Embodied carbon in building services: a calculation methodology

1 Introduction

The construction industry needs to improve its knowledge of embodied carbon in MEP systems while continuing to reduce operational carbon emissions in order to holistically mitigate global warming.

1.1 Context

Improving the environmental impacts of the built environment has become a priority given our climate crisis. Greenhouse gas emissions responsible for global warming — measured in carbon dioxide-equivalent — need to be drastically reduced.

The construction industry has long focused on operational carbon emissions and has paid much less attention to emissions related to the rest of the life cycle stages of buildings. To make well-informed decisions that will mitigate global warming, engineers, architects and developers need to embrace whole life carbon (WLC) emissions. This term refers to both operational and embodied carbon emissions, from manufacturing, transporting, constructing, operating, repairing and maintaining a building, through to deconstructing the building and processing waste. All this can be quantified through life cycle assessments (LCA).

Building services engineers have so far been considering operational carbon reductions through the impacts of wider mechanical, electrical and public health (MEP) strategies aimed at reducing energy consumptions of systems, such as encouraging natural ventilation and specifying highly efficient equipment. However, the whole life carbon impacts of MEP systems do not end with operational carbon. MEP equipment represent both a significant embodied carbon impact when a building is first constructed (sometimes referred as upfront carbon (WGBC, 2019)) and repeated carbon impacts through a building lifetime due to high equipment replacement rates. Engineers need to understand the embodied carbon emissions of the systems they design and the products they specify, so that informed choices can be made using 'whole life carbon' thinking.

Based on limited studies that have been carried out so far, MEP could account for 2–27% (Bagenal George et al., 2019) of embodied carbon of new-build schemes (excluding refrigerant leakage impact). In retrofit schemes, the proportion of embodied carbon related to building services can be considerably higher, with one study showing MEP could account for 75% of the embodied carbon (Hamot, 2019). CIBSE Research Report 9 is a useful resource that summarises research in the area of embodied carbon of MEP (Hitchin, 2013).

Environmental product declarations (EPDs) are a standardised way of expressing embodied carbon and other environmental impacts throughout the life cycle stages of a product. However, very few manufacturers of MEP products offer EPDs, mainly due to the complexity of MEP products and their supply chain, but also because incentives from the market and regulation are missing. Therefore, comprehensive knowledge is lacking in the building services industry about the embodied carbon of MEP products and how it varies across different systems and products.

1.2 Aim of this document

Engineers need to understand the embodied carbon emissions of the systems they design and the products they specify, so that informed choices can be made considering whole life carbon (WLC), not just operational carbon.

The aim of this document is to provide:

— an introduction to whole life carbon and embodied carbon within the context of building services

— guidance for engineers and consultants on actions that can be taken to reduce the embodied carbon emissions of MEP equipment
— guidance on environmental product declarations (EPDs), how to use and create them
— where no EPDs are available:
    - guidance on how to calculate embodied carbon of MEP products
    - a consistent approach for collecting the data required for the calculations
    - a consistent approach to the way embodied carbon calculations for MEP products are carried out and reported (at product level).

This guide does not aim at replacing EPDs, but rather allows initial conservative embodied carbon estimations for MEP products to be made, while waiting for EPDs to become available. It provides a consistent approach to facilitate research and thus increase understanding on this subject.

Hopefully, this guidance will move the industry towards a better understanding of the whole life carbon impacts of MEP-related decisions and will incentivise more EPDs for MEP products.

1.3 Scope of this document

The focus of this guide is the calculation of embodied carbon emissions for MEP products. In this document the term 'carbon' captures all greenhouse gas emissions responsible for global warming. It is important to note that global warming potential (GWP) is one of many different environmental impact indicators, which can be estimated through a life cycle assessment (LCA). Further environmental impact indicators can be found in Appendix A.

This guide covers MEP products used for heating, cooling, ventilation, lighting, electrical and public health, it does not include non-standard equipment such as photovoltaics.

As a first step, this document provides guidance on how to estimate embodied carbon at product level, rather than at system or building level. Guidance on system-level whole life carbon assessment may be included in a subsequent version of this guide. Meanwhile, for systems or building-level assessment, dedicated standards and guidance are available to assess whole life impacts and should be followed. These include BS EN 15978:2011, the European EeB Guide (Wittstock, et al., 2011) and *Whole life carbon assessment for the built environment* (RICS, 2017) within a UK context. Supplementary information and guidance on overall environmental impacts specific to building services can be found in CIBSE TM56: *Resource efficiency of building services* (2014) and CIBSE Guide L: *Sustainability* (2020).

