



Department
for Transport

Infrastructure Carbon Benchmarks – Methodology Report

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Context

This report and its appendices, produced by ARUP Consultants and commissioned by the Department for Transport (DfT), details the methodological approach taken to develop a set of whole life carbon benchmarks.

These benchmarks are intended to support early-stage carbon assessments for road and rail infrastructure projects.



Department for Transport

CARBON PROFILE AND BENCHMARKING

DfT Benchmark Calculation Methodology Report

Job number 296705-07

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DfT Infrastructure Carbon Benchmarks
Methodology Report

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Definitions and acronyms

Term	Name
ALB	Arm's Length Body
BECD	Built Environment Carbon Database
CCC	Climate Change Committee
CMP	Carbon Management Plan
DfT	Department for Transport
EWR	East West Rail
FBC	Full Business Case
GHG	Greenhouse gas
ICMS	International Cost Management Standards
IPA	Infrastructure and Projects Authority
NH	National Highways
NR	Network Rail
OBC	Outline Business Case
RICS	Royal Institution of Chartered Surveyors
RSSB	Rail Safety and Standards Board
SD	Standard Deviation
SOBC	Strategic Outline Business Case
TfL	Transport for London
WLCA	Whole Life Carbon Assessment
Term	Definition
Carbon benchmark	A carbon value normalised by functional unit which can be used as a reference point.
Whole life carbon	Sum of GHG emissions and removals from all work stages of a project and/or programme of works within the specified boundaries.
Construction carbon	Considers the GHG emissions and removals associated with the creation of an asset, network or system. Interchangeable with 'Upfront carbon'.
Maintenance carbon	Considers the GHG emissions and removals associated with the maintenance of an asset, network or system.
Operational carbon	Considers the GHG emissions and removals associated with the operation of an asset, network or system.
End-of-life carbon	Considers the GHG emissions and removals associated with the end of life of an asset, network or system.
Capital carbon	GHG emissions and removals associated with the creation and end-of-life treatment of an asset, network or system, and optionally with its maintenance and refurbishment.
Operational carbon	GHG emissions and removals associated with the operation of an asset, network and/or system required to enable it to operate and deliver its service.
User carbon	GHG emissions associated with users' utilisation of an asset, network and/or system, and the service it provides during operation.
Taxonomy	Categorisation of items into groups based on shared characteristics.
Functional unit	A standard measure of which the carbon emissions is divided by to enable comparison.

1. Executive summary

The Department for Transport (DfT) has commissioned the development of whole life carbon (WLC) benchmarks to support early-stage carbon assessments for road and rail infrastructure projects. These benchmarks are intended to provide transparent estimates of the whole life carbon impacts at the Strategic Outline Business Case (SOBC) stage, where detailed design and material data are typically unavailable. While they are not a substitute for detailed carbon tools used at later stages, they offer a consistent and practical approach for early-stage decision-making.

Since 2023, as part of the “Management Case” all DfT-funded infrastructure projects are required to complete a Carbon Management Plan (CMP) at each business case milestone. However, many organisations face challenges in producing bottom-up Whole Life Carbon Assessments (WLCAs) at the SOBC stage due to limited design information. To address this, DfT engaged Arup to develop whole life carbon benchmarks that enables early, consistent, and transparent carbon estimation. These benchmarks can be used to establish initial carbon baselines and to compare options.

The project developed a taxonomy for road and rail assets aligned with ICMS3 Level 1 and Level 4 and developed carbon benchmarks across the asset lifecycle, including construction, maintenance, operation, and end-of-life stages. Stakeholder engagement was used to ensure the taxonomy provides the appropriate level of granularity to build up a carbon estimate for transport infrastructure schemes with the level of data typically available at SOBC.

Secondary and primary data was collected for the carbon benchmark development and an Excel-based Carbon benchmarking model was developed incorporating over 240 data points. Each data point was evaluated using data quality metrics and weighted in the analysis, ensuring that higher-quality data had a greater influence on the development of the benchmark. The standard deviation was used as the primary means to account for uncertainty in any estimates developed using the benchmarks. This provides insight into the variability of the data, with lower standard deviations indicating more consistent values. It also helps identify datasets with significant outliers which can be excluded to improve the reliability of early-stage carbon estimates. The Carbon benchmarking model provides a valuable tool for organisations to conduct WLCAs at the SOBC stage.

To support continuous improvement of the Carbon benchmarking model, it is recommended that additional data continues to be collected from across the industry to enhance the reliability and accuracy of the carbon benchmarks. Furthermore, it is recommended to identify infrastructure projects to be used as case studies to validate the model by comparing the estimated whole life carbon values with actual project data. In addition, when user carbon from regional transport models is more mature, user carbon benchmarks could be derived to inform early concept decision-making.

2. Introduction

2.1 Project context

All transport investment projects start with thorough appraisal through the business case process which has three key stages, as illustrated in Figure 1 below. The Department for Transport (DfT) follows the HM Treasury 2022 Green Book [1] core business case process and the “five case model”; strategic, economic, financial, commercial, and management. Since 2023, as part of the “Management Case” all DfT-funded infrastructure projects are required to complete a Carbon Management Plan (CMP) at each business case milestone. The CMPs should set out the approach to managing the scheme’s whole life carbon impact, including completing a quantified Whole Life Carbon Assessment (WLCA).

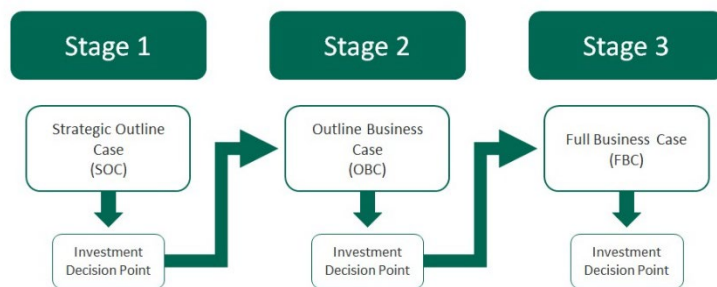


Figure 1 - Overview of the DfT business case process, reproduced from DfT Transport Business case guidance [2]

The Strategic Outline Business Case (SOBC) is the first key stage in the business case process for infrastructure projects submitted to the Department for Transport (DfT) by organisations such as Local Authorities and Arm’s Length Bodies (ALBs). SOBC submissions to date have surfaced the challenges which these organisations face in completing bottom-up Whole Life Carbon Assessments (WLCA)s at this first milestone where design information of the infrastructure scheme is often scarce. To assist with this requirement, DfT has commissioned Arup to develop carbon benchmarks, providing teams with a resource to help with the SOBC requirement for whole life carbon assessment.

2.2 Purpose of the carbon benchmarks

The objective of the commission is to develop whole life carbon benchmarks with transparent carbon values to help estimate the capital and operational carbon impact of road & rail infrastructure projects at early business case stages where designs and material quantities are not known. The term “benchmarks” herein refers to a set of carbon factors (with units tCO_2/km , tCO_2/m^2 , $\text{tCO}_2/\text{£m}$ etc. as appropriate) which can be used as “building blocks” to develop top-down estimates for transport infrastructure schemes at SOBC. These benchmarks are not intended to replace carbon tools or emissions databases used at later business case milestones for more accurate carbon assessments when sufficient design detail is available for bottom-up assessments.

