considering the sector through a more resource-focused lens. For example, the importance of the separate accounting of hazardous and non-hazardous wastes may not be obvious when accounting GHGs alone. Also important is the monitoring of re-use, recycling, and materials sent for energy recovery. Again, suitability for re-use and recycling is not always apparent when selecting materials based solely on their GHG emissions. The Waste and Resources Action Plan (WRAP) have excellent tools and guidance on waste management for the construction industry which seek to align concerns over GHG emissions with the need to minimise waste.

Awareness about resource scarcity, and its impact on construction, has grown substantially in recent years as the industry has developed a better understanding of its wider ecological footprint[8]. This has paralleled a rise in the more extensive use of natural (biotic) materials within the sector (for example, strawboard, biofuels, wood pellets, glulam and so on) which has highlighted supply chain constraints in the production of these alternatives.

Resource scarcity can impact on not only the amount, but also the choice, of materials used on a project. Design decisions can often be at odds with the need to manage GHG emissions. For

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[6] BS EN 15978:2011 identifies a range of other relevant indicators based on conventional life cycle analysis (LCA) impact categories. These include impact potentials, resource use, and waste; all are pertinent to any broader environmental assessment of the sustainability of construction works. Companion standards EN 15643-3 and 15643-4 provide a similar framework for assessing the sustainability of construction works from social and economic perspectives respectively.
[7] (Defra, 2011)
[8] See, for example, the 2008 RIBA award-winning book *The ZEDbook: solutions for a shrinking world* (Dunster et al., 2008).

example, the London Energy Partnership has reported on potential future supply constraints on wood fuel within London[9] and the controversy surrounding biofuels is well documented[10].

The impact of resource scarcity on the availability of natural construction materials is less well researched although there are clear price signals for forest products, a major source of low carbon alternatives, which has been linked to the increased use of such materials in sustainable construction[11].

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9 (BioRegional et al., 2008)
10 (The Royal Society, 2008)
11 http://www.fimltd.co.uk/fim_timber_index.asp

3 The business case for carbon reductions

3.1 Building low carbon

There are many disparate estimates of the cost of building low carbon. This is partly as a result of the wide variation in building types but also reflects the many differing approaches to design and durability.

Pioneering low carbon architect Bill Dunster (designer of the award-winning BedZED) has convincingly shown for certain building types how cost steadily increases as building fabric is enhanced, but then sharply falls at the point where building services can be simplified. Adding more and more insulation, for example, progressively increases cost but once a certain thermal performance is reached it is possible to dispense with central heating systems at a considerable cost saving.

High profile projects such as London 2012 have also demonstrated how lightweight, low carbon, buildings can also be cost effective due to their reduced material use.

At the other end of the spectrum, some authorities quote high premium costs for construction[12].

Most comparative studies draw on domestic buildings for their evidence base. Research commissioned by the Department of Communities and Local Government (DCLG) found that most of the additional cost of building 'zero carbon' (Code 6) homes was associated with the provision of on-site renewable energy systems (typically photovoltaics). Improvements to the building fabric added little to the cost.

Individual case studies provide the most useful insights into build costs for non-commercial developments. The TargetZero initiative website[13] provides guidance on schools, offices, supermarkets, warehouses and mixed use developments. Cost premiums to achieve BREEAM 'Outstanding' rating are typically cited as being between 5% and 10%.

One benefit of the rising interest in low carbon developments is that many 'green' construction products are more readily available and falling in price. The dramatic reduction in the cost of solar photovoltaics is one example with prices (per watt) halving in recent years.

3.2 In-use cost savings

Whereas there continues to be a debate over the cost premium associated with low carbon construction, what is amply clear is that the whole life cost savings due to lower energy in use can be substantial, although those that benefit are not always the same group that bear the cost of development. With energy prices consistently tracking ahead of inflation this cost advantage can only grow.

Figure 3.1 shows the cumulative cost savings over a 70 year period from three functionally-equivalent commercial building designs undertaken for the same client using comparable assumptions about energy use. The low carbon design (green line) was shown to cut operational costs by 75%. Note that this low carbon design also had embodied carbon emissions which were less than half the alternatives.

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12 (RICS, 2010)
13 www.targetzero.info also see http://www.communities.gov.uk/documents/planningandbuilding/pdf/1940106.pdf

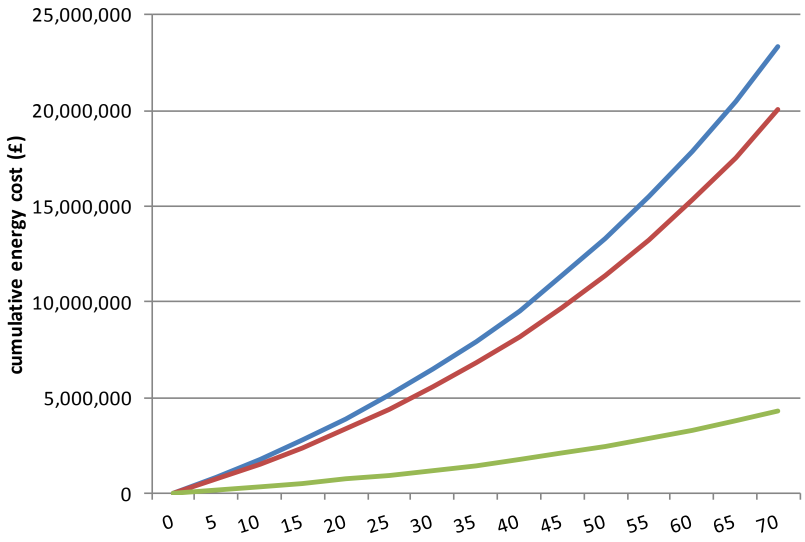

Figure 3.1: Cumulative energy costs for operating three equivalent commercial building designs (based on 2010 prices) Source: Best Foot Forward. The performance of the low carbon building is indicated with a green line.

CASE STUDY for in use energy savings: RAMPTON DRIFT

Building 12 privately-owned homes

Client South Cambridgeshire District Council

Assessor Willmott Dixon Energy Services

Purpose of assessment The energy retrofit of the 12 houses used a variety of low-carbon measures (a mix of traditional and experimental) to showcase the transition to lower-carbon living.

Methodology of assessment Four of the houses (1, 13, 68, 69) were monitored by the University of Cambridge after the installation of different improvements (see below). An inventory of the materials and components used came from the design specifications, contractors and through interviews with the site manager and manufacturing companies in the supply chain.

Improvement Work	68	69	1	13
Cavity Wall Insulation			✓	✓
External insulation behind tile hung areas	✓	✓		
Loft Insulation, hatch insulation and insulated boarding	✓			✓
Draught proofing - Window / Door Overhaul	✓	✓	✓	✓
Radiator System Installation		✓		✓
High Efficiency Combi Boiler		✓		✓
Solar Hot Water System + new cylinder	✓			
Heat Recovery Fans	✓	✓	✓	✓
Flue Gas Heat Recovery Unit		✓		✓
Insulated Plasterboard under the stairs	✓	✓		

Period of assessment and life cycle stages covered Life cycle stages included in the project were A1-A5 in BS EN 15978:2011 Assessment of environmental performance of buildings – cradle-to-gate processes of extraction transport and manufacturing as well as the construction process (transportation, energy consumption and waste).

Assumptions used for life cycle stages Locally sourced materials were transported 50km. All waste material was sent to landfill – transported a default distance of 30km away by diesel-fuelled HGV. End of life phase not included in scope.

Data sources Inventory of Carbon & Energy (ICE) Version 2

Results

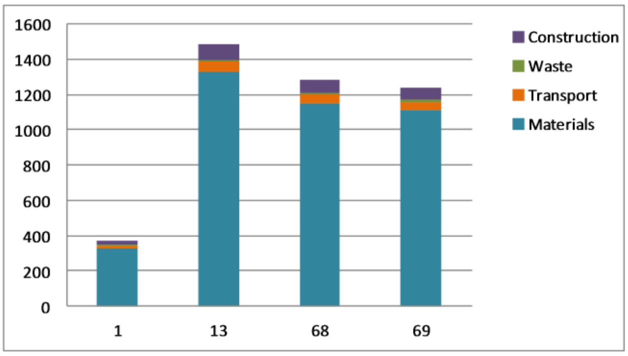

Figure 1: Embodied carbon (kgCO2e) of combinations of retrofit measures in 4 houses

Embodied carbon from materials accounted for 95% of the total. 4% of the embodied carbon was attributed to the transportation of manufactured products from the site of manufacture to the renovation site. Using SAP 2009 methodology to model the operational carbon footprint of the four buildings, it was also possible to predict that the carbon payback period (the minimum being 4 months for pilot 1 and the maximum being 18 months for pilot 13).

3.3 Carbon risk management

Research by the Carbon Trust found that risk management was a key issue in developing low carbon buildings[14]. Their template risk register, based on the outcome of 28 case studies, understandably focuses on avoiding the potential threats. However, the same process can also be used to identify opportunities. For example, low carbon buildings can better protect the occupants against energy price rises and security of supply problems, they are more likely to meet future environmental requirements, may suffer less from material price fluctuations during the planning phase and can provide reputational benefits.

A fuller awareness and familiarity with carbon risks can also reduce contingency costs and development time.

