Embodied Carbon Measurement for Infrastructure

Technical Guidance

April 2025

www.infrastructure.nsw.gov.au

Contents

Version	Date	Comment
V1	April 2024	Initial release
V1.1	June 2024	Updated to align with national adoption at the Infrastructure Transport Ministers' Meeting
V1.2	April 2025	Updated to align with additional supplementary measurement guidance and reporting template

1 | About this Guide

The *Embodied Carbon Measurement for Infrastructure: Technical Guidance* (Guide) is designed to support consistent measurement of embodied carbon by NSW Government agencies, their advisors, delivery partners, and emissions tool vendors.

This Guide supports consistency by providing common methodology, assumptions, approach to data use, and reporting approaches.

Measurement of embodied carbon is crucial for its effective management. Embodied emissions are set to form an increasing share of infrastructure-related emissions, as the electricity grid transitions to decarbonised sources and operational emissions decline.[1]

This Guide is intended as a starting point to support the consistent measurement of embodied carbon emissions across NSW Government projects. The Guide presents minimum expectations for carbon measurement and reporting, as well as some additional guidance for agencies with the ability to capture broader emission modules. This Guide will evolve over time to enhance measurement and reporting as maturity increases across NSW Government agencies.

This document should be read in conjunction with the *Decarbonising Infrastructure Delivery Policy, NSW Government Business Case Guidelines*[2] and the *NSW Government Guide to Cost-Benefit Analysis.*[3] Other supporting tools and resources for users are provided in Appendix 1.

A brief overview of each section of this Guide is shown in the figure below.

Table 1.1 Guide overview

Section	Overview
1 About this guide	Provides context and purpose
2 Terms and definitions	A glossary of key terms and definitions used in this guide
3 What to measure	Explanation of the scope of measurement and how to consider whole of life carbon trade-offs
4 When to measure?	Introduction to the three main project stages requiring measurement and data expectations
5 How to measure?	More technical and detailed measurement guidance for robust and consistent estimation of embodied carbon. This includes targeted sections for each of the three measurement stages
6 How to report	Detail on how and when to report embodied carbon across the three stages of measurement
Appendices	Detailed supporting reference information to support measurement, including carbon intensity benchmarks, default assumptions, emission factors, and reporting templates

1 Green Building Council of Australia (GBCA) and thinkstep-anz, Embodied Carbon and Embodied Energy in Australia's Buildings, GBCA and thinkstep-anz, 2021; Architecture 2030, Why the Built Environment?, Architecture 2030 website, n.d., accessed 18 January 2024; Clean Energy Finance Corporation (CEFC). Australian bodies and infrastructure: Opportunities for cutting embodied carbon, CEFC, 2021.
2 NSW Treasury, TPP18-06 Government Business Case Guidelines, NSW Government, 2018
3 NSW Treasury, TPG23-08 NSW Government Guide to Cost-Benefit Analysis, NSW Government, 2023

2 | Terms and definitions

Term	Definition
Activity data	Data based on a unit quantity of input or output of the studied system or a process within, including materials, energy, waste, transport and land clearing.[4]
Agency	All infrastructure delivery agencies.
Assets	All non-financial assets recognised by the agency including, but not limited to, land and buildings, plant and equipment, infrastructure systems, leased assets, works in progress, cultural and heritage collections, ICT systems and digital services.[5] Note that this guidance only covers building and linear infrastructure assets and systems.
Baseline (or reference case)	A business as usual scenario for the level of carbon emissions in the absence of additional measures to reduce emissions levels. It should be based upon consistent as-built data sets from prior project or comparable projects that reflect the time, scale, and scope. [6]
Benefit Cost Ratio (BCR)	The ratio of social benefits to costs that is obtained by dividing the total value of social benefits by the costs to achieve such benefits. The BCR highlights the relationship between the expected gains, and the resources expended to achieve those benefits.[7]
Capital expenditure (or capex)	A form of expenditure that is incurred when money is spent to buy, construct, renovate or acquire an asset. Capital expenditure is clearly assigned to the acquisition and maintenance of capital assets including property, raw materials or technology. [8]
Carbon	Carbon dioxide equivalent for all greenhouse gas emissions.[9]
Carbon emissions	Emissions of greenhouse gases, measured in kilograms or tonnes of carbon dioxide equivalent emissions (CO_2-e).
Carbon intensity benchmarks	Estimates of carbon emissions for an asset, element or process which is based off actual data from comparable projects. The following types of carbon intensity benchmarks are referred to in this Guide: • **Sub-asset or element carbon intensity benchmark –** an element level rate of carbon emissions per item, length or area (e.g., tCO_2-e/m² of roadway or tCO_2-e/km). These carbon intensity benchmarks can be used to estimate an asset's upfront emissions where details of the asset's key elements and size are known but material quantity data is unavailable. • **Asset level carbon intensity benchmark –** An asset level rate of carbon emissions per dollar of capital investment (i.e., tCO_2-e/$). These carbon intensity benchmarks are used to estimate an asset's upfront emissions when material quantity data and sub-asset carbon intensity benchmarks are not available for the asset type.

4 British Standards Institution, PAS 2080 - Carbon Management in Buildings and Infrastructure (2023), Section 3.2 Terms and Definitions, BSI, 2023
5 NSW Treasury, TPP18-07 Organisational Resilience: Practitioners Guide for NSW Public Sector Organisations, NSW Government, 2018
6 British Standards Institution, PAS 2080 - Carbon Management in Buildings and Infrastructure (2023), Section 3.5 Terms and Definitions, BSI, 2023
7 NSW Treasury, TPG23-08 NSW Government Guide to Cost-Benefit Analysis, NSW Government, 2023
8 Methodology from: Australian Bureau of Statistics, Private New Capital Expenditure and Expected Expenditure, Australia, Australian Government, (2023)
9 British Standards Institution, PAS 2080: 2023 Carbon management in infrastructure, BSI Standards Limited, 2023.

Term	Definition
Carbon management	Assessment, reduction and removal of carbon emissions during the planning, optioneering, design, delivery, operation, use, end of life (and beyond) of new, or the management of existing assets, networks and/or systems.[10]
Carbon Management Plan	A carbon management plan is a framework designed to identify and manage greenhouse gases (in the form of CO_2-e) for the identified project, asset or organisation. It is intended to be a **living** document that is revised and updated over the project lifecycle. It allows agencies and their delivery partners to: • define their approach to and opportunities for carbon management and reduction at procurement, design and construction stages • demonstrate who will be responsible for driving, tracking and reporting carbon reductions achieved at various stages of project delivery • document the methodologies used to assess carbon reductions.
Carbon sequestration	The capture and storage of carbon emissions from the atmosphere.[11]
Circular economy	An economy that is restorative and regenerative by design, and which aims to keep products, components and materials in circulation through processes like reuse, refurbishment, and recycling (as opposed to a linear "take-make-dispose" model).[12]
Contribution analysis	Analysis undertaken to determine the importance of different elements of an asset in contributing to overall carbon emissions to identify hotspots and target mitigation efforts to inform decision-making.
Cost Benefit Analysis (CBA)	An evidence-based, systematic and comprehensive economic analysis that aims to measure the full impacts of government decisions on New South Wales, including economic, social, environmental and cultural impacts.[13]
Declared unit	A reference quantity used to report carbon results of a product, project or process when the full life cycle is not being assessed e.g. m^2 Gross Floor Area (GFA) for a building. Unlike a functional unit (see definition below), a declared unit typically does not have a time dimension and so is not suitable when comparing the full life cycle of an asset.
Design life	The period of time during which an asset is expected by its designers to function within its specified parameters.
Embodied carbon (or broader embodied carbon)	The greenhouse gas emissions and removals associated with the creation, maintenance and end-of-life disposal of an asset. This includes the emissions associated with the production and transportation of materials, construction related emissions and end-of-life emissions. In-use stage material-related emissions associated with maintenance, repair, replacement and refurbishment over the asset life are also considered part of embodied carbon. Note: this aligns with definitions in PAS 2080:2023 and RICS *Whole life carbon assessment for the built environment*[14], excluding in-use stage emissions relating to operational expenditure, which is part of operational carbon (see definition below).

10 British Standards Institution, PAS 2080: 2023 Carbon management in infrastructure, BSI Standards Limited, 2023.
11 Green Building Council Australia (GBCA), A practical guide to upfront carbon reductions, GBCA, 2023
12 International Organization for Standardization, ISO 20400:2017 Sustainable Procurement - Guidance, (2017), Section 3.1, ISO, 2017
13 NSW Treasury, TPG23-08 NSW Government Guide to Cost-Benefit Analysis, NSW Government, (2023)
14 Royal Institute of Chartered Surveyors (RICS), Whole life carbon assessment for the built environment (2nd Ed.), Glossary, RICS, 2023

Term	Definition
Emission factor	A conversion factor used to estimate the quantity of carbon dioxide equivalent emissions generated by an activity or process (e.g. the manufacture of a product).
Emissions life cycle module	The different periods of an asset's life are known as its life-cycle stages. Life cycle modules provide standardised designations for each life cycle stage, from A1 to D. They are referred to as product (A1-A3), construction (A4-A5), in-use (B1-B5), end-of-life (C1-C4), operational carbon (B6-B7), user carbon (B8), and benefits beyond the asset life cycle (D).
Enabled emissions (user carbon)	Emissions associated with activities enabled by an asset (e.g. emissions from third-party vehicles driving on a road).
End-of-life carbon	Carbon associated with the deconstruction, transport, waste processing, and disposal of capital assets at the end of their useful life. This forms part of embodied carbon.[15]
Environment Product Declaration (EPD)	An independently verified and registered document that communicates transparent and comparable information about the life-cycle environmental impact (including carbon emissions) of products and services in a credible way. An EPD is compliant with the standard ISO 14025 and is known as a Type III environmental declaration.
Functional unit	The reference quantity or performance measure of the product, process, or service being assessed. It defines the primary function or purpose of the system under analysis, allowing for comparison of different alternatives that fulfill the same function, e.g., generation of one MWh of electricity. Where relevant to make a comparison, a functional unit must also specify a time dimension, e.g., one m^2 of conditioned floor area for one year, with a minimum floor-to-ceiling height of 2.4m.
Maintenance	All actions necessary for retaining an asset as near as practicable to its original condition, or to reduce its rate of deterioration. Road maintenance, as an example, is the work required to keep a road at its specified level of service, including the road surfacing, structure, furniture and drainage system.[16]
Operational carbon	The emissions associated with the operation (i.e., the in-use stage) of assets, particularly operational energy (module B6) and operational water (module B7). It can also include any module from B1 to B5 linked to operational expenditure. Examples include fugitive emissions of refrigerants (B1) and treatment chemicals for (waste)water infrastructure (B2).
PAS 2080:2023 Carbon management in buildings and infrastructure	Specifies requirements for the management of whole life carbon emissions in buildings and infrastructure in the provision, operation, use and end-of-life of new projects or programmes of work as well as the management or retrofit of existing assets and networks.
Refurbishment	Refurbishment (also called retrofit or rehabilitation), as distinct from replacement, is defined as a planned alteration or improvement to the physical characteristics of the built asset, in order for it to perform a future function that was identified and quantified at the outset.[17]
Rehabilitation	Refer to refurbishment definition above.

15 British Standards Institute, PAS 2080 - Carbon Management in Buildings and Infrastructure (2023), Section 3.22 Terms and Definitions, BSI, 2023
16 Austroads, AP-C87-15, Glossary of Terms, Austroads, 2015
17 Royal Institute of Chartered Surveyors (RICS), Whole Life Carbon Assessment for the Built Environment 2nd Edition. "Assessing life cycle stages and information modules". RICS website. 7 March 2023.

Term	Definition
Supply chain	A network of organisations that convert raw materials into finished products and deliver them to the consumer.
System boundary	The spatial, temporal, and functional scope of a life cycle assessment or carbon assessment. It outlines what must be taken into account for the assessment and, therefore, what must be excluded.[18]
Upfront carbon	The carbon emissions and removals associated with the creation of an asset, network or system up to practical completion. This includes the emissions associated with the production and transportation of materials and construction related emissions. It excludes emissions generated during the use and end-of-life stage of an asset.
Upscaling	A technique which can be applied to carbon calculations to account for emissions that are not quantified. It involves determining the coverage of the calculated emissions (for instance, covering 80% of all materials used), and scaling the measured emissions up to 100% for a more accurate representation of the complete carbon account.
Value chain	The organisations, agencies, and industry stakeholders involved in creating, operating, and managing assets and may include government and policy makers, asset owners and managers, designers, constructors and builders, product and material suppliers and lenders.[19]
Whole life carbon (or whole of life carbon)	The total greenhouse gas emissions and removals associated with the creation, operation, maintenance and end-of-life disposal of an asset. This includes upfront carbon as well as in-use emissions (from maintenance, repair, refurbishment, operation, and user utilisation of the asset), end-of-life disposal, and benefits and loads beyond the system boundary (e.g. avoided material production from utilisation of recycled or reused products).

18 British Standards Institution, BS EN 17472:2022 Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods, BSI, 2022

19 British Standards Institution, PAS 2080 - Carbon Management in Buildings and Infrastructure (2023), Section 3.52 Terms and Definitions, BSI, 2023

3 | What to measure?

3.1 Life cycle stages and system boundary

The system boundary determines the asset life cycle stages that will be included in the carbon assessment. This Guide aligns with PAS2080:2023 *Carbon management in buildings and infrastructure,* a global standard, which specifies requirements for the management of whole life carbon in buildings and infrastructure (refer to Box 1). PAS2080 refers to the following more detailed life cycle assessment standards for definition of life cycle stages and the system boundary, which should also be referred to for detailed calculation guidance, depending on the type of project:

- **Buildings or Social Infrastructure** – EN 15978:2011 *Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method.*[20]
- **Civil (or economic) Infrastructure** – EN 17472:2022 *Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods.*[21]

Box 1: PAS 2080:2023 decarbonisation principles

PAS 2080:2023 is an internationally recognised standard, which provides guidance for management of whole life carbon. This includes the management of carbon in the provision, operation, use and end of life of new projects and/or programmes of work, as well as the management or refurbishment of existing assets and networks.

Key principles for PAS 2080:2023 include:

- **Managing whole life carbon under the control and influence of the value chain.** This includes demonstrating the approach to integrating carbon in decision-making when delivering projects.
- **Aligning to a net zero carbon transition,** e.g., taking a system approach by optimising carbon to reduce whole life emissions in the built environment. The "systems" or "network" approach integrates and balances carbon reductions with co-benefit opportunities such as climate adaptation, resilience improvement, nature-based solutions, circular economy, and biodiversity in a whole of life carbon management framework.
- **Implementing appropriate governance to manage whole life carbon.** This includes ensuring consistency in the process of carbon management, including assessment, use of data, procurement, target setting, continuous improvement, monitoring, reporting, leadership, governance and collaboration for decarbonisation.
- **Managing whole life carbon by applying the carbon reduction hierarchy:** the "Avoid, Switch, Improve" hierarchy encourages carbon consideration at the earliest stages of a project.

20 British Standards Institution, BS EN15978:2011 Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method, BSI, 2011

21 British Standards Institution, BS EN 17472:2022 Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods, BSI, 2022

This Guide is also largely aligned with the Royal Institute of Chartered Surveyors (RICS) *Whole life carbon assessment for the built environment* standard[22], which uses these same underlying life cycle assessment standards. RICS' document provides detailed guidance for buildings, and for assessing broader embodied carbon emissions. Agencies and project teams may also wish to refer to additional guidance in the RICS document but should note that there are differences in the approaches to upscaling and uncertainty assumptions.

Figure 3.1 provides an overview of life cycle emissions by modules from EN17472:2022, which incorporates EN 15978 modules and adds pre-construction (A0) and user's utilisation (B8) emissions (note that module A0 is shown in Figure 3.1 below and not required to be assessed in this Guide).

This Guide focuses on modules A1-A5, or upfront carbon associated with the product and construction stages. Additional high-level guidance is provided for in-use (B1-B5) and end of life stage (C1-C4) embodied carbon emissions. These life cycle stages can be included by agencies with maturing carbon measurement capabilities.