The primary purpose of these benchmarks is to provide projects with a set of ‘typical’ carbon values to help produce a WLCA at SOBC. Although not mandatory, widespread use of these benchmarks will also standardise approaches to early carbon calculations. Across modes, there is variation in the project stage and level of detail at SOBC which influences the decision-making which the benchmarks can feed into. For some schemes, the benchmarks can be used to establish transparent initial estimates of whole life carbon to use as a baseline against which the scheme can be monitored as it progresses through the design stages. For other schemes, the benchmarks can be used as a parameter for option comparison and preferred option selection. The whole life carbon benchmarks have been developed in a Carbon benchmarking model in Excel.

The benchmarks have been developed for a level of granularity to:

- be appropriate for the level of data available at SOBC, recognising the different level of data that may be available between the preferred option and the other options being considered,
- be able to capture where the difference in carbon impact lies between options where applicable,
- be representative (in so far as is possible) of the concept being considered,
- provide insight into carbon hotspots within the scheme at sufficient granularity to enable targeting and follow-through in subsequent design stages (e.g. target the bridges on the scheme for reduction opportunities rather than the km of road, or vice-versa),

- e) provide visibility of the impact of decision-making as projects develop (i.e. avoid re-baselining every time you improve the level of detail of data available).

2.2.1 Scope of the benchmarks

The benchmarks are intended to capture typical road and rail infrastructure “assets”, refer to Figure 2 for example definitions. The carbon impact for each “asset” is provided across the BS EN 17472 life-cycle modules [3], grouped into Construction Carbon (A0 – A5), Maintenance Carbon (B2 – B5), Operational Carbon (B6 – B7), and End-of-life carbon (C1 – C4). Each carbon benchmark provided includes the value of carbon emissions, the functional unit, the number of data points which fed into generating the benchmark and the standard deviation from the mean as a measure of uncertainty. Benchmarks have been developed for capital and operational emissions only. Benchmarks for user carbon (B8) at the early stages of project development are outside the scope of this work; when user carbon from regional transport models is more mature, user carbon benchmarks could be derived to inform early concept decision-making. Physical assets and activities across road and rail projects have been considered for benchmark development. The benchmark development excludes both the embodied carbon of rolling stock and road vehicles, and the operational carbon associated with Track assets. Benchmarks for in use carbon (B1) is excluded, as it is generally insignificant for structural materials, even if allowances are made for concrete carbonation [4].

Such sub-projects/assets should be assessed and captured individually, and all of them reported in the WLCA for the entire project, as shown in Figure 9.

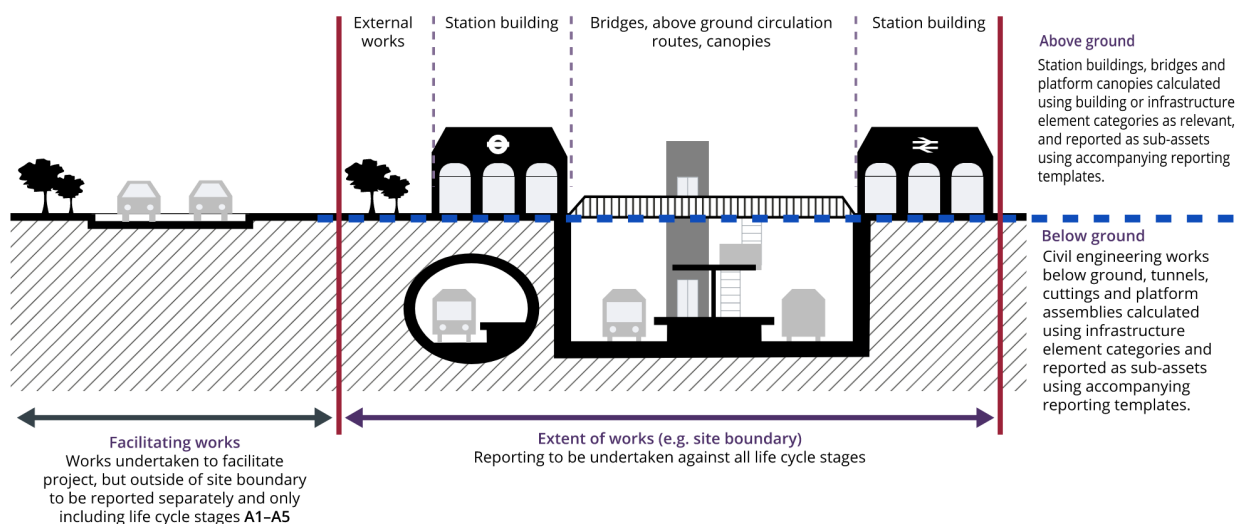


Figure 2 - Transport infrastructure project example “assets”, reproduced from RICS Whole life carbon assessment for the built environment Figure 9 [5]

2.3 Purpose of this report

This report is intended to sit alongside the Carbon benchmarking model to provide context, clarity and transparency on the inputs and methodology used to develop the benchmarks. It is structured as follows:

- Section 2 provides the context and need for the carbon benchmarks, as well as setting out the purpose and anticipated use cases for them.
- Section 3 outlines the methods followed, including stakeholder engagement, to define a taxonomy and functional units for the carbon benchmarks that are useful for the industry.
- Section 4 details the approach to carbon benchmark development, including the sources of the primary and secondary data used, the approach to data quality, the benchmark calculation methodology, uncertainty, case study, checking, and assumptions and limitations.
- Section 5 proposes an approach for continuous improvement of the carbon benchmarks.
- Section 6 provides a final summary and conclusions.

3. Taxonomy and functional units definition

It is important to establish the right taxonomy and functional units to develop carbon benchmarks that can be used to compare different options and schemes with the right level of granularity as described in Section 2.2. A desk review was undertaken of existing taxonomies and common functional units for benchmarks to align with industry as much as possible, whilst meeting the needs for the benchmarks to be used on road and rail projects at the SOBC stage.

3.1 Approach to defining taxonomy and functional units

3.1.1 Desk study review

To provide further understanding of taxonomy and functional units used within the infrastructure industry, a desk study review of existing taxonomy was conducted. Sources were found using recommendations from internal subject matter experts and included, ICMS [6], BECD [7], Spon's Civil Engineering and Highway Works Price Book [8]. See the full list of sources reviewed in Appendix A .

The desk study review concluded that there was little consistency between taxonomies, at both transport mode level and at asset group level. At transport mode level the rail and road taxonomy differed significantly – see Figure 3. At the asset group level, the granularity varied significantly, with taxonomies being defined in different ways—such as grouped assets, single assets, materials, and activities. The functional units also varied between the same asset group – see Figure 4. The desk study concluded that existing taxonomies were not the most suitable to use for the development of the carbon benchmarks for road and rail projects at SOBC stage.