Risk Identification					Current Assessment				Risk Management		
1	1b	2	3	3a	4	5	6	7	8	9a	13
No	**Threat, Opp or Issue**	**Risk Description**	**Consequence**	**Category**	**Likelihood**	**Sustainability**	**Rating**	**Risk Status**	**Risk Response Strategy**	**Management Actions Planned**	**Comments**
1	Threat	Planning Approvals Planning permission delays or permission not granted for wind turbines Causes 1. Resident complaints 2. Adjacency to residential areas 3. Failure to comply Planning legislation guidance	1. Not able to implement technology of choice 2. Potential delays to the programme 3. Potential cost overruns	Approvals	3	5	8000	RED	Early discussions with Planners and on-going discussions with Case Officers	1. On larger/ complex projects appoint a Planning Consultant. 2. Pro-active discussions with the Planners.	Higher risk on smaller projects.

Figure 3.2: Extract from Carbon Trust template low carbon buildings risk register.

[14] [http://www.carbontrust.co.uk/emerging-technologies/current-focus-areas/buildings/tools-and-support/pages/default.aspx]

4 What is a carbon footprint?

4.1 Definition

Put simply, a **carbon footprint** measures the total GHG emissions caused directly and indirectly by a person, organisation, event or product[15].

The term 'carbon footprint' is now commonly, and often loosely, used to describe all types of climate change-related impacts. However, properly used, it refers to the full life cycle impact of a product, event, person or organisation; including scope 1, 2 and 3 GHG emissions.

In the context of the construction industry, the 'product' is usually a completed construction form e.g. a building, civil project or refurbishment project.

4.2 Accounting Principles

> ***Recommendation 1: Base the accounting and reporting of embodied emissions on the following principles: relevance, completeness, consistency, transparency and accuracy.***

All common GHG assessment frameworks are based on a set of straightforward accounting principles. These provide useful guiding principles.

- Relevance: Select sources, data and methods appropriate to assessing the chosen product's life cycle GHG emissions
- Completeness: Include all GHG emissions and storage that provide a 'material' contribution to a product's life cycle emissions
- Consistency: Enable meaningful comparisons in GHG-related information
- Transparency: When communicating, disclose enough information to allow third parties to make decisions
- Accuracy: Reduce bias and uncertainty as much as is practical

Materiality

Practical constraints usually mean that items are excluded from an analysis. The accounting of life cycle emissions is therefore rarely complete and, as a result, there are some inherent inaccuracies. Every effort should be made to include all likely emission sources but, where there are omissions, these must be clearly documented and justified. A materiality threshold is often used to determine whether an error or omission is a material discrepancy or not. That is, whether it's inclusion or exclusion would impact on any decisions or actions arising from the reported results.

While it is not possible to be prescriptive, it is generally considered that any error whose value exceeds 5% of the total footprint is materially misleading.

[15] [Definition from the Carbon Trust. http://www.carbontrust.co.uk/cut-carbon-reduce-costs/calculate/carbon-footprinting/pages/carbon-footprinting.aspx]

4.3 Global Warming Potential

Recommendation 2: Accounting and reporting of embodied emissions should be in tonnes of carbon dioxide equivalents (tCO_2e) and consider all six Kyoto Protocol GHGs.

A carbon footprint is measured in tonnes of carbon dioxide equivalent (written as tCO_2e). The use of carbon dioxide equivalents (CO_2e) allows the impact of different GHGs to be weighted and aggregated using a consistent unit of measurement. CO_2e is calculated by multiplying the emissions of each of the six Kyoto Protocol GHGs included in the carbon footprint[16] by its global warming potential (GWP). Recommended GWP at the time of writing are those given in the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)[17].

Carbon dioxide, the most abundant of the GHGs, has a global warming impact of one. It is primarily associated with the combustion of fossil fuels (natural gas, oil, diesel, coal and so on) throughout the life cycle. This may be due to the energy used in manufacture, distribution, maintenance, to heat, cool or light a building, or demolition.

Carbon dioxide is the most important GHG to consider when assessing the embodied emissions of a construction works as it is the most abundant. However, other GHGs, such as HFCs, may arise during product manufacture, use or disposal[18].

Given the high GWP of some GHGs, even small amounts can have a significant impact. Sulphur hexafluoride (SF_6), for example, is still in use as a tracer gas to test the air tightness of specialist equipment and as an electrical insulator. It has a staggering GWP of more than 22,000. In other words, emitting one tonne of SF_6 has the same climate changing impact as releasing 22,000 tonnes of CO_2.

Of course, these GHGs with a high GWP are only significant when, or if, they leak into the atmosphere – which may occur during manufacture or use, more slowly over their lifetime, or when they are disposed.

4.4 Calculating a simple carbon footprint

Recommendation 3: Quantities, emission factors and functional units should all be clearly stated.

Carbon measurement has a lot in common with the cost planning process which provides an inventory of all the materials, products, assemblies and elements within a building. Indeed, cost plans, along with bills of materials where available, are the best sources of the critical quantity data which is required to measure the embodied carbon footprint of a completed construction project.

To calculate the carbon footprint requires information about the embodied emissions associated with the product and the quantities of that product used within each element of the construction project.

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[16] Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydroflurocarbons (HFCs), perflurocarbons (PFCs), and sulphur hexafluoride (SF_6).

[17] (Forster et al., 2007, pp.212-213)

[18] Manufacturers of foam insulation products, for example, have worked hard to find replacements for HFC blowing agents; some of which have a GWP more than a 1,000 times that of carbon dioxide (Moomaw and Moreira, 2001; Wilson, 2010).

Embodied emissions values for different materials and activities, often referred to as emission factors, are most commonly derived from specialist databases – details of which are provided later in this Guidance.

The carbon footprint is calculated by multiplying the quantity by the appropriate emission factor:

Carbon footprint = quantity x emission factor

This is usually calculated for specific life cycle stage or stages. For example, manufacture, distribution, use and so on. Emission factors are usually expressed in tonnes or kilogrammes of CO_2e per functional unit. Common functional units, and their typical uses within carbon databases, are given in Table 4.1 below. For ease of use, those conversion factor databases aimed at the construction industry try and align the functional units with those most frequently used in cost plans.

Functional unit	**Typical use**	**Examples**
tonne (t)	Raw and bulk materials	tCO_2e/t steel
cubic metre (m^3)	High volume materials	tCO_2e/m^3 concrete
square metre (m^2)	Materials associated with wall and floor surfaces	$kgCO_2e/m^2$ glazing
litre (L)	Liquid fuels and materials provided in a liquid states	$kgCO_2e/L$ diesel
Number (nr)	Finished products	tCO_2e/door
tonne-kilometre (tkm)	Transportation of materials (the impact of transporting one tonne of material for one kilometre)	$kgCO_2e$/tkm rail freight

Table 4.1: Table of common functional units, and their typical uses within carbon databases.

To give a specific example, the carbon footprint (cradle to gate) for 'average' UK steel is around 1.53 tCO_2e per tonne[19]. Assuming, a steel frame using 100 tonnes of material, the total GHG emissions would be:

$$tCO_2e = 1.53tCO_2e/t \times 100 \text{ tonnes} = 153tCO_2e$$

A second example, calculating the footprint of $1m^2$ of brick skin, is adapted from the Building Cost Information Service (BCIS)[20]:

Each $1m^2$ (the functional unit) of brick skin, requires approximately:

$$60 \text{ bricks} \times 0.55kgCO_2e/\text{brick} = 33kgCO_2e$$

$$0.018m^3 \text{ of mortar} \times 287.78kgCO_2e/m^3 = 5kgCO_2e$$

$$\text{Total} = 33kgCO_2e + 5kgCO_2e = 38kgCO_2e/m2 \text{ brick skin}$$

Note that this covers manufacturer only. It is necessary to also consider other life cycle stages; for example, the transportation of the bricks and raw materials for the mortar to site.

[19] (Hammond and Jones, 2011)
[20] (Martin, 2011)

CASE STUDY for correct units: KEYNSHAM TOWN HALL

Assessor Aedas R&D

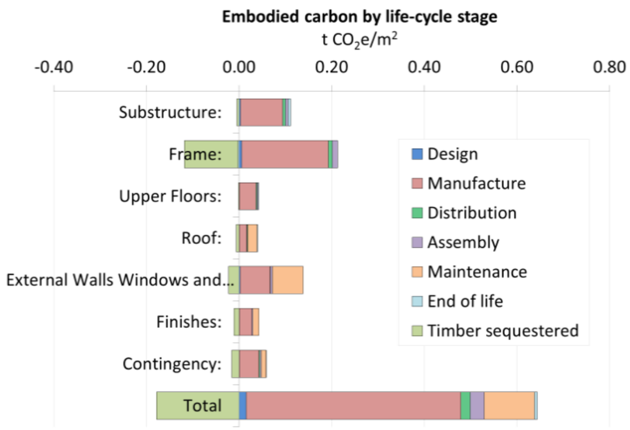
Purpose of assessment Use the embodied carbon footprint to inform the design of the building.

Methodology The embodied carbon footprint constructed using the Low Carbon Construction IGT report.

Data sources Material quantities came from the cost plan and emissions factors were sourced from BSRIA's ICE v2.0 and Defra's GHG Conversion Factors

Results Sequestration of the timber was analysed separately (see table below) and amounted to -0.178tCO2e/m2. The majority of this was captured in the cross-laminated timber frame of the building (see graph).

Embodied carbon by lifecycle stage – preliminary analysis	tCO_2e/m^2
Design	*0.015*
Manufacture	*0.464*
Distribution	*0.020*
Assembly	*0.030*
Maintenance	*0.109*
End of life	*0.006*
Timber sequestered	*-0.178*
Total	**0.644**
Total with sequestration	**0.465**



5 Embodied carbon assessment and the design process

5.1 The need for early intervention

Done properly, GHG emissions assessments are not one-off analyses but inform the on-going design and build process.