Figure 3.1 Sources of whole life carbon emission and illustration of definitions use in this document (adapted from PAS2080:2023 and modules in EN 17472:2022)

Note: circular economy principles can be applied across all work stages of projects and/or programmes of work to assess materials/products in terms of reuse and recycling potential after end of life, as well as their flexibility in being repurposed or refurbished whilst satisfying the whole life performance required from their respective assets and networks.[23]

22 Royal Institute of Chartered Surveyors (RICS), Whole Life Carbon Assessment for the Built Environment 2nd Edition, RICS, 2023.
23 British Standards Institution, PAS 2080 -Carbon Management in Buildings and Infrastructure (2023), Section 3.14, BSI, 2023

3.1.1 Upfront carbon

Detailed measurement guidance is included for the following activities as part of **upfront carbon** (the focus of this Guide):

- **Modules A1-A3**: Carbon emissions from the manufacture of products and materials used in the building or infrastructure asset.
- **Module A4**: Carbon emissions from the transport of products to site
- **Module A5**: Carbon emissions from construction, installation and commissioning processes, including:
  - Energy (primarily diesel and electricity) used in construction machinery or site offices. E.g., operation of cranes, excavators, tunnel boring machines, building site services.
  - Manufacture, transport, and end-of-life treatment of material that becomes construction waste.
  - Land use change from any land clearing activities (especially important for greenfield developments)
  - Enabling works to prepare land for the delivery of the project (note that this could be considered part of A0 but is included here for simplicity)
  - The commissioning of an asset prior to handover to the client.

3.1.2 Broader embodied carbon

Some high-level guidance and recommendations are provided for the following activities as part of **broader embodied carbon** (beyond upfront carbon). Further information on the considerations of trade-offs for these emission sources can be found in Section 3.3:

- Module B1: Use (material emissions and removals)
- Module B2: Maintenance
- Module B3: Repair
- Module B4: Replacement
- Module B5: Refurbishment (rehabilitation)
- Module C1: Deconstruction
- Module C2: Transport of waste
- Module C3: Waste processing for any reuse, recycling and recovery
- Module C4: Waste disposal (e.g., to landfill).

Module D (benefits and loads beyond the asset life cycle, including reuse, recycling and energy recovery) is not considered part of embodied carbon. However, it does relate to embodied carbon impacts as part of whole of life carbon, and may also be relevant to consider.

Further information on the considerations of trade-offs for these emission sources can be found in Section 3.3.

3.1.3 Operational and asset user carbon

The following modules, part of whole life carbon assessment, do not form part of embodied carbon and, as such, are **not covered by this Guide:**

- Module B1: Use (operational expenditure and other operational related activities)
- Module B6: Operational energy use
- Module B7: Operational water use
- Module B8: User carbon (also known as enabled emissions)
- Module D: Benefits and loads beyond the asset life cycle (including from reuse, recycling, and energy recovery).

Refer to Appendix 1 for additional resources that can be used to support measurement of operational and user carbon.

3.2 General exclusions

The following activities **can be excluded** from assessments, as they typically contribute relatively little to embodied carbon and are time consuming to measure:

- Module A0 (from EN17472:2002[24] and not shown in Figure 3.1 above): pre-construction activities, such as land acquisition, site investigations and design, including electricity used off-site for professional services. However, any significant enabling civil works or land clearing should be captured in A5
- Manufacture of machinery and other capital goods used during construction activities (component of A1-3)
- Transport of temporary construction plant and equipment to site (component of A4)
- Demolition of existing structures (for which the majority of embodied carbon is considered part of the previous asset's life cycle) (component of A5).
- Transport of staff to and from the construction site (component of A5).

24 British Standards Institution, BS EN 17472:2022 Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods, BSI, 2022

3.3 Consideration of trade-offs and whole life carbon

This Guide focuses on the quantification of broader embodied carbon. However, agencies and project teams should recognise the importance of considering whole life carbon in decision-making, and the potential carbon trade-offs that could occur when only assessing upfront carbon or broader embodied carbon.

To support agencies with considering trade-offs, Table 3.1 identifies in-use (B1-B5), operational carbon (B6-B7) and user carbon (B8) that may have carbon trade-offs. Table 3.2 provides examples of whole life carbon trade-offs. Where a life cycle stage has a greater contribution or influence on carbon emissions, it is more important to consider it and potential trade-offs when making decisions. This is particularly important during early options analysis.

Plans to shift towards renewable energy in the electricity grid are an important consideration for in-use and operational carbon emissions. The emission intensity of the NSW grid is steadily declining (see Appendix 2). This should be considered when conducting operational carbon emissions calculations (B6-B7), particularly for operational energy use calculations (B6).

Projects should undertake analysis to determine the whole life carbon implications to take into account potential trade-offs. Qualitative assessment can be undertaken where the required data for a quantitative assessment are not available.

Any potential trade-offs should be identified and considered where relevant. Table 3.2 provides some examples of potential whole life carbon trade-offs that could occur.

Table 3.1 Sources of in-use, operational carbon and user carbon emissions of different asset types that may have carbon trade-offs when reducing upfront or embodied emissions

Asset type	In-use (B1-B5) and operational carbon (B6-B7)	User carbon emissions – enabled and avoided (B8)
Building (e.g., precincts, schools, hospitals, correctional facilities)	• Refrigerant leakage (B1) • Operational energy, when not from a renewable source (B6)25	• Energy and transport associated with tenants (if not captured in B6 'operational energy') (enabled)
Road	• Pavement rehabilitation (B4-B5) • Concrete rehabilitation (B4-B5) • Operational energy associated with street lighting, ITS, tunnel ventilation (B6)	• Emissions associated with road users (enabled) • Induced demand of road vehicles (enabled) • Improvement in network efficiency (avoided)
Rail	• Replacement of cable support and cabling (electrified rail) • Operational energy, when not from a renewable source (B6)	• Rolling stock energy use (enabled)26 • Modal shift from more carbon intensive road and air transport, including passenger and freight (avoided)
Water and Sewerage – treatment, supply (network/pipelines), dams	• Fugitive emissions from wastewater and decomposition of vegetation in dams/reservoirs (B1) • Treatment chemicals (B2) • Operational energy (B6)	• If dams/reservoirs are associated with hydroelectric or pumped hydro schemes that may avoid emissions from existing or new fossil-based power generation (avoided)
Energy – generation (renewables) and transmission	• Sulphur hexafluoride (SF6) leakage from substations (B1)	• Displacement of emissions from existing or new fossil fuelled generation (avoided) e.g., for transmission this would apply to Renewable Energy Zones or equivalent (avoided)

25 This is expected to become a progressively smaller share of emissions as the grid transitions to renewable sources and a greater share of building services are electrified.

26 Rolling stock energy could be classified as operational or enabled emissions, depending on ownership of the fleet

Table 3.2 Example whole life carbon trade offs

Trade off example	Description
Surface road vs tunnel	• Tunnels have significantly higher operational energy requirements than surface roads due to 24/7 lighting and ventilation requirements.
Building insulation and operational energy performance	• The addition of insulation or the selection of façade materials with better insulating properties may increase material demand (higher upfront carbon). However, they may reduce operational energy demand (operational carbon).
Road pavement type	• Different pavement types may have trade-offs between upfront and in-use phase carbon emissions; for example, a pavement type with greater upfront carbon may also have improved durability requiring less refurbishment/rehabilitation (and less emissions) over the asset life. • Increased pavement roughness of an option may result in greater fuel consumption and carbon emissions in use (B8 – user carbon).
Electrified vs non-electrified railway	• Electrified rail networks require more infrastructure such as cabling, overhead wiring and gantries (higher upfront carbon). However, they will generally have a lower operational emission intensity (operational carbon) compared to diesel rail networks.
Water treatment process complex in-use emissions	• A certain secondary treatment process may have smaller tank structures (lower upfront carbon) but require greater operational energy and treatment chemicals (operational carbon).
Renewable vs fossil power generation	• Renewable energy generation options such as wind and solar require more materials (embodied carbon) per unit of electricity produced, compared to fossil fuel power plant alternatives. However, renewable energy generation has far less in-use and operational carbon emissions, and only a small fraction of the whole life carbon per unit of electricity output.
Cable sizing and transmission losses	• Cables with smaller cross sections would result in lower upfront carbon, but could increase resistance and result in higher transmission losses (operational carbon).

4 | When to measure?

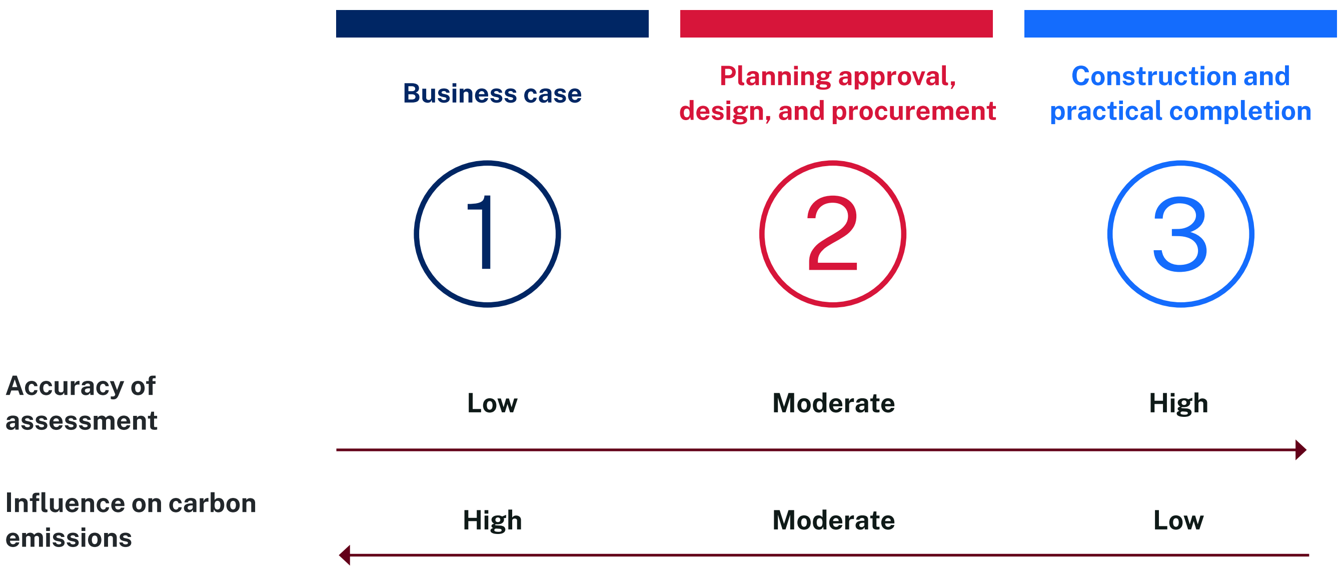
Measurement of upfront and broader embodied carbon is an important aspect of project decision making at key project stages.

During the early stages of a project, the ability to influence carbon outcomes is greatest and intervention is likely to be more cost effective, even though estimates are less accurate. As the project progresses through the various stages, the accuracy of assessments increases with more data availability, while influence over emissions declines. This section discusses the three key stages for measuring emissions.

4.1 Three key measurement stages

In alignment with the *Decarbonising Infrastructure Delivery Policy*, guidance on how to measure upfront carbon and broader embodied carbon is provided over the key stages, shown in Figure 4.1, which also shows the relationship between the ability to influence carbon at each project stage, and the accuracy of embodied carbon assessments.

Figure 4.1 Accuracy of measurement and ability to influence carbon emissions at each measurement stage (adapted from PAS2080:2023 s7.1 Figure 7)



4.2 Purpose of measurement at each stage

Table 4.1 outlines the purpose of measurement at the three stages when measurement must be undertaken.

Table 4.1 Recommended stages for the measurement and reporting of embodied carbon

Stage	Purpose
Stage 1 **Business case**	• Enable effective consideration of carbon emissions in decision-making during early planning and options analysis, when there is a greater ability to influence the option selection process. • Enable earlier identification of lower carbon alternative options. • Enable embodied carbon emissions to be included as a monetised benefit/ cost in Cost Benefit Analysis (CBA). • Inform the development of a Carbon Management Plan at Final Business Case (in line with the *Decarbonising Infrastructure Delivery Policy*). • Option to set an early carbon baseline and reduction objective and target (for agencies with mature carbon measurement capabilities).
Stage 2 **Planning approval, design and procurement**	• Inform planning and other statutory approval applications where relevant. • Focus design and procurement teams' efforts on carbon reduction opportunities. • Inform design development, procurement, and the implementation of lower-carbon solutions in tendering and detailed design. • Where applicable, enable the setting of informed carbon reduction targets, and the monitoring, tracking, and reporting of carbon reductions achieved through design and delivery activities (for agencies with mature carbon measurement and management capabilities).
Stage 3 **Construction and practical completion**	• Enable construction contractors during delivery to readily compare the carbon intensity of different materials and construction methods to facilitate triple-bottom line decision-making. • Enable regular review and monitoring of carbon data during delivery to ensure performance is aligned to emissions reduction target. • Confirm the carbon emissions resulting from the project using actual data. • Inform carbon intensity benchmarks. • Where applicable, assess whether carbon reduction objectives and targets were met (for agencies with mature carbon measurement and management capabilities).

5 | How to measure?

The approach to measuring upfront carbon and broader embodied carbon varies throughout the stages of the infrastructure life cycle and depends heavily on the level of information available at each stage.

The level of detail in estimating carbon emissions should be proportionate to data availability, project size and time available to inform decisions.

This section steps out the process of measuring carbon emissions at each stage and provides key considerations to ensure carbon calculations are consistent, complete and provide meaningful results. A worked example across the three reporting stages is provided in Appendix 3.

5.1 Overview of measurement process

At each stage of the project life cycle where carbon measurement is being undertaken, the following process in line with PAS2080:2023 must be used:[27]

1. **Establish the system boundary for assessment (see section 3)** by identifying the infrastructure's design life, sources of emissions and removals, and considering potential trade-offs (in-use, operational carbon, end of life, and impacts on the network or system).
2. **Assess the impact of carbon emissions and removals (this section)** to the appropriate level of accuracy and detail for the stage in the infrastructure life cycle. Where data to enable quantification is limited in the early project stages, available carbon intensity benchmarks, initial quantities and qualitative assessment may be used to allow options comparison (refer to following sections with additional guidance and the worked example for each key stage of measurement).
3. **Monitor and report carbon emissions and removals (see sections 4 and 6)** to the level of detail appropriate for the stage in the infrastructure life cycle.

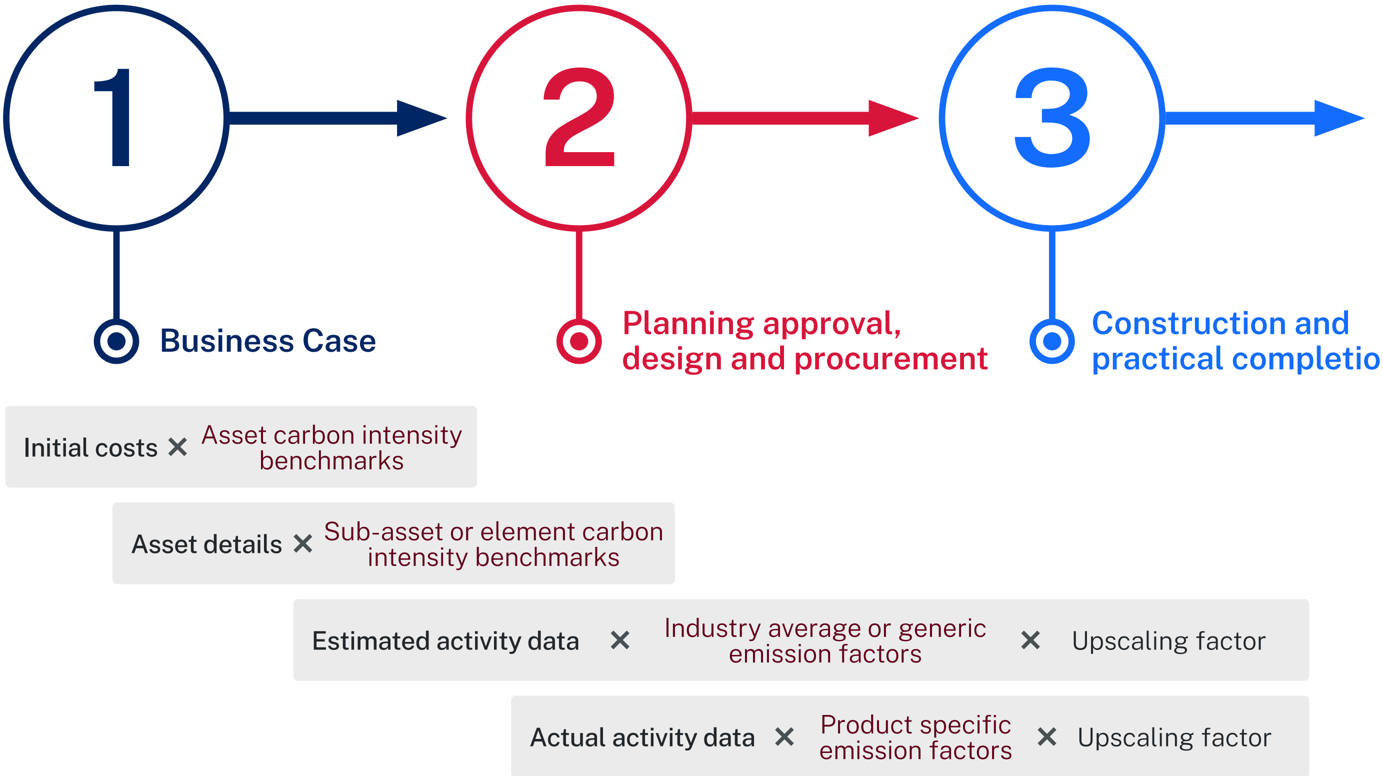
5.2 Calculation approaches by project stage

The approach to measuring embodied carbon varies depending on the project stage and level of information available. At the early project stages, if detailed project data are not available, agencies can estimate carbon emissions based on high-level carbon intensity benchmarks rather than material quantities. However, as more detailed information becomes available throughout the project stages, the approach to calculating carbon emissions becomes more accurate.