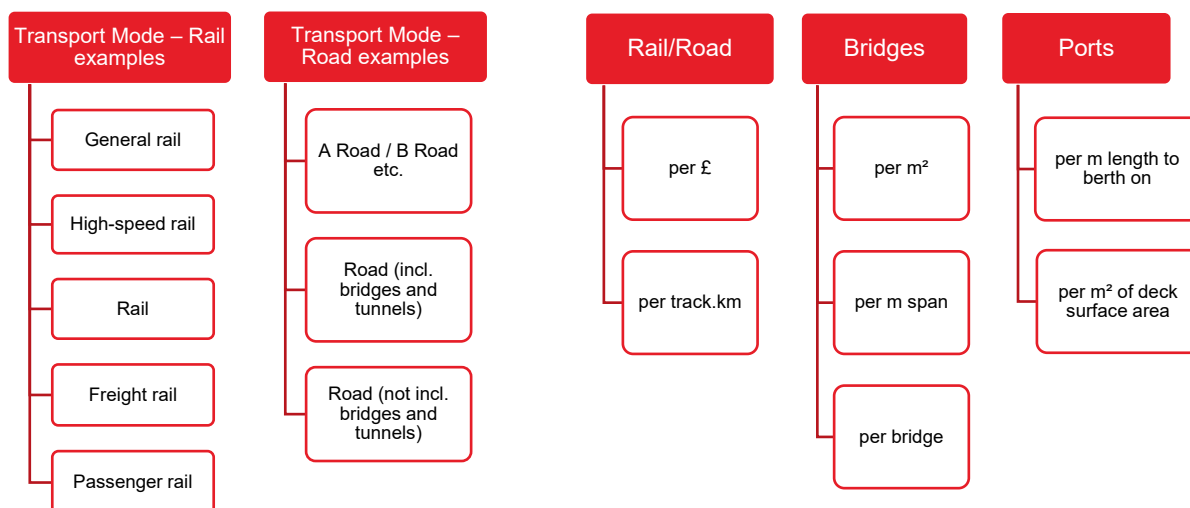


Figure 3 - Transport mode taxonomy comparison

Figure 4 - Functional unit comparison

An example of this is ICMS3, which is a globally recognised standard for cost and carbon management [6]. It provides a consistent approach to considering construction costs and carbon throughout the life cycle of projects. ICMS3 splits the carbon impacts into 4 categories – see Figure 5. Level 1 provides categorisation by asset. However, further levels were found unsuitable for developing carbon estimates from benchmarks – ICMS3 Level 2 is broken down by life cycle modules, and ICMS3 Level 3 is divided into non-specific asset categories (e.g., substructure and structure), which were deemed too granular for the purpose of the benchmarking tool through stakeholder engagement. ICMS3 Level 4 defines the subgroups which details the assets and activities applicable to ICMS3 Level 1. This is detailed in Appendix C of the ICMS3 Standard.

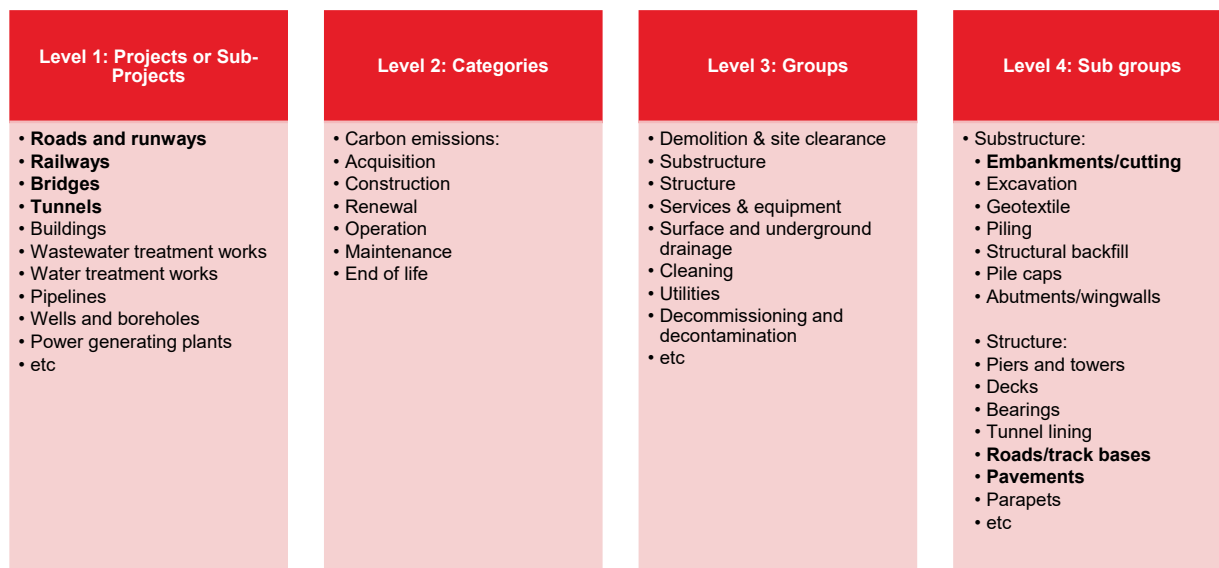


Figure 5 - ICMS 3 Carbon hierarchy [6]

3.1.2 First pass of taxonomy and functional units

A first pass of an infrastructure taxonomy including functional units was defined, this was discussed and verified with subject matter experts internally. The taxonomy was developed using the reviewed taxonomies where relevant, for example some more granular asset taxonomies helped to inform the build-up of components within the assets, and other less granular taxonomies provided insight to the potential categorisation of assets at Level 1. The first pass taxonomy had 3 Levels defined:

- Level 1: Asset group - Identifies the category of the assets
- Level 2: Asset - Identifies key items within the Asset group
- Level 3: Asset component - Elements contributing to the asset build up

Table 1 illustrates the location of an example asset, in this case a footbridge, within the taxonomy build up. Level 1 identifies the asset as a 'bridge' which is then given more detail by Level 2 as it is designated as a 'footbridge'. Level 2 would be used to inform the whole life carbon assessment at SOBC stage. Level 3 would be visible to allow transparency and clarity in the carbon benchmarks. The functional units for each Level 2 asset subgroup were defined against Construction, Maintenance, Operation, and End of life. We presented the first pass taxonomy and functional units for feedback in a workshop with stakeholders from a range of organisations.

Table 1 - Example location of a footbridge asset within the first pass taxonomy

Level 1	Level 2	Level 3	Life cycle modules Functional unit			
Asset group	Asset	Asset component	Construction A0-A5	Maintenance B2-B5	Operation B6-B7	End of life C1-C4
Rail						
Road						
Bridge						
	Road bridge					
	Rail bridge					
	Footbridge	Deck, surfacing, parapets, lighting, access stairs/ramps, piers, foundations	<i>tCO2e/m2</i>	<i>tCO2e/m2 per yr</i>	<i>tCO2e/m2 per yr</i>	<i>tCO2e/m2</i>

3.1.3 Stakeholder engagement

Stakeholder engagement took place in the form of an online collaborative workshop. Stakeholders were invited from a range of organisations including TfL, National Highways, Network Rail, East West Rail, and RSSB as well as DfT as the client.