Again, a comparison with cost planning is warranted. Cost estimates are produced at an early stage and iterated into cost plans and refined as the design evolves. Similarly, an embodied carbon assessment should start off with a target 'carbon budget' which is assessed and reviewed as the design progresses. Assessments should evolve along with the design and should be used to appraise options and inform procurement choices.

As with any design intervention, the opportunities for influence diminish during the development process as more and more aspects of the design are fixed. Late design changes to accommodate environmental measures are likely to be more costly and disruptive, emphasising again the need for early consideration of embodied emissions (Figure 5.1).

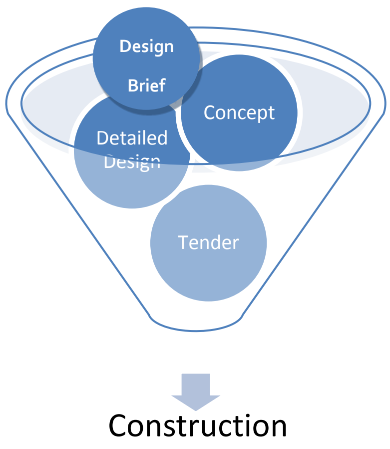


Figure 5.1: The opportunities to influence the environmental performance of a building (or refurbishment) diminish during the development process.

5.2 Outline GHG Plan of Work

The RIBA Outline Plan of Work and subsequent Green Overlay[21], lays out a clear process for managing, and designing building projects and administering building contracts into a number of key Work Stages. The GHG Overlay in Table 5.1 adds an embodied emissions 'checkpoints' column which relates specifically to the accounting and reporting of embodied emissions[22].

RIBA Work Stage			Description of Key Tasks	Embodied Emissions Checkpoints
Preparation	A	Appraisal	Identification of client's needs and objectives, sustainability aspirations, business case and possible constraints on development. Preparation of feasibility studies and assessment of options to enable the client to decide whether to proceed.	Assess potential for re-use of existing facilities and materials or delivery of objectives using temporary, re-usable facilities. Consider end of life options and issues. Consider GHG impact of site choices.
	B	Design Brief	Development of initial statement of requirements into the Design Brief by or on behalf of the client confirming key requirements and constraints. Identification of procurement method, project and sustainability procedures, building design lifetime, organisational structure and range of consultants and others to be engaged for the project.	State embodied emissions target. Consider GHG impact of decisions on building design life and maintenance cycles and other GHG trade-offs such as incorporation of on-site low carbon energy plant, incorporation of thermal mass, high levels of insulation etc.
Design	C	Concept	Implementation of Design Brief and preparation of additional data. Preparation of Concept Design including outline proposals for structural and environmental strategies and systems, site landscape and ecology, outline specifications and preliminary cost and energy plans. Review of procurement route.	Allocate responsibility for carbon management within design team. Set out carbon management plan for design stage. Conduct GHG review of Concept Design. Undertake first embodied emissions assessment based on preliminary cost plan.
	D	Design Development	Development of concept design to include structural and environmental strategies and services systems, site landscape and ecology, updated outline specifications and cost and energy plans. *Completion of Project Brief* *Application for detailed planning permission.*	All significant design options appraisals to include GHG assessment. Update embodied emissions assessment based on new cost plan. Consider recommendations from Concept Design GHG review and update as necessary.
	E	Technical Design	Preparation of technical design(s) and specifications, sufficient to co-ordinate components and elements of the project and *information for statutory standards, sustainability assessment and construction safety*.	Incorporate GHG assessment and supporting design decisions into sustainability assessment.
Pre-Construction	F	Production Information	**F1** Preparation of detailed information for construction. *Application for statutory approvals.* **F2** *Preparation of further information for construction required under the building contract. Review of information provided by specialists.*	Prepare necessary supporting information to meet planning requirements etc. Determine procurement requirements with respect to embodied emissions.
	G	Tender Documentation	Preparation and/or collation of tender documentation in sufficient detail to enable a tender or tenders to be obtained for the project.	Ensure tender documentation includes concise information on GHG requirements; material specification, sourcing, reporting etc.
	H	Tender Action	Identification and evaluation of potential contractors and/or specialists for the project.	Contractor credentials assessed against GHG requirements within tender. Consider whole life carbon cost/benefit

[21] (Gething, 2011)

[22] Both publications are freely available at: http://www.ribabookshops.com/item/riba-outline-plan-of-work-2007-updated-including-corrigenda-issued-january-2009/100004/

			Obtaining and appraising tenders; submission of recommendations to the client.	analysis to support evaluation process.
Construction	J	Mobilisation	Letting the building contract, appointing the contractor. Issuing of information to the contractor. Arranging site hand over to the contractor.	Establish and agree clear procedures for the measuring and monitoring of GHG during construction process.
	K	Construction to Practical Completion	Administration of the building contract to Practical Completion. Provision to the contractor of further Information as and when reasonably required. Review of information provided by contractors and specialists. Assist with preparation for commissioning, training, handover, future monitoring and maintenance.	Consider GHG implications and options when considering specification changes. Update embodied emissions assessment based on 'actual' quantities.
Use	L	Post Practical Completion	**L1** Administration of the building contract after Practical Completion and making final inspections. **L2** Assisting building user during initial occupation period. **L3** Review of project performance in use.	Report and communicate embodied emissions assessment. Document lessons learned. Consider verification of results.

Table 5.1: Based on the Green Overlay to the RIBA Work Plan.

6 Which standard?

Recommendation 4: The accounting and reporting of embodied emissions should be based on the BS EN 15978 environmental performance standard.

Recent years have seen a flurry of new national and international GHG accounting and reporting standards. A few are specifically targeted at the construction industry but most are generic, recognising the need for continuity across sectors.

The European Committee for Standardisation (CEN) are in the process of producing an integrated family of BS EN standards on the Sustainability of Construction Works which will inevitably determine best practice in the assessment of the environmental, social and economic performance of construction projects[23].

The aim of developing these standards is to encourage Europe-wide harmonisation within the construction industry – it is therefore the approach recommended in this Guidance.

Figure 6.1 below maps out how these BS EN standards sit alongside existing framework, project and product standards. Note that there is one framework standard but potentially competing standards at the project and product levels[24].

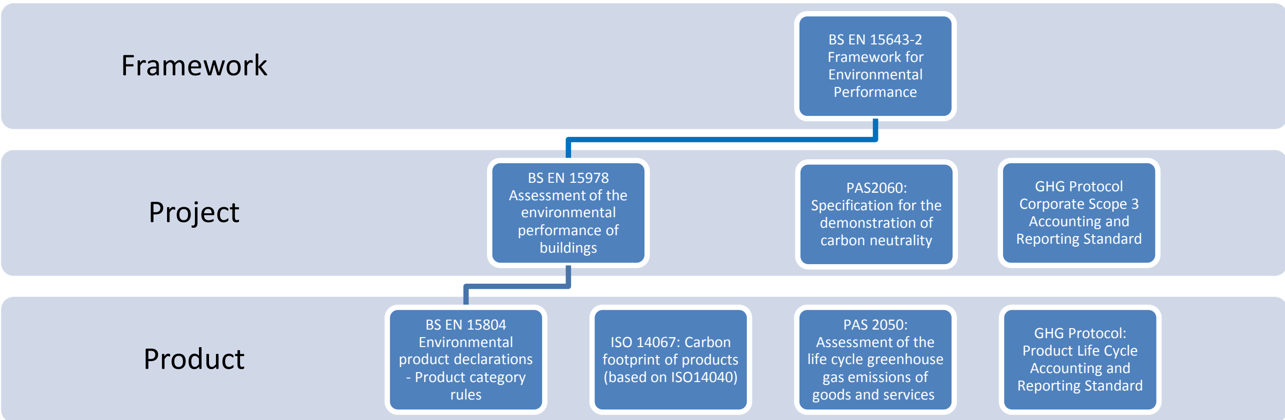


Figure 6.1: Standards landscape for embodied emissions accounting and reporting.

On closer inspection, however, there are many commonalities between the product level standards as all take a life cycle approach to embodied emissions accounting[25]. In reality, there are relatively few construction products to date that have had their embodied emissions measured using the product life cycle standards identified here. Many, however, have been subject to some form of environmental labelling or declaration (many in accordance with ISO14025[26]), less formal life cycle analysis or research study thus facilitating the production of secondary datasets. These are widely used within the industry. They are dealt with in more detail in a later section of this Guidance.

Manufacturers looking to accurately report their product scope 3 data can, technically speaking, safely use any of the standards listed. Comparability aside, there are other factors likely to impact on the decision as to which standard to support (see Table 6.1).

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[23] [Technical Committee CEN/TC 350]
[24] Figure 6.1 excludes several standards that may be of general interest. For example, BS8905:2011 *Framework for the assessment for the sustainable use of materials* and a host of LCA standards such as ISO 14040, ISO14025 and ISO 14044 which underpin all the product level standards.
[25] A comparison of ISO 14067, PAS 2050 and the GHG Product Protocol undertaken by the BSI found few differences of practical significance. The main difference was the degree of flexibility offered by the standards (BSI, 2011).
[26] http://www.iso.org/iso/catalogue_detail?csnumber=38131

Standard	**Covers a range of environmental impacts – not just GHG?**	**International**	**Requires dedicated life cycle tools and LCA expertise**	**Clear reporting and dissemination route?**	**Heavily prescriptive?**
BS EN 15804 (based on ISO 14040, 14044, 14025)	Yes	Yes	Yes	Yes – Environmental Product Declarations	Yes
ISO14067	No	Yes	No	No	No
PAS 2050; 2011	No	No	No	Yes – Option to go for carbon labelling	Yes
GHG Product Protocol	No	Yes	No	No	Yes

Table 6.1: Considerations for manufacturers in deciding which product level GHG accounting and reporting standard to use.