Figure 5.1 provides an overview of the suitability of data and calculation approaches over the project life cycle. Each stage is not limited to one calculation approach, and a combination could be used depending on data availability and purpose of assessment. Note that the more accurate methods further on in the project lifecycle should be utilised in earlier stages if available.

27 British Standards Institution, PAS 2080 Carbon Management in Buildings and Infrastructure (2023), Section 3.22 Terms and Definitions, BSI, 2023

Figure 5.1 Suitable emission calculation approaches at each project stage



5.3 Data hierarchy

The below input data hierarchy shows which data sources must be prioritised when conducting embodied carbon assessments depending on the level of data available.

1. **Actual construction data** - resource use quantities reported or collected during the construction stage.
2. **Estimated quantities** - resource use quantities estimated from design e.g., Quantity surveyor estimates or material take-offs from a digital model.
3. **Early asset details (linked to sub-asset or element specific carbon intensity benchmarks)** - project scope information broken down to the sub-asset element, for example, m^2 of road pavement.
4. **Material/capital spend (asset level carbon intensity benchmarks)** - project scope information at the asset level e.g., $ capex or material spend for the asset.

Appendix 4 provides further guidance on suitable data requirements and potential sources of data.

As actual construction data is the most accurate source of information, carbon assessments should prioritise using this when available. However, where actual data are not available, projects can use estimated quantities from a quantity surveyor, digital model take-offs, or other project measurements such as quantities placed for respective materials' contract cost items. Where data from a quantity surveyor is available, this will be more accurate and should be prioritised over digital models. Projects in the earlier stages may not have access to either of these and can refer to their asset details or material spend data to estimate the carbon emissions.

Carbon intensity benchmarks must only be used when material quantity data are unavailable. These should only be required in Stage 1 – Business case. Asset level carbon intensity benchmarks and information about these are provided in Appendix 6.

5.3.1 Suitability of data sources at each stage of measurement

Acknowledging that there are limitations in data availability across infrastructure project stages, Table 5.1 below provides an overview of the data available and relevant calculation method at each project stage. Refer to Section 6.1 for tracking measurement through a Carbon Management Plan.

Table 5.1 Suitability of the data sources across the three stages

Data Input	Benchmark or emission conversion factor (priority)	Stage 1 Business case	Stage 2 Planning approval, design, and procurement	Stage 3 Construction and practical completion
Material spend	• Asset-level carbon intensity benchmarks	✓ Where estimated quantities and sub-asset benchmarks unavailable		
Early asset details	• Sub-asset or element specific carbon intensity benchmarks	✓ Where early asset details are available	✓ Where estimated data are unavailable	
Estimated quantities	• Industry average emission factor • Generic emission factor from database • Generic emission factor from global literature scan	✓ Where estimated quantities are available	✓ Where estimated quantities are available	✓ Where actual data are unavailable
Actual construction data	• Product specific emission factor • Industry average emission factor • Generic emission factor from database or global literature scan			✓ Where data available (focusing on key emission sources)

Note: the ticks represent the suitability of each data input across the three measurement stages.

The **blue** ticks indicate the likely suitable input for each stage.

5.4 Emission factors and carbon intensity benchmarks

Emissions calculations are most accurate when based on measured/estimated material quantities, while carbon intensity benchmarks enable earlier carbon measurement when project data are limited. The following sections provide guidance on how to prioritise different types of emission factors, and how to obtain these from various sources. Section 5.5.1 provides guidance on carbon intensity benchmarks that should be used when estimated quantities are unavailable.

5.4.1 Emission factor and carbon intensity benchmark hierarchy

The below hierarchy must be followed when selecting emission factors depending on availability.

There are efforts underway to develop centralised database of emission factors, and tools that incorporate carbon intensity benchmarks. The following hierarchy has been provided to show the recommended sources of emission factors that are available now, and others that should be prioritised once available (with interim options also provided).

Table 5.2 Emission factor and carbon intensity benchmark hierarchy to be applied when calculating embodied carbon

	Emission factor type and hierarchy	Supported data sources
1	**Product specific emission factor**	• Environmental Product Declaration (EPD) for specific products and suppliers • Climate Active carbon footprint data
2	**Industry average emission factor***	• Australian National Greenhouse Account Factors • Industry average EPD for a product type • NABERS National Emission Factor Database • TfNSW Engineering Cost in Carbon Library** • TAGG – Land clearing emission factors from Appendix E in Greenhouse Gas Assessment Workbook for Road Projects**
3	**Generic emission factor from database**	• TfNSW Carbon Tool and Sydney Metro Carbon Tool emission factors • AusLCI 1.42 and Shadow Database • ICM database (process-based data)** • ICE v4.0**
4	**Generic emission factor from global literature scan**	• Generic emission factors from global literature, where the worst value found for the product type should be used (only where above emission factor sources do not provide coverage)
5	**Sub-asset or element level carbon intensity benchmark**	• There are currently no suitable published data sources available in Australia, and agencies and industry bodies are encouraged to develop benchmarks specific to asset types.
6	**Asset level carbon intensity benchmark**	• Asset level carbon intensity benchmarks are provided in the NSW ECD • Agencies and industry bodies are encouraged to further develop benchmarks specific to asset types.

↑ More accurate and representative
↓ Less accurate and representative

* The following source was removed from this category since the release of the Measurement Guidance v1.0: Infrastructure Australia's industry average emission factors from the Supporting Appendices of the Embodied Carbon Projections for Australian Infrastructure and Buildings.

** Source has been added to the table since the release of the Measurement Guidance v1.0.

The NSW Embodied Carbon Databook (ECD) acts as a non-exhaustive directory to underlying industry average and generic emission factor data. In addition to these, agencies or their tool providers may be required to source their own emission factors and are encouraged to follow the emission factor hierarchy in Table 5.2 above. Appendix 5 also provides guidance on how to source emission data from literature.

5.5 Stage 1 – Business case (measurement guidance)

The Strategic Options and Business Case stages are when agencies and project teams will have the greatest ability to influence carbon emissions through option selection, scope definition, and investment decision. Although the accuracy of assessment may be low, measurement at this stage encourages low-carbon behaviours and decisions, even in the absence of detailed data. The use of initial estimates (where available), high-level project details and carbon intensity benchmarks can overcome data availability barriers to measurement.

While assessments using carbon intensity benchmark data are less accurate, they are appropriate in earlier stages of the infrastructure asset life cycle, since estimated quantities are often unavailable (or limited to major civil and structural elements). The accuracy of the assessment should be proportionate to the size, risk, available information, and complexity of the investment proposal. Project teams should consider and consult with NSW Treasury on whether more detailed and accurate assessment is required in CBA and business case submissions. Where further detail and accuracy is required and data are available, please refer to section 5.6 for the Stage 2 measurement approach.

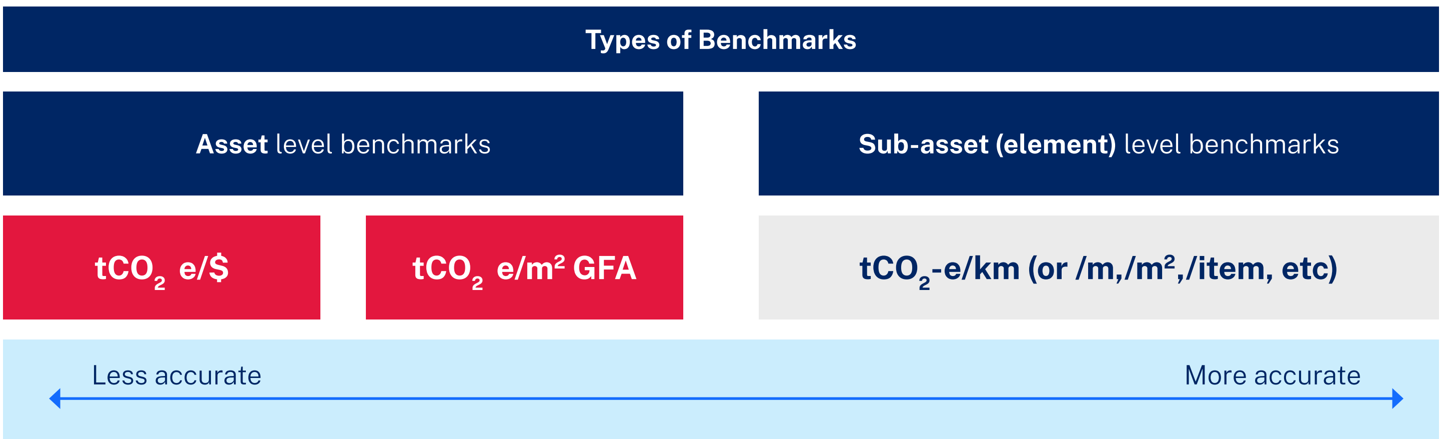
Measurement of emissions, and the application of the suitable carbon value, is required within business cases as part of the *NSW Government Guide to Cost-Benefit Analysis* and will therefore inform a project's benefit-cost ratio. At Final Business Case, the carbon measurement undertaken should also be documented in a Carbon Management Plan (as required in the *Decarbonising Infrastructure Delivery Policy*).

5.5.1 Use of early project details and carbon intensity benchmarks

Figure 5.2 below provides an illustration of the information and example units for the two key types of carbon intensity benchmarks referred to in this guidance:

- **Asset-level carbon intensity benchmarks** represent carbon intensity for the whole asset and allow carbon to be estimated based on physical characteristics or materials expenditure. These have low accuracy and are most suitable at early stages in the project life cycle (Stage 1) when little project information is available. Default asset-level carbon intensity benchmarks for upfront carbon have been provided in Appendix 6. These are based on the predicted expenditure on materials and are detailed further in the section below.
- **Sub-asset or element specific carbon intensity benchmarks** are generally bottom-up benchmarks that have been developed for a certain type of asset and should ideally be based off design standards or a representative sample of projects. These should be prioritised relative to asset-level benchmarks if available. These have not been provided in this Guide, but agencies may wish to develop and use their own sub-asset or element carbon intensity benchmarks if they have been developed.

Figure 5.2 Types of carbon intensity benchmarks



Note: asset-level benchmarks outlined in **red** are provided in Appendix 6 (for upfront carbon only).

Asset-level carbon intensity benchmarks provided in Appendix 6

Asset-level carbon intensity benchmarks have been developed as a part of the Infrastructure Australia's *Supporting Appendices: Embodied Carbon Projections for Australian Infrastructure and Buildings*[28] and are provided in Appendix 6. These asset-level carbon intensity benchmarks are based on predicted expenditure on materials and aggregated carbon emission activity data at the economy level. These are provided for the product stage (A1-A3), transport (A4) and construction and installation process (A5) separately, and account for all emissions within the module.

When using asset-level carbon intensity benchmarks, the following must be noted:

- Asset-level carbon intensity benchmarks for A1-A3 should not be used alongside other measurement techniques (e.g. material quantity estimates and emission factors).
- Where A1-A3 specific material quantities are known and used to calculate these impacts:
  - A4 transport to site impacts should be calculated from quantities using the default assumptions in Appendix 8.
  - A5 construction carbon intensity benchmarks may still be used (in the absence of available data on construction activities).
- Where the predicted expenditure on materials is unknown, projects can use default assumptions for the proportion of capital expenditure on materials, provided in Appendix 6. Projects may also choose to adopt qualitative and semi-qualitative assessment when data are limited.
- Where estimating embodied carbon (beyond upfront carbon), the current carbon intensity benchmarks are limited and do not cover in-use modules (B1-B5). Estimation of these impacts will either require material quantity data to be used, or further development of carbon intensity benchmarks.

Case Study 1 below demonstrates how asset-level carbon intensity benchmarks and default assumptions can be used during the early planning stages of a project.

Case Study 1

Using asset level carbon intensity benchmarks

A project is conducting an upfront carbon calculation during the Business Case phase. In the absence of better information such as high-level material quantities or sub-asset carbon intensity benchmarks, the following asset-level benchmark methodology was used:

$$\textbf{Total Upfront Carbon } (tCO_2\text{-}e)=(a+b+c)\times(d)\times(\$)$$

Where:

a is the asset level benchmark for the product stage (A1-A3) module

b is the asset level benchmark for the transport (A4) module

c is the asset benchmark for the construction and installation process (A5) module

d is the percentage of project CAPEX which is typically allocated to materials

$ is the project CAPEX

Note: inputs **a-d** can be found in Appendix 6.

28 Infrastructure Australia, Supporting Appendices: Embodied Carbon Projections for Australian Infrastructure and Buildings, Infrastructure Australia website, 2024

5.6 Stage 2 - Planning approval, design and procurement (measurement guidance)

At this stage of measurement, estimated quantities will become available through design development, quantity surveyors or more detailed cost estimation. Carbon measurement should be undertaken during design development and inform procurement. A robust carbon assessment can help to identify high impact areas for potential reductions and should be completed prior to procurement and / or detailed design. This assessment can be used to inform carbon reduction targets and requirements in procurement.

5.6.1 Minimum inclusions

Carbon calculations should cover a minimum of 80% of materials and 80% of construction activities (based on predicted spend on materials). To achieve the 80% completeness target in embodied carbon calculations, minimum inclusions (for modules A1-A5 and B1-B5) have been outlined for some of the main asset types (as defined in Infrastructure Australia's *Infrastructure Market Capacity Report 2022*, shown in Figure 5.3 below).[29] These have been provided in Appendix 7.

Figure 5.3 Infrastructure asset types covered in this Guide (aligned with Infrastructure Australia's *Market Capacity Report*)

Super sector	Master type	Typecast
Transport	Road	State road (highways/freeways)
		Bridge (road)
		Tunnel (road)
	Rail	Main line works (rail) (greenfield)
		Bridge (rail)
		Tunnel (rail)
Utilities	Water and Sewerage	Water pipeline
		Water treatment plant
		Dam
	Energy	Wind
		Solar (utility)
Buildings	Eduction, Health and Justice	School and higher education, hospital, correction centre

29 Infrastructure Australia, Infrastructure Market Capacity Report, Australian Government, 2022

For the construction stage (modules A4-A5), the following activities should be included in the embodied carbon calculation as a minimum:

- Construction energy
- Land use change
- Transport of materials to site
- Waste generated during construction (on-site)
- Commissioning energy

Further details on construction stage minimum inclusions are provided in Appendix 7.

Where project teams do not have the data to cover the minimum inclusions, default calculation assumptions provided in Appendix 8 can be used.

This Guide provides default calculation assumptions across the following areas:

- Transport distances and vehicle load assumptions for materials and waste
- Construction waste generation rates
- End-of life treatment rates (recycling vs disposal).

For construction electricity and fuel use, fuel burn rates for site vehicles and stationary plant can be obtained from the TfNSW Carbon Tool (when available) where this is unknown.

The following case study (Case Study 2) demonstrates how to use transport distance assumptions to calculate the emissions from transport when no supplier distances are available.

Case Study 2

Note the data used in this case study is out of date.
Please refer to the NSW Embodied Carbon Databook for the most current data.

Calculating carbon emissions from transport of materials to site

During the detailed design phase, a project is seeking to calculate the transport emissions associated with the **50 tonnes of gravel** required.