The purpose of the stakeholder engagement was as follows:

- a) To understand what carbon benchmark requirements would be most useful for road and rail projects completing a CMP at SOBC stage
- b) To verify appropriateness of the first pass of taxonomy and functional units
- c) To agree the approach to uncertainty

Minutes from the stakeholder engagement are in Appendix B . The key themes and notes are summarised as follows:

Benchmark reliability

- The perceived reliability of existing benchmarks was raised as the main blocker to using them for early-stage carbon estimates. Key factors affecting reliability:
 - Insufficient transparency to determine the reliability
 - Too small sample sizes, particularly when data is divided into level of granularity to improve representativeness
 - Variation in carbon calculation methods used
 - Fundamentally infrastructure projects are all unique, therefore projects that have gone into a benchmark may not be representative and appropriate to use
 - Inconsistency in taxonomy means you can't tell if projects/benchmarks are similar or not
- It was noted that the IPA uncertainty factors are not appropriate for carbon baselines because they are based on factors such as inflation and duration which don't carry across to carbon. It was recognised the RICS approach to uncertainty was too optimistic for the SOBC stage.
- Transparency on the benchmarking assumptions and caveats, and a defined continuous improvement process will improve the reliability of the output of this commission.

Taxonomy

- There are advantages in aligning with existing taxonomies, for example ICMS3, which are already embedded/used elsewhere in the DfT business case process, to improve consistency across the industry. However, existing taxonomies do not necessarily meet the level of granularity that would make the benchmarks useful, they are either too high-level (ICMS3 Level 1), or too detailed (ICMS3 Level 3).
- Level 2 was generally agreed to be the correct level of granularity for the intended use of these benchmarks, although it was noted that the Level 2 list was not comprehensive and needed further refinement. It was also agreed that the Level 3 components which contribute to each Level 2 asset should be visible, to increase transparency and confidence in the Level 2 benchmarks.
- It was agreed that a long list of Level 2 asset sub-groups should be defined and agreed to be comprehensive of transport infrastructure assets. A short list of 20 can then be identified for development under this commission on the basis of:
 - Address significant gap in existing benchmarks
 - Benchmarks which capture where the "difference" in carbon impact lies between projects/options
 - Benchmarks which will provide most value in decision-making

Functional Units

- Many attendees were most familiar with cost-to-carbon benchmarks. It was recognised that experience suggests that this is not the most robust or reliable correlation but does have the benefit of having a large dataset.¹
- It was generally agreed that the proposed combination of "per unit measure" functional units (tCO_2e/km , tCO_2e/m^2 , and $tCO_2e/unit$) would be suitable for the intended use of these benchmarks at SOBC stage.
- Further refinement of the functional units could improve representativeness of the benchmarks (e.g. $tCO_2e/lane\ km$ would capture both dual and single lane roads).

3.1.4 Long list taxonomy

In the workshop it was noted that the proposed Level 2 (Asset) strikes the right balance between accuracy and granularity for the SOBC stage, with Level 3 providing visibility to understand Level 2. We further developed Levels 2 and 3 based on feedback from the workshop and internal reviews with engineers, transport consultants, and carbon experts. Additionally, we included Level 1.5 (Asset subgroup), which groups Level 2 into categories for easier use – see Table 2.

Table 2 - Long list taxonomy

Asset group	Asset subgroup	Asset	Asset subcomponent
Level 1	Level 1.5	Level 2	Level 3
Rail	Track	Track ballasted	Rail, ballast and formation, sleepers, trough route, walkway, under track crossings (UTX), access points TBC
		Track slab	Rail, concrete slab, sleepers, trough route, walkway, under track crossings (UTX), access points
		Embedded rail	Rail, concrete
	Traction Power	OLE	Lineside equipment (overhead wires, gantry, transformers TBC)
		Third rail	Lineside equipment (conductor rails, insulators, transformers TBC)
		Fourth rail	Lineside equipment (2no. conductor rails, insulators, transformers TBC)
		Battery	Lineside equipment (charging infrastructure)
		Diesel	User emissions only
		Hydrogen	Lineside equipment (hydrogen fuel cell TBC)
	Station	Station building overground	Station building including concourse, platform access, comms equipment, lighting (including platform), vertical transport, back of house spaces (incl. staff accommodation and MEP requirements), and foundations.
		Station building underground	Station box and station building including concourse, platform access, comms equipment, lighting (including platform), vertical transport, back of house spaces (incl. staff accommodation and MEP requirements), and foundations.
		Rural station building/canopy	Station building including lighting (platform)
		Platform	Platform
		Car park / cycle park	Car park / cycle park build up, including access points
	Depot	Depot	Depot building, depot equipment
	Signalling & Telecoms	Signalling	Lineside equipment (signals, cabinets, cables)
		Telecoms	Cables, GSM masts
Road	Pavement	Vehicle lane - Major road	Pavement build up, kerb, verge, road marking
		Vehicle lane - Minor road	Pavement build up, kerb, verge, road marking
		Footway / Cycle track / Bridleway	Pavement build up, verge, road marking

¹ Cost based benchmarks are based on historic construction prices. Construction prices have been changing in recent years and are likely to continue changing in the future due to rapid policy change and changing procurement incentives/penalties. This rapid change will likely impact the cost of construction in the future and therefore cost based benchmarks will no longer be as reliable or robust for benchmarking purposes.

Bridge	Roadside assets	Lighting	Lighting columns, cables, ducting, foundations
		Operational technology	CCTV, sensors, signals and mast structures, cables, ducting, foundations and posts
		Signage	Signage, masts, foundations
	Bridge	Footbridge	Deck, surfacing, parapets, lighting, access stairs/ramps, piers, foundations
		Road bridge	Deck, surfacing, parapets, lighting, piers, foundations
		Rail bridge	Deck, surfacing, parapets, lighting, piers, foundations
Tunnel	Tunnel	Bored	Lining, cross passages, waterproofing, drainage, M&E
		Mined	Lining, cross passages, waterproofing, drainage, M&E
		Cut and cover	Lining, waterproofing, drainage, M&E
	Underground structures	Shaft	Lining, waterproofing, drainage, M&E, control building
		Pedestrian underpass	Lining, waterproofing, drainage, M&E, lighting
Civil engineering & earthworks	Earthworks	Cutting	Excavation, transport, disposal/reuse
		Embankment	Fill, compaction, reinforcement
	Civils	Retaining wall	Retaining wall structure
	Drainage	Attenuation tank	Attenuation tank, pump
		SuDs	Land take, fill, natural components
		Culvert	Culvert
	Barrier	Fencing	Fence structure, foundations
		Noise barrier	Noise barrier structure, foundations
		Vehicle restraint - Normal	Normal containment
		Vehicle restraint - High	High containment

3.1.5 Short list taxonomy

A short list was determined based on feedback from stakeholders which was circulated for review. See Table 3 for the suggested shortlist.