This guide is primarily for engineers and consultants working in the UK and in Europe. The principles can be applied to other countries with the appropriate adjustments to certain assumptions such as transport distances; this is detailed in section 4.4.

This document is also relevant to manufacturers, in order to understand and estimate the global warming impact of their products in a conservative way, in the path towards creating full EPDs in the future.

1.4 How to use this document

This guide consists of the following sections:

— Section 1 provides an introduction to this guide.
— Section 2 provides guidance on embodied carbon reductions for MEP products.
— Section 3 provides an introduction to EPDs and how to use them.
— Section 4 outlines two calculation methods that estimate embodied carbon of MEP equipment if no EPDs are available:
    - The 'basic' calculation method requires less information and includes a scale-up factor to cover further life cycle stages
    - The 'mid-level' calculation method requires more information, thus is more comprehensive, but is still not as robust as information available in an EPD.

— Section 5 provides a worked example for each of the calculation methods.

— Section 6 outlines an extension of the method for more advanced users.

— Section 7 outlines next steps and further considerations in production selection including social and health issues.

— Appendices provide further detail on EPDs; guidance on data collection by manufacturers; the differences between EPDs and CIBSE calculation methods; and an 'evidence base' section, providing details on the assumptions behind both calculation methods.

1.5 Definitions

1.5.1 Abbreviations

ASHP: air source heat pump

EPD: environmental product declaration

EC: embodied carbon

GWP: global warming potential

GHG: greenhouse gas emissions

HGV: heavy goods vehicle

HVAC: heating, ventilation and air conditioning

LCA: life cycle assessment

MEP: mechanical, electrical, public health

ODP: ozone depletion potential

PCR: product category rule

VRF: variable refrigerant flow

WLC: whole life carbon

WTT: well to tank

1.5.2 General definitions

Carbon assessment: an LCA that only looks at one environmental impact indicator: global warming potential (GWP), measured in carbon dioxide equivalent (CO_2e).

***Environmental product declaration* (EPD)**: an independently verified and registered document that communicates transparent and comparable information about the life cycle environmental impact of a product.

***Embodied carbon* (EC)**: see 1.5.4.

***Greenhouse gases* (GHGs)**: gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the earth's surface, the atmosphere, and clouds. GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) (ISO, 2018).

***Global warming potential* (GWP)**: an index, based on radiative properties of GHGs, measuring the radiative forcing following a pulse emission of a unit mass of a given GHG in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide (CO_2) (ISO, 2018). In simple terms it is an indicator for the earth's rising temperatures due to GHG emissions.

***Life cycle assessment* (LCA)**: a multi-step procedure to quantify global warming potential and other environmental impacts through the life stages (see Figure 1.1) of a building or a product or system. European Standards BS EN 15804:2012+A2:2019 and BS EN 15978:2011 govern LCA for construction at product and building level, respectively.

Operational carbon: see 1.5.4.

***Product category rule* (PCR)**: defines the rules and requirements for EPDs for specific product types categories. Information to be included: calculation approaches, assumptions and reporting.

Product service life: the number of years for which a product is typically used, until it needs to be replaced (under a set of reference in use conditions (BSI, 2019)).

Whole life carbon **(WLC)**: see 1.5.4.

1.5.3 Life cycle stage modules

The life cycle of a built asset (so, in the case of this document, MEP equipment) is structured in different life cycle stages defined by BS EN 15978:2011, which are sub-categorised into modules. This standardised structure (detailed below in Figure 1.1) is used throughout the document to explain which part of the life cycle the calculations are referring to. The following terms are found in this document:

— ***Life cycle stages***: which describe a general phase of the life cycle; e.g. stage A. These can be broken down by sub-stage, e.g. product stage.

— ***Life cycle stage modules***: which are more specific and describe a precise phase of the life cycle; e.g. A1 (material extraction), A2 (transport to factory), A3 (manufacturing), etc.

