Department for Transport

Local Transport Quantifiable Carbon Guidance

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Terminology used

The following terms are used throughout this document:

- **Quantifiable Carbon approach:** the approach advocated within this Quantifiable Carbon Guidance (QCG) that involves use of carbon evidence and assessment to inform the development of transport strategies and schemes.
- **Greenhouse Gases (GHGs)**: gases that contribute to global warming by absorbing heat in our atmosphere. The largest proportion of GHG emissions relate to carbon dioxide although they also include methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride.
- **Carbon**: carbon dioxide equivalent of all greenhouse gases, for which it is frequently used as shorthand throughout this document.
- **Carbon impact:** refers to the effect of proposed interventions and/or policies on carbon, either an increase or decrease in emissions.
- **UK Carbon Budgets:** legally binding long-term emission reduction targets set at the national level.
- **Carbon management** (as defined in PAS 2080:2023): assessment, reduction and removal of greenhouse gas 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.
- **Carbon assessment**: the quantification or estimation of carbon emissions.
- **Carbon appraisal**: consideration of carbon in a systematic process used to evaluate the impacts, costs, and benefits of proposed transport interventions. This process is detailed in DfT Transport Appraisal Guidance (TAG) and includes the monetisation of carbon emissions as an input to a benefit-cost ratio (BCR) for use in Business Cases.
- **Evaluation:** is a systematic assessment of an intervention's design, implementation, and outcomes. It involves understanding the implementation process, its effects, and identifying areas for improvement. It also estimates the intervention's overall impacts and cost-effectiveness.
- **Net Zero:** the total greenhouse gas emissions released are equal or less than the emissions removed from the atmosphere.
- **Authorities:** used throughout this report to refer to local or regional authorities responsible for local transport planning (e.g., Local Transport Authorities).
- **User carbon:** direct emissions generated from the use of the transport network (for example tailpipe emissions).

- **Capital carbon:** emissions associated with the construction, maintenance and end-of-life of an infrastructure asset (for example manufacturing and transport of materials e.g. cement and steel). This also includes changes in the carbon stored in natural assets (habitats).
- **Operational carbon:** emissions associated with the operation of an infrastructure asset (for example carbon due to the power consumed by traffic lights, but not any change in carbon emitted by vehicles due to the working of the traffic lights).
- **Land use change emissions**: Emissions associated with a change in carbon stored in natural assets (habitats) (e.g. from the felling or planting of trees).
- **Infrastructure carbon:** emissions associated with the construction, operation, and maintenance of an infrastructure asset. This includes capital and operational carbon, including land use change emissions.
- **Whole Life Carbon (WLC):** emissions associated with an infrastructure asset over its lifecycle. This includes user carbon and infrastructure carbon.
- **Zero Emission Vehicles (ZEV):** a vehicle that produces no emissions from the on-board source of power (for example all-electric or hydrogen fuel cell vehicles).
- **Transport strategy**: a plan that outlines the vision, goals, and priorities for the development and management of transport systems.
- **Strategic Outline Case (SOC):** the initial phase in the transport business case process. It establishes the potential scope of a transport proposal, setting out the rationale for intervention (the case for change) and confirming how the proposal aligns with strategic priorities.
- **Outline Business Case (OBC):** the second phase in the transport business case process. The OBC builds on the SOC by providing more detailed analysis and evidence to support the preferred option.
- **Full Business Case (FBC)**: the final phase in the transport business case process. The FBC provides a comprehensive and detailed justification for the preferred option, ensuring it is ready for implementation.
- **Business-as-Usual, Baseline and Do-Minimum**: these terms generally refer to comparators that represent the future without intervention (for example without policies and interventions proposed in a transport strategy, or prior to carbon reduction measures in design). These terms are each used with more specific interpretations in different contexts covered in this guidance, which are explained when used.
- **Carbon Factor (Emission Factor)** – a value that when multiplied by project data quantifies the amount of greenhouse gases released into the atmosphere by a specific activity or process. This is typically expressed as a mass of CO_2e per unit of the activity or material, for example kgCO_2e per tonne of concrete used.

1. Introduction

Purpose of this guidance

1.1 The 2008 Climate Change Act requires the UK to reduce its carbon dioxide and other greenhouse gas emissions to reach 'net zero' emissions by 2050. Transport is the UK's largest carbon emitting sector - ambitious action is needed across the sector to ensure we are on-track to reach net zero. Local authorities can contribute to accelerating carbon reduction through the delivery of transport and place-based solutions.

1.2 This technical guidance provides practical advice on how authorities can prepare and use carbon analysis to inform the development of their transport strategies and schemes and quantify their impact.

1.3 This guidance will:

- Provide advice on how and when carbon analysis can be integrated into the process of developing transport strategies and schemes.
- Provide guidance on different methods for assessing carbon impacts, including the methodologies and datasets that can be used.
- Provide the foundation from which carbon analysis methods and data can continue to be developed by the Department for Transport (DfT) and the sector.

1.4 An absence of carbon analysis guidance at a transport strategy level has limited authorities' ability to influence carbon impacts at the earliest stages of transport planning. While carbon quantification methods and tools have significantly evolved in recent years, the absence of guidance can hinder their effective application. Authority capacity and capability to implement these methods also differ and there is no 'one size fits all' solution to local transport decarbonisation; carbon analysis should support the development of transport strategies that reflect local circumstances and address local issues, contributing to transport decarbonisation.

1.5 Carbon analysis at later stages of scheme development is more established. Carbon quantification has, for some time, been applied within business case development and for consenting purposes and there are a number of existing and established standards and guidance documents relating to carbon management and assessment, such as PAS2080. These existing guidance and standards outline fundamental principles that apply to building and infrastructure projects across all sectors. However, they lack advice on how these principles should apply specifically to local transport planning, leading to inconsistent practices.

1.6 This guidance has been developed in recognition of these challenges. It provides authorities with an evidence-based approach to transport planning and the pursuit of local decarbonisation goals in a way that reflects local circumstances and addresses local issues while supporting the UK's target of reaching Net Zero by 2050. The analysis outlined can be used to understand local transport emissions sources and potential carbon impacts of policies and infrastructure.

1.7 This guidance is designed to help authorities to include carbon analysis in their transport planning/scheme development process in a high-quality, structured way. Methodological guidance is also provided to assist authorities in preparing this analysis. However, it does not provide direction on specific interventions to be applied or avoided. It focuses explicitly on carbon analysis in developing local transport strategies and schemes and does not influence other existing business case processes, guidance, or consideration of other metrics.

Guidance at a glance

1.8 This Quantifiable Carbon Guidance (QCG) has been designed for a variety of users, from policy officers to analysts. It has been structured as follows:

- A high-level overview of the process is provided in Chapter 2.
- Advice on how and when carbon analysis can be used to support transport strategy and scheme development is provided in Chapters 3 – 5.
- Methodological guidance on how to estimate carbon impacts is provided in Chapters 6 – 8. These Chapters provide detailed technical guidance to assist analysts in undertaking the quantitative assessments identified as part of the process outlined in Chapters 3 – 5.
- Advice on how carbon impacts can be evaluated is provided in Chapter 9.

1.9 The steps involved in this carbon analysis process and corresponding Chapters of this guidance are illustrated in Figure 2-1. The guidance is not intended to be read end-to-end. Chapters 2 – 5 are likely to be most useful for policy officers while Chapters 6 – 9 will be most applicable to analysts. Links are also provided throughout the document to aid navigation.

1.10 This guidance has been designed to be applicable to all local transport strategies and schemes, regardless of whether a business case is required or not. It does not mandate when it should be applied; but advises where such analysis could support decision-making and how it can be undertaken where authorities choose to do so or are required to by existing guidance or legislation.