Table 3 - Suggested shortlist and justification

Asset group	Asset subgroup	Asset	Included in shortlist Y/N	Justification
Level 1	Level 1.5	Level 2		
Rail	Track	Track ballasted	Y	Common & significant carbon
		Track slab	Y	Common & significant carbon
		Embedded rail	N	Less common across UK, although it is recognised that it may be significant for a tram scheme
	Traction Power	OLE	Y	Common & significant carbon
		Third rail	?	
		Fourth rail	?	
		Battery	N	Less common, less data to inform robust benchmarks
		Diesel	N	Excluded as user only
		Hydrogen	N	Novel, not common, no data to inform benchmark
	Station	Station building overground	Y	Common & significant carbon
		Station building underground	Y	Common & significant carbon
		Rural station building/canopy	N	Less significant
		Platform	Y	Common & significant carbon
		Car park / cycle park	Y	Common & significant carbon
	Depot	Depot	Y	Common & significant carbon

	Signalling & Telecoms	Signalling	Y	Common & significant carbon
		Telecoms	N	Less significant
Road	Pavement	Vehicle lane - Major road	Y	Common & significant carbon
		Vehicle lane - Minor road	Y	Common & significant carbon
		Footway / Cycle track / Bridleway	Y	Common & significant carbon
	Roadside assets	Lighting	Y	Common & significant carbon
		Operational technology	N	Less significant
		Signage	N	Less significant
Bridge	Bridge	Footbridge	Y	Common & significant carbon
		Road bridge	Y	Common & significant carbon
		Rail bridge	Y	Common & significant carbon
Tunnel	Tunnel	Bored	Y	Common & significant carbon
		Mined	N	Less common
		Cut and cover	Y	Common & significant carbon
	Underground structures	Shaft	Y	Common & significant carbon
		Pedestrian underpass	N	Less data available for robust benchmarking
Civil engineering & earthworks	Earthworks	Cutting	Y	Commonly used
		Embankment	Y	Commonly used
	Civils	Retaining wall	N	Common & significant carbon
	Drainage	Attenuation tank	N	Less significant
		SuDs	N	Less significant
		Culvert	N	Less significant
	Barrier	Fencing	N	Less significant
		Noise barrier	N	Less significant
		Vehicle restraint - Normal	Y	Common & significant carbon
		Vehicle restraint - High	N	Less common

3.1.6 Alignment with ICMS3

Through further consultation with industry experts, it was noted that there were benefits to utilising an already accepted industry standard taxonomy, such as maintaining consistency with current processes and increased compatibility and data sharing of carbon calculations across industry. Therefore, it was concluded to develop a bespoke taxonomy within the ICMS3 Level 1 categories (Roads, Railways, Bridges, Tunnels) with the assumptions behind the bespoke taxonomy defined using ICMS3 Level 4 subgroups.

3.2 Final taxonomy and functional units

Based on stakeholder feedback, and with input from internal subject matter experts a final taxonomy was developed and a shortlist for which carbon benchmarks are developed for – see Table 4.

Table 4 - Final taxonomy

Asset group	Asset subgroup	Asset	Asset component	Proposed unit (tonnesCO ₂ e per)				
				Construction	Maintenance	Operation	User	End of life
Level 1 (Aligns to ICMS3 Level 1)	Level 1.5	Level 2	Level 3 (ICMS3 Level 4 used as guidance)	A0-A5	B2-B5	B6-B7	B8	C1-C4
Rail	Electrified	Track ballasted	Rail build up, earthworks, OLE	stk	stk.yr			stk
		Track slab	Rail build up, earthworks, OLE	stk	stk.yr			stk
	Non-electrified	Track ballasted	Rail build up, earthworks	stk	stk.yr			stk
		Track slab	Rail build up, earthworks	stk	stk.yr			stk
	Station	Overground	Station building, earthworks	m ²	m ² per yr	m ² per yr		m ²
		Underground	Station box, station building, earthworks	m ³	m ³ per yr	m ³ per yr		m ³
	Depot		Depot building, rail build up, earthworks	m ²	m ² per yr	m ² per yr		m ²
Road	Major road	Minimal earthworks (at grade)	Road build up, minimal earthworks	lane km	lane km per yr	lane km per yr		lane km
		Major earthworks (Embankment/cutting)	Road build up, major earthworks	lane km	lane km per yr	lane km per yr		lane km
	Minor road	Minimal earthworks (at grade)	Road build up, minimal earthworks	lane km	lane km per yr	lane km per yr		lane km
		Major earthworks (Embankment/cutting)	Road build up, major earthworks	lane km	lane km per yr	lane km per yr		lane km
Bridge	Road	Road bridge	Bridge, road build up	m ²	m ² per yr	m ² per yr		m ²
	Rail	Rail bridge	Bridge, rail build up	m ²	m ² per yr	m ² per yr		m ²
	Pedestrian	Footbridge	Footbridge	m ²	m ² per yr	m ² per yr		m ²
Tunnel	Road	Bored	Excavation, tunnel, road build up	km	km per yr	km per yr		km
		Mined	Excavation, tunnel, road build up	km	km per yr	km per yr		km
		Cut and cover	Excavation, tunnel, road build up	km	km per yr	km per yr		km
	Rail	Bored	Excavation, tunnel, rail build up	km	km per yr	km per yr		km
		Mined	Excavation, tunnel, rail build up	km	km per yr	km per yr		km
		Cut and cover	Excavation, tunnel, rail build up	km	km per yr	km per yr		km
				km	km per yr	km per yr		km

4. Benchmark development

4.1 Approach to developing benchmarks

The following sections provide detail of each stage of the benchmark development process, as illustrated in Figure 6 below. The data collection from secondary sources was the first task, followed by the primary data collection once the stakeholder engagement had been held. To ensure reliability and robustness, a data quality assessment was conducted for each data source. Each data point was then weighted, with higher quality benchmarks receiving greater weight in the aggregation into average carbon benchmarks.

This approach has been provided to allow clarity and robustness of the benchmarks, it is not a recommendation of a benchmark production methodology, only an illustration of the methodology used recognising it is the first step and should be reviewed as part of a continuous improvement process.



Figure 6 - Flowchart illustrating the benchmark development approach

4.2 Data collection

Secondary data was collected from a range of external sources and primary data was collected from stakeholders and internal project carbon assessments – see ‘I;Data source’ tab in the Carbon benchmarking model. Each data source was systematically reviewed and the relevant information for the project was extracted and summarised. Table 5 below is a sample showing 2 data sources from the table to illustrate the summary process for each data source.

Table 5 - Data source table

Data source	Primary or secondary	Description	Date of calculation	Data type	Asset type				Life Cycle Modules			
					Rail	Road	Bridge	Tunnel	A0 – A5	B2 – B5	B6 – B7	C1 – C4
DecarboN8 (Rail)	Secondary	Report quantifying embodied and operational carbon from rail and rail associated systems.	2022	Benchmark	✓				✓	✓	✓	
DecarboN8 (Road)	Secondary	Report quantifying embodied and operational carbon from roads and road associated systems.	2022	Benchmark		✓			✓	✓	✓	
TfL Early Stage Calculator Data map v2	Primary	TfL Early Stage Calculator Data map	2020	Project	✓				✓			
Arup tunnel project	Primary	A0-A5 Carbon baseline calculated by Arup which uses an array of primary and secondary sources for the benchmark	2023	Project		✓		✓	✓			

4.3 Data quality assessment

One limitation with using existing publicly available carbon benchmarks identified in the stakeholder engagement workshop was the need for greater transparency and reliability in the carbon benchmarks, assumptions, and data sources used. A data quality assessment enables the user to see the quality of data that has built up the benchmark.