Without knowing who the supplier will be, the project used the default transport distances and transport mode provided in Appendix 8 and transport emission factors in Appendix 2.

- **Gravel transport assumptions** – 66km via **articulated truck**.
- **Articulated truck emissions** – 0.00007 tonnes CO2-e/tonnes.km transported

These were then multiplied by the quantity of gravel needed using the following equation.

$$\textbf{Transport emissions } (tCO_2\text{-}e) = 50 \text{ tonnes (gravel)} \times 66 \text{ km} \times 0.00007\ tCO_2\text{-}e\ /\text{tonnes.km}$$

The total transport emissions for the gravel required was calculated to be **0.231 tonnes CO_2-e.**

5.6.2 Scope and completeness of assessment

Carbon calculation at the planning approval, design and procurement stages should aim to include all emission generating activities as far as feasible. However, it is recognised that there will be emissions that are not quantified due to time or information constraints. Where this has occurred, upscaling should be used to ensure carbon assessments are complete and comparable.

To upscale an assessment, project teams must determine completeness of the carbon assessment, and then upscale for the remainder to account for the activities not quantified. Completeness and upscaling can be conducted using the following approach for each module:

- **Product stage (A1-A3), repair, replacement, and refurbishment (B3-B5)** – completeness is to be assessed against the total material cost, and then upscaled to 100%
- **Transport (A4)** – completeness is to be assessed against the total material cost and calculations in line with coverage for A1-A3, with calculations upscaled to 100%
- **Construction and installation process (A5)** – the approach for assessment of completeness will vary with data availability, and calculations are to be upscaled to 100%. If available, using estimated data will improve the accuracy of assessments and support consistent comparison between options and assets. While less accurate, carbon intensity benchmarks and upscaling for A5 emissions, are suitable where data is limited and will reduce the burden of data collection and analysis. The approach to calculating completeness based on each data source is as follows:
  - where construction data is not available to estimate carbon emissions, the module A5 carbon intensity benchmarks in Appendix 6 can be used
  - where construction waste data is available, waste generation estimates should be based on materials included in the product stage calculations, and the same completeness as module A1-A3 can be assumed
  - where data for plant and equipment use is available, then completeness for electricity and fuel use calculations should be assessed against the total plant and equipment costs
  - estimates of land clearing impacts should be aiming for 100% completeness based on the best information available.

For modules B1 (use – material emissions and removals), B2, C1-C4, and D, the contribution to emissions is typically relatively low, and therefore outside the 80% threshold for minimum inclusions.

Where projects have included all minimum inclusions outlined in Appendix 7, and available spend data does not allow for completeness of calculations to be assessed, a default completeness of 80% can be assumed (where coverage of estimated quantities that emissions have been calculated are unknown). Case Study 3 below outlines the methodology which is to be used when upscaling calculated emissions to 100%.

Case Study 3

Using the upscaling methodology

During detailed design stage, a school project is conducting an upfront carbon assessment and has included all the product stage (A1-A3), transport (A4) and construction and installation process (A5) minimum inclusions outlined in Appendix 7.

With all minimum inclusions covered, the project has assumed a **default completeness rate of 80%**, requiring each module to be upscaled by 20%. However, if the upfront carbon calculations went above and beyond the minimum inclusions, a project specific completeness rate can be calculated instead, increasing the accuracy of the assessment.

To upscale the upfront carbon calculation from 80% to 100%, the following methodology was used.

$$\textbf{Total Upfront Carbon } (tCO_2\text{-e}) = \frac{a}{(80\%)} + \frac{b}{(80\%)} + \frac{c}{(80\%)}$$

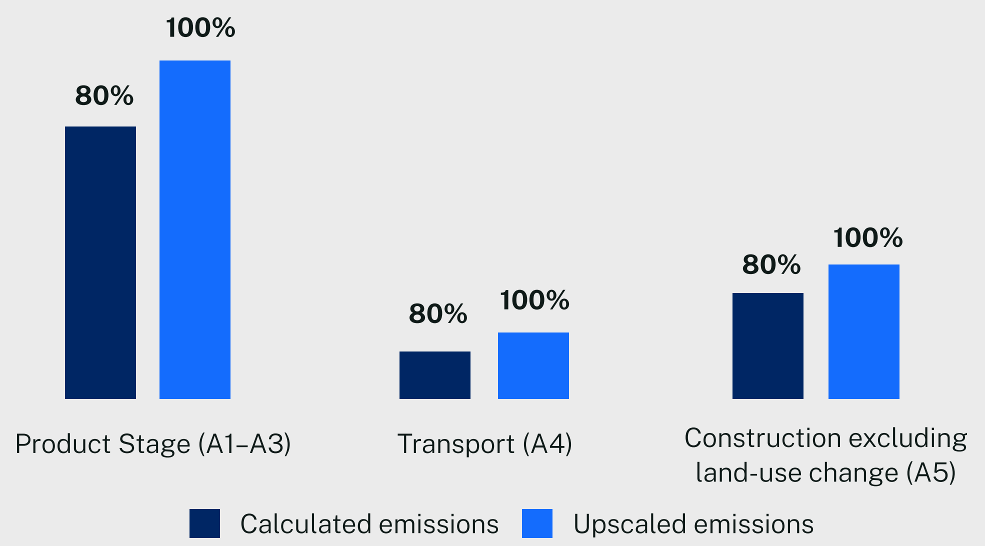
Where:

a is the calculated product stage (A1-A3) emissions (*80% completeness*)

b is the calculated transport (A4) emissions (*80% completeness*)

c is the calculated construction energy and waste (A5) emissions (*80% completeness*)

d is the calculated land-use change emissions (*100% completeness*)



5.7 Stage 3 - Construction and practical completion (measurement guidance)

At construction and practical completion, the accuracy of carbon measurement should be improved with actual data on key activities (major contributors to upfront carbon). This Guide recognises that data accuracy will improve over time as capability to track emissions increases across industry and agencies will be able to report actual data on a larger share of their activities.

5.7.1 Updating assessment with available actual quantity data

To facilitate this process, key activities should be tracked throughout the construction stage, including:

- **Material use for major elements** – e.g., concrete, steel, asphalt, granular pavement material, etc.
- **Construction energy use** – including grid electricity, renewable electricity, diesel, biofuels, and gasses
- **Construction waste** – including quantities and disposal/treatment methods.

For any inputs or activities for which actual data are not available, the latest available design estimates can be used, for example, design estimates that are Issued for Construction (IFC). Where there are significant changes to design in construction, these estimates should be updated with as built documentation.

5.8 Additional measurement guidance

This section is for agencies and project teams with maturing carbon measurement capabilities, or those setting baselines and target or comparing options. The following sections cover how to ensure consistency in:

- options analysis and comparisons
- contribution analysis
- setting baselines
- measuring reductions through the project life cycle.

5.8.1 Consistency in options analysis and comparisons

The embodied carbon assessments conducted at different project stages cannot be used for absolute comparison, due to changing data quality.

If project teams are undertaking comparative carbon assessment, such as for options analysis or target setting, the options must have consistent:

- Scope, function, and level of services, except where options with differing scope and function are being compared in the Strategic Options or Business Case phases. Where this is the case, this should be acknowledged when making comparisons
- Practical asset lifetime, used to account for in-use phase emissions
- Life cycle stage system boundary
- Calculation methodology
- Data sources, quality and completeness (noting that level of detail can vary significantly with level of design)
- Carbon intensity benchmarks and/or emission factors data hierarchy
- Site work boundary
- Building and infrastructure asset elements boundary
- Cut-off rules
- Assumptions on carbon sequestration, carbon neutral products, and carbon offsets
- Considerations for demolition and reuse of existing building and infrastructure assets
- Functional or declared units to enable fair comparison in decision-making (sometimes options may provide differing levels of function or service). For comparisons against a reference project in tendering, the tendered offer should have the same function or service provision.

The baseline must represent business-as-usual performance, i.e., it must not be an artificially high-carbon option to make the improvements look larger.

- Account for improvements that would typically be made during the project for reasons other than carbon, e.g., through value engineering.

Differences between the base case and proposed projects or options can include:

- Reuse of existing elements
- Novel and innovative improvements through value engineering that are beyond business as usual design development (where explanation of the interventions taken should be provided for context)
- Material selection and procurement (products which provide the same function with lower impact)
- Transport mode, distance, and emissions such as savings through locally sourced materials.
- Construction process and emissions.

If considering in-use embodied carbon differences, additional differences between the base case and proposed project or options can include:

- Design life of materials/ elements reducing or increasing replacement rates
- Material or product selection that influences maintenance scheduling and ease of refurbishment or replacement
- Agencies are encouraged to use a Carbon Management Plan to track these considerations and ensure appropriate comparative carbon assessments.

5.8.2 Using contribution analysis to inform decision-making

Contribution analysis is an important step in carbon assessments for building and infrastructure. It provides valuable insights into the relative importance of different elements, processes, specific materials, or life cycle stages in contributing to the overall carbon emissions. It helps decision-makers to:

- **Identify hotspots** or better understand drivers of carbon emissions e.g., specific construction materials which may be responsible for a large share of embodied carbon
- **Target mitigation efforts** by focusing on the most significant opportunities to reduce carbon emissions
- **Compare alternative options** within the assessment boundary
- **Provide more transparent communication** of results
- **Support benchmarking** of sub-asset elements if there is consistent classification and reporting by asset elements.

Contribution analysis is important to understand which project elements and processes contribute most to the overall carbon footprint. It also pinpoints areas for implementing carbon reduction opportunities.

When performing contribution analysis by asset element, it is recommended to align with an appropriate classification system for your agency and project. The following examples are often used for quantity surveying:

- *Australian Cost Management Manual*30
- *CESMM4: Civil Engineering Standard Method of Measurement, Fourth edition*31 (most appropriate for linear infrastructure)
- *ICMS3: Global Consistency in Presenting Construction Life Cycle Costs and Carbon Emissions*32 (most appropriate for buildings)

The following case study (Case Study 4) demonstrates the value of conducting a contribution analysis and how this can inform decision making.

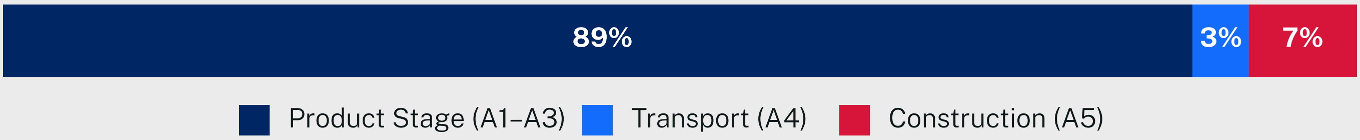
30 Institute of Quantity Surveyors, Australian Cost Management Manual, IQS, 2023
31 ICE, CESMM4: Civil Engineering Standard Method of Measurement, Fourth edition, ICE Publishing, 2012
32 Royal Institution of Chartered Surveyors, ICMS3: Global Consistency in Presenting Construction Life Cycle Costs and Carbon Emissions, RICS,2021

Case Study 4

Contribution analysis for an example road project

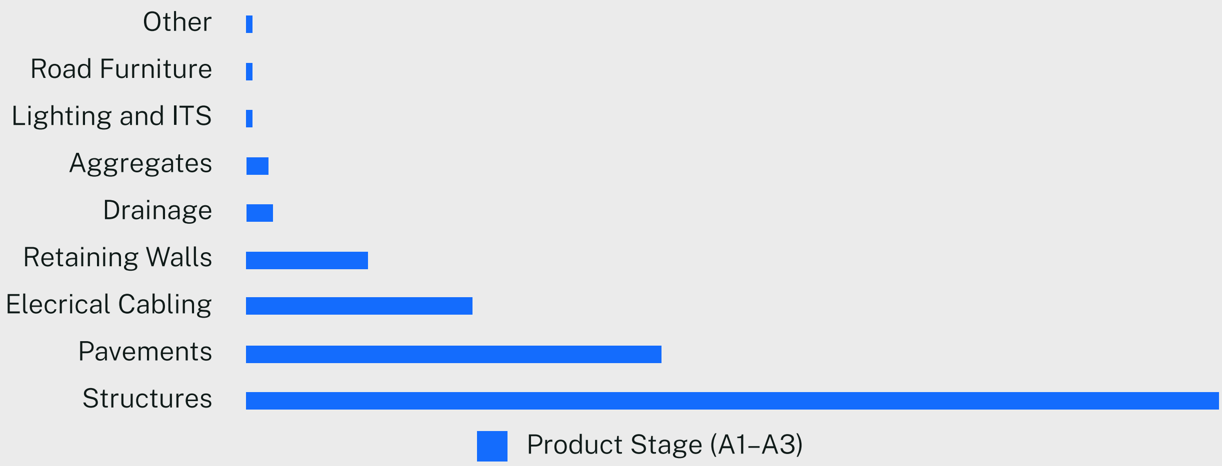
A major road project with significant bridge structures could generally result in upfront carbon emissions per lifecycle stage shown in the chart below. That is, most emissions result from the product stage. However, to understand the source of emissions, further contribution assessments are required.

Upfront carbon contribution by life cycle stage (A1–A5)



The chart below shows a material (A1-A3) contribution assessment, displaying the major sources of emissions for the product stage. This further analysis reveals that the structural components contribute the most to product stage emissions, therefore warranting more focus for mitigation efforts.

Material upfront carbon contribution (A1–A3)



5.8.3 Measuring carbon reductions through stages of measurement

Setting baselines

If setting a carbon reduction target, an accurate and comparable baseline (or reference case) should be used to measure the carbon reductions expected or achieved for a project against that target.[33] A baseline provides a scenario for carbon emissions that will be produced under a business-as-usual approach.

When a baseline has been set, projects can measure carbon reductions available. This can be used to compare against various design options, or to assess reductions achieved through design refinement and construction through to practical completion. When doing so, the baseline and any compared options must follow the guidance in section 5.8.1 above (consistency in options assessment and comparisons).

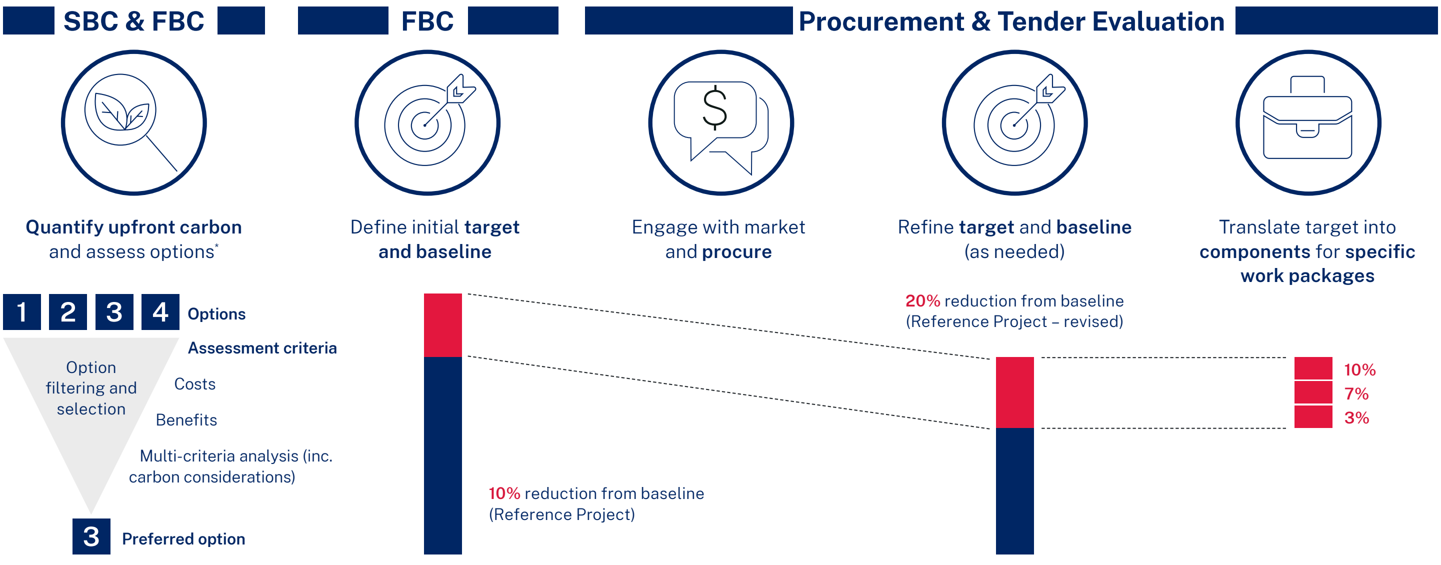
For some design and procurement options, a complete project baseline may not be required. However, reference or baseline assumptions should still be clearly shown for completeness.