At the project level, PAS 2060, the GHG Scope 3 Protocol and BS EN 15978 fulfil very different needs.

- BS EN 15978 – Construction sector specific guidance on how to account and report construction projects. This is the core methodology described and promoted in this Guidance.
- PAS2060 – Can be used to demonstrate and substantiate claims of carbon neutrality for buildings or refurbishment projects. This is a supplementary standard which is only required when making claims of carbon neutrality.
- GHG Scope 3 Protocol – This can be used alongside BS EN 15978 for assessing and reporting company wide scope 3 emissions (rather than looking at a construction project in isolation).

7 Emission factor datasets

Recommendation 5: The selection of datasets and emission factors should be subject to a quality assessment.

Many product and material lifecycle datasets exist and it can be difficult to decide which is the most appropriate for any particular circumstance.

A survey of UK construction sector professionals undertaken in the course of developing this Guidance found that most were using emission factors from several sources. One-third (32%) were using in-house datasets, the vast majority (87%) used third party free (or previously free) datasets (such as Defra and Bath ICE) with around one-fifth (19%) using subscription life cycle datasets (such as Ecoinvent).

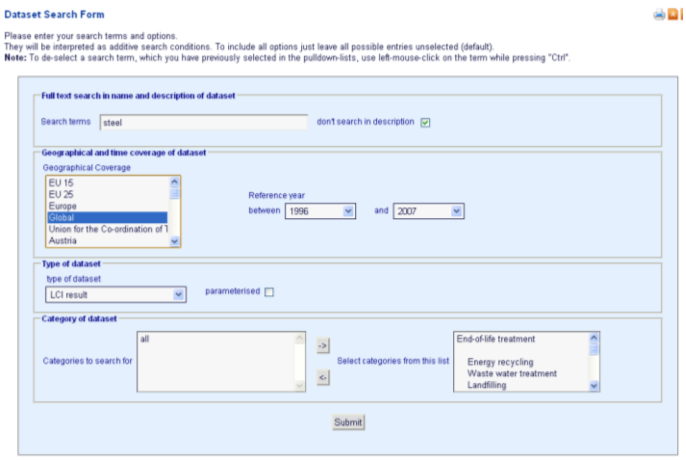
As datasets are continually being developed and updated, it is not possible to provide a definitive list within this document. However, guidance is included below to help:

- Find and select datasets; and
- Assess the most appropriate emission factor from the chosen database(s).

7.1 Finding and selecting potential datasets

A list of online LCA datasets provided by the Greenhouse Gas Protocol and EU respectively can be found at http://www.ghgprotocol.org/Third-Party-Databases and http://lca.jrc.ec.europa.eu/lcainfohub/databaseList.vm

This latter website also includes a simple query capability which operates across databases and can be used to interrogate the European Life Cycle Database – a free and growing data source backed by the EU.



These full life cycle datasets can be overwhelming hence the emergence of simplified, sector-specific, datasets which contain those items which are most commonly required and which contain GHG emission factors only.

The GHG Product Protocol provides a useful set of eight questions to assist with the quality assessment of datasets (Table 7.1 below).

1.	Is the data original or estimated from other data sources?
2.	Were the data developed using a consistent methodology?
3.	As land-use impacts included in the life cycle data?
4.	How long has the dataset existed and how extensively has it been used?

5.	How frequently is the dataset updated?
6.	How current are the data sources used for developing the life cycle emissions data?
7.	Does the dataset include an assessment of data quality or uncertainty?
8.	Is there any risk that the data will be perceived as biased? If so, has the data been independently reviewed?

Table 7.1: Questions to assist with selecting a lifecycle dataset (adapted from the GHG Protocol Product Standard).

On the basis of the GHG Protocol questions, it is possible to broadly rank datasets in terms of their quality. Table 7.2 is intended to further assist in the selection of datasets[27], the results of which should be reported. Practical matters, such as cost and availability, may also impact on the choice of dataset.

Quality Assessment	Type of dataset	Examples	Likely disadvantages
Very Good	Standards compliant third party maintained lifecycle databases.	Ecoinvent (ISO 14040), ELCD (ISO14040), Carbon Trust Footprint Expert (PAS 2050), EPDs (ISO14025)	Most likely to be subscription datasets though EPD are free to access. Also, their complexity may require additional expertise to use and interpret. Not necessarily appropriate for UK projects. Limited construction-related content.
Good	UK construction specific and Government-backed GHG databases underpinned by a clear methodology and which are actively maintained.	Bath ICE, Defra/DECC, CESMM3 Carbon & Price Book, UK Building Blackbook, BRE Green Guide to Specification (ISO 14040)	Do not include all life cycle impacts. Not necessarily appropriate for international projects. Data quality and uncertainty not always clearly specified.
Fair	Non-UK databases which are underpinned by a clear methodology and which are	Bilan Carbone (France), Athena LCI Product Database (North America), , oekobau.dat	Do not include all life cycle impacts. Not necessarily appropriate for UK

[27] [Note that details of all these datasets are available at: http://www.ghgprotocol.org/Third-Party-Databases except the CESMM3 Carbon and Price Book (http://www.franklinandrews.com/publications/capittool) and the Hutchins UK Building Blackbook (http://www.franklinandrews.com/publications/hutchins/)]

	independently maintained.	(Germany)	projects. Data quality and uncertainty not always clearly specified.
Poor	Unverified or one-off historical databases collated for a specific project or purpose. Databases which are based on methodologies other than process-based life cycle analysis (for example, input-output analysis).	3EID (Japan), Carnegie Mellon (USA)	May be out of date. Generic results may be misleading. Can be biased.

Table 7.2: Further information to assist in the selection of datasets.

BS EN 15978:2011 specifically recommends the use of Environmental Product Declarations (EPDs) as these are independently verified, robust and cover generic and product-specific data [28]. The relevant core Product Category Rules, or PCRs, are set out in EN 15804. EPDs are prescriptive declarations of a product's environmental performance and are valid for five years only. They must include information such as:

- Name and address of manufacturer;
- A full description of the product;
- Information on life cycle coverage;
- Description of functional or declared unit (see below);
- A range of environmental impact data, including the carbon footprint expressed in CO_2e per functional/declared unit; and
- Independent verification of the data within the declaration.

For construction products, inclusion of the initial life cycle stages of a product (cradle to gate) is mandatory, full life cycle analysis (cradle to grave) is optional.

Although there are a number of EPDs now available for construction products, their number is expected to increase still further as the demand for environmental information grows. Figure 7.1 shows an extract from an EPD for steel reinforcement from the Norwegian company Celsa Steel Service AS[29].

[28] Construction EPDs to ISO 14025 are catalogued centrally on the web at www.environdec.com, http://www.greenbooklive.com/search/scheme.jsp?id=9, bau-umwelt.de, www.inies.fr etc.

[29] (Celsa Steel, 2011)

Climate change:
340kg CO_2 eq/tonnes

ENVIRONMENTAL PERFORMANCE DECLARATION*

Declared unit; 1 tonne of average reinforcement product in Norway	Unit/tonne	Upstream processes	Transports to the core process	Core process	Total
Impact category result					
Climate change	kg CO_2 eq.	310	21	8.3	340
Acidification	kg SO_2 eq.	0.99	0,22	0.0099	1.2
Eutrophication	kg PO_4^{3-}eq.	0.16	0.049	0.0015	0.21
Stratospheric ozone depletion	kg CFC-11 eq.	$1.5 \cdot 10^{-5}$	$2.4 \cdot 10^{-6}$	$5.7 \cdot 10^{-9}$	$1.7 \cdot 10^{-5}$
Ground level photochemical ozone (including impact from NO_x)	kg C_2H_4 eq.	0.13	0.028	$7.2 \cdot 10^{-3}$	0.16

Figure 7.1: Extract from Environmental Product Declaration produced by Celsa Steel for steel reinforcement showing a range of cradle to gate environmental impacts including the carbon footprint (340kgCO_2e per tonne of average reinforcement product).

Figure 7.2 shows an extract from a 'cradle to grave' EPD for 1kg of Antica Calce, a white masonry paint from Italian manufacturers San Marco[30]. This includes not only raw materials and manufacture but also includes assumptions for the use phase and end of life disposal of the packaging.

Antica Calce (1 kg)			Upstream	Core	Downstream	Total
Environmental indicators		Unit				
Impact category	Global warming	kg CO_2 eq	0,482	0,053	0,198	0,733
	Ozone depletion	mg CFC-11 eq	0,026	0,006	0,022	0,053
	Photochemical smog	g C_2H_4 eq	0,439	0,050	0,077	0,566
	Acidification	g SO_2 eq	1,03	0,213	0,754	2,00
	Eutrophication	g PO_4^{3-} eq	0,314	0,075	0,239	0,628
	Human toxicity	kg 1,4-DB eq	0,096	0,012	0,042	0,150

Figure 7.2: Extract from Environmental Product Declaration produced by San Marco for their Antica Calc paint. It provides a full cradle to grave environmental assessment including the carbon footprint (0.733kgCO_2e per kg of paint).