4.3.1 Data quality metrics

Several standards were reviewed to evaluate the data quality metrics including ISO 14044:2006 [9], BS EN 15941:2024 7.1.3 [10], and RICS guidance [5] - see Table 6 below. The Inventory of Carbon and Energy (ICE) database also uses data quality metrics to assess the data quality of each data point collected. They use a scoring system of 1-5, with 1 being the lowest quality and 5 being the highest. They detail the sample size against the results and presents the overall data quality as a percentage out of 100% [11]. The data quality metrics detailed in BS EN 15941:2024 [10] were determined to be most applicable for this project and therefore were used for the data analysis.

Table 6 - Data quality metrics

ISO 14044:2006 [9] Environmental management – Life cycle assessment – Requirements and guidelines	BS EN 15941:2024 7.1.3 [10] Sustainability of construction works — Data quality for environmental assessment of products and construction work — Selection and use of data	RICS Professional Standard [5] Whole life carbon assessment for the built environment (2023) (summarised from the carbon data quality matrix (Table 11) for key products / materials) [5]		Data Quality Metrics
Time related coverage: age of data and the minimum length of time over which data should be collected	Time related coverage	Temporal representativeness: how close to the construction date was the reference or publishing year? (Used generic datasets category as EPD not relevant to this project).		Time related coverage: When was the benchmark produced / calculated?
Geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the CFP study	Geographical coverage	Geographical representativeness: level of similarity between the geographic contexts.		Geographical representativeness: Is the benchmark region specific?
Technology coverage: specific technology or technology mix	Technology coverage	Technological representativeness: Technology: Technology and technical characteristics	Technological representativeness: Product specificity: Is the data specific to the actual product?	Technology coverage: Is the benchmark calculated using data that is representative of the material/technology? E.g. carbon factors, database, EPD
Precision: measure of the variability of each data value expressed (e.g. variance)	Precision	Data aspects: Granularity (i.e. site specific, manufacturer etc.)	Data aspects: verification (i.e. third-party independently verified, peer reviewed etc.).	Precision (Design stage): At which stage of design is the carbon benchmark calculated? I.e. concept, scheme, detailed, construction. More precision for a later design stage/construction.
Completeness: percentage of total flow that is measured or estimated	Completeness			Completeness (Emission sources build up): Is the benchmark complete? E.g. does it include all parts of the asset
Representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e. geographical coverage, time period and technology coverage);	Not included			Not included
Consistency: qualitative assessment of whether or not the study methodology is applied uniformly to the various components of the sensitivity analysis	Consistency			Consistency (Same system boundaries): Does the benchmark have the same system boundaries as that being collected? E.g. A0-A5, B2-B5, B6-B7 and C1-C4
Reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study;	Not included			Not included
Sources of the data	Sources of the data			Sources of the data: Is the methodology and data values transparent to allow an

			independent practitioner to reproduce the results?
Uncertainty of the information	Uncertainty of the information		Not included. uncertainty is quantified using the standard deviation of the carbon benchmark data. See Section 4.5.

4.3.2 Data quality scoring

A bespoke scoring system was developed for the data quality metrics – see Table 7. The data quality rating was applied to all data points used in the benchmark development to allow a weighted aggregation of data into benchmarks which reflects a higher weighting for the higher quality data points. The highest possible score is 21. The data quality scoring is also used to report the average data quality score of all data points alongside the final carbon benchmark.

Table 7 - Data quality scoring

DQ Metrics	Time related coverage	Geographical representativeness	Technology coverage	Precision (Design stage)	Completeness (Emission sources build up)	Consistency (Same system boundaries)	Sources of the data (Transparency)
Score / Description	When was the benchmark produced / calculated?	Is the benchmark region specific?	Is the benchmark calculated using data that is representative of the material/technology? E.g. carbon factors, database, EPD.	At which stage of design is the carbon benchmark calculated?	Is the benchmark complete? E.g. does it include all parts of the asset	Does the benchmark have the same system boundaries as that being collected? E.g. A0-A5, B2-B5, B6-B7 and C1-C4.	Is the methodology and data values transparent to allow an independent practitioner to reproduce the results?
3	Benchmark calculated within 5 years	Refers to specific geographic context, same region (e.g. UK for UK)	EPD or as-built applicable for the UK	Detailed / construction stage	Predominately reflects the asset (e.g. the build up includes majority of key components specified in ICMS3 Level 4, e.g. includes superstructure, substructure, earthworks)	Matches the system boundary required (e.g. A0-A5 for A0-A5, and A1-A5 for A0-A5 assuming A0 is negligible)	The data and assumptions used to construct the benchmark is transparent
2	Benchmark calculated within 10 years	Refers to a similar geographic context (e.g. Ireland for UK, EU for UK, France for UK)	Similar material/technology as used in the UK e.g. ICE DB V3.0	Scheme design	Partially reflects the asset (e.g. most are captured but a few key components missing from ICMS3 Level 4, e.g. includes superstructure, substructure but not earthworks)	Partially matches the system boundary required (E.g. A1-A3 for A0-A5)	Some of the data and assumptions used to construct the benchmark is transparent
1	Benchmark calculated within 15 years	Refers to a totally different context (different continent, e.g. Canada for UK, EU for China)	Not specific material/technology for the UK e.g. ICE DB V2.0, Ecolnvent (Europe, Global)	Early stage / concept design	Does not satisfactorily reflect the asset (e.g. significant components missing from ICMS3 Level 4, e.g. includes superstructure but not substructure)	Does not clearly state the system boundary but can be interpreted (E.g. states operational energy but not clear if includes B6 and B7)	The data and assumptions used to construct the benchmark is not transparent
0	No evaluation made	No evaluation made	No evaluation made	No evaluation made	No evaluation made	No evaluation made	No evaluation made

4.4 Benchmark calculation methodology

4.4.1 Data aggregation and weighting

The carbon data from primary and secondary sources, with associated data quality scores, were aggregated together within the Carbon benchmarking model and categorised by asset e.g. Road bridge, Electrified Track ballasted, Bored road tunnel (Level 2 (Asset) in the final taxonomy). Each carbon data point was multiplied by the number of the data quality score to determine a weighted average carbon benchmark. A higher data quality score indicates a higher quality carbon benchmark, which results in a greater weighting in the sample.

The calculated weighted average carbon benchmark was reported in the output benchmark summary table within the Carbon benchmarking model, which also records the functional unit, standard deviation (SD) of the weighted values, number of data points, and the average data quality scores of the input data.

4.4.2 Data analysis and benchmark development

Within the Carbon benchmarking model, the weighted carbon data points were categorised into the carbon benchmark taxonomy (e.g. Road bridge) and a lifecycle stage (e.g. A0-A5). The weighting, applied based on the data quality score, allows higher quality data to have a greater influence in the analysis. The weighted mean of each asset subgroup was calculated by averaging the weighted data.