Baseline refinements

Baselines should be refined over time as scope and data certainty increase over time (see Figure 5.4). The baseline must be revised to reflect any changes to the assumptions and quantities used for the carbon calculations, such as changes in level of detail (affecting data quality and completeness), or changes to the scope of the project (e.g. reducing the number of lanes on a road).

For example, updates to the baseline may be made prior to procurement to better inform contributions to carbon reduction opportunities. Both the baseline and the target should also be revisited following procurement to reflect any further carbon reductions proposed by the successful bidder.

Figure 5.4 Baseline and target setting for maturing agencies, refining with data and scope certainty[34]



* The quantification and assessment process will occur as part of the Strategic Business Case (SBC) and the Final Business Case (FBC).

Note: Percentage values provided in the figure above are indicative only

33 British Standards Institution, PAS 2080 Carbon Management in Buildings and Infrastructure (2023), Section 8, BSI, 2023
34 Adapted from Infrastructure Partnerships Australia (IPA), Decarbonising Construction: Putting Carbon in the Business Case, IPA, 2022.

Measuring carbon reductions

When carbon reductions are measured during the construction phase or at practical completion, the assessment must use actual data available to assess the reduction achieved. Refer to Section 5.8.1 and Section 5.8.2 above for further details on setting baselines and making fair comparisons.

Projects undertaking Green Star or Infrastructure Sustainability Ratings should refer to associated guidance for the development of a baseline and measuring carbon reductions.

The following case study (Case Study 5) demonstrates a scenario where the baseline would need to be recalculated due to significant project and scope changes in detailed design.

Case Study 5[36]

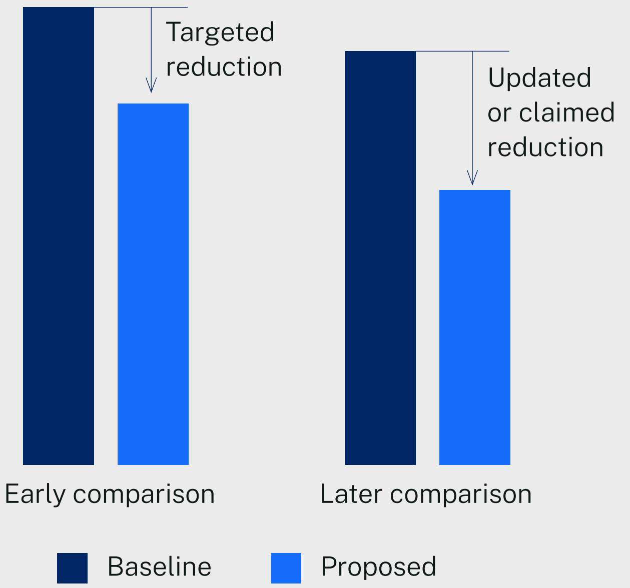
Updating the baseline as you move through stages of measurement

During the concept design stage, a carbon assessment was conducted for a school project that led to the development of a carbon emissions baseline and carbon reduction target.

However, during detailed design, the scope of the project was refined, resulting in a reduction to the size of the buildings and number of classrooms provided. This significantly decreased the total gross floor area of the project.

As this was a scope change from the original design, a revised baseline was required.

The carbon baseline was updated at practical completion to reflect the scope changes. The project's carbon emissions at practical completion were then compared against the updated baseline to understand the level of carbon reductions achieved.



35 Adapted from Infrastructure Partnerships Australia (IPA), Decarbonising Construction: Putting Carbon in the Business Case, IPA, 2022.

6 | How to report?

Consistent reporting of embodied carbon at key project delivery stages should be undertaken to support decision-making and reducing carbon within projects.

- Iterative reporting within project teams and agencies is recommended to monitor progress against targets and KPIs.
- External reporting is also required at Final Business Case, as part of planning approval submissions, and at practical completion.

Collecting consistent external reporting data across agencies will assist comparison of asset types across the NSW Government and will be essential to develop improved carbon intensity benchmarks and assumptions across the infrastructure sector.

Where possible, reporting should use consistent units to convey the project's embodied carbon, as well as provide breakdowns of carbon emissions based on the asset's life cycle stage, asset type and, where possible, key asset elements contributing to carbon emissions. Further details to guide consistent embodied carbon reporting are provided in the section below.

6.1 Agency monitoring and reporting

Aligning with PAS2080:2023, project teams should establish robust, frequent, and transparent monitoring and reporting. Agencies with maturing capability may also report internally to demonstrate projects and/or programmes of work that are progressing against carbon reduction targets. Reports should:

- address relevant legislative, policy, and funding obligations,
- support decision-makers to manage whole life carbon,
- provide information for future continuous improvement.

The *Decarbonising Infrastructure Delivery Policy* introduces the Carbon Management Plan for projects and programs. The objective of a Carbon Management Plan is to document the project's carbon management processes including measurement. Once created at the Final Business Case stage, it is best practice to update the Carbon Management Plan with measurement data at:

- design and procurement (ideally prior to tender)
- practical completion (for use in evaluation and development of lessons learned).

Agencies may instead select to include the results of carbon assessment as part of other plans and progress reports.

6.2 External reporting requirements

An overview of the external reporting at each project stage is outlined in Figure 6.1 and discussed in this section below. Where a project is seeking planning approval, external reporting of carbon measurement is required within planning approval documentation. As the carbon calculations become more detailed throughout each measurement stage, it is recommended that reporting also becomes more detailed to provide clear, transparent, and useful data.

Figure 6.1 External reporting of carbon emissions at each project stage

	Strategic Options and Business Case	Planning Approval, Design and Procurement	Construction and Practical Completion
	1	2	3
Recommended reporting stages	**Final Business Case**	**Planning Approval**	**Practical Completion**
What to report	• Total emissions • Project input data	• Total project emissions • Emissions per life cycle module • Emissions per declared unit • Emissions per asset type • Project activity data	• Total project emissions • Emissions per life cycle module • Emissions per declared unit • Emissions per asset type • Project activity data • Reductions compared to base case (if target setting)
	Submitted as part of Business Case	Align with planning approval reporting	Reporting in line with templates in Appendix 9

During Stage 2, agencies should consider additional iterations of measurement and reporting to inform design development and/or procurement. During both Stage 2 and Stage 3, projects should aim to report on total emissions per life cycle module and emissions per declared unit (see Appendix 9).

Where assets have multiple asset types, a separate reporting template with results for each asset type should be reported. This will facilitate the accurate comparison and benchmarking of emissions for project types and allow a better understanding of carbon emissions associated with assets and sub-asset components. For example, when comparing road projects, the carbon emissions for at grade portions (with no bridge or tunnel components) will be significantly different to those with bridges or tunnels included.

Reporting templates which capture the components discussed above have been provided in Appendix 9.

6.3 Use of functional or declared units

In addition to reporting the total embodied carbon quantified, carbon totals should be provided in relation to suitable declared units. This is important to support the comparison and evaluation of options and enable the development of carbon intensity benchmarks.

Functional or declared units are an important concept in life cycle and carbon assessments for building and infrastructure projects, as they provide a standardised basis for comparison and evaluation of options. The declared unit acts as a reference quantity that represents the primary purpose or function of the project or options being assessed.

For instance, the embodied carbon from a road project relating to a functional or declared unit is often expressed in tonnes of carbon dioxide equivalent per lane kilometre (tonnes CO_2-e/lane.km), whilst the embodied carbon metric for building projects is typically tonnes of carbon dioxide per gross floor area (tonnes CO_2-e/GFA).

Recommended declared units for different asset types are given in Appendix 10.

The specific benefits of functional and declared units include:

- **Fair comparison:** they enable meaningful comparisons between different products or services that might have different characteristics, functions, or production processes.
- **Normalisation of results:** carbon impacts often depend on the scale of asset or service provided. The functional or declared unit allows normalising the impacts to a standardized reference quantity, ensuring that the results can be interpreted correctly regardless of the scale of production.
- **Decision-making:** they help in making more informed decisions during evaluation of options, as they provide a clear representation of impact relative to the desired function or service (project needs).
- **Enabling development of future carbon intensity benchmarks:** reporting of embodied carbon by a functional or declared unit can help to develop future carbon intensity benchmarks across projects of differing scale and service capacity, which can then be used to inform early planning and business cases.

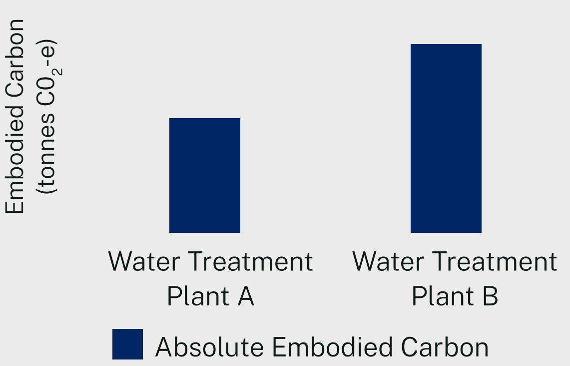
Case Study 6 below demonstrates the use of declared units when comparing two design options.

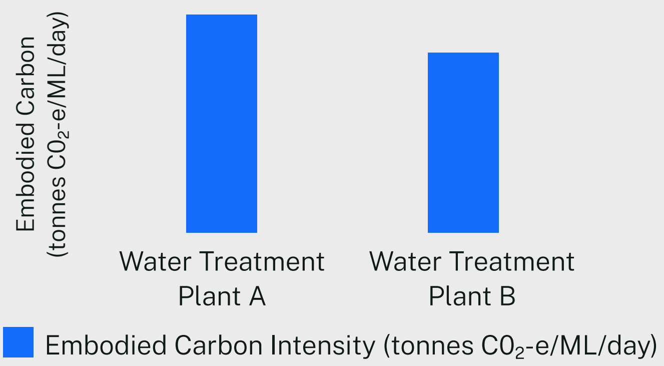
Case Study 6

Use of declared units for comparison

Two designs for water treatment plants are being compared in an early-phase options analysis. Water Treatment Plant A is designed to treat a total of 150 ML/day of wastewater, whilst Water Treatment Plant B has the capacity to treat 250 ML/day.

In comparing the options, Water Treatment Plant A results in a lower total embodied carbon, however, it is not until you compare based on the declared unit (ML water treated per day) that you see Water Treatment B is a more efficient design.





6.4 Stage 1 – Business case (reporting guidance)

The results of carbon assessments are required as part of business case submissions by incorporating carbon considerations into a project's cost-benefit analysis.[36] At these early stages of the infrastructure life cycle, limited project information means that achieving detailed and accurate estimates of embodied carbon is challenging, and therefore reporting is likely to be less detailed. Use of high-level carbon intensity benchmarks is also a limitation to detailed reporting.

Where possible, results for embodied carbon estimates (t CO_2-e) should be broken down as follows (refer EN15978[37] or EN17472[38] stages and modules):

- **Product stage (A1-A3)**
- **Construction transport (A4)**
- **Construction process (A5)**, excluding land use change emissions and removals.
- **Construction land use change emissions (A5)**, with emissions and removals also reported separately.
- **Total upfront carbon (A1-A5)**

Where options have a differing scale, function or service provision, reporting of carbon emissions per declared unit (t CO_2-e/unit) can be considered to support comparison. Where projects include structural timber elements, emissions and removals for these products should also be reported separately (in line with PAS2080:2023[39]). Refer to Appendix 5 and Appendix 9 for more details.

Where any significant trade-offs with in-use stage or end of life stage carbon emissions are identified, these should also be assessed and considered. Where significant trade-offs have been identified, upfront carbon emissions alone should not be used to inform the evaluation of options. Refer to section 3.3 for further information on consideration of trade-offs.

The results of carbon assessment must be incorporated in CBA and documented as part of business case submissions. Refer to Reporting Template 1 in Appendix 9 for reporting template to be used.

6.5 Stage 2 - Planning approval, design and procurement (reporting guidance)

As infrastructure projects proceed to planning approval and design, more detailed project information will be available for the embodied carbon assessment.

Reporting must include a breakdown by the following **life cycle modules** (refer EN15978[40] or EN17472[41] stages and modules), for both absolute emissions (t CO_2-e) and per functional or declared unit (t CO_2-e/unit), as follows:

- **Product stage (A1-A3)**
- **Construction transport (A4)**
- **Construction process (A5)**, excluding land use change emissions and removals.
- **Construction land use change emissions (A5)**, with emissions and removals also reported separately.
- **Total upfront carbon (A1-A5)**

The following life cycle modules are optional to report. If included, the results should be reported with the following breakdown:

- **Use phase material emissions and removals (B1)**
- **Maintenance (B2)**
- **Repair, refurbishment and replacement (B3-B5)**
- **Deconstruction/demolition (C1)**
- **Waste transport (C2)**
- **Waste processing for reuse/recycling (C3)**
- **Waste disposal (C4)**
- **Benefits and loads beyond the system boundary (D)**
- **Total embodied carbon (A1-A5, use phase material emissions and removals B1, B2-B5, C1-C4, D)**

36 NSW Treasury, TPG23-08 NSW Government Guide to Cost-Benefit Analysis, NSW Government, NSW Government, 2023
37 British Standards Institution, BS EN15978:2011 Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method, BSI, 2011
38 British Standards Institution, BS EN 17472:2022 Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods, BSI, 2022
39 British Standards Institution, PAS 2080 - Carbon Management in Buildings and Infrastructure (2023), Section 3.2 Terms and Definitions, BSI, 2023
40 British Standards Institution, BS EN15978:2011 Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method, BSI, 2011
41 British Standards Institution, BS EN 17472:2022 Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods, BSI, 2022

Templates for reporting on the above modules are provided in Appendix 9 of this Guide.

As discussed in Section 3, whole life carbon assessments are recommended where possible. However, reporting of these modules is not required.

- **Use (B1)**
- **Operational energy use (B6)**
- **Operational water use (B7)**
- **User carbon (B8)**

Where projects include structural timber elements, emissions and removals for these products should also be reported separately (in line with PAS2080:2023[42]). Refer to Appendix 5 and Appendix 9 for more details.

For large and complex project with multiple asset types, results should be broken down by asset types. To support decision-making and the development of future carbon intensity benchmarks, emissions may also be broken down by locations or sub-asset elements within a project boundary.

6.6 Stage 3 - Construction and practical completion (reporting guidance)

At construction and practical completion, sufficient as-built data will be available to conduct a detailed carbon assessment based on actual quantities of resources used.

Reporting must include breakdown by the following life cycle modules (refer EN15978[43] or EN17472[44] stages and modules in Section 3.1), for both absolute emissions (t CO_2-e) and per functional or declared unit (t CO_2-e/unit), as follows:

- **Product stage (A1-A3)**
- **Construction transport (A4)**
- **Construction process (A5),** excluding land use change emissions and removals.
- **Construction land use change emissions (A5),** with emissions and removals also reported separately.
- **Total upfront carbon (A1-A5)**

The following life cycle modules are optional to report, and if included in the assessment, should be reported with the following breakdown where included:

- **Use phase material emissions and removals (B1)**
- **Maintenance (B2)**
- **Repair, refurbishment and replacement (B3-B5)**
- **Deconstruction/demolition (C1)**
- **Waste transport (C2)**
- **Waste processing for reuse/recycling (C3)**
- **Waste disposal (C4)**
- **Benefits and loads beyond the system boundary (D)**
- **Total embodied carbon (A1-A5, use phase material emissions and removals B1, B2-B5, C1-C4, D)**

Templates for reporting on the above modules are provided in Appendix 9 of this Guide.

As discussed in Section 3, whole life carbon assessments are recommended where possible. However, reporting of these modules is not required.

- **Use (B1)**
- **Operational energy use (B6)**
- **Operational water use (B7)**
- **User carbon (B8)**

Where projects include structural timber elements, emissions and removals for these products should also be reported separately (in line with PAS2080:2023[45]). Refer to Section 6 and Appendix 9 for more details.

For large and complex projects with multiple asset types, results must be broken down by asset types. To support decision-making and the development of future carbon intensity benchmarks, emissions may also be broken down by locations or sub-asset elements within a project boundary.