7.2 Assessing the most appropriate emission factor from the chosen dataset(s)

Once a dataset, or datasets, is chosen there may still be a degree of selection required to determine the most appropriate emission factor. In some cases it is possible to find an up-to-date and accurate emission factor for a specific product and supplier. For example, Footprint Expert contains emission factors for a wide selection of Marshall's products all of which have been assessed using PAS 2050. EPDs will typically also be linked to a specific product (see previous section). More often than not, though, it is necessary to work with secondary data (which is based on typical or similar products and materials) whose fitness-for-purpose needs to be assessed. Table 7.3 lists five quality criteria that can be used for the assessment of emission factors adapted from the GHG Product Protocol. It is good practice to report the outcome of any quality assessment to aid the interpretation of results.

Quality Assessment	Technological specificity	How up to date	Geographically relevant	Completeness	Reliability
Very good	Emission factor relates to the same technology	Data source is less than 3 years old	Data originates from the same geographical area	Data available by life cycle stage (cradle to grave) and based multiple data	Third party verified data based on primary data collection.

[30] (San Marco, 2011)

				points	
Good	Relates to an equivalent technology	Less than 6 years old	Data is from a similar area	Data available for main life cycle stages (cradle to gate or site) and based multiple data points	Verified data based on clearly stated assumptions
Fair	Uses different technology	Less than 10 years old	Data is from a different area	Data not broken down by life cycle stage and/or based on limited number of data points	Unverified data based on assumptions or estimated data
Poor	Technology unknown	More than 10 years old or unknown age	Area unknown	Life cycle coverage and data points unknown	Unknown

Table 7.3: Data quality assessment criteria to assist in selecting the most appropriate emission factor.

8 Tools

The selection of calculation tool is less important than the choice of data, standard or methodology. Variations in the latter are more likely to lead to inconsistent results, the choice of tool is more a matter of personal preference. Note that some tools are tied to specific datasets and/or methods thus restricting choice.

The survey of industry professionals indicated that most (84%) used Excel spreadsheets, either internally or externally developed, to undertake embodied emissions calculations. There was some overlap with the use of dedicated tools; 23% said they used internal software and 27% used externally sourced solutions.

A diverse range of tools were mentioned[31] including:

- Simapro, GaBi and Footprinter – process-based tools which are available with a variety of proprietary and third party datasets;
- Trucost and TBL2 – tools based primarily on proprietary input-output (financially derived) databases; and
- Environmental Agency (EA) and Highways Agency (HA) Calculators – Freely available Excel based tools based primarily on the Bath ICE dataset.

Other commonly used embodied emissions construction tools which were not mentioned in the survey include[32]:

- Athena Impact Estimator for Buildings;
- Oasys software;
- CapIT Carbon and Cost Estimator;
- BuildCarbonNeutral Construction Carbon Calculator; and
- WRAP Net Waste tool (focuses on waste).

There are signs that the drive towards Building Information Modelling will lead to significant advances in software provision within the construction industry[33].

[31] Simapro; http://www.simapro.co.uk, GaBi; http://www.gabi-software.com, Footprinter; http://www.footprinter.com, EA calculator; http://www.environment-agency.gov.uk/business/sectors/136252.aspx, TBL; http://www.censa.org.uk and ARUP, Trucost; http://www.trucost.co.uk, HA calculator; http://www.highways.gov.uk/business/31530.aspx
[32] Athena IEB; http://www.athenasmi.org/tools/impactEstimator/, Arup Oasys; http://www.oasys-software.com/, CapIT; http://www.mottmac.com/skillsandservices/software/capittool/, BuildCarbonNeutral; http://buildcarbonneutral.org/, WRAP; http://www.wrap.org.uk/construction/
[33] Several Technology Strategy Board (TSB) funded projects have been focused in this area. iCIM (a project led by AEC3 – aec3.com) and LIDX (an output of the Low Impact Buildings project consortium – lowimpactbuildings.org) were two demonstration BIM tools mentioned during the consultation.

9 Assessment Process

This section draws on the background in earlier chapters to provide specific guidance on accounting and reporting in accordance with the calculation method as set out in BS EN 15978.

Figure 9.1 sets out the steps necessary to perform an embodied emissions assessment for construction works.

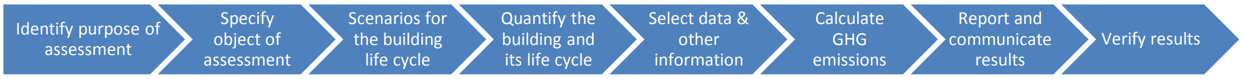


Figure 9.1: Assessment process (adapted from BS EN 15978.

9.1 Purpose of the assessment

> Recommendation 6: The purpose of the assessment, including the goal and intended use of the outputs, should be clearly stated.

It is first necessary to consider, agree and document the purpose of the assessment. This will determine the scope and focus of the analysis.

Assessments are commonly performed for one, or more, of the following reasons:

- Comparing carbon strategies – for example, the trade-offs between embodied emissions and energy in-use;
- Comparing design alternatives – for example, whether to use a timber or steel superstructure;
- Identifying environmental 'hotspots' in a design – for example, understanding the most impactful elements in a building
- Complying with voluntary or mandatory reporting requirements – for example, to measure progress against corporate GHG reduction targets or report to a third party;
- External stakeholder engagement – for example, for marketing or investor benefit; and
- Measuring for the purpose of carbon offsetting – to try and deliver a 'zero carbon' development.

9.2 Specifying the object of the assessment

> Recommendation 7: The object of the assessment should be clearly described. It is recommended that the assessment includes product manufacture and supply, and construction life cycle stages (cradle to gate plus construction). Other life cycle stages are discretionary.

An assessment may cover a complete building, an extension, refurbishment or another part of the works. This is referred to as the 'object' of an assessment.

Where this object is a complete building, the assessment should include all external works within the curtilage of the building's site but exclude construction works outside of the curtilage of the site (for example, infrastructure for transportation, communication, water and energy). Embodied emissions from all life cycle stages should be covered where possible; product manufacture and supply, construction, use and end-of-life (see Figure 9.2). Of these, the first two categories are recommended – the latter two are discretionary.

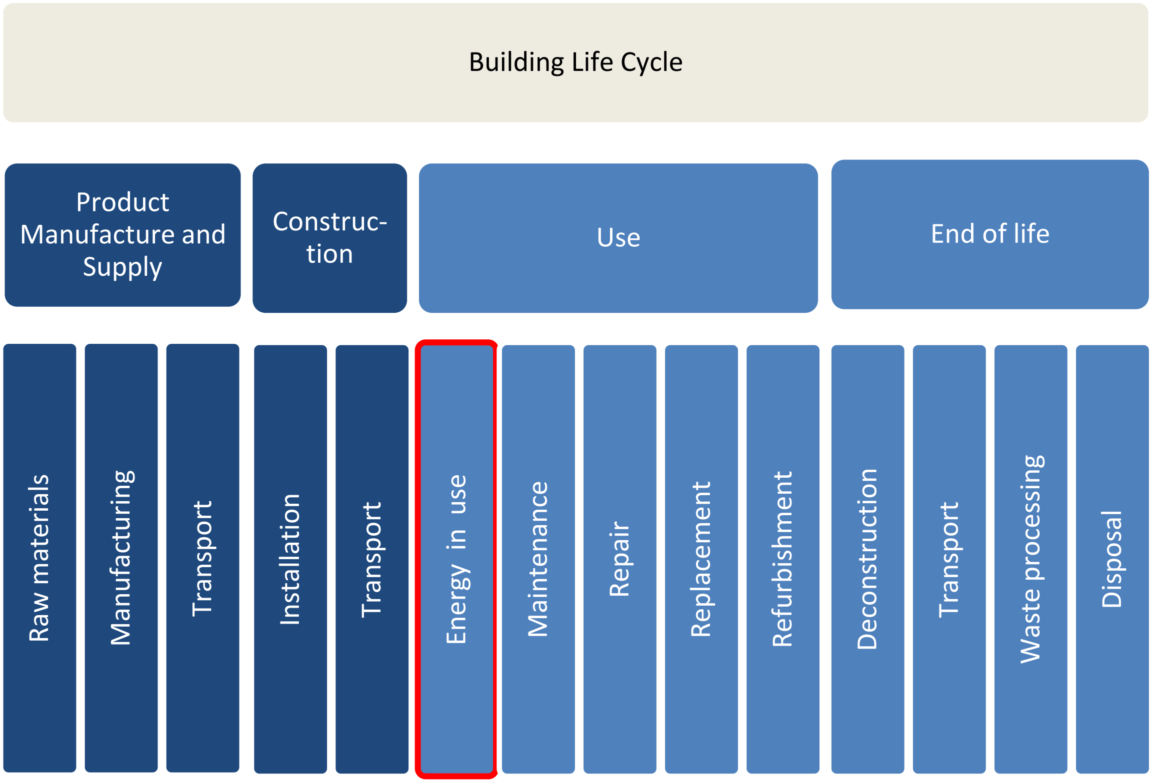


Figure 9.2: Building Life Cycle Stages. Adapted from BS EN 15978:2011. Note that all are considered embodied emissions except 'Energy in use'. Recommended stages are dark blue, discretionary stages are in lighter blue.

Where an assessment is restricted to elements of a building only, or to part of its life cycle, the object of the assessment should be clearly described and the reasons for a restricted life cycle analysis justified.

The description of the construction works must be comprehensive and include, but not be limited to, the following information:

- Building type;
- Relevant technical and functional requirements;
- Pattern of use (for discretionary stages); and
- Required service life or design life (for discretionary stages).