The standard deviation from the mean was also calculated to understand the spread of data. A high standard deviation indicates greater variability and less consistency within the sample. The calculated standard deviation can be used to identify outliers in the collected data, defined herein as any points beyond $\pm 2SD$. The user can decide whether to exclude outlier through a toggle in the output benchmark summary table within the Carbon benchmarking model. When outliers are excluded, a new average and standard deviation is calculated and reported in the output benchmark summary table

Figure 7 below illustrates the effect of excluding outliers for the datapoints collected for the four different road assets included within the study for B2-B5 modules. For each road asset, the graph details the raw data and the data after the outliers have been excluded. The mean is indicated by the central horizontal line for each sample, and the extended vertical lines illustrate $\pm 2SD$ of the sample. Table 8 details the numerical results from Figure 7.

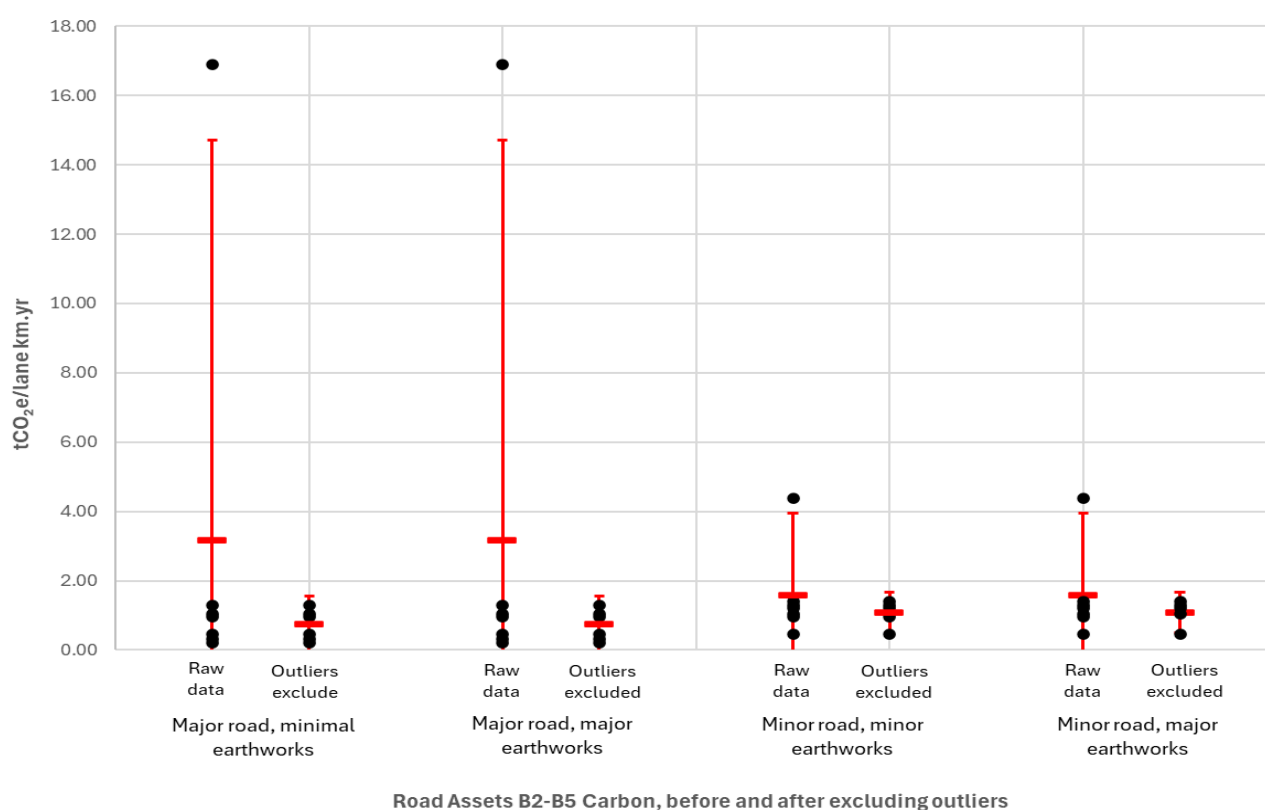


Figure 7 - Graph of road assets before and after eliminating outlier data points

Table 8 - Road assets data analysis results for data without removing outliers

B2-B5 Carbon Values	Major road, minimal earthworks (tCO ₂ e/lane km.yr)		Major road, major earthworks (tCO ₂ e/lane km.yr)		Minor road, minor earthworks (tCO ₂ e/lane km.yr)		Minor road, major earthworks (tCO ₂ e/lane km.yr)	
Range of data used	All data	Data without outliers	All data	Data without outliers	All data	Data without outliers	All data	Data without outliers
Number of data points	7	6	7	6	7	6	7	6
Weighted mean	3.16	0.73	3.16	0.73	1.56	1.08	1.56	1.08
± 2 Standard deviations	± 11.56	± 0.82	± 11.56	± 0.82	± 2.39	± 0.59	± 2.39	± 0.59

4.4.3 Transparency in benchmark reporting

Each carbon benchmark was reported with the number of data points, the standard deviation, and average data quality score. This allows users to quantify the variability and reliability of the benchmarks, providing a clearer picture of the uncertainty involved. See Table 9 for the carbon benchmark reporting with the major road example using the data without outliers excluded. It is used to report the construction, maintenance, operation, and end of life carbon benchmarks.

Table 9 - Final carbon benchmark reporting – major road, minimal earthworks example

Life Cycle Module		B2-B5			
Asset	Carbon benchmark	Functional unit	Standard deviation	No. of data points	Average data quality score
Major road, minimal earthworks	3.16	tCO ₂ e /lane km per yr	±5.78	7	17 - Good

4.5 Uncertainty

To account for uncertainty, standard deviation (SD) was used as the primary measure. Standard deviation provides an indication of the spread of data in relation to the mean, with lower values showing that the data is more closely gathered to the mean than those with higher standard deviations. The standard deviation can be used to identify datasets with significant outliers as the standard deviation will be higher.

4.5.1 Uncertainty of benchmarks

Uncertainty of the carbon benchmarks was defined as ±1 standard deviation from the mean of the data collected for each asset. It is noted that in this first revision of the benchmarks, the reported uncertainty is relatively high. It is likely that this can be improved through additional data gathering, refer to Section 5.1. However, for the level of asset granularity which was determined through stakeholder engagement to be useful for SOBC carbon benchmark, there will always be variability in individual scheme constraints which will fundamentally result in variability in carbon emissions.

4.5.2 Uncertainty of project (sum of the standard deviations)

The standard deviation for each asset is calculated by quadratically summing each life cycle module using the quantity (q) and design life (dl) inputs so that the units are consistent (tCO₂e). The standard deviation for each asset uses the following formula:

$$\text{Asset Uncertainty} = \sqrt{(SD_{A0-A5} * q)^2 + (SD_{B2-B5} * q * dl)^2 + (SD_{B6-B7} * q * dl)^2 + (SD_{C1-C4} * q)^2}$$

The standard deviation for the project is calculated by quadratically summing the individual assets that makeup the scheme, e.g. Tunnel, Road, Station. It was assumed that each asset is independent of each other, therefore the final standard deviation for the whole life carbon baseline was calculated using the following formula:

$$\text{Project Uncertainty} = \sqrt{(SD_{\text{Asset 1}})^2 + (SD_{\text{Asset 2}})^2 + (SD_{\text{Asset 3}})^2 + (SD_{\text{etc...}})^2}$$

4.6 Case study to demonstrate benchmark application

A case study is provided in the Carbon benchmarking model to demonstrate how the benchmarks can be used to generate a whole life carbon assessment at SOBC/early design stage. A hypothetical project was used as the case study with a range of asset types and example quantities.