1.11 A variety of methods are outlined in this guidance to enhance authorities' awareness of the analytical options and guide practitioners application of these to support their decision-making. Authorities however have the flexibility to use other data, methods and tools that may be suitable to their situation, and indeed may wish to go above and beyond the approaches suggested here. Authorities are also encouraged to contact DfT for further advice on the availability of tools that might support the analysis outlined in this guidance.

2. Local Transport Quantifiable Carbon Guidance: An Overview

Context

2.1 Reducing transport-related carbon emissions is vital for the UK to reach net zero. While the transition to Zero Emission Vehicles (ZEVs) will have the most impact in reducing surface transport emissions, lower carbon transport options, including supporting people to choose public transport and active travel, will have an important role to play.

2.2 While responsibility for achieving carbon budgets and Net Zero lies with national Government, local authorities are uniquely placed to influence transport decarbonisation through transport and place-based planning. To support decarbonisation across all emissions sources associated with transport, authorities should consider and account for emissions from the construction and maintenance of infrastructure, as well as user carbon.

2.3 Transport strategies can have a significant influence on local transport emissions. They set a place-based vision for local transport and identify projects for investment that can help realise that vision through changes to the transport network.

2.4 There is also significant opportunity to influence carbon impacts through the process of scheme development. Decisions such as which option to take forward, how the scheme is designed and what materials or construction processes are chosen, will all influence carbon impacts.

2.5 It is therefore important that carbon is considered in both strategy and scheme development. This guidance provides practical advice on how this can be done, drawing on best-practice across the sector.

Relevant stages of transport planning

2.6 The general stages of transport planning that this guidance provides carbon analysis advice for are as follows:

- **Strategic planning stage (e.g. Local Transport Plans)** – development of transport strategies that define a vision for local transport and identify projects for investment. Considering carbon in decision making at this stage should be strategic in nature; primarily considering the need for and influencing the types of interventions to be delivered, rather than how or what is delivered (for example material choices in design). It is at this early, strategic stage that the opportunity to influence carbon outcomes is greatest. Methods and advice for undertaking this analysis to inform the planning stage is provided in Chapters 3, 4, 6, 7 and 8.
- **Scheme development** – option development, appraisal and design. Considering carbon in this process should influence the selection of options and design (for example, application of PAS2080's carbon reduction hierarchy). It should also improve the consideration of carbon in business cases to inform funding decisions. Advice on the assessment of carbon in transport scheme development is provided in Chapters 5, 6, 7 and 8.
- **Evaluation** – evaluating predicted scheme impacts against observed data collected prior to and after a scheme's construction. While carbon evaluation will not influence the carbon impact of the scheme in question, it can improve understanding of carbon impacts that will help improve decision-making in future. High-level advice on the key principles and concepts of carbon impact evaluation is provided in Chapter 9.

2.7 Even in the absence of detailed data during strategic planning and early stages of intervention development it is important to undertake Whole-Life Carbon (WLC) assessments and encourage behaviours and decisions that bring about carbon reduction. These carbon analytical principles are likely to evolve as:

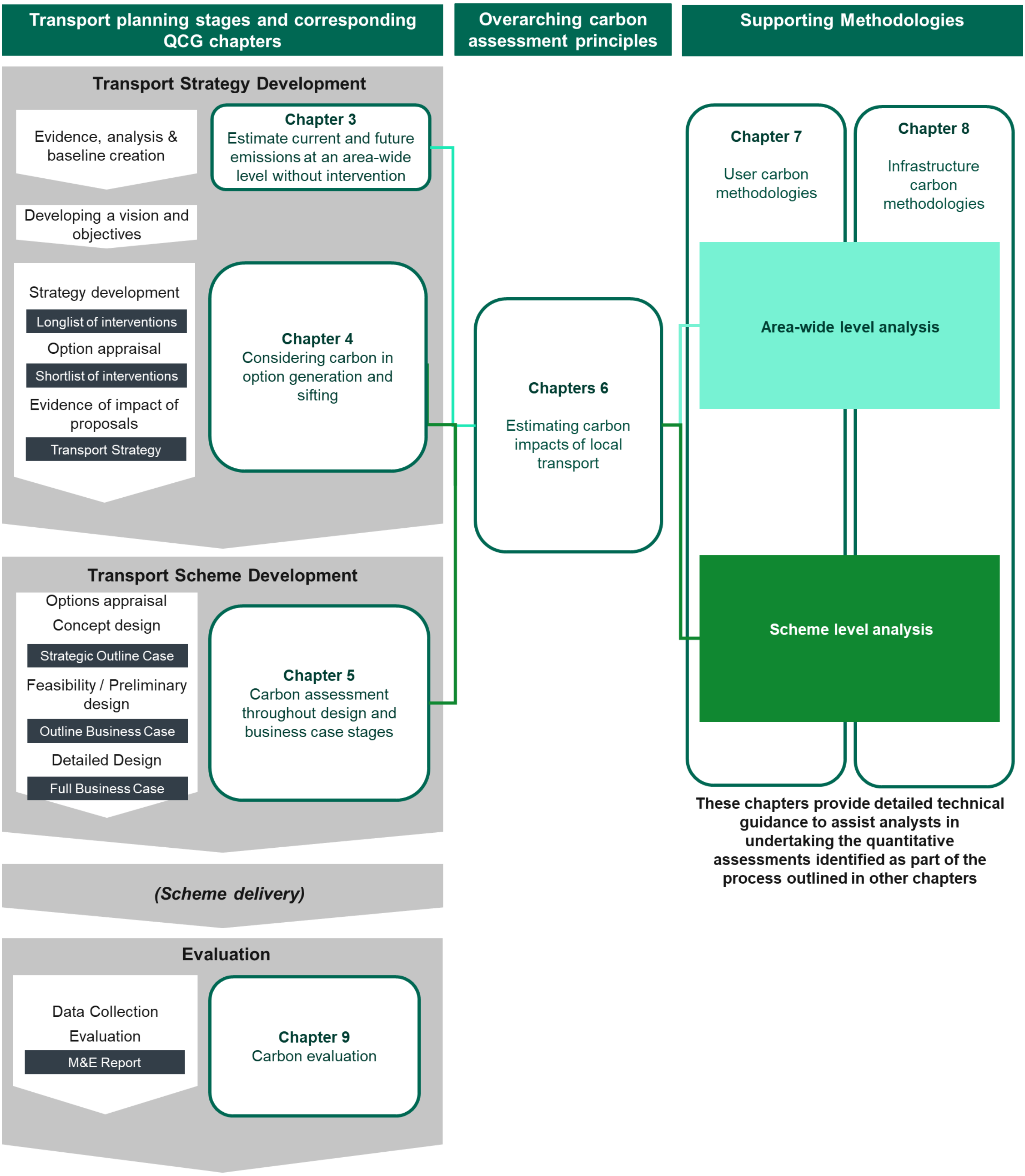
- The ability to reduce WLC in projects and programmes of work diminishes as interventions progress through the project lifecycle.
- The accuracy of assessment improves as the project or programme develops.

2.8 Carbon management (i.e. influencing carbon impacts) should take place throughout the whole project lifecycle. This should include consideration of carbon in optioneering and transport strategy / policy development and in the preparation of a Carbon Management Plan during scheme development.

Process outline

2.9 Figure 2-1 illustrates the process outlined in this guidance and its corresponding chapters. This provides a process authorities can use to consider carbon in the local transport planning process, as well as methodological guidance on how to do this.

Figure 2-1 QCG carbon analysis process outline



2.10 Authorities can choose to apply the process and related methods set out in this guidance flexibly, subject to their local needs and circumstances, or develop other approaches, where this improves the quality of analysis and decision-making.

2.11 The approach and methodologies outlined in this guidance may have wider application beyond transport strategies, intervention and policy development and evaluation. For example, the analysis of current and future emissions at an area-wide level could be of value to local authorities when developing climate strategies or Local Plans.

Relation to other guidance

2.12 This guidance does not replace or supersede existing guidance or standards related to carbon management and assessment. It is intended to be complementary and has been aligned to the documents described below.