42 British Standards Institution, PAS 2080 - Carbon Management in Buildings and Infrastructure (2023), Section 3.2 Terms and Definitions, BSI, 2023
43 British Standards Institution, BS EN15978:2011 Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method, BSI, 2011
44 British Standards Institution, BS EN 17472:2022 Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods, BSI, 2022
45 British Standards Institution, PAS 2080 - Carbon Management in Buildings and Infrastructure (2023), Section 3.2 Terms and Definitions, BSI, 2023

7 | References

ALCAS. (n.d.). *AusLCI Carbon Emissions Factors*. Retrieved from https://www.alcas.asn.au/auslci-emissions-factors

Australian Bureau of Statistics. (2023). *Private New Capital Expenditure and Expected Expenditure, Australia.* Retrieved from https://www.abs.gov.au/statistics/economy/business-indicators/private-new-capital-expenditure-and-expected-expenditure-australia/latest-release

BSI. (2023). *PAS 2080 - Carbon management in buildings and infrastructure*. Retrieved from https://www.bsigroup.com/en-GB/our-services/product-certification/product-certification-schemes/pas-2080-carbon-management-in-infrastructure-verification/

European Standards. (2011). *EN 15978:2011 Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method.* Retrieved from https://www.en-standard.eu/bs-en-15978-2011-sustainability-of-construction-works-assessment-of-environmental-performance-of-buildings-calculation-method/

European Standards. (2019). EN 15804:2012+A2:2019 *Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.* Retrieved from https://www.en-standard.eu/bs-en-15804-2012-a2-2019-sustainability-of-construction-works-environmental-product-declarations-core-rules-for-the-product-category-of-construction-products/

European Standards. (2022). *EN 17472:2022 Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods*. Retrieved from EN 17472:2022 Sustainability of construction works. Sustainability assessment of civil engineering works. Calculation methods

Government Information (Public Access) Act 2009 No 52, s 4(1), Sch 4. Retrieved from https://legislation.nsw.gov.au/view/whole/html/inforce/current/act-2009-052#statusinformation

Green Building Council of Australia. (2023). *A practical guide to upfront carbon reductions - For new buildings and major refurbishments.* Retrieved from https://gbca-web.s3.amazonaws.com/media/documents/a-practical-guide-to-upfront-carbon-reductions.pdf

ICE. (2012). *CESMM4: Civil Engineering Standard Method of Measurement, Fourth edition*. Retrieved from https://www.icevirtuallibrary.com/doi/book/10.1680/cesmm.57517

Infrastructure Australia. (2022). *Infrastructure Market Capacity Report*. Retrieved from https://www.infrastructureaustralia.gov.au/publications/2022-market-capacity-report

International Organization for Standardization. (2017). *ISO 20400:2017 Sustainable Procurement - Guidance*. Retrieved from https://www.iso.org/standard/63026.html

IQS. (2023). *Australian Cost Management Manual*. Retrieved from https://www.aiqs.com.au/shop/australian-cost-management-manual-volume-1

NSW Treasury. (2018). *TPP 18-06 NSW Government Business Case Guidelines.* Retrieved from https://www.treasury.nsw.gov.au/sites/default/files/2021-05/TPP18-06%20%20NSW%20Government%20Business%20Case%20Guidelines.pdf

NSW Treasury. (2018). *TPP18-07 Organisational Resilience: Practitioner Guide for NSW Public Sector Organisations.* Retrieved from https://www.treasury.nsw.gov.au/sites/default/files/2018-09/TPP18-07%20Organisational%20Resilience%20-%20Practitioner%20guide%20for%20NSW%20Public%20Sector%20Organisations%20-pdf.pdf

NSW Treasury. (2023). *TPG23-08 NSW Government Guide to Cost-Benefit Analysis*. Retrieved from https://www.treasury.nsw.gov.au/sites/default/files/2023-04/tpg23-08_nsw-government-guide-to-cost-benefit-analysis_202304.pdf

Paul, K.I et al. (2016). Testing the generality of above-ground biomass allometry across plant functional types at the content scale. *Global change biology*, 22(6), 2106-2124.

Paul, K.I et al. (2019). Testing the generality of above-ground biomass allometry across plant functional type. *Forest Ecology and Management*, 432, 102-114.

RICS. (2021). *ICMS: Global Consistency in Presenting*. Retrieved from https://www.rics.org/profession-standards/rics-standards-and-guidance/sector-standards/construction-standards/icms3

Transport for NSW. (2023). *Carbon Estimate and Reporting Tool (CERT)*. Retrieved from https://www.transport.nsw.gov.au/industry/doing-business-transport/sustainability-at-transport

Appendix 1: Supporting tools and resources

This guidance aims to improve consistency in data and assumptions used by NSW Government infrastructure agencies. A range of embodied carbon calculation guidance documents and tools are available to support the carbon assessments process. It is anticipated that more tools that align with this guide will be available over time. These are outlined below in Table A1.1.

The principles in this Guide can be used to support carbon calculations through the various tools available. Projects undertaking Green Star and Infrastructure Sustainability Ratings should be able to align well with the reporting requirements of this Guide.

Table A1.1 Sector specific guidance and tools for carbon measurement

Document	Author	Relevant content
Carbon Calculators		
Transport Carbon Tool	**Transport for NSW**	Calculator for the measurement of carbon emissions during detailed design and construction of Transport for NSW projects.
Sydney Metro Carbon Tool	**Sydney Metro**	Calculator used for the measurement of carbon emissions on Sydney Metro projects and programs.
Sydney Water Greenhouse Gas (GHG) Estimators (Planning and Design/Delivery) – under development	**Sydney Water**	A carbon emission estimating tool that can be used to assess and measure greenhouse gas emissions for projects in the design and delivery stages. The tool has been created to meet a need for a standardised methodology to calculate and capture greenhouse gas emissions in the design and delivery stages of projects.
Infrastructure Sustainability Materials Calculator	**Infrastructure Sustainability Council**	Calculator and user guide for the measurement of embodied (material related) carbon emissions and other environmental impacts for infrastructure projects.
Upfront Carbon Calculator	**Green Building Council of Australia (GBCA)**	Calculator and interim guide for the measurement of upfront emissions in buildings projects during design and at practical completion.
Embodied Emissions Tool – under development	**NABERS**	Calculator (in development) to measure embodied carbon in new buildings and major refurbishments.
Origins Asset Impact	**NSW Department of Customer Service / KPMG**	Calculator that enables measurement, benchmarking and reporting of upfront embodied carbon for buildings.

Document	Author	Relevant content
Other guidance covering carbon estimation and management		
Australian Transport Assessment and Planning (ATAP) Economic Analysis Framework and Parameter Values	**Australian Transport Assessment and Planning (ATAP)**	The economic analysis framework provides guidance on the inclusion of environmental externalities in business cases and cost-benefit analysis for transport projects. The PV5 Environmental Parameter Values provide fuel consumption and carbon emission conversion factors.
Guide to assessing greenhouse gas emissions	**Infrastructure Australia**	A guide which sets recommendations for assessing greenhouse gas emissions in infrastructure proposals.
Guidance note – Valuing emissions for economic analysis	**Infrastructure Australia**	The guidance note sets out the monetised value of GHG emissions for use in economic analysis, including cost-benefit analysis and cost effectiveness analysis. The values will support more transparent and consistent decision making for decarbonisation initiatives as well as other projects with emissions impacts.
PAS2080:2023 *Carbon management in buildings and infrastructure*	**BSI Group**	A global standard which specifies requirements for the management of whole life carbon in buildings and infrastructure
Whole life carbon assessment (WLCA) for the built environment	**RICS**	A global standard for carbon measurement in the built environment.

Note the information in this appendix has been replaced by the NSW Embodied Carbon Databook

Appendix 2: Default emission factors

Appendix 3: Detailed worked example – social infrastructure

Note the data used in this worked example is out of date.
Please refer to the NSW Embodied Carbon Databook for the most current data.

The following section provides an example of how carbon measurement and reporting can take place at each project stage (focused on upfront carbon only). This **example is hypothetical only** and aims to demonstrate the practical application of the guidance in this document.

Stage 1 – Strategic Options and Business Case

With a growing and ageing population, the demand for health services is increasing. In this hypothetical example, Health Infrastructure NSW and a Local Health District are exploring options to increase the provision of hospital capacity to meet this growing demand in an urban area. At the Strategic Options phase, the project team are exploring options outlined in Table A3.1 below, including a new build hospital, the expansion of existing hospitals, and a non-build option.

Table A3.1 Worked example: Potential strategic options to cater for growing demand in health services

New build	Upgrade and expansion of existing hospitals	Non build option
Development of a new hospital on a greenfield site: • 400 beds • 100,000 m2 GFA • Approx. $600m	Refurbishment and expansion of existing hospitals on a brownfield site: • 400 beds • 100,000 m2 GFA • Approx. $600m	Improve efficiency of the current capacity within hospitals through provision of virtual services and improved outpatient care

The non-build option was investigated, and due to space limitations in existing hospitals, it was determined that this option would not be able to meet the forecast increase in demand for services.

The option to refurbish and expand existing hospitals was seen as an opportunity to reduce embodied carbon by utilising existing site infrastructure, and potentially some existing building structures.

Step 1 - Define the system boundary

To understand the carbon emissions associated with each option, the agency first outlined the lifecycle stages which were to be included in the assessment (also known as the **system boundary**). The following modules were included in the system boundary:

- Product Stage (A1-A3)
- Transport (A4)
- Construction and installation processes (A5)

The project team had limited data available for estimating other modules such as In-Use (B1-B5) or Operational Carbon (B6-B7), however, will consider these at a high-level when developing options and exploring trade-offs.

Step 2 - Consider potential trade-offs

Potential trade-offs between upfront carbon, in-use carbon and operational carbon were identified and qualitatively considered when exploring the following options for the hospital development:

- **Electrification of building systems** (e.g. heat pumps instead of gas boilers) – resulting in a higher upfront carbon due to additional materials required, however, reducing in-use carbon due to the avoided use of gas.
- **Inclusion of rooftop solar photovoltaic (PV)** – increasing upfront and in-use carbon from greater initial and replacement materials required, but lowering the amount of grid-based electricity the building will consume, lowering the associated operational carbon emissions.

When the preferred option is selected, these trade-offs will be considered further and integrated into the future stages of the project design.

Step 3 - Assess carbon emissions and removals

The agency reviewed the data available to determine the most suitable methodology for conducting the carbon assessment. At this stage, the agency had access to the predicted capital spend for each option, however, no further estimates of material quantities or area breakdowns were available. For this reason, the agency used the asset-level carbon intensity benchmarks for the initial assessment, which are based on predicted capital spend.

There were no suitable sub-asset level benchmarks available. However, the team did find that some had been developed by the UK National Health Service, as part of the 'carbon limits' in the *Net Zero Building Standard User Guide* and noted that similar could be developed for Australia in the future.

The carbon associated with each option was estimated using the following approach:

Worked example: Initial carbon assessment using asset-level benchmarks

Inputs:

- Predicted CAPEX for each option
- Default material share of CAPEX estimations (provided in Appendix 6). The new-build option applied the mid-range estimate for material share of CAPEX (29%), while the upgrade and expansion option applied the low-range estimate for material share of CAPEX, based on quantity surveyor advice that this would involve a lower share of material costs (22%)
- Asset-level carbon intensity benchmarks (provided in Appendix 6)

Equation:

Estimated carbon per module (kg CO_2-e) = CAPEX ($) × Material share of CAPEX (%) × Carbon intensity benchmark (kgCO_2-e/$)

The above equation was used to calculate the product stage (A1-A3), transport (A4) and construction (A5) stage emissions separately.

As recommended, **low, mid and high scenario** carbon intensity benchmarks were used to account for the uncertainty involved.

Results:

The following table shows the predicted carbon intensity of each option. As t he carbon intensity benchmarks exclude land-use change, this was calculated separately using site-specific data regarding the location and level of vegetation present.

	New build (tonnes CO_2-e) [uncertainty range low-high]	Expansion of existing hospitals (tonnes CO_2-e) [uncertainty range low-high]
Product Stage (A1-A3)	87,500 [65,000 – 109,500]	66,500 [49,500 – 83,000]
Transport (A4)	3,800 [2,800 – 4,500]	2,900 [2,100 – 3,500]
Construction (A5)	12,500 [9,200 – 15,500]	9,400 [7,000 – 11,500]
Land-use change (A5)	600	0
Total estimated upfront carbon	**104,400 [78,100 – 130,100]**	**78,800 [58,600 – 98,000]**

Note – carbon emissions have been approximated for simplicity.

This high-level carbon assessment was considered as part of the cost-benefit analysis conducted in line with the NSW Treasury *NSW Government Guide to Cost-Benefit Analysis*, noting these results have limited accuracy and offer high-level indications of carbon only.

Following the Strategic Options assessment, the expansion of existing hospitals was selected as the preferred option. The assessment concluded that current hospitals had sufficient space on-site to expand the current buildings and accommodate rising service demands. Moreover, the potential to utilise existing structures for the expansion can reduce the materials required for the works and associated carbon emissions.

Stage 2 – Planning Approval, Design and Procurement

At concept design, the project team are developing the details of the 'expansion of existing hospitals '. Carbon measurement was important to identify areas of focus for the design development. Leading up to the planning submission under the Sustainable Buildings State Environmental Planning Policy, the project prepared a carbon assessment to inform the development of the design and ensure low-carbon options were included in the submission.

Step 1 - Define the system boundary

The project team reviewed the **system boundary** and confirmed the same life-cycle modules would be explored. These are:

- Product Stage (A1-A3)
- Transport (A4)
- Construction and installation processes (A5)

Step 2 - Considering trade-offs

The trade-offs highlighted at the Strategic Options phase were included in the design, such that:

- The 'expansion of hospitals' option will include an upgrade to all electric systems
- Rooftop solar PV was included in the design

Additional design options and potential trade-offs were identified at Stage 2 and qualitatively assessed. These are:

- **Improved building fabric for higher operational energy efficiency** – requiring more materials and increasing upfront carbon, but resulting in lower operational energy use and associated carbon emissions.
- **Batteries for back-up energy storage instead of generators** – resulting in a higher upfront carbon and replacement carbon due to the additional materials required, but reducing in-use carbon from the avoided use of diesel fuel.

Step 3 - Assess carbon emissions and removals

Product Stage (A1-A3)

At this stage, the project team had access to high-level material quantity estimates for the expansion of existing hospitals, including the additional structure, foundation, and building envelope required. The project teams were able to utilise approximately 15% of the existing hospitals' structure and envelope for the new expansion works, reducing the materials required and associated carbon emissions.

The team then used the **emission factor hierarchy** in section 5.4.1, and recommended emission factor sources outlined in Appendix 2 to understand the best emission factor to use for this data.

Finally, the product stage (A1-A3) calculations were conducted using the below approach.

Worked example: Initial carbon assessment using asset-level benchmarks

Inputs:

- Material quantity estimates
- Emission factors (EFs) selected using the **emission factor hierarchy** provided in section 5.4.1, and approved emission sources outlined in **Appendix 2**

Equation:

Total product stage carbon (kg CO_2-e) = material quantity (unit) × product stage EF (kgCO_2-e/unit)

Results:

Element	Material	Quantity	Total product stage emissions (tonnes CO_2-e)[1]
Earthworks	Aggregates	2,000 t	5
Structure	Concrete	48,800 m^3	22,000
	Reinforcing Steel	7,000 t	11,000
	Structural Steel	170 t	450
Foundation	Concrete	12,000 m^3	6,500
	Reinforcing Steel	960 t	1,500
Envelope	Façade aluminium	425 t	8,000
	Glazing	3,850 m^2	200
	Steel roof sheeting	30,000 m^2	350
	Insulation	10,000 m^2	200
Total			**50,205 t CO_2-e**

Notes: 1 - Estimated carbon has been approximated for simplicity

Transport to site (A4)

At this stage of the project, the material suppliers had not been selected, and specific transport distances for each material were not available. For this reason, the **default transport distances** provided in Appendix 8 were used alongside the **default transport emission factors** in Appendix 2.

Worked example: Transport (A4) carbon calculations using material quantity estimates

Inputs:

- Material quantity estimates
- Default transport distances (provided in Appendix 5) as no better estimates were available
- Default transport emission factors (EFs) in Appendix 2

Equation:

Total transport carbon (kg CO_2-e) = material quantity (tonnes) × distance (km) x transport EF (kgCO_2-e/tonnes.km)

Results:

Element	Material	Total transport emissions (tonnes CO_2-e)[1]
Earthworks	Aggregates	30
Structure	Concrete	250
	Reinforcing Steel	1,000
...	...	...
...	...	...
Total		**1,500 tonnes CO_2-e**

Notes: 1 - Estimated carbon has been approximated for simplicity

Construction and installation process (A5)

For the construction emissions, the project team included estimations for the following:

- Construction electricity and fuel use
- Waste generated on site & transport of waste to end-destination
- Commissioning energy

For construction electricity and fuel use, the project team had access to high level estimations benchmarked off previous projects. These were multiplied by emission factors for electricity and fuel use provided in Appendix 2 to understand the carbon emissions associated with construction activities.