The case study demonstrates the required inputs to the model (scheme data such as road length and design life) and how the benchmarks are used to calculate the carbon values and their corresponding uncertainties. The total carbon for each asset within the hypothetical scheme is detailed with the resulting uncertainty. The final whole life carbon is reported with the total uncertainty – see ‘O;Case study’ tab in the Carbon benchmarking model.

The ‘O;Case study’ tab is an example for reference of the application of the benchmarks and should not be used as a calculation tool or to verify the benchmarks.

4.7 Checking

The Carbon benchmarking model was checked in line Arup's companywide "Arup Health & Safety, Environment and Quality Management System" (AHSEQMS) which incorporates the requirements of ISO 14001:2015 [12], ISO 9001:2015 [13], ISO 45001:2018 [14], and is based on and aligned to several industry-standard frameworks (APM, Prince2 and PMI). All deliverables have been thoroughly quality assured and challenged through a process of "Do, Check, Approve". Refer to the "VersionCtrl" tab in the Carbon benchmarking model and the Document Verification table in this report.

4.8 Assumptions and limitations

Assumptions and limitations for the project have been detailed in the "Assumptions" and "Limitations" tabs within the Carbon benchmarking model.

5. Approach to continuous improvement

The process of continuous improvement should begin by addressing the limitations outlined in the "Limitations" tab of the Carbon benchmarking model. Key areas for improvement are outlined in the following sections.

5.1 Addition of data

To improve reliability of the benchmarks within the Carbon benchmarking model, it is strongly recommended that additional data is added, provided the data is not generated using a benchmark already recorded within the model. The data should be analysed according to the data quality review process detailed in the report and model. The data should be recorded within the "I:Raw data inputs" tab, ensuring accuracy and detail in all input columns to allow for transparency and reliability of the model. The "I:Data source" tabs should be updated with the new data, to allow the model to function efficiently as well as provide transparency to the sources used. Other relevant tabs should be updated when appropriate such as the "Assumptions" and "Limitations" tabs, ensuring any assumptions and limitations are made clear and represented in the notes and data quality analysis columns.

5.2 Benchmark development

There is an opportunity for DfT to identify assets with few data points, low quality, or high uncertainty, and perform additional bottom-up carbon assessments to provide greater robustness and reliability to the benchmarks. The calculations shall be in accordance with BS EN 17472 [3], to a level of detail that is appropriate for the intended use of the benchmarks in correlation to the taxonomy defined in this work, in accordance with the PAS2080:2023 [15] assessment requirements. In addition, when user carbon from regional transport models is more mature, user carbon benchmarks could be derived to inform early concept decision-making.

5.3 Benchmark verification and validation

Future work is required to verify the benchmarks within the Carbon benchmarking model. This requires coordination with DfT to identify relevant projects for infrastructure schemes to use as case studies to demonstrate the successful application of the benchmarks in generating whole life carbon assessment at SOBC/early design stage. These would also help to determine rules of thumb for scheme constraints which result in larger deviation from the benchmark values (for example poor ground conditions, or bridge spans greater than 100m). Care should be taken to ensure the projects that are used in the verification process are not included in the raw data inputs for the Carbon benchmarking model. The quantity and design life should be inputted to the model and the resulting whole life carbon values with uncertainty should then be compared with known values from bottom-up whole life carbon assessments of the projects. Verification with sufficient projects could also provide rule-of-thumb insights into key factors which may lead a project to be in the high- or low-end of the average benchmark, for example bridge span lengths above 100m increase the benchmark by 20%.

6. Conclusions

The project established a comprehensive taxonomy for road and rail assets through a series of engagements with industry organisations. The final taxonomy aligns with ICMS3 at both Level 1 and Level 4. Using this taxonomy, whole life carbon benchmarks were developed using a combination of primary and secondary data sources.

An Excel-based Carbon benchmarking model was developed which incorporates over 240 data points. Each data point was assessed using data quality metrics, ensuring that higher-quality data had a greater influence on the benchmark outcomes. To quantify uncertainty, standard deviation from the mean was used, with outliers beyond two standard deviations excluded. This method provides insight into data variability, where lower standard deviations indicate more consistent and reliable values. The Carbon benchmarking model will be a valuable tool for organisations conducting whole life carbon assessments at the SOBC stage.

To support continuous improvement, it is recommended that additional data be collected from across the industry to enhance the accuracy and robustness of the benchmarks. Furthermore, it is recommended to identify infrastructure projects to be used as case studies to validate the model by comparing the estimated whole life carbon values with actual project data. In addition, when user carbon from regional transport models is more mature, user carbon benchmarks could be derived to inform early concept decision-making.

Appendix A Taxonomy desk study review

<i>Taxonomy sources reviewed</i>	<i>Link</i>
<i>CCC (sector level)</i>	<u>CCC Mitigation Monitoring Framework - Climate Change Committee</u>
<i>CCC (transport mode)</i>	<u>The-Sixth-Carbon-Budget-Methodology-Report.pdf</u> Note at the time of the taxonomy review the 7 th carbon budget had not been published yet by the CCC, therefore this was not used due to the timing of this work. This is not anticipated to change the conclusions of this work.
<i>Gov.uk</i>	<u>2023 UK greenhouse gas emissions, provisional figures</u>
<i>ICMS 3rd edition</i>	<u>icms_3rd_edition_final.pdf</u>
<i>DfT Source 1</i>	<u>Domestic Transport Usage by Mode - GOV.UK</u>
<i>DfT Source 2</i>	<u>Mode of travel - GOV.UK</u>
<i>DfT Source 3</i>	<u>Annual Report and Accounts 2022–23</u>
<i>Shared Digital Carbon Architecture</i>	-
<i>BECD/Uniclass</i>	<u>En_80_Transport entities Uniclass</u>
<i>CISA</i>	<u>https://www.cisa.gov/resources-tools/resources/infrastructure-data-taxonomy</u>
<i>BECD/Uniclass Source 1</i>	<u>En_80_35_Road entities Uniclass</u>
<i>BECD/Uniclass Source 2</i>	<u>En_80_50_Railway entities Uniclass</u>
<i>Gov.uk</i>	<u>Guidance on road classification and the primary route network - GOV.UK</u>
<i>National Highways Asset Reference Catalogue</i>	<u>admmv13_part_4_asset_reference_catalogue_final.pdf</u>
<i>National Highways</i>	<u>Carbon emissions calculation tool - National Highways</u>
<i>Spon's Civil Engineering and Highway Works Price Book 2025</i>	<u>Spon's Civil Engineering and Highway Works Price Book 2025 AECOM </u>
<i>Civil Engineering Standard Method of Measurement, Fourth Edition (CESMM4)</i>	<u>CESMM4 CESMM</u>
<i>National Highways Data Dictionary</i>	<u>https://nationalhighways.co.uk/media/sr2isspr/admmv13_part_3_data_dictionary_final.xlsx</u>

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