- **PAS2080:2023 Carbon Management in Buildings and Infrastructure** – this guidance provides a process and principles for managing carbon in the built environment. It is not transport specific and does not include guidance on assessment methodologies but should be referred to for establishing how to manage carbon impacts across the project lifecycle.
- **BS EN17472:2022** – this guidance establishes the requirements and specific methods for the assessment of environmental (including carbon), economic and social performances of a civil engineering works. It is not transport specific and does not provide detailed guidance on assessment methodologies (for example how to estimate user carbon impacts).
- **RICS Professional Standard - Whole-life Carbon Assessment for the Built Environment, 2023 (2nd Edition)** – this standard provides guidance on a range of topics involved in WLC assessment, including spatial boundaries and units of measurement.
- **TAG Unit A3** – Chapter 4 of TAG Unit A3 provides guidance on how to consider carbon as part of a business case appraisal (for example how to monetise estimated carbon impacts and reporting requirements for a business case).
- **GHG Protocol** - Annex A.2 explains how WLC emissions relate to the GHG Protocol's scope 1, 2 and 3 emission categories.

Key principles and boundary for assessment

A proportionate and flexible approach

2.13 This guidance has sought to cater to a range of analytical capabilities within an authority by providing advice on different methodologies that can be used for each step in the carbon analysis process. This includes simple methodologies that can be undertaken without specialist skills or any undue burden and more advanced analysis that can provide more comprehensive and detailed analysis but may need to be prepared by technical analysts.

2.14 It is recognised that the costs, scales and potential carbon impacts of schemes considered through this carbon analysis process will vary widely. For example, a carbon assessment for a major new road scheme is likely to be more extensive and detailed than a carbon assessment for a minor junction improvement. Efforts however should be made to consider carbon in the development of all policies and interventions, even if this involves qualitative or less detailed quantitative assessment methodologies where appropriate for some schemes.

2.15 Authorities should therefore consider proportionality when deciding on which schemes to apply these methodologies to and which methodologies to apply. The level of detail and data required in a carbon assessment should also be commensurate to the development stage of a project.

2.16 Guidance on the use of methodologies is not prescriptive, and authorities have the flexibility to use other data, methods and tools that may be suitable to their situation. However, in some instances, this guidance encourages that specific datasets or assumptions are used as a minimum standard to enable consistent comparison of results between authorities.

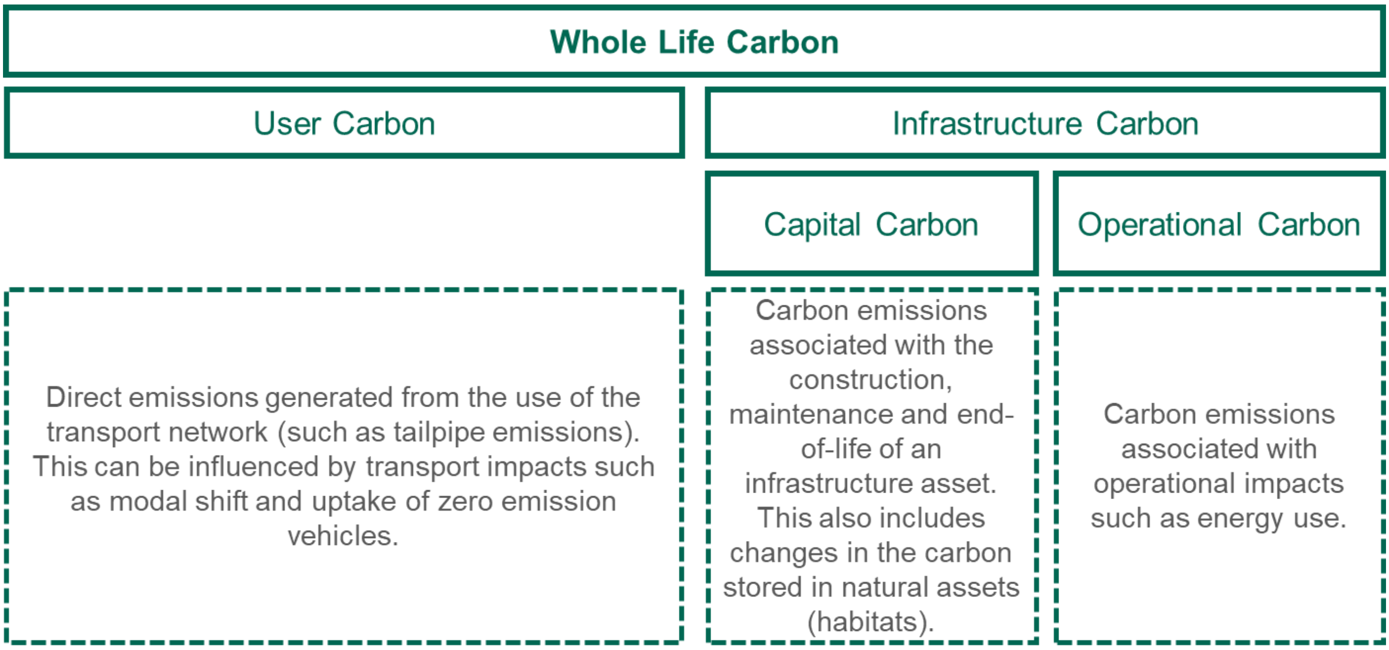
2.17 Authorities should always clearly report the assumptions and methodology used in their analysis, particularly where the methods used are not covered by this or other guidance.

Consider key carbon impacts across the lifecycle of policies and interventions

2.18 WLC is the full carbon impact of a transport intervention across the project lifecycle (cradle to grave) and thereby represents an intervention's full contribution to climate change. This includes infrastructure related emissions that may be accounted for at a national level (e.g., Government's GHG inventory) under sectors such as industry as well as transport. To support decarbonisation of the economy as a whole it is important that the impacts of proposed transport schemes on carbon emissions over their whole lifecycle are considered in decision-making (whether they result in increases or decreases in emissions).

2.19 WLC comprises the key categories presented in Figure 2-2. A more granular breakdown can be found in WLC guidance such as PAS2080 and BS EN 17472. A review of these documents is however not required to conduct this QCG carbon analysis process, which adopts the key principles of PAS2080 and BS EN 17472. More detailed breakdowns of WLC emissions can be found in Chapters 6, 7 and 8.

Figure 2-2 WLC and related carbon definitions used in this guidance



2.20 As carbon impacts over the lifetime of infrastructure assets and schemes should be considered, this will involve estimating 'current' emissions and forecasting how these might change in the future (often in both a Do Minimum and Do Something scenario). The assessment period used in the analysis should, in all cases, cover at least up to 2050 (the UK's Net Zero target), and where analysis is part of a business case, it should align with the project assessment period which may be longer than the time to 2050 (e.g. 60 years). See Chapter 6 (paragraphs 6.6 to 6.9) for further advice on assessment periods.

2.21 The units typically used in carbon assessments and how to convert between these are detailed in Annex A.1.

User carbon

2.22 Decarbonising transport requires intervention to reduce user carbon, that is, the carbon generated from the use of vehicles on the transport network. User carbon is therefore an important consideration in the transport planning process, particularly in strategic planning and early stages of scheme development.

2.23 The user carbon impacts that can be considered depend on the available data. For instance, in strategic planning, traffic modelling may not be feasible or necessary. However, benchmarks for potential demand changes can help estimate carbon savings, as detailed in Chapter 7. In such cases, estimates related to vehicle routeing, speeds, and demand impacts might not be available and may need qualitative consideration with quantification postponed until later stages when traffic modelling is available.