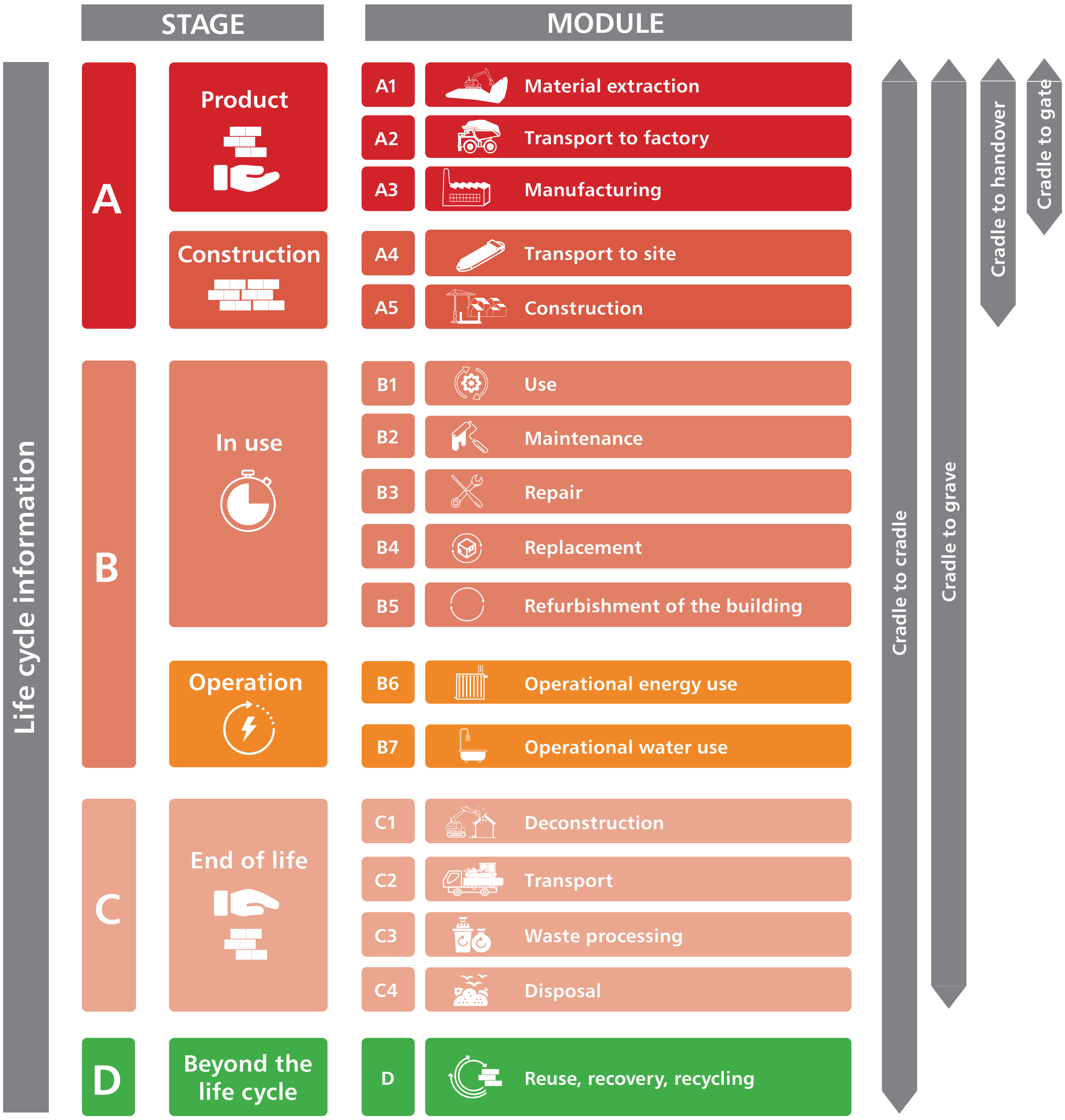

Figure 1.1 Information for a life cycle assessment as defined by BS EN 15978:2011, including typical system boundaries

1.5.4 Carbon definitions

Embodied carbon **(EC)**: in the context of this document, EC refers to the greenhouse gas emissions released[1] to the atmosphere responsible for global warming, associated with the all life cycle except operational emissions and any benefits or load from reuse, recovery or recycling. Following the BS EN 15978:2011 approach to life cycle, embodied carbon can be defined as GHG emissions related to A1–A3 (product), A4–A5 (construction), B1–B5 (in use) and C1–C4 (end of life), as illustrated in Figure 1.2.