What to include in each life cycle stage can be unclear. Figure 9.2 provides an overview of the elements to include within each stage. Further guidance is given below.

- **Product manufacture and supply** – includes 'cradle to gate' emissions associated with the materials, products and services used in the construction works.
- **Construction** – includes the emission from transporting items from the factory gate to the site and the transportation of all construction equipment (cranes, generators etc.) to, and from, the site as well as the manufacture and transport of the materials which are wasted and transportation and disposal of waste off-site. Also includes all the emissions associated

with energy used for construction (for example, fuel use for equipment and the electricity and gas used in temporary buildings). Where water use is significant during the construction phase, the embodied emissions associated with its supply should also be included.

- **Use** – this stage covers all emissions from the practical completion of the works to deconstruction/demolition. This includes the emissions associated with maintenance, repair, replacement and refurbishment. Examples include: painting, cleaning, servicing of a boiler, fixing a broken window, replacing a broken heating pump replacing a roof membrane or refurbishing a facade. The embodied emissions associated with furniture, fixtures and fittings which are not buildings-related[34] can be excluded. If they are measured they must be reported separately.

  Note that operational energy use (scopes 1 and 2) should be considered as part of an overall GHG emissions assessment but does not form part of this Guidance.

- **End of life** – this stage commences when the building is decommissioned and is not intended to have any further use. In almost all cases, the emissions associated with this phase will be based on one, or more, possible end of life scenarios (e.g. the reuse, recycling or landfill of various elements of the dismantled building). In all cases, it is only necessary to include the emissions associated with the buildings elements up to the point where they are no longer consider to be waste products. For example, the assessment should only include the emissions associated with the dismantling of a steel frame and its transportation to a recycling facility , but for concrete demolition waste, they must include the crushing process.

  Note that it is possible to extend an assessment to include the carbon benefits of displacing the use of virgin materials – covered by Module D in EN 15978. For example, the carbon savings accruing to a second user from the use of recycled steel. If this is assessed then the associated savings should be reported separately.

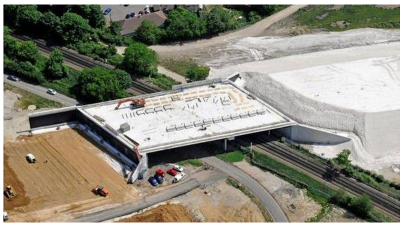
In some cases, it may be necessary, or desirable, to look at the performance of a project over a limited time period. For example, to see how a design performs during its first five years of operation. Where this occurs, the use and end of life phases (where these are measured) should be adjusted downwards in proportion to the reference period chosen. Again, if these life cycle stages are excluded it should be clearly stated.

For example, the product and construction phases of a building are estimated to be responsible for 100,000tCO_2e of GHG emissions. A further 500,000tCO_2e are expected to be emitted over the use (energy in use, maintenance and so on) and end-of-life (demolition, disposal and so on) phases. The service life of the building is 25 years. To calculate the emissions from the first 5 years of the building's life (20% of the service life):

[34] Building-related furniture, fixtures and fittings are those products which are fixed to the building and whose removal impacts on the performance of the building. Conversely, items with are not building-related include appliances, office equipment and other equipment intended to support industrial or commercial processes within the building.

Product and construction phases:	100,000tCO_2e
+	
20% of use and end-of-life phases:	100,000tCO_2e
=	___________
Total:	200,000tCO_2e

CASE STUDY for defining 'object': COTTINGTON ROAD OVERBRIDGE



Building Bridge abutment

Client Atkins Rail

Assessor oCo Carbon

Purpose of assessment To compare embodied carbon footprint for the use of expanded clay and EPS (expanded polystyrene) against a granular aggregate benchmark (6N) in the backfill section of Cottington Road overbridge.

Methodology of assessment Atkins Rail undertook the structural calculations and provided a bill of quantities. oCo Carbon then completed the embodied carbon exercise.

Assumptions used for life cycle stages The backfill of the overbridge was assumed to only affect the design of the foundations and abutment, therefore no other aspects of the bridge construction were considered.

Data sources Embodied carbon factors gathered from ICE version 2 and an EPD for expanded clay. Transport and end-of-life factors came from Defra's GHG Conversion factors 2011.

Results

Boundary	Expanded Clay	EPS
Cradle to gate	26.6	-215.0
Cradle to site	507.2	-215.4
Cradle to grave	504.3	-219.7

Table 1: the marginal embodied carbon of two backfill materials as compared to a 6N granular fill (all figures in tCO2e)

The very low density of the EPS significantly reduces the transport-related carbon dioxide emissions achieved through preferentially choosing EPS blocks over expanded clay (and 6N granular fill). In addition EPS is generally sourced from the UK, keeping transportation distance short as well as light.

In future the large difference in emissions between the two materials may favour the use of EPS where the cost argument is marginal or if policy measures are introduced that give embodied carbon saved a greater financial value.

9.3 Scenarios for the building life cycle

Recommendation 8: The assumptions and scenarios used for predicting future life cycle embodied emissions should be robust and clearly stated.

To estimate the complete life cycle emissions of a building it is necessary to make certain assumptions about its future use and end of life.

Early assessments of a project's embodied emissions will also need to make estimates about the product manufacture and supply as well as the construction process.

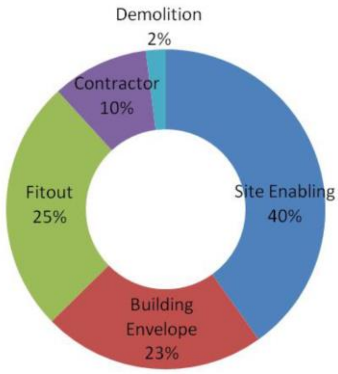
These scenarios should be fully described and documented as part of the assessment. It is important to include, for example:

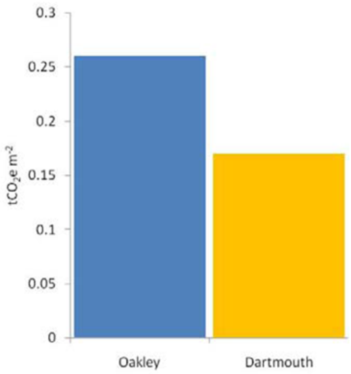
- Consideration of the cleaning, maintenance and replacement cycles of all construction products (e.g. machinery, floor coverings, windows) taking into account intended use, client requirements and manufacturer recommendations.
- Details of the waste processing scenario – how the building will be dismantled / deconstructed and how the various products and materials will be managed and transported to the point where they cease to be considered as waste. For example, they are reused, recycled, sent for energy recovery or landfilled. These scenarios should be based on currently used, technically and economically viable solutions.

- Note that the scenarios described above are only required where the discretionary use and end of life phases are included.

CASE STUDY for end of life assumptions: SAINSBURY'S DARTMOUTH BUILDING

Building	New supermarket
Client	Sainsbury's
Assessor	dcarbon8
Purpose of assessment	To reduce the embodied carbon footprint by 20% of the Oakley supermarket benchmark.
Methodology of assessment	The Planet Positive Protocol Product Carbon Footprint Methodology, based on ISO 14044:2006 - Environmental management - Life cycle assessment was used. The scope included the building material and infrastructure, on site delivery, contractor carbon, building maintenance, building demolition and the recycled content of the building materials.
Period of assessment and life cycle stages covered	Monthly data was collected over the period of construction (October 2007 to June 2008) but the period of assessment included the 30 years the building was presumed to stand. The data covered all building materials from cradle to factory gate, delivery to site, onsite construction activities, and end of life management of products and building demolition emissions.
Assumptions used for life cycle stages	The life of the building to be 30 years with 3 fit outs during that time. The impact of demolishing the building at the end of life was assumed to be 2 percent of the total lifetime carbon impacts (excluding building operations) and added to total lifetime impacts. Carbon sequestration by timber products was not included.
Data sources	Datasheets were sent to Kier Group (main contractors), who filled in data on building materials, fuel and energy consumption and employees transportation.
Results	2,438 tCO2e is embodied in the Dartmouth supermarket (within scope and time period) and can be subdivided into these categories:





Against a 20% reduction target from the Oakley supermarket baseline, the Dartmouth building should in fact achieve a 35% reduction on a per m^3 basis (see bar chart above), a difference of $0.9tCO_2e/m^3$.

9.4 Quantifying the building and its life cycle

Recommendation 9: Material and product quantities should be based on the best available data at the time of the assessment.

Material and product quantities should be based on the best available data at the time of the assessment. These may be rough early estimates based on design drawings, more accurate line-by-line figures from cost plans or actual, or predicted, bills of materials.

There may be very little information on which to base early design stage assessments in which case a pragmatic approach is recommended (as described in the Encord *Construction CO_2e Measurement Protocol*[35]) whereby data is first sourced for a selection of priority, energy intensive materials:

- Ferrous metals;
- Non-ferrous metals;
- Concrete (especially cement);
- Brick;
- Glass;
- Insulation (for non-renewable materials);
- Gypsum based products; and
- Bituminous products (e.g. asphalt).

For consistency with the BCIS New Rules of Measurement (NRM)[36], and where sufficient detail is available, quantities should be collated using the NRM structure.

In all cases quantities should be gross amounts including wastage, losses and any contingencies. Care needs to be taken that the quantities accurately represent the likely material use and are not an artefact of the approach taken to cost planning.

An extract from a cradle-to-gate embodied emissions assessment for a whole building based on an early stage cost plan is shown in Figure 9.3. Note that it includes contingencies and conforms to the NRM structure.