2.24 Further advice on user carbon assessment is provided in Chapter 7.

Infrastructure carbon

2.25 The influence of transport strategy, policy and interventions on infrastructure carbon will include capital and operational carbon impacts. As with user carbon, there is a significant opportunity to influence infrastructure carbon outcomes if these are considered early in the development of transport strategy and schemes. As well as helping to mitigate climate change, reducing and managing infrastructure carbon can provide co-benefits, PAS 2080: 2023 suggests “examples of co-benefits include, but are not limited to, reduced air pollution, increased resilience, reduced cost and risks, employment possibilities, security, social justice, nature restoration and regeneration, and biodiversity net gain.”

2.26 Authorities are encouraged to consider the infrastructure carbon associated with proposed measures (strategies, policies and schemes), as well as the maintenance of existing infrastructure (for example, highway resurfacing). A defined project scope should be determined and recorded before completing the carbon assessment.

2.27 Typically for infrastructure projects, construction-stage capital carbon will account for a significant proportion of the whole life carbon impact over the project’s lifetime, as this accounts for the materials and construction processes used to build the assets. However, a large proportion of emissions can also be produced as a result of maintenance activities across the asset’s lifetime. Operational carbon impacts associated with the asset’s consumption of water or energy are typically less significant than other infrastructure carbon impacts.

2.28 As acknowledged in TAG Unit A3, it will typically not be necessary to assess carbon impacts at the end of the project lifecycle for schemes where asset demolition and removal is expected to fall under the purview of a successor project.

2.29 Further advice on infrastructure carbon assessment is provided in Chapter 8.

Geographic study area

Area-wide analysis

2.30 The area-wide analysis described in Chapter 3 that is used to develop a transport strategy evidence base should seek to quantify all emissions resulting from transport activities occurring within the geographic boundary of the authority. This should include user carbon from all vehicle use on the road network, and all infrastructure carbon emissions associated with that local authority’s transport infrastructure within that boundary.

2.31 It is recognised that some of these emissions will be produced from a source outside the geography of that authority. For example, energy generation for ZEVs or industrial emissions for manufacture of construction materials. Authorities however, can still influence these emissions so should seek to account for them where possible.

2.32 It is also acknowledged that not all emissions occurring from transport activities occur within the geographic boundary of an authority will be within the direct influence of that authority. For example, through-trips (trips without an origin or destination within the administrative boundary of the authority) and rail. Such emissions outside the direct influence of authorities may be higher where the Strategic Road Network is present within the authority boundary. Chapter 3 provides advice on how such emissions outside the direct influence of an authority can be quantified.

Scheme level analysis

2.33 In contrast, scheme-level analysis involves carbon assessment of individual schemes and should account for carbon impacts regardless of where they occur. Policies and interventions delivered in one authority will often influence emissions in others. For example, a Workplace Parking Levy instigated in an urban authority will also likely reduce commuting trips and associated emissions that occur in a neighbouring rural authority. Regardless of where carbon impacts occur, they will contribute to the UK's emissions and climate change so the net impact must be accounted for (i.e. not just impacts within the geographic boundary of the local authority that instigates a policy or intervention).

3. Estimating current and future emissions at an area-wide level without intervention

3.1 Carbon emissions in each authority are influenced by the unique characteristics of their location. Different authorities face varying challenges and conditions that affect the scale and sources of their emissions.

3.2 Understanding this challenge involves estimating current and future emissions at an area-wide level (in the absence of the interventions outlined in the transport strategy). This should reflect how variables such as demand, speed and vehicle types influence local emissions. These estimates will provide a 'baseline' against which the impact of a transport strategy and programme can be measured. It can also provide an insight into different sources of emissions to help authorities target interventions where they will have the greatest effect.

3.3 This Chapter relates to both user carbon and infrastructure carbon impacts that occur on an authority's network through business-as-usual activities. For user carbon, this relates primarily to vehicle movements on the road network. For infrastructure carbon this relates to maintenance activities such as repair and replacement. Impacts associated with planned policies and interventions (e.g. scheme impacts such as modal-shift or construction) are not considered in this Chapter.

3.4 In most regions, area-wide estimates of user carbon have already been prepared at a regional level. Where this is the case, authorities can obtain this and will not need to undertake the analysis themselves. Tools and resources also exist to help local authorities estimate infrastructure emissions across their activities.

3.5 This Chapter is intended to help authorities understand key concepts and methods underpinning this analysis and how it can be used in a transport strategy evidence-base. Advice on the scope and scenarios used in this analysis is also provided to enable outputs that are comparable between different authorities. This advice and more detailed methodological guidance in Chapters 6, 7 and 8 can also support those unable to access existing analysis or tools and who wish to prepare this carbon analysis themselves.

3.6 The following sections of this Chapter – with sub-sections relating to both user carbon and infrastructure carbon - cover:

- **Scope of emissions –** advice on the geographic study area and emission scope that should be considered. For example, advice on which infrastructure carbon impacts should be considered as a minimum.
- **Scenarios –** advice on how a consistent business-as-usual scenario should be defined so that analysis can be compared between areas. Advice is also provided on further sensitivity tests that can be undertaken to understand the impact of national policies and trends on local emissions.
- **Area-wide carbon analysis methodologies –** a summary of the methodologies that can be used to undertake this analysis and advice on their use.
- **Area-wide carbon analysis outputs –** a summary of the different categories of carbon emission estimates that this analysis can provide.
- **Understanding emissions under local authority influence –** advice on how user emissions can be broken down to report emissions within the direct influence of an authority.

Scope of emissions

3.7 The full operational impact of transport networks will primarily be comprised of:

- User carbon impacts (mostly tailpipe emissions).
- Infrastructure carbon impacts associated with maintenance and replacement activities and energy consumption (e.g. highway lighting).

3.8 Other impacts may include carbon sequestration from green infrastructure associated with transport networks (e.g. carbon sequestered by trees within highway verges). However, these land use emissions are not included within the scope of this Chapter.

User carbon

3.9 The geographical scope for an estimate of current and future user carbon should lie within the relevant administrative boundary of the transport strategy.

3.10 Authorities are only expected to quantify domestic surface transport emissions. Quantification of aviation and shipping emissions are not expected as they are governed by policies outside of the control of the authority. Emissions associated with surface transport to and from airports and ports should however be included.

3.11 The scope of emissions quantified should be made clear when reporting. This should clarify which modes are included in the estimate of current and future emissions and provide a clear justification where sources of emissions are excluded.

3.12 The scope of quantification should focus on the largest impacts or those most relevant to decision-making. As a minimum, emissions associated with cars, light good vehicles (LGVs) and heavy goods vehicles (HGVs) should be quantified. Data on the relative emissions by mode at a national level can be found in published transport energy and environment data tables.

3.13 Assessment of current and future bus emissions is encouraged but the feasibility of this and extent to which they can be quantified and disaggregated will be reliant on the tools and data available to authorities. Authorities are encouraged to contact the DfT to enquire about available tools to assist with the quantification of bus emissions. The carbon impacts of any bus intervention put forward in a transport strategy (for example a bus priority measure or zero emission buses) should be considered as part of analysis outlined in Chapter 4.

3.14 Assessment of current and future rail emissions will often not be proportionate. Quantifying rail emissions within a local authority boundary is currently challenging; these emissions will typically not be captured in local transport models and national emission inventories only capture emissions from diesel railways. The majority of rail emissions are typically not under local authority control. The carbon impacts of any rail intervention put forward in a transport strategy should be considered as part of analysis outlined in Chapter 4.

3.15 Emissions from bus and rail use, which account for both user carbon (tailpipe) and energy consumption (for example electric or hydrogen propulsion) are typically a small source of overall emissions in comparison to user carbon from cars, LGVs and HGVs. Available area-wide user emission methodologies described in this guidance do not all include bus or rail emissions by default (see Table 3-2). Authorities are therefore encouraged to consider availability of existing analysis and the importance of quantifying bus and rail use to decision-making when deciding whether to quantify bus and rail emissions.