It is important to note that this document considers embodied carbon at an individual product level, not at the building level. At product level, embodied carbon does not include emissions associated with B4 (replacement) and B5 (refurbishment), as illustrated in Figure 1.2, therefore only A1–A5, B1–B3 and C1–C4 emissions are considered. If calculations are to be used for building level assessments, B4 (replacement) and B5 (refurbishment) emissions would need to be included. If components are replaced within the product service life (see 1.5.2 above), then this is included in B3 (repair).

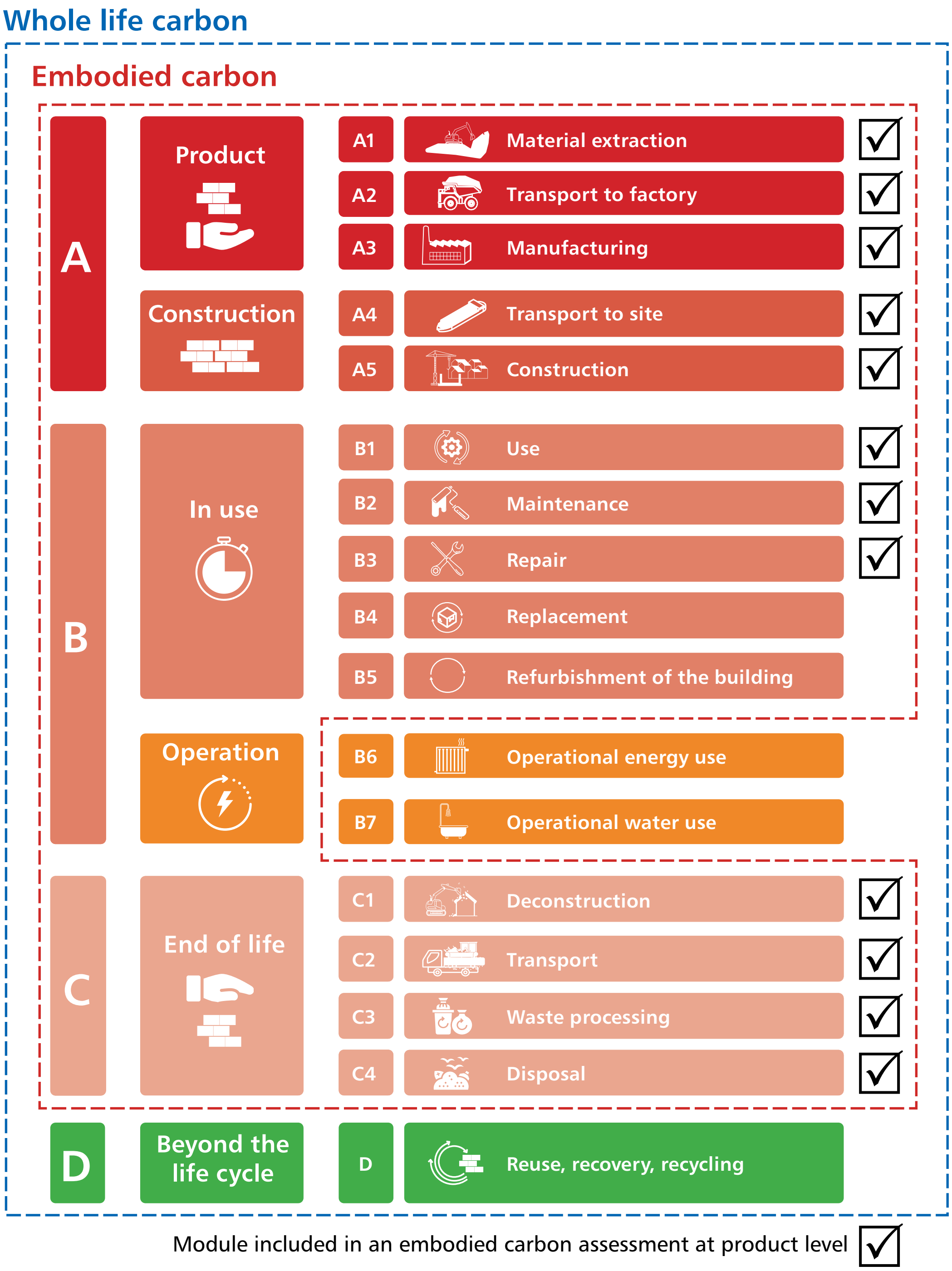

Figure 1.2 Information required for embodied carbon assessment at product level

[1] In some case, GHGs can also be removed from the atmosphere, for example in the case of carbon sequestration of timber.