As the developments were on existing brownfield sites, there was no land clearing required to accommodate the hospital expansions.

To understand the amount of waste that will be generated during construction, the project team applied the **default waste generation factors** in Appendix 8 to the product stage (A1-A3) material estimates.

The total waste quantity could then be multiplied by the transport emission factors and end-of-life treatment emissions factors in Appendix 2 to understand the total waste-related carbon emissions from the project.

Overall, the emissions calculated for the construction and installation processes are outlined below.

Worked example: Construction and installation processes (A5) carbon assessment

Inputs:

- Outlined in the table below

Equation:

The following equations were used for the transport and end of life treatment of waste:

Transport of waste (kg CO_2-e) = waste quantity (tonnes) × transport EF (kgCO_2-e/tonnes.km) × default transport distance (km)

End-of-life treatment of waste = waste quantity (tonnes) x waste treatment EF (kgCO_2-e/tonnes)

Results:

Key inputs	Quantity	Emission factor	Emission factor source	Estimated carbon emissions[2]
NSW Grid Electricity	576,000 kWh	0.73 kg CO_2-e/kWh[1]	NGA 2023	420 tonnes CO_2-e
Diesel	1,700 kL	87.5 kg CO_2-e/GJ1 38.6 GJ/kL	NGA 2023	5,740 tonnes CO_2-e
Waste treatment – landfill	8,000 t	0.2 tCO_2-e/t	NGA 2023	1,600 tonnes CO_2-e
Waste transport – landfill	8,000 t x 50km	0.0002 tCO_2-e/t.km	TfNSW Carbon Tool	80 tonnes CO_2-e
Total				**7,840 tonnes CO_2-e**

Notes: 1 – Emission factor includes Scope 3 emissions, 2 – Estimated carbon has been approximated for simplicity

As the material estimates included in the carbon assessment cover all of the minimum inclusions outlined for social infrastructure in Appendix 7, the project was able to assume the **default completeness rate of 80%**, and upscale the carbon calculation to account for the remaining 20%.

Worked example: Upscaling for completeness

Inputs:

- Calculated product stage emissions (a) and completeness (80%)
- Calculated transport emissions (b) and completeness (80%)
- Calculated construction energy and waste emissions I and completeness (80%)
- Calculated land-use change emissions (d) (completeness should be 100%)

Equation:

$$\textbf{Total Upfront Carbon } (tCO_2\text{-}e) = \frac{a}{(80\%)} + \frac{b}{(80\%)} + \frac{c}{(80\%)}$$

(Note – the completeness of land-use change carbon assessments are assumed to be 100%, and do not need to be upscaled)

Results:

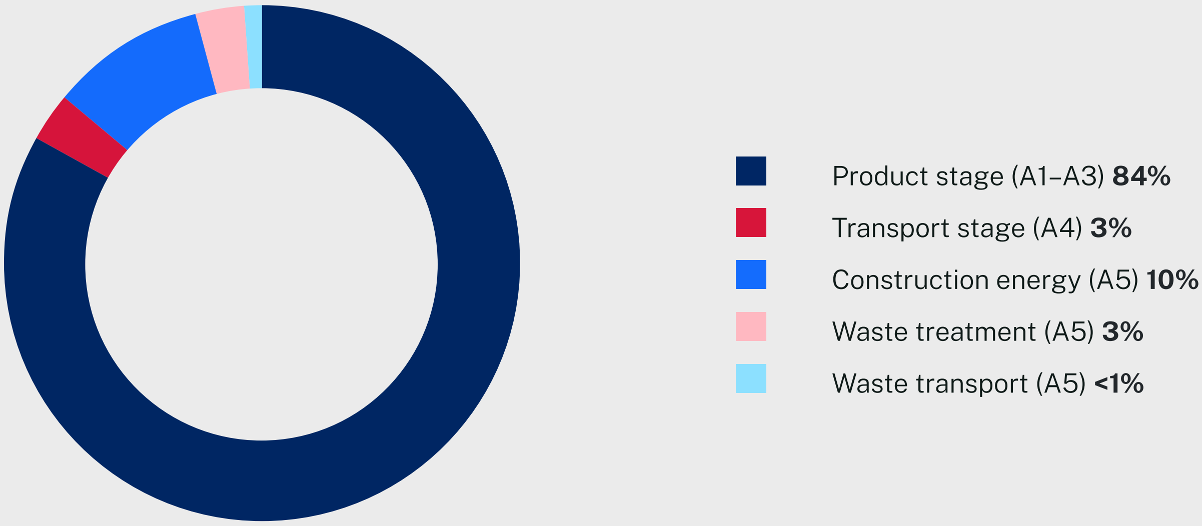
	Calculated emissions[1]	Upscaled emissions
Product Stage (A1-A3)	50,205	62,750
Transport (A4)	1,500	1,875
Construction (A5)	7,840	9,800
Total	**59,545**	**74,430**

Notes: 1 - Estimated carbon has been approximated for simplicity

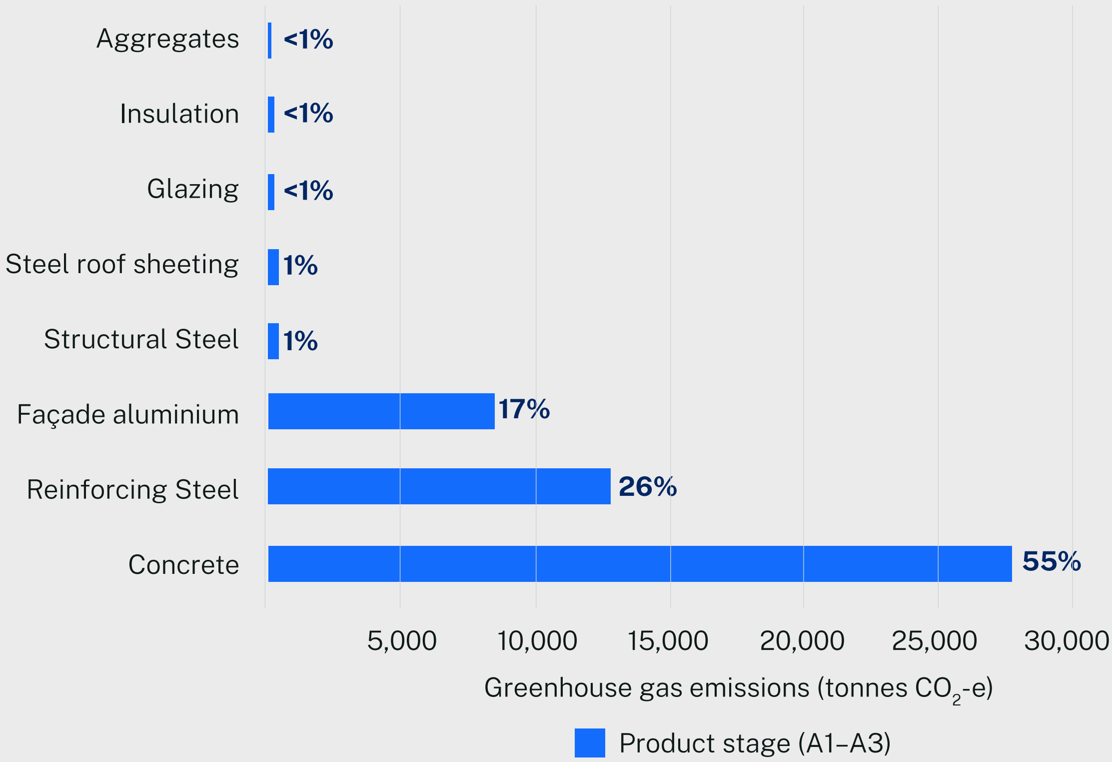
Final results

Using the results above, the project team developed the following results chart and contribution analysis to display the main sources of carbon for the project.

Worked example: Total upfront carbon



Worked example: Product stage contribution analysis



Stage 3 – Construction and Practical Completion

At practical completion, the project is updating the design phase carbon calculations with actual data gathered during construction.

Firstly, the team reviewed the design phase carbon calculations to understand the scope and boundary of included and identify any changes to the design that may have taken place since the assessment.

With no scope or boundary changes occurring since the previous assessment, the project proceeded to update the design phase carbon assessment with actual data.

Step 1 – Define the system boundary

The project confirmed there will be no changes to the system boundary between the two carbon calculations, and the product stage (A1-A3), transport (A4) and construction (A5) modules will be included.

Step 2 – Consider trade-offs

The trade-offs identified at planning approvals were included in the design, such that:

- The hospital included the improved building fabric to increase operational energy efficiency
- Batteries were chosen for back-up energy storage to realise operational carbon savings.

Step 3 – Updating the assessment with available actual quantities

During construction, the project collected the material use data on the key materials (concrete and steel), transport distance data on the heaviest products (concrete and aggregates), and tracked all construction clearing, energy and fuel use. For the remaining inputs, the design based estimations were used.

Worked example: Updating the assessment with available actual quantities

Key inputs	Designs estimates (Stage 2)	Actual construction data (Stage 3)
Product stage (A1-A3)		
Concrete	60,800 m^3	62,000 m^3
Structural Steel	170 t	200 t
Reinforcing Steel	7,960 t	8,000 t
…	…	…
Transport (A4)		
Concrete	18km	30km
Aggregates	62km	50km
Construction and installation processes (A5)		
NSW grid electricity	576,000 kWh	600,000 kWh
Diesel	1,700 kL	2,000 kL
Waste treatment – construction and demolition	8,000 t	8,000 t

For the remaining inputs, the design-based estimations were used.

Note reporting requirements have been updated.
Please use the Reporting Template - Decarbonising Infrastructure Delivery Policy.

Step 4 - Reporting on final emissions

The following report was issued to Infrastructure NSW at practical completion.

Table A3.2 General project data

Input	Project Details
Project or contract name	Hospital refurbishment and expansion program
NSW Government agency	Health Infrastructure NSW
Applicable reporting requirements	Sustainable Buildings SEPP Green Star
Date of assessment undertaken	February 2024
Primary asset class (IA Master Type)	Education, health and justice
Primary asset type (IA Typecast)	Hospital
Other sub-assets included within the scope (IA Typecast)	Not applicable

Table A3.3 General asset level or sub-asset level data

Input	Project Details
Declared unit	m^2 GFA
Project scale (quantity in declared unit)	100,000 m^2 GFA
Data sources (optional)	• Actual construction data • Design estimates
Emission factor sources (EPDs, bill of quantities etc) or carbon intensity benchmark (optional)	• Aus LCI emission factors • EPD's

Table A3.4 Reporting carbon by life cycle module for asset and sub-asset level reporting

Life cycle module	Final Design	
	Absolute (tonnes CO_2-e)	**Per declared unit (tonnes CO_2-e/unit)**
Product stage (A1-A3)	64,500	0.65
Transport to site (A4)	2,000	0.02
Construction (A5)	9,500	0.095
Total upfront carbon (A1-A5)	**76,000**	**0.76**

Appendix 4: Data required and potential sources

The most typical data needed to complete an embodied carbon assessment at each stage of measurement, and potential sources of these data are provided in Table A4.1 below.

Table A4.1 Data inputs required for an upfront carbon assessment and potential sources

Data input	Description	Potential data source
General Information		
Project scope information	The project type in line with the Infrastructure Australia's classification system (mastertypes and typecasts) to facilitate the use of carbon intensity benchmarks and for accurate reporting and carbon disclosure.	• These are defined in the Infrastructure Australia's *Market Capacity report 2022*.
Design life of the asset and elements	The number of years the overall asset is being designed for as well as the design life of each element to determine rates of replacement.	• Design specifications / standards • Contract documentation
Use, maintenance and refurbishment activity data	The quantities of materials, energy, waste used during routine maintenance activities. Fugitive and process emissions included in definition (B1)	• Asset operator or benchmarked from other operating assets
Stage 1 – Using carbon intensity benchmarks		
Total project cost and expected spend on material	This is important when using carbon intensity benchmarks (which will be provided in tonnes of carbon per total spend on materials), and to assist the development of future carbon intensity benchmarks.	• Project quantity surveyor

Data input	Description	Potential data source
Carbon intensity benchmarks	Carbon emission benchmarks per asset level (typecast) or sub-asset or element specific benchmarks.	• Asset level (typecast) have been developed by Infrastructure Australia and provided in Appendix 6. • Agencies may develop their own sub-asset or element specific benchmarks (preferred data source if available).
Stage 2 and Stage 3 – Using construction quantities and emission factors		
Construction quantities	The quantities of materials, energy, waste and land used to construct the asset are required for the upfront carbon assessment. These quantities are often referred to as the activity data.	• Bill of quantities from quantity surveyor • Material take off from digital model • Equipment schedules from quantity surveyor/ cost estimator • Actual construction quantities.
Emissions factors	The carbon footprint per unit of resource use or construction activity (or activity data).	• There are a range of emission factor sources available to use. Refer to Appendix 2 for more information.

Appendix 5: How to source emission factor data from literature

Impact assessment methods for Global Warming Potential

When sourcing emission factor data from literature, it is important to interrogate the impact assessment methods used to ensure that the appropriate emission factor is selected. All embodied carbon calculations must be performed using Global Warming Potential (GWP) over a 100-year time horizon (GWP100) in line with ISO 14067:2018. The most recent characterisation factors from the Intergovernmental Panel on Climate Change (IPCC) should be used where possible. At the time of writing, the *IPCC Sixth Assessment Report* (AR6) contains the most recent factors. However, GWP100 factors following older assessment reports may also be used.

Following EN 15804:2012+A2:2019, the total carbon footprint **(GWP-Total)** is the sum of three constituent parts:

- **GWP-Fossil:** Carbon emissions arising from fossil sources.
- **GWP-Biogenic:** Carbon emissions arising from biogenic sources (net of emissions and removals).
- **GWP-LULUC:** Carbon emissions due to land use and land use change.

Emissions and removals should be clearly separated in line with PAS2080:2023 (e.g., biogenic carbon uptake from land use and carbonation of concrete). This is particularly important for the following types of projects:

- Projects where biogenic carbon is significant (e.g., buildings with timber structure). In this case, GWP-Biogenic and GWP-Fossil should be reported separately.
- Linear infrastructure with significant land use change impacts like land clearing or revegetation (e.g., greenfield linear infrastructure projects). In this case, GWP-LULUC or ‘land clearing’ impacts should be reported separately.

Example of sourcing data from an Environmental Product Declarations (EPD)

An Environmental Product Declaration (EPD) presents the results of a Life Cycle Assessment (LCA) conducted to a certain set of rules, known as a PCR (Product Category Rules).

EPD data must be third-party verified in line with one of these Product Category Rules, unless being used in the absence of no other representative data of higher quality. While all EPDs should follow ISO 14025, the international standard for EPDs, they do not all follow the same PCR.

Project teams should only choose EPDs that comply with one of the following PCR documents:

- **EN 15804:2012+A1:2013:** European standard EN 15804+A1 was the first widely accepted PCR for construction products internationally. It did not require carbon footprint (GWP) to be separated into its component parts, so carbon footprint results are often just reported as GWP. While this standard is no longer valid, thousands of EPDs worldwide were produced to it so it is still often seen today.
- **EN 15804:2012+A2:2019:** European standard EN 15804+A2 replaced EN 15804+A1 (see below). It separates GWP into its component parts.

- **ISO 21930:2017:** This PCR is broadly aligned with EN 15804+A1, while making changes to make its rules and indicators more applicable to other jurisdictions. It is widely used in North America.

All three PCR documents above use the same base life cycle modules, i.e., A1-A5, B1-B6, C1-C4 and D. All three sets of rules also have a similar system boundary and underlying approach.

When reading an EPD, focus on the results for modules A1-A3. These are the cradle-to-gate results and include all life cycle stages from extraction of raw materials through to manufacture of the finished product. Results for downstream life cycle stages are typically calculated at the material group level (e.g., total concrete and total timber), rather than product-by-product.

Table A5.1 below presents an example of the results for 1 m^3 of a concrete product. Table A5.2 presents similar results for 1 m^3 of a timber product. The column for A1-A3 has been highlighted in both tables.