Infrastructure carbon (maintenance, replacement and operational energy consumption emissions)

3.16 Area-wide level carbon emissions from maintenance, replacement and operational energy consumption will primarily comprise of:

- The maintenance of existing assets e.g. carriageway surface dressing, pothole repairs, gully cleaning.
- The replacement of asset elements at the end of their service life e.g. full depth carriageway reconstruction.
- The energy used to operate these assets e.g. energy for street lighting and traffic management systems.

3.17 Estimates of emissions from maintenance, replacement and operational energy consumption should focus on the transport network within the authority's control.

3.18 The maintenance and replacement of highway infrastructure assets and elements includes those typically captured in an authority's Asset Management Strategy, such as highways (e.g. bridges carriageways, footways, cycleways), structures (e.g. bridges), drainage, street lighting and highway verges and trees.

3.19 The repurposing of an existing asset (for example re-allocation of carriageway to cycleway) is considered a new intervention.

3.20 The largest carbon impacts associated with in-use maintenance, replacement and operational energy consumption of local transport infrastructure will typically be associated with highways resurfacing, owing to the significant quantities of materials such as asphalt involved. As a minimum therefore, it is suggested that any quantification of infrastructure carbon at an area-wide level considers highway resurfacing. Where suitable data is available to enable a proportionate assessment, authorities are encouraged to account for other relevant activities.

Scenarios

3.21 Assessment of emissions at an area-wide level should be estimated for a 'Business-as-Usual' (BaU) scenario on a yearly basis from a recent baseline up to at least 2050. This BaU scenario should represent firm and funded policies and thereby provide an understanding of the scale and sources of these emissions without further intervention.

3.22 It is acknowledged however, there are significant uncertainties in future trends that may influence emissions over this time period. For example, uptake of ZEVs will influence user carbon, and decarbonisation of the energy grid and materials will influence infrastructure carbon. Alternative scenarios and sensitivity testing can therefore be useful to inform planning for uncertainty.

3.23 A suitable base year of the emissions can be determined reviewing the available traffic models and selecting the latest base year available. It should be noted that the base year of the emissions calculation should be no later than the last published set of Government statistics, such as DfT Road Traffic Statistics and DESNZ GHG inventory estimates. This is to ensure that the model data can be constrained and validated against published statistics. Once a baseline has been set, this should be used for all assessments (both user carbon and infrastructure carbon). Guidance on forecasting and uncertainty can be found in TAG Unit M4. Guidance on creating scenarios and conducting scenario analysis can be found in the TAG Uncertainty Toolkit.

User carbon

3.24 In order to enable consistent comparisons, authorities should as a minimum develop an estimate of future emissions under a BaU scenario that uses current DfT/TAG datasets and recognised growth forecasts such as the National Transport Model (NTM) / National Road Traffic Projections (NRTP). Fleet assumptions for a BaU scenario should be based on the latest version of the TAG Data Book (A1.3.9 provides fleet proportions of vehicle kilometres by fuel type).

3.25 Future user carbon will be significantly influenced by the rate of ZEV uptake. Authorities may therefore wish to test alternative scenarios of ZEV uptake, such as scenarios of mileage split by fuel type provided in DfT's Common Analytical Scenarios (CAS).

3.26 National policies such as the ZEV mandate will influence the rate of ZEV uptake in local authorities and therefore the user carbon on their networks. Authorities however have a critical role to play in planning and delivering the charging infrastructure that will enable accelerated uptake of ZEVs; particularly where the market may fail to do so. While future national policies will likely drive higher uptake than currently assumed in TAG data, the ambitious levels of ZEV uptake included in the CAS can only be achieved with delivery of local charging infrastructure at a pace that enables this trajectory.

3.27 The ambition and delivery of a local EV charging strategy will be a key determinant of future fleet composition. Local conditions will also influence the pace and scale of ZEV uptake between areas. Through the development of a transport strategy and EV charging strategy it is for the authority to decide, where possible supported by evidence of the QCG process, what mix, pace and scale of interventions, including EVs are required. Authorities can also consider using localised forecasts where available to establish a more realistic and locally specific scenario.

3.28 The use of 'accelerated ZEV uptake' scenarios based on CAS or other datasets can be used as part of transport strategy carbon analysis to provide evidence of:

- The potential contribution of an ambitious scenario of ZEV uptake nationally if enabled by local charging infrastructure.
- Illustrate the scale of the challenge that remains even after a scenario of ambitious ZEV uptake. This will inform consideration of the contribution that other local interventions might provide in addition to the transition to ZEVs.

3.29 Additional scenario tests that could be considered to inform planning for uncertainty include running one or multiple Common Analytical Scenarios in full (for example in addition to mileage splits also testing scenario assumptions for fuel efficiency, fuel costs, etc.). The basis of any assumptions should be clearly set out and justified.

Infrastructure carbon (maintenance, replacement and operational energy consumption)

3.30 A BaU scenario of infrastructure carbon emissions at an area-wide level should assume maintenance, replacement and operational energy consumption continues at current levels out to 2050, while accounting where possible for a BaU (firm and funded) scenario in which material extraction, transportation and manufacturing processes will decarbonise. The RICS Whole-life Carbon Assessment for the Built Environment, 2023 (2nd Edition) includes a number of infrastructure decarbonisation scenarios that can be considered for this scenario analysis.

3.31 A scenario of more ambitious background decarbonisation of infrastructure emissions (e.g. an 'accelerated industrial decarbonisation scenario') could also be tested to understand how national policies may influence local infrastructure carbon emissions. The Climate Change Committee (CCC's) carbon budget advice and associated sector-level decarbonisation pathways provides one possible source that can be considered for this scenario analysis. Further advice on how these scenarios could be applied can be found in Chapter 8.

Area-wide carbon analysis methodologies

3.32 Table 3-1 summarises the area-wide carbon analysis methodologies that can be used to support a transport strategy evidence base. Further detail on these methodologies is provided in Chapters 6 – 8.

3.33 In most regions, 'disaggregated traffic modelling-based user carbon analysis' has already been prepared and can be accessed by readily available and accessible tools. Authorities are encouraged to contact DfT for more information. An outline description of this methodology and explainers of some of the key concepts are provided in Chapters 7.

3.34 It should be noted that these methods may not quantify bus and rail (passenger and freight) emissions by default. Further guidance is provided in Table 3-2. Where existing analysis prepared by others is obtained, authorities are encouraged to clarify whether bus and rail emissions are quantified and how. Where authorities require more detailed analysis of bus emissions they are encouraged to contact the DfT who can advise on alternative tools and methodologies.

3.35 The Association of Directors of Environment, Economy, Planning & Transport (ADEPT) has developed tools that will support authorities in preparing an 'area-wide operational maintenance emissions estimation'. Authorities are encouraged to contact the DfT for further information.

Table 3-1 Summary of area-wide carbon analysis methodologies

Methodology	Relevant impacts	Description	Advice on use
Area-wide disaggregated traffic modelling-based analysis	User carbon	Quantifying user carbon emissions from traffic model data but using additional data sources and data processing to provide detailed disaggregation of emission sources.	This will be the preferred methodology for authorities where it is readily available. This provides a localised and detailed estimate of local and regional emissions requiring no further analysis by local authorities where already prepared regionally. Where analysis is not already available, Chapters 3 and 7 provides high-level advice on how this analysis can be prepared.
Area-wide traffic modelling-based analysis	User carbon	Quantifying user carbon emissions from traffic model data.	Authorities may choose to use this method when suitable local or regional strategic models are available, but a disaggregated traffic modelling-based user carbon calculation is not readily available.
Area-wide GHG inventory-based forecasting	User carbon	Forecasting future user carbon emissions from existing carbon estimates in the Government's GHG inventory.	This analysis won't be necessary where more localised and detailed network-based estimation analysis has been prepared at a regional level.
Area-wide maintenance emissions estimation	Infrastructure carbon (maintenance, repair, energy consumption)	Applying benchmarks to asset inventory data (e.g. m^2 of carriageway, number of potholes filled annually) to prepare a high-level estimate.	Where existing tools are available, this analysis only requires the collation of basic input data (e.g. m^2 of carriageway) to estimate historical annual emissions from which simple methods can be applied to prepare forecasts of future emissions under different scenarios.