Operational carbon: greenhouse gases emitted as a result of a building's energy (B6) and water (B7) use during the building's operational lifetime. Operational carbon is outside the scope of this document. It typically includes emissions associated with heating, hot water, cooling, ventilation and lighting systems as well as the energy used in cooking, equipment and lifts. It also includes emissions associated with water usage such as drinking water supply and wastewater treatment.

Whole life carbon **(WLC)**: includes embodied carbon, as defined above, operational carbon as well as any carbon benefits or loads associated with the reuse, recovery or recycling of building materials after its building life (D). The purpose of using WLC is to move towards a building or a product that generates the lowest carbon emissions over its whole life. WLC is also known as 'cradle to cradle'.

Embodied, operational and whole life carbon are expressed as 'CO_2 equivalent' (CO_2e).

1.6 Embodied carbon impact in MEP design

A large proportion of embodied carbon from MEP products is associated with the product stage (A1–A3). This is due to the fact that the majority of MEP components are made of metals, electronics and plastics, and have a complex supply chain. The product stage includes the carbon emissions associated with extraction, transport and processing of materials and the energy consumption used to manufacture the product.

Analysis from 180 mechanical, electrical and public health products from various databases[2] showed that the product stage (A1–A3) represents 92% of the embodied carbon impact, as shown in Figure 1.3. It is important to note that the analysis shown in Figure 1.3 considers embodied carbon of MEP equipment at 'product level', hence replacement of the product is not included (but would be included at 'building level'). Maintenance, repair, deconstruction and transport to waste processing are not included due to lack of data.

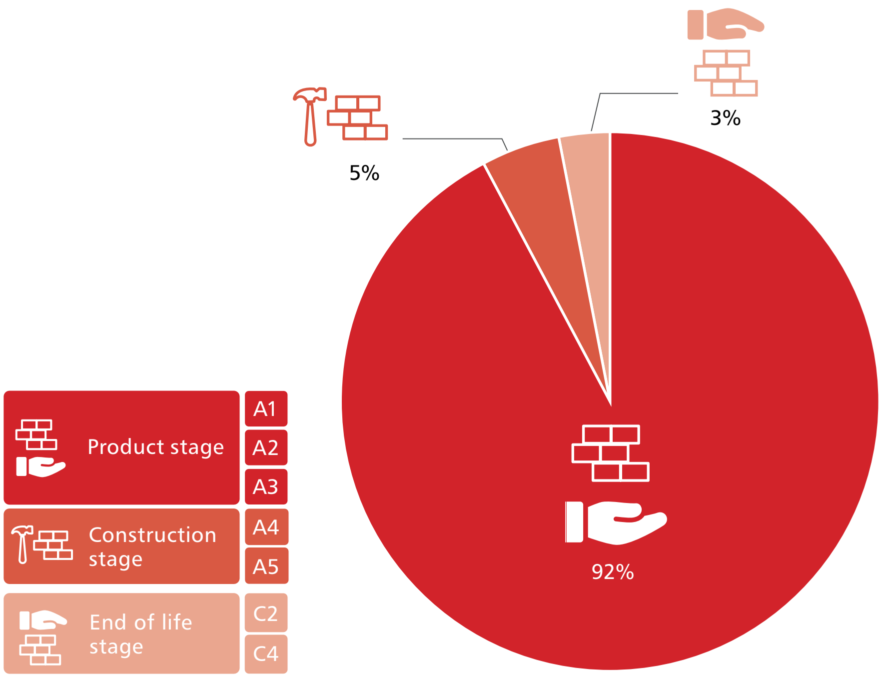

Figure 1.3 Breakdown of embodied carbon per life cycle stage; average results for 180 MEP products

It is important to note that if analysis is undertaken at a 'building level', where replacement must be included, the results would be different; the impact of life cycle stage B (in-use, as shown in Figure 1.1) would become significant. MEP products usually have a relatively short lifespan, which means that they need to be replaced multiple times during a building's lifetime. For more information concerning lifespans of building services products, refer to CIBSE Guide M (2014/2019).

It should also be noted that carbon emissions relating to transport are currently not well understood for MEP products and thus could be larger because of the complexity of the supply chain. It is hoped that this guidance will encourage further research in this area, and updates to this guide may incorporate further details on this aspect of embodied carbon.

[2] Ökobaudat, INIES, EPiC, EPDs