Based upon the example in Table A5.1:

- GWP-Total = 255 kg CO2-e/m^3. Because the concrete product does not contain stored carbon, this is also the total gross GHG emissions.
- GWP-Fossil = 250 kg CO2-e/m^3
- GWP-Biogenic = 4 kg CO2-e/m^3
- GWP-LULUC = 1 kg CO2-e/m^3

Table A5.1 Example EPD results for 1 m^3 of a concrete product, assuming 100% recycling at end-of-life following EN 15804+A2

Indicator	Abbr.	Unit	A1-A3	C1	C2	C3	C4	D
Global warming potential	GWP	kg CO_2e	255	10	5	8	0	6
Global warming potential (fossil)	GWPf	kg CO_2e	250	10	5	8	0	6
Global warming potential (biogenic)	GWPb	kg CO_2e	4	0	0	0	0	0
Global warming potential (land use change)	GWPluc	kg CO_2e	1	0	0	0	0	0
...	...	...	...	...	...	...	...	...

Based upon the example in Table A5.2:

- GWP-Total = -715 kg CO2-e/m^3. This number is negative because of stored carbon in the timber. It can only be used if you plan to release (part of) this stored carbon later in the life cycle. It cannot be used like this in upfront carbon calculations because upfront carbon does not include end-of-life.
- GWP-Fossil = 100 kg CO2-e/m^3
- GWP-Biogenic = -815 kg CO2-e/m^3
- GWP-LULUC = 0 kg CO2-e/m^3
- Following PAS2080:2023, GHG emissions and GHG removals must be reported separately.
- Total GHG removals (when expressed as a negative number)
  = -1 biogenic carbon content (44/12)
  = -1 225 (44/12)
  = -825 kg CO2-e/m^3
- Total GHG emissions
  = GWP-Fossil + (GWP-Biogenic - GHG removals) + GWP-LULUC

= 100 + (-815 - -825) + 0
= 100 + 10 + 0
= 110 kg CO2-e/m^3

- **Note:** You can sense-check your calculations, as GWP-Total = GHG removals + GHG emissions.
- **Note:** If using an EPD for timber that does not declare biogenic carbon content, you can approximate it as follows: stored biogenic carbon = mass (1 - water content) 50%. In the example in Table A5.2, the density of the timber is 500 kg/m^3 and the water content (on a wet basis) is 10%. Stored biogenic carbon = 500 (100%-10%) 50% = 225 kg carbon/ m^3.

Table A5.2 Example EPD results for 1 m^3 of a timber product, assuming 100% landfill at end-of-life following EN 15804+A2

Indicator	Abbr.	Unit	A1-A3	C1	C2	C3	C4	D
Global warming potential	GWP	kg CO_2e	-715	1	2	0	926	-1
Global warming potential (fossil)	GWPf	kg CO_2e	100	1	2	0	50	-1
Global warming potential (biogenic)	GWPb	kg CO_2e	-815	0	0	0	875	0
Global warming potential (land use change)	GWPluc	kg CO_2e	0	0	0	0	1	0
...	...	...	...	...	...	...	...	...
Biogenic carbon content – product	BCC-prod	kg C	225	0	0	0	0	-225

Note the information in this appendix has been replaced by the NSW Embodied Carbon Databook

Appendix 6: Asset level carbon intensity benchmarks

Appendix 7: Asset specific minimum inclusions

Where carbon is being estimated from material quantities and sub-asset or element carbon intensity benchmarks, assessments should aim to cover at least 80% of the project elements (by material spend). The following section provides guidance on the asset elements that are to be included in the embodied carbon assessment for major infrastructure types and sub-types where an asset-level carbon intensity benchmark is not used. Construction stage (A4-A5) minimum inclusions, applicable to all asset types, are also provided at the end of this appendix in Table A7.6. For the remaining 20% an upscaling approach should be undertaken as discussed in Section 5.6.2.

In-use (B1-B5) minimum inclusions have been provided to quantify the carbon associated with routine maintenance, replacement and refurbishment of key elements that have a shorter design life than the asset. An example on how to calculate the in-use embodied carbon has been provided in Case Study 6 below.

This guidance on minimum inclusions does not cover all asset types. For example, many transport projects and programs would fall outside of the 'road' and 'rail' major asset types, such as transport interchanges, wharfs, fleet and access upgrades, depot and maintenance facilities. Where these are a significant source of emissions for road and rail projects, these should form part of minimum inclusions as part of the 80% minimum scope.

While conveyances (e.g., rolling stock, light rail vehicles, bus fleet, ferries) can also be a significant source of embodied carbon emissions, the Guide focuses on fixed and permanent infrastructure assets. As such, conveyances do not feature as part of the minimum inclusions for transport assets. However, where relevant to agency investments and programs, agencies are encouraged to consider their embodied carbon. To help in measuring this source of embodied carbon, agencies may consider requesting manufacturer Environmental Product Declarations when procuring conveyances.

Social Infrastructure

This section provides the minimum product stage inclusions (A1-A3) and in-use embodied carbon (B1-B5) for the following asset typecasts:

- Schools and higher education
- Hospitals
- Correctional centres

The following elements represent 80% scope for A1-A3 and B1-B5 (optional) stages for social infrastructure. Refer to Table A7.6 at the end of Appendix 7 for construction stage (A4-A5) minimum inclusions. Where information on a project element is unavailable, the predicted material quantity can be estimated using an informed methodology (such as material-use benchmarks derived from similar projects).

Table A7.1 Minimum inclusions for social infrastructure projects

Asset Typecast	Product stage (A1-A3) minimum inclusions	In-use embodied carbon (B1-B5) (optional)
School and higher education, Hospital, Correction centre	• Structure • Foundation • Envelope – façade, cladding, glazing, roof, insulation • Temporary civil and structural works • Associated infrastructure (where relevant): roads and pavements, car parks, and site civil works e.g. drainage and retaining structures	• Façade replacement **Note**: operational emissions from refrigerant leakage (B1) are also significant, but not considered in the definition of embodied carbon used in this Guide.

Roads

The material inputs for road projects can vary depending on the pavement types, and the inclusion of tunnels or bridges (any elevated sections requiring structure). The following section outlines the asset elements that should be included in the embodied carbon calculation for various road projects.

The following Infrastructure Australia's asset typecasts are covered under this category:

- State Roads (Highway/Freeway)
- Bridges (Road)
- Tunnels (Road)

The following elements represent 80% scope for A1-A3 and B1-B5 (optional) stages for roads. Refer to Table A7.6 at the end of Appendix 7 for construction stage (A4-A5) minimum inclusions. Where information on a project element is unavailable, the predicted material quantity can be estimated using an informed methodology (such as material-use benchmarks derived from similar projects).

Table A7.2 Minimum product stage inclusions for State Roads, Bridges and Tunnels

Asset Typecast	Product stage (A1-A3) minimum inclusions	In-use embodied carbon (B1-B5) (optional)
State roads (highways / freeways)	• Pavement • Road base • Civil structures • Retaining walls • Drainage • Aggregates • Temporary civil and structural works • Associated infrastructure (where relevant): major civil and structure components for bus stops, interchanges, and active transport links.	• Pavement rehabilitation and resurfacing • Drainage structure replacement • Aggregates replacement
Road bridges (in addition to the above)	• Bridge structure (deck, piers, piles/footings)	

Asset Typecast	Product stage (A1-A3) minimum inclusions	In-use embodied carbon (B1-B5) (optional)
Road tunnels (in addition to the above)	• Tunnel lining • Grout • Epoxy • Ventilation systems	• Replacement of ventilation systems

Rail

The following Infrastructure Australia's asset typecasts are covered under this category:

- Mainline Works (Rail)
- Tunnels (Rail)
- Bridges (Rail)

The following elements represent 80% scope for A1-A3 and B1-B5 (optional) stages for rail. Refer to Table A7.6 at the end of Appendix 7 for construction stage (A4-A5) minimum inclusions. Where information on a project element is unavailable, the predicted material quantity can be estimated using an informed methodology (such as material-use benchmarks derived from similar projects).

Table A7.3 Minimum product stage inclusions for Mainline Works, Bridges and Tunnels

Asset Typecast	Product stage (A1-A3) minimum inclusions	In-use embodied carbon (B1-B5) (optional)
Mainline Works	• Rail tracks • Sleepers and fastening system • Track slab • Ballast • Drainage • Aggregates • Major electrical equipment and cabling (including major transformers) • Electrical support structures • Service/access walkways • Temporary civil and structural works • Associated infrastructure (where relevant): major civil and structure components for stations and active transport links.	• Rail tracks replacement, sleepers, and fastening system replacement • Drainage structure replacement • Major electrical equipment and cabling replacement • Electrical support structures replacement
Bridges (in addition to the above for Mainline Works)	• Bridge structure (deck, piers, piles/ footings)	
Tunnels (in addition to the above for Mainline Works)	• Tunnel lining • Grout • Epoxy • Ventilation system	• Replacement of ventilation system

Asset Typecast	Product stage (A1-A3) minimum inclusions	In-use embodied carbon (B1-B5) (optional)
Stations	• Structure • Foundation • Envelope – façade, cladding, glazing, roof, insulation • Temporary civil and structural works • Associated infrastructure (where relevant): roads and pavements, car parks, and site civil works e.g. drainage and retaining structures	• Façade replacement **Note:** operational emissions from refrigerant leakage (B1) are also significant, but not considered in the definition of embodied carbon used in this Guide.

The following Case Study (Case Study 7) demonstrates the approach to estimating the replacement materials required throughout the asset life cycle. This is a weighted approach to ensure the design life of the asset does not drastically change the in-use embodied carbon emissions from replacements. It is recommended that if the design life of elements is certain then the replacement rate should be rounded down to the closest whole number. However, if the design life is uncertain and only an estimate is available, it is suggested to adopt the more conservative unrounded rate. Alternatively, project teams may follow the approach for replacements set out in the RICS *Whole life carbon assessment for the built environment* standard.

Case Study 7

Calculating the replacement rate of asset elements

An electrified rail project identified that cabling is a significant sources of in-use stage embodied carbon. The project team calculates the in-use embodied emissions which will result from the replacement of materials over the asset lifespan (module B4).

The **asset life is 100 years**, whilst the project knows the estimated **design life of its cabling components is only 30 years**, meaning they will need to be replaced during the asset life cycle. To calculate the replacement rate for the cabling component, the following equation was used:

$$\textbf{Replacement rate} = \frac{\textbf{(c) asset design life}}{\textbf{(d) element design life}} = \frac{100}{30} = 3.33$$

Note: Round down to a replacement rate of 3 if design life of the element is certain.

Initially, **50 tonnes** of cabling will be needed to construct the asset (module A1-A3), and the project team expects that the cabling will likely need to be replaced after 30 years and multiple times over the asset life. To calculate the materials required for cabling replacements (B4), the following equation was used:

Replacement Quantity= 50 tonnes × 3.33 = 166.5 tonnes

This calculation shows that an additional **166.5 tonnes of cabling** will be required during the in-use stage of the asset.

Water and Sewerage

This section provides the minimum product stage (A1-A3) and in-use embodied carbon (B1-B5) inclusions for the following asset typecasts:

- Water pipelines
- Water Recycling / Treatment Plants
- Dams and reservoirs

The following elements represent 80% scope for A1-A3 and B1-B5 (optional) stages for water and sewerage projects. Refer to Table A7.6 at the end of Appendix 7 for construction stage (A4-A5) minimum inclusions. Where information on a project element is unavailable, the predicted material quantity can be estimated using an informed methodology (such as material-use benchmarks derived from similar projects).

Table A7.4 Minimum product stage inclusions for water pipelines, water recycling/treatment plans and dams

Asset Typecast	Product stage (A1-A3) minimum inclusions	In-use embodied carbon (B1-B5) (optional)
Water Pipeline (including associated network infrastructure)	• Major pipes (>DN100) • Foundations and structures for pipes, pumping stations and maintenance shafts (e.g., above ground support structures and footings) • Major mechanical and electrical equipment and cabling (e.g., pumps and transformers) • Aggregates • Access/service roads • Temporary civil and structural works	• Major mechanical and electrical equipment and cabling replacement (e.g., pumps) • Pipe replacement and slip lining (refurbishment)
Water Recycling / Treatment Plants (in addition to the above)	• Above ground structures (e.g., bioreactors, screening, sedimentation and clarification tanks)	**Note:** Operational emission sources of fugitive emissions (B1), use of treatment chemicals (B2), and biosolids transfer/ disposal (B2) are significant, but not considered in the definition of embodied carbon used in this Guide.
Dams (in addition to the above)	• Crest/roadway • Spillway • Foundation • Embankments • Intake and outlet towers • Temporary civil and structural works	**Note:** Operational emission sources of fugitive emissions (B1) from decomposition of vegetation are significant, but not considered in the definition of embodied carbon used in this Guide.

Energy

This section provides the minimum product stage (A1-A3) and in-use embodied carbon (B1-B5) inclusions for the following asset typecasts:

- Transmission lines
- Wind
- Utility (solar)

The following elements represent 80% scope for A1-A3 and B1-B5 (optional) stages for energy projects. Refer to Table A7.6 at the end of Appendix 7 for construction stage (A4-A5) minimum inclusions. Where information on a project element is unavailable, the predicted material quantity can be estimated using an informed methodology (such as material-use benchmarks derived from similar projects).

Table A7.5 Minimum product stage inclusions for transmission lines, wind and utility (solar)

Asset Typecast	Product stage (A1-A3) minimum inclusions	In-use embodied carbon (B1-B5) (optional)
Transmission lines	• Foundations • Lattice towers / structure • Conductor system • Aggregate • Insulation system • Earthing system • Substation transformer • Substation switchgear Access/ service road • Temporary civil and structural works	• Major electrical equipment and cabling replacements
Wind	• Foundations • Wind tower • Nacelle (fibreglass shell for drive shaft and gearbox) • Rotor and blades • Aggregate • Power cables • Turbine transformer • Turbine switchgear • Substation transformer • Substation switchgear • Access/service roads • Temporary civil and structural works	• Major electrical equipment and cabling replacements

Asset Typecast	Product stage (A1-A3) minimum inclusions	In-use embodied carbon (B1-B5) (optional)
Solar (utility)	• Solar PV Cells • Racking System • Electrical cabling • Inverters • Batteries • Aggregate • Substation transformer • Substation switchgear • Transformer foundation • Access/service roads • Temporary civil and structural works	• Solar PV cell replacement • Major electrical equipment and cabling

Construction stage (A4-A5)

Additional guidance for construction stage minimum inclusions is provided in Table A7.6 below. This is applicable to all asset types.

Table A7.6 Minimum inclusions for the construction stage

Asset Typecast	Construction (A4-A5) minimum inclusions
All	• Electricity purchased • Fuel consumption associated with plant, equipment and site vehicles • Land use change (stored carbon and loss of future sequestration from vegetation removal) • Transport of materials to site • Waste generated during construction (on-site) • Inert waste from earthworks • Construction material wastage • Vegetation waste • Site office waste • Transport of waste to end destination

Note the information in this appendix has been replaced by the NSW Embodied Carbon Databook

Appendix 8: Default calculation assumptions

Note reporting requirements have been updated.
Please use the Reporting Template - Decarbonising Infrastructure Delivery Policy

Appendix 9: Reporting templates

Appendix 10: Recommended declared units

Recommended declared units are provided in Table A10.1 below. These are broken down by Infrastructure Australia mastertype (asset class) and typecasts (asset type).

Table A10.1 Recommended functional and declared units

IA Mastertype (asset class)	IA Typecasts (asset type)	Declared units
Higher level declared units (linked to function or service)		
Social Infrastructure	Schools, hospitals, precincts, correctional facilities, other vertical infrastructure	• Customer service provided for (e.g., patient, student)
Transport	Passenger transport	• Passenger.km
	Freight transport	• Tonne.km
Water	Water supply	• ML supplied
	Wastewater	• ML/day treated (Average Dry Weather Flow) • Equivalent population serviced
	Storage	• ML storage
Power	Generation	• MWh provided over asset life
More detailed declared units (more specific)		
Social infrastructure	Schools, hospitals, precincts, correctional facilities, other vertical infrastructure	• m2 GFA
Road	Road - general	• Lane.km or m^2 road surface area
	Road - Bridge	• m^2 usable bridge deck
	Road - Tunnel	• Lane.km • km at a fixed tunnel diameter
Railway	Railway – Greenfield/Brownfield/ Light Rail/Bridge/Tunnel	• track.km
	Railway - Station	• m^2 GFA
Power	Transmission	• km for a fixed capacity
	Generation	• MW capacity

E: mail@infrastructure.nsw.gov.au

W: Infrastructure NSW