Table 3-2 Inclusion of modes in area-wide user carbon analysis

Mode	GHG inventory based analysis	Traffic modelling-based assessment
Cars, LGVs and HGVs	Quantified	Quantified
Bus	Included within total emissions but not reported	Not quantified - requires additional analysis
Rail (passenger, freight, light rail and heavy rail)	Diesel railways included. Other rail types not identified	Not quantified - requires additional analysis

Area-wide carbon analysis outputs

3.36 Area-wide carbon analysis can provide annual estimates of carbon emissions from the baseline year to at least 2050. This can be used to produce graphs of how emissions within an authority might change in the future under a business-as-usual and other scenarios.

3.37 Subject to the methodologies used, this analysis will also provide disaggregation of emission sources. Table 3-3 lists example user carbon disaggregation outputs and which of the methodologies can typically provide these. This list may not be exhaustive.

Table 3-3 Example user carbon disaggregation outputs provided by area-wide user carbon analysis

Example user carbon disaggregation category	Area-wide disaggregated traffic modelling-based analysis	Area-wide traffic modelling-based analysis	Area-wide GHG inventory-based forecasting
Vehicle type (e.g. car, LGV, HGV)	✓	✓	✓
Road class (e.g. local, A-road, motorway)	✓	✓	✓
Road management type (e.g. SRN, MRN)	✓	✓	
Fuel type	✓	✓	✓
Time period	✓	✓	
Trip length	✓		
Journey purpose	✓		
Place type	✓		
Trip genesis	✓		

3.38 Area-wide infrastructure carbon analysis can provide disaggregation of carbon emissions generated by different maintenance activities such as those referenced in Paragraph 3.18. Examples of these outputs and how they can be used can be found in Table 8-2.

3.39 These outputs can provide valuable insights to stages of transport strategy development as described in Chapter 4. It may also inform authoring of a strategic case as part of a scheme business case, for example by providing the proportion of emissions from short-distance trips which an active travel intervention is proposed to address.

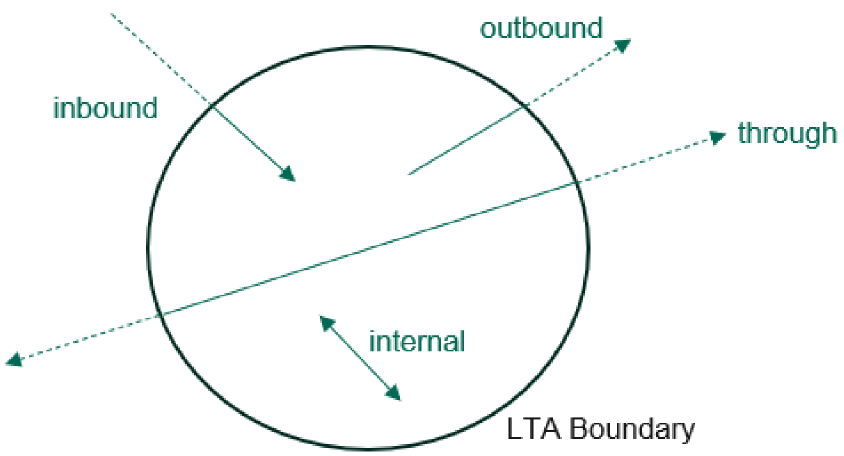
Understanding emissions under local authority influence

3.40 Chapter 2 acknowledges that not all emissions from transport activities occurring within the geographic boundary of an authority will be within the direct influence of that authority.

3.41 Analysis using the ‘disaggregated traffic-modelling based user carbon methodology’ can be used to identify what proportion of user carbon emissions are associated with vehicle trips outside the direct influence of an authority. Such analysis uses traffic modelling matrices to quantify and report emissions depending on trip origins and/or destinations (this may also be referred to as trip genesis). As illustrated indicatively in Figure 3-1, trip origins/destinations, can generally be split into the four following trip types:

- Internal (trips starting and ending within the authority).
- Inbound (trips starting outside the authority and ending within the authority).
- Outbound (trips starting within the authority and ending outside of the authority).
- Through (trips starting and ending outside of the authority, but passing through the authority).

Figure 3-1 Trip types determined by origin and destination



3.42 In accordance with advice in Chapter 2 authorities should consider total user carbon within their relevant administrative geography to provide a holistic and consistent understanding of all transport emissions. Where an authority chooses to conduct analysis to present a sub-set of these emissions under their influence, the basis of the analysis should be clearly reported and the reason for this choice explained.

4. Considering carbon in option generation and sifting

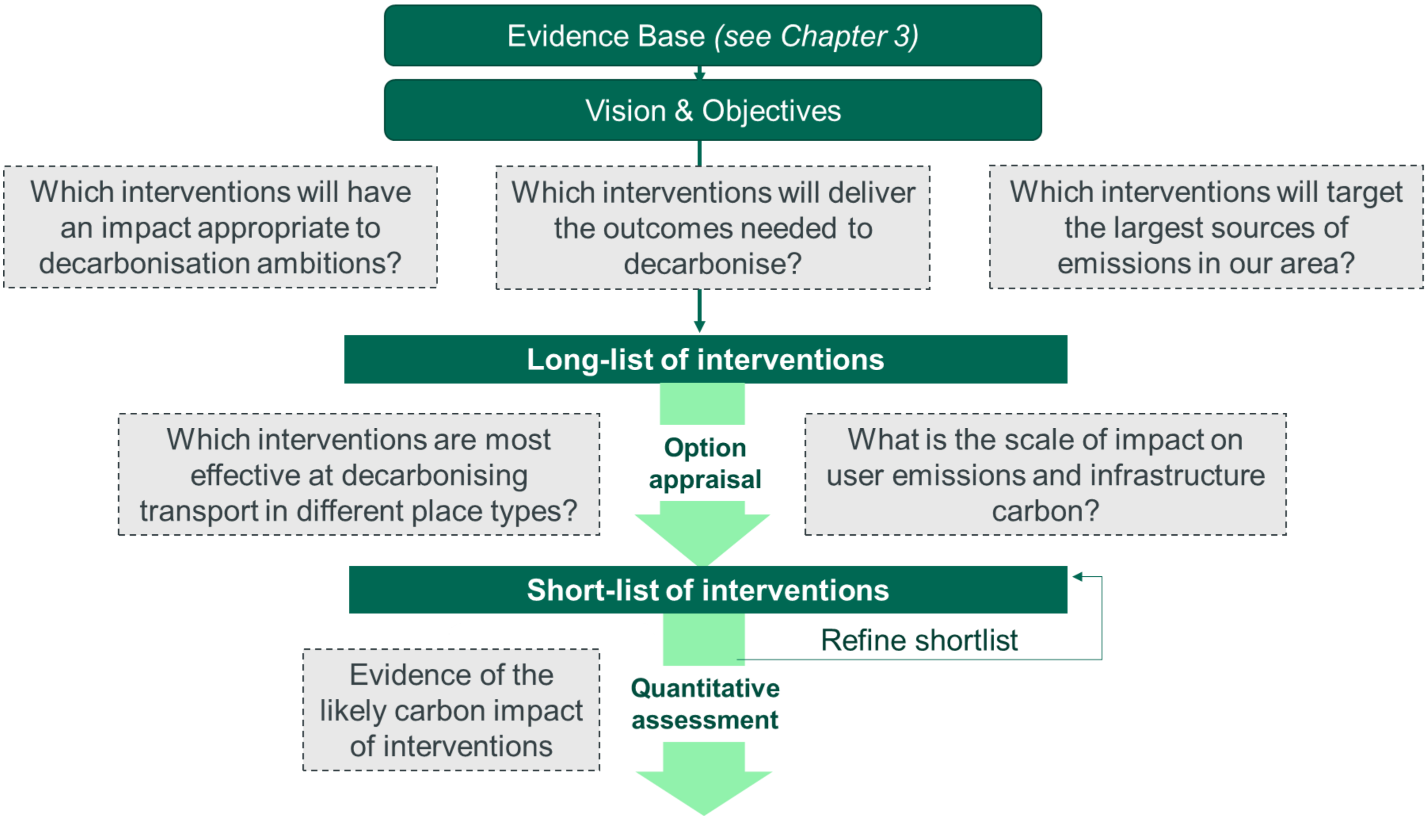
4.1 A transport strategy will contain policies and implementation plans that define the interventions that will be undertaken to deliver change and contribute towards a vision and objectives. Interventions may not be limited to infrastructure schemes and could include other local activities or policies.