	Quantity	Unit	Quantity	Unit	kg CO2e
Substructure	1.00	Unit	1.00	Unit	395,376
Foundations	1.00	Unit	1.00	Unit	264,321
Site Strip to .2m level dig	1.00	Unit	1.00	Unit	22,356
Allowance for excavation and mass concrete founda	1.00	Unit	1.00	Unit	0.00
Aggregate	0.00	kg	0.00	kg	0.00
Sand	0.00	kg	0.00	kg	0.00
Cement (Low)	0.00	kg	0.00	kg	0.00
Allowance for excavation and reinforced concrete gr	1.00	Unit	1.00	Unit	0.00
Extra over; for excavation for tunnel void	1.00	Unit	1.00	Unit	0.00
Extra over; for formwork to inside face of tunnel wall	1.00	Unit	1.00	Unit	0.00
Allowance for trapped carbon in timber products note	1.00	Unit	1.00	Unit	0.00
Allowance for piled foundations; pile caps and groun	1.00	Unit	1.00	Unit	211,900
Allowance for excavation and 150mm hardcore fill; 1	1.00	Unit	1.00	Unit	8,855
Handling of excavated material to final location on site	1.00	Unit	1.00	Unit	3,912
Steel base plates to RC Plinths/Glulam supports	1.00	Unit	1.00	Unit	1,457
Lift pit	1.00	Unit	1.00	Unit	1,270
Base for escape stair	1.00	Unit	1.00	Unit	635
Provisional allowance for forming mounds for PV (ap	1.00	Unit	1.00	Unit	8,655
Allowance for detailing, Earth Work Support	1.00	Unit	1.00	Unit	5,281
Ground Floor Construction	1.00	Unit	1.00	Unit	131,054
Superstructure	1.00	Unit	1.00	Unit	613746

Figure 9.3: Extract from a detailed embodied emissions assessment (cradle to gate) based on a cost plan with drill-down to raw materials for the substructure. Source: Footprinter and Best Foot Forward.

[35] (Encord, 2011)
[36] http://www.rics.org/nrm

As previously noted, it is important to allow for replacements where the estimated product service life is less than the building service life. Where the product service life is less than that of the building then the total number of replacements must be rounded up. For example, a boiler with an estimated service life of 20 years is being installed in a building with a 50 year expected life:

Boiler quantity = 50 years/20 years = 2.5 = *rounded up to* 3 boilers

9.5 Selection of environmental data and other information

> Recommendation 10: For consistency, accounting of carbon sequestration, carbonation, recycling and waste should follow the approaches set out here.

Having secured quantities data, and descriptions of the materials and products in the construction works, the selection of appropriate databases and GHG emission factors can begin – as described in Section 7 of this Guide.

There are several complex and contentious accounting issues surrounding the selection and application of emission factors. These are described below with recommended solutions.

9.5.1 Carbon sequestration

> Recommendation 10a: Carbon sequestration should be included in any assessment, based on a 100-year life span, with the assumptions used clearly stated.

Some natural building materials, for example glulam, timber and strawboard, absorb carbon dioxide as they grow, locking carbon into the manufactured product. There are inconsistencies in how this sequestered carbon is accounted – with some studies ignoring it and others including it. If sequestered carbon is included then timber, for example, has a negative footprint. This can have a substantial impact on the overall GHG assessment for a timber frame building.

It is recommended that sequestered carbon is included using an assumed 100-year life span (as described in PAS 2050, EN 15804 and EN 15978). The emission savings are reduced proportionately for applications with a service life of less than 100 years.

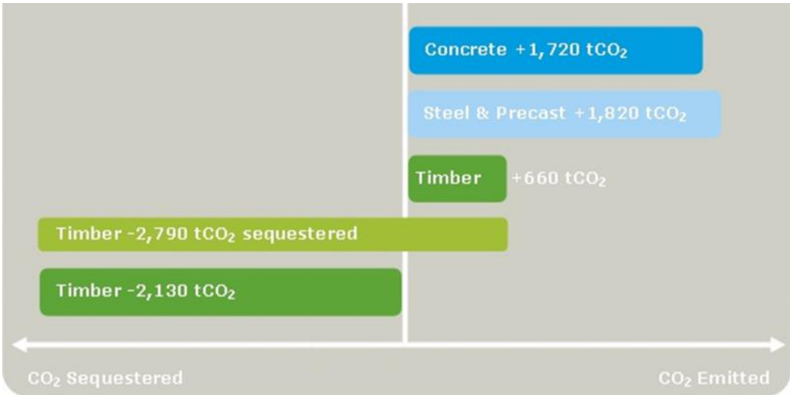
CASE STUDY for carbon sequestration: OPEN ACADEMY NORWICH

Assessor Ramboll

Purpose of assessment Compare three alternative structural systems: traditional concrete frame, steel and precast concrete planks and cross-laminated timber.

Data sources BSRIA's ICE v2.0 database for the construction materials. Timber sequestration is not present in this cradle-to-grave database but a factor of -0.8tCO2/m^3 was used.

Results The embodied carbon footprint of each scenario was calculated and is shown diagrammatically below:



Carbon sequestration was modelled separately as well was with the cross-laminated timber frame. Even without sequestration considered, the timber frame has a much smaller embodied carbon footprint

9.5.2 Carbonation

Recommendation 10b: The impact of carbonation should be excluded except when a building's end of life is considered.

Unlike natural building materials, which sequester carbon during their growth phase, concrete (and some other materials, such as lime mortar) can absorb small amounts of carbon dioxide from the atmosphere over the life time of a building through a process known as carbonation. Absorption rates are typically very low (<1% reabsorbed per year), highly variable and depend on climatic conditions. However, carbonation rates can increase significantly at the end of a building's life if concrete is crushed and/or reused.

Since most studies focus on the construction phases, it is recommended that carbonation of concrete and other materials are excluded. Where a building's end of life is being studied, carbonation can be calculated but must be presented separately from the main results[37].

9.5.3 Treatment of recycling

Recommendation 10c: Recycling should be accounted on a 100:0 basis with no allowance for end of life reuse or recycling.

[37] The recommended methodology for calculating the carbonation from concrete is described here: *Guidelines - Uptake of carbon dioxide in the life cycle inventory of concrete* by K. Pommer & C. Pade, DTI, Oct. 2005, 82 pp. ISBN 87-7756-757-9

The study boundaries proposed by BS EN 15978 are consistent with accounting recycled materials on a 100:0 basis. This means that the user of a recycled material takes all the benefit of recycling but, in return, can claim no end of life benefit for the 'recyclability' of a material.

For example, if you procure recycled steel this is reflected in the selection of emission factors; with recycled steel having lower embodied emissions than virgin steel (the exact factor will depend on the level of recycled content). However, no benefit can then be claimed at end-of-life if/when that steel is sent for recycling or reuse. The system boundary is at the "end of waste" state where the waste is not longer legally considered a waste, as per the Waste Framework Directive. The impact of recycled products must include any manufacturing processes which occur after the end of waste state is reached.

9.5.4 Reuse of waste materials

> Recommendation 10d: Emissions from waste materials should be accounted up until the point at which they are transformed into a useful construction material.

Construction products and projects frequently make use of materials which would otherwise be considered as waste. Leftover concrete from a previous demolition can be crushed and recycled as fill, doors and windows may be reused, a steel frame might be reused or recycled to create new components, and so on.

As with the treatment of recycling, the proposed method is to account for only those emissions required to turn the waste material into a useful construction material after the materials has reached the end of waste state. This should include any required reprocessing and transportation.

Where demolition materials are reused on site, then any emissions from the relocation or reprocessing will be captured as part of construction installation life cycle stage.

Where demolition materials are sent for reuse or recycling elsewhere then an assumption needs to be made about when, and where, these 'waste' materials become a useful construction material. Only the emissions up until this point need to be included in the study boundaries.

Whether the material is covered by a waste transfer note or waste management licence is a useful indicator.

9.6 Calculate GHG emissions

> Recommendation 11: Total embodied emissions should be determined by summing the individual product footprints across the life cycle of the construction project.

As described in Section 4, the total GHG emissions for a construction project can be determined by summing the individual footprints of all the constituent products and services over the whole life of the works for the recommended and discretionary life cycle stages.

As an example, consider the calculation of the embodied emissions for a steel frame. This weighs 100 tonnes with a 'cradle to gate' emission factor of 1.46tCO_2e per tonne. It is transported 100 kilometres from the factory gate to the construction site where it is bolted together using an impact wrench connected to a grid supply.

Other assumptions are:

- $0.15kgCO_2e$ per tonne km[38];
- 500kWh electricity used to power impact wrenches; and
- $0.60kgCO_2e/kWh$ grid electricity.

At the end of life it is assumed that the steel frame is dismantled (using the same method as assembly) and then transported 200km to a recycling facility at a cost to the project. Note that accounting for end of life is discretionary.

Note that, in most cases, on-site construction energy use will not be metered separately by use, so it is necessary to report these emissions in an aggregated form. Similarly, transport to site may not be monitored by material so it is often necessary to cluster products together and apply common assumptions.

Product Manufacture & Supply:

Steel = 100t * $1.46tCO_2e/t$ = $146tCO_2e$

Construction:

Transport to site = 10000 tonne-km * 0.15kg/tkm = $1.5tCO_2e$

Electricity use = 600kWh * $0.6kgCO_2e/kWh$ = $0.3tCO_2e$

End of life:

Transport to recycling facility = 20000 tonne-km * 0.15kg/tkm = $3tCO_2e$

Electricity use = 600kWh * $0.6kgCO_2e/kWh$ = $0.3tCO_2e$

It is assumed that the steel frame has no use phase emissions during the service life of the building and does not require painting, cleaning or maintenance.