4.2 In line with the HM Treasury Green Book, the process of developing policies and implementation plans for inclusion in a transport strategy is likely to involve a process of generating a longlist and option sifting to refine this to a shortlist. While there are many different approaches that can be used for option generation and sifting, the process should embed consideration of carbon in a meaningful and proportionate way throughout, alongside other factors and objectives. This should involve responding to the carbon evidence-base, established through the methodologies described in Chapters 3, and consider potential WLC impacts.

4.3 Quantitative carbon assessments can provide useful evidence of the impact of proposed policies and interventions and extent to which they achieve decarbonisation ambitions. In the development of a transport strategy this can also help identify whether further action or refinement is needed.

4.4 Figure 4-1 illustrates example carbon considerations during the option generation and sifting process.

Figure 4-1 An illustrative overview of example carbon considerations during option generation and sifting



4.5 Decisions taken in this stage of transport strategy development will have a significant influence on WLC outcomes. In order to effectively align transport strategies and intervention pipelines with decarbonisation ambitions, it is important to consider carbon impacts in the option generation and sifting process. It is recognised however, that carbon will be one of many factors and objectives considered. There may therefore be reasons why specific interventions that increase carbon are considered and included. Carbon evidence and assessments, however, can support authorities in minimising adverse carbon impacts and ensuring a programme, or portfolio as a whole reduces carbon.

4.6 It is recognised that this option generation and sifting process may involve large numbers of schemes, many of which might be less well defined and lack any of the data needed for detailed WLC assessments.

4.7 The number and nature of carbon assessments undertaken through the option generation and sifting process may therefore vary depending on local processes and what is proportionate, but authorities should consider WLC impacts wherever possible. An appropriate approach is likely to involve quantitative benchmarking approaches described in Chapters 7 and 8 and/or qualitative methodologies, drawing on available evidence and professional judgement.

4.8 Guidance on how to prepare quantitative analysis of the carbon impacts of policies and interventions is provided in Chapters 6 – 8. This Chapter provides advice on how carbon can be considered in the process of option generation and sifting.

Developing interventions (longlisting)

4.9 Authorities should consider a wide range of options when establishing a longlist of potential interventions. When considering interventions, authorities should not assume options that have been under consideration historically or interventions that may currently be in development are still the most appropriate. The policy landscape is evolving, and previous measures may no longer be appropriate to address identified challenges – including decarbonisation. Carbon analysis can assist authorities in the identification of interventions that best respond to this challenge.

4.10 As indicated in Figure 4-2 the longlist of interventions should be consistent with the vision and objectives of an authority’s transport strategy and respond to insights from the evidence base produced through analysis described in Chapters 3. For example, local authorities should consider:

- Which interventions will target the largest sources of carbon in our area?
- Which interventions will have an impact appropriate to decarbonisation ambitions?
- Which interventions will deliver the outcomes needed to decarbonise transport?
- Which interventions will be most effective in different place types?

4.11 Analysis described in Chapter 3 can provide a detailed understanding of the sources and breakdown of carbon emissions within an authority’s geography. Authorities can use this analysis to determine interventions that are tailored to the local circumstances and thereby produce a transport strategy that is relevant to characteristics of place. Figure 4-2 and Table 4-1 provide examples of how interventions could be identified in response to this evidence.

Figure 4-2 Example of how carbon analysis could be used to support generation of a long-list

Evidence Base *(see Chapter 3)*

Example evidence:

X% of emissions come from trips over 25 miles in length

X% of emissions come from rural place types

Vision & Objectives

Generating a long-list
(considering a wide range of possible interventions)

Example interventions included in the long-list in response to carbon evidence:

Public transport intervention A

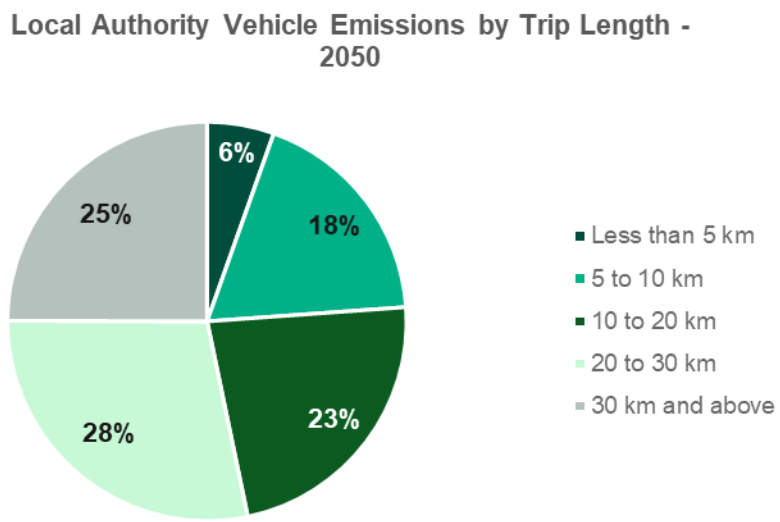
Active travel intervention B

Consideration of a wide-range of possible interventions, for example:

Urban conurbation (30% of emissions)	**Rural town and fringe** (50% of emissions)	**Rural village / hamlet** (20% of emissions)
Intervention A	Intervention C	Intervention F
Intervention B	Intervention D	
	Intervention E	

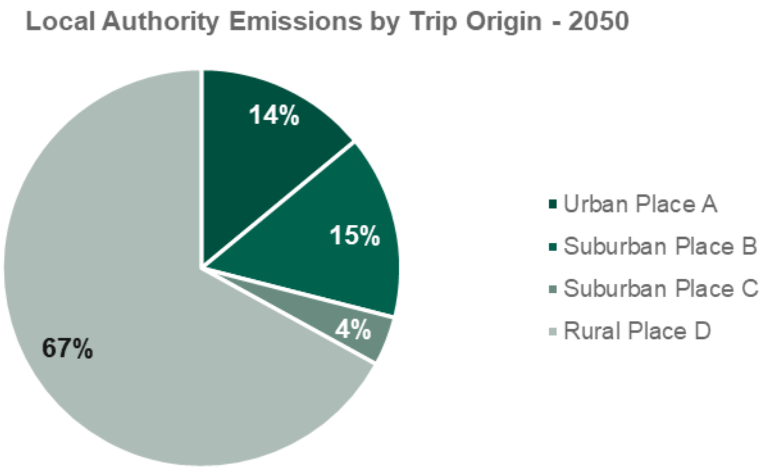
Table 4-1 Hypothetical example of using evidence of emission sources to inform generation of a long-list: generating interventions in response to sources of emissions identified in baseline evidence

Through obtaining existing baseline evidence prepared at a regional level a semi-urban local authority has identified that 24% of emissions are generated by trips under 10km in length and 76% are from trips over 10km in length.



In response to this split, the authority has recognised that different interventions will be needed to tackle emissions from short distance and long-distance trips. For short distance, active travel interventions will aim to shift individuals from vehicles to walking and cycling. For long-distance trips, the authority has recognised that active travel interventions are unlikely to be as influential for trips over 10km and so has considered measures to encourage public transport, car sharing and new parking regulations.