$146tCO_2e$ $1.8tCO_2e$ $0tCO_2e$ $3.3tCO_2e$ $151.1tCO_2e$

Figure 9.4: Steel frame example.

This process is repeated for other products and materials. As already noted, emissions may not be available by product for all life cycle stages. In this case, it is permissible to aggregate emissions as long as the assumptions are clearly stated. In the example below, construction stage emissions are aggregated across three products.

[38] This emission factor is taken from the dataset published by DEFRA/DECC.

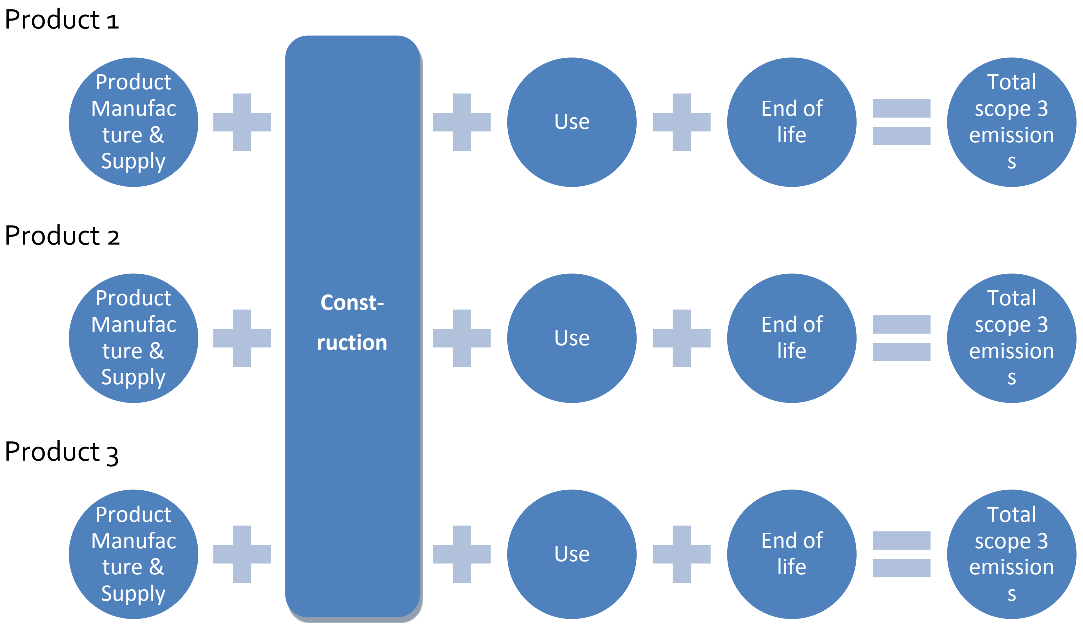


Figure 9.5: Example of three products with aggregated construction stage emissions. Note that use and end of life phases are discretionary.

Software tools can considerably ease the burden of calculation. Spreadsheets can make short work of such repetitive formulations and the specialist tools mentioned in Section 8 can add further value with integrated databases and other desirable features.

9.7 Reporting and communicating results

Recommendation 12: Emissions should be reported and communicated in accordance with the outline presented.

Throughout this Guide the emphasis has been on documenting the process, assumptions, data and justifications. A reporting template has been prepared (Annex A) to support the consistent reporting and communication of results. Reporting should include (but not be limited to) the following information:

General Information

- Identification of building and client
- Name and details of the assessor
- Date of assessment
- Details of verifier, if appropriate
- Statement regarding verification
- Purpose of the assessment
- Description of the assessment method
- Period of assessment and life cycle stages covered

Information on object of assessment

- Functional equivalence – building type, technical and functional requirements, pattern of use, service life
- Reference study period
- Other relevant building information – for example, description of structure and services

Assumptions and Scenarios

- Scenario descriptions and assumptions used for product manufacture and supply
- Scenario descriptions and assumptions used for construction process
- Scenario descriptions and assumptions used for use phase including maintenance, repair, replacement and refurbishment
- Scenario descriptions and assumptions used for end of life including processing for reuse, recycling, energy recovery and disposal
- Materiality threshold(s)

Data sources

- Source, type and quality of quantities and materials data
- Quality assessment and selection process for database(s)
- Quality assessment and selection process for emission factors

Presentation of results by:

- Life cycle stage
- NRM elements
- Functional unit and as total embodied emissions

Other analyses may also add insight – for example, categorising the footprint by material group.

9.8 Verification

Recommendation 13: The results should be assured by independent first or third parties.

Verification is an independent assessment of the reliability of the results. It can be first party (undertaken by someone else within the reporting company) or third party (conducted by an independent organisation).

The nature and extent of verification procedures can vary depending on whether the purpose is to obtain 'reasonable' or 'limited' assurance (as described below) but generally comprises a critical review of the GHG assessment which considers:

- Transparency

- Accuracy
- Consistency
- Relevance
- Completeness

Particular attention is given to any factors which may materially affect the stated results. For example, poorly formulated scenarios or badly chosen emission factors.

The verifier will provide an opinion based on their assessment of the documentation provided.

Limited assurance is exception based and may result in a statement such as:

> *Based on our review we are not aware of any material modifications that should be made to the company's assertion that the total embodied emissions of the construction project are 100,000 tCO_2e and are in conformance with the requirements of GLA Construction Scope 3 (Embodied) Greenhouse Gas Accounting and Reporting Guidance.*

Reasonable assurance is the result of a more rigorous process and results in a more positive opinion:

> *In our opinion the reporting company's assertion that the total embodied emissions of the construction project are 100,000 tCO_2e is fairly stated, in all material respects, and is in conformance with the requirements of GLA Construction Scope 3 (Embodied) Greenhouse Gas Accounting and Reporting Guidance.*

Annex A: Reporting template

Building	*e.g. An oak timber community hall*
Client	*e.g. Hampshire County Council*
Assessor details	*e.g. Best Foot Forward*
Date of assessment	*e.g. 15/5/2012*
Verifier details	*Incl. competence*
Statement of verification	*e.g. In our opinion the reporting company's assertion that the total embodied emissions of the construction project are 100,000 tCO_2e is fairly stated, in all material respects, and is in conformance with the requirements of GLA Construction Scope 3 (Embodied)*
Purpose of assessment	*e.g. to achieve a 25% reduction in embodied carbon based on earlier design*
Assessment methodology	*e.g. reference to the approach being used; GLA Construction Scope 3 Guidance*
Period of assessment	*e.g. the 13 months it took to construct the building*
Life cycle stages covered	*e.g. Cradle-to-grave for construction materials*
Functional equivalence	
Reference study period	
Other relevant building information	
Scenario descriptions and assumptions used for product	
Scenario descriptions and assumptions used for	
Scenario descriptions and assumptions for use phase	
Scenario descriptions and assumptions used for end of life	*e.g. The building is estimated to remain standing for 40 years after which time it was assumed 3% of the total carbon impact would be required (in addition) for demolition of the building. 30% of the material would be recycled and the rest go to landfill*
Data source	*e.g. Inventory of Carbon & Energy (ICE) Version 2 and a EPD of oak timber*
Quality assessment of materials data	
Quality assessment and selection process for database	
Quality assessment and selection process for emission	
Results by life cycle stage	*e.g. bar chart splitting the total embodied carbon footprint into appropriate life cycle stages*
Results by NRM elements	
Results by functional unit and as total embodied emissions	

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Acknowledgements

This Guidance has benefited enormously from the input of experts who either responded to the original industry-wide survey, contributed case studies (not all of which the authors were able to use) or acted as reviewers.

In particular, the authors would like to thank John Davies (Davis Langdon), Jane Anderson (PE International), Peter Mouncey (Faulkner Brown), Peter Johnson (Kier Construction), Honor Cowen (Best Foot Forward), Dave Marsh (WRAP) for their considered reviews of early drafts of the guidance and the following organisations for providing case studies:

- Aedas R&D/UCL
- Atkins Rail/oCo Carbon
- Best Foot Forward
- dcarbon8
- Faithful+Gould
- Ramboll
- Willmott Dixon
- WSP
- ZedFactory

Survey respondees included:

Best Foot Forward, Price & Myers, ZEDfactory, Aedas R&D, Valpak, Railpen Investments, Timber Trade Federation, The Berkeley Group, Beyond Green, BAM Construct UK, Sweett Group UK Limited, Amey plc, Penoyre & Prasad LLP, Timber Trade Federation, BioRegional, Transport for London, Ranne Creative Interiors, Construction Industry Council, Saint-Gobain Isover, AEC3 UK Ltd, Thomas Vale Construction, Midas Group Limited, Mace, Severfield Rowen, VINCI Construction UK, Alliance for Sustainable Building Products, Leadbitter Group, Faithful+Gould, Interserve Construction, Balfour Beatty, cushman & wakefield, Elvet Construction Consultants, Willmott Dixon, BLP Insurance, Atkins, Davis Langdon, WSP Group, Waterman Building Services London, Mansell Construction, Skanska, Rider Levett Bucknall, Buro Happold, Ramboll UK, nunelah design consultants, Zero2050, Wates Group, Seddon Construction Ltd, A Man With A Plan Ltd, Wates, Polypipe Terrain, PE INTERNATIONAL, Kier Group, American Hardwood export Council, Architype Ltd, TWP, CSIRO