It was also identified that 67% of emissions are generated by vehicle trips originating in rural areas. In response, the authority considers interventions such as demand responsive transport to reduce vehicle emissions whilst increasing connectivity across communities. The authority also commits to collaboration with regional and neighbouring authorities to develop a rural mobility strategy.



4.12 Analysis described in Chapter 3 and 7 can also be used to understand the scale of ambition needed to meet decarbonisation ambitions. It can also support analysis to scenario test the carbon impact of different transport outcomes (e.g. a percentage increase in trips by active travel) which can inform which types of intervention to include in a longlist. An example of this is provided in Figure 4-1.

4.13 In this context, it should be recognised that some interventions will result in a greater carbon reduction than others; understanding this relative impact of different policies and interventions can help inform what is included in a longlist. Benchmarking datasets described in Chapters 7 and 8 and qualitative considerations outlined in Table 4-2 Table 4-4can provide an indication of the carbon impact of interventions, including those that will deliver the most effective reductions in user carbon. Such quantitative and qualitative methods can also be used to identify the potential scale of infrastructure carbon, which can inform the likely net-impact interventions may have.

4.14 This evidence may highlight that some interventions have a relatively modest impact. For example, it may suggest some sustainable transport interventions (e.g. new cycle lanes) have a relatively minor impact on carbon emissions. This may reflect factors such as a limited impact on behaviour in-isolation or a change measured against a low baseline of demand. However, when appraising such interventions authorities should consider wider factors such as whether they are enablers i.e., provide sustainable travel choices that are critical to instigating a wider behaviour change in combination with delivery of other policies and interventions. For example, bus priority measures in combination with improved ticketing systems and information.

Table 4-2 Case study of intervention identification by the Greater London Authority responding to desired transport outcomes aligned to decarbonisation commitments

It was identified that a 27% reduction in passenger vehicle kms was needed by 2030 (relative to a 2018 baseline) for Greater London to achieve its decarbonisation ambition for transport. Other identified outcomes included the share of vehicle kms by Zero Emission Vehicles to reach 46% by 2030.

Interventions that were identified to support these targeted outcomes included:

- Introduce London-wide road user charging by the mid-late 2020s.
- Traffic and parking control measures, such as changes to parking supply and pricing.
- Road space reallocation to public, shared and active travel infrastructure, accelerated by 10 years compared with the Mayors Transport Strategy.
- Measures to encourage transition to ZEVs for high mileage vehicles, such as enhanced licencing requirements for taxis, PHVs and car clubs, and encouraging company car EV adoption.

Further details can be found at Pathways to Net Zero Carbon by 2030 | London City Hall

Option sifting (shortlisting)

4.15 Once a long-list of potential interventions has been drawn up, the next step is often to sift them to produce a short-list of interventions, or packages of interventions, which best deliver the transport strategy objectives.

4.16 It is for authorities to decide how best to undertake this sifting. Approaches that might be considered include multi-criteria analysis (MCA), an Option Framework Filter (OFF) or use of the Early Appraisal and Sifting Tool (EAST). Further guidance on sifting methodologies can be found in the Green Book. Whichever methodology is used, the purpose of option sifting is to determine objectively a shortlist of interventions that will most effectively deliver the transport strategy objectives.

4.17 Where decarbonisation is an objective of a transport strategy, at its simplest level an MCA could be used to sift interventions against this objective (i.e., a single column for decarbonisation in an appraisal tool). The risk of this approach however, is that it may prove too simplistic to meaningfully reflect the likely WLC impact of a scheme. For example, a new highway scheme could lead to either a reduction or increase in carbon emissions depending on the nature of its user carbon impacts (impact on journey lengths, speeds, demand, etc) and scale of infrastructure carbon impact.

4.18 There may therefore be merit to 'unpacking' the appraisal of carbon impacts to sub-categories that provide a more detailed appraisal that better addresses the complexity of a transport intervention's impact on carbon emissions.

4.19 This should give consideration to the following:

- The potential scale and direction (e.g. a reduction or increase) of user carbon impacts in the context of decarbonisation ambitions and evidence of emission sources provided by analysis described in Chapters 3.
- The likely scale of infrastructure carbon that may result from the option. This can be informed by professional judgement (see Table 4-3) and benchmark methods described in Chapter 8.

Table 4-3 - The importance of considering WLC impacts in option generation and sifting.

Within the UK Carbon Budgets, transport infrastructure is a significant contributor to industrial emissions, which must be rapidly decarbonised to meet the 2050 Net Zero target. The processes involved in manufacturing materials such as steel and concrete account for a substantial proportion of these emissions. Additionally, the consumption of fuel by on-site machinery further increases the carbon emissions of the construction sector. Resource and energy efficiency will play an important role alongside electrification, hydrogen and Carbon Capture and Storage (CCS) in decarbonising industry. Resource efficiency measures involve reducing demand for materials through material switching and reducing consumption and waste. The types of intervention selected in transport strategy development will be influential in whether such improvements in resource efficiency are achieved. There may be circumstances in which the vision and objectives of a transport strategy could be achieved through various types or designs of policy or infrastructure interventions, each with differing levels of carbon reduction potential. There remains significant opportunity to influence whole life carbon emissions through intervention and policy development (see Chapter 5) but option generation and sifting will be most influential. It is therefore important that WLC emissions are factored into decision-making at this stage.

4.20 Authorities may choose to use quantitative carbon tools and evidence, where available, to support this. However, given the significant number of policies and interventions under consideration a qualitative or risk-based assessment may instead be appropriate.

4.21 Table 4-4 below presents some suggested qualitative considerations of whether an intervention will support a carbon reduction and Net Zero.

Table 4-4 Example questions to inform qualitative option assessment

Sub-criteria	**Suggested considerations**
User carbon	To what extent will the intervention impact vehicle use? For example, to what extent will the intervention lead to a modal-shift to active travel or public transport? To what extent will the intervention impact the transition to Zero Emission Vehicles? When considered in-combination with other policies and interventions to what extent might the intervention have a greater impact than it would in isolation?
Infrastructure carbon	To what extent will construction of the intervention involve quantities of new material, their transportation and other construction processes? There is typically a direct correlation between scheme cost and infrastructure carbon impact. To what extent will the intervention increase maintenance requirements?

	To what extent will the intervention change the carbon intensity of highway maintenance activities?

4.22 Chapters 6 – 8 provides advice on quantitative methods that can be used to conduct assessments of a shortlist or provide evidence that supports qualitative or risk-based scoring. For example, if there is uncertainty as to which of two options will give greater carbon savings, benchmarks for user carbon and infrastructure carbon could be applied and inform the qualitative scoring within the option sifting.

Understanding the impact of proposed policies and interventions

4.23 Once a shortlist of options has been selected, a quantitative assessment of this shortlist using the methods set out in Chapters 6 – 8 can provide insights to the impact of the transport strategy in full.

4.24 Outputs of this assessment may then inform further refinement of the shortlist that is progressed to the transport strategy intervention pipeline. For example, the quantitative assessment may suggest more ambitious or different policies are needed. Alternatively, the assessment may show that certain ‘segments’ of emissions (for example certain place types or trip distances) are not being sufficiently addressed by the strategy.

5. Carbon assessment at a scheme level throughout design and business case stages

5.1 There is significant opportunity to influence carbon outcomes through the process of developing transport schemes. Decisions such as which option to take forward, how the scheme is designed and what materials or construction processes are chosen will all influence carbon impacts. These decisions should also shape schemes to maximise their contribution to the vision and objectives of a transport strategy, including any objectives relating to decarbonisation. It is important therefore that carbon is a central consideration to the scheme development process.

5.2 This chapter provides practical advice on how carbon analysis can be integrated into the process of developing local transport schemes, including advice on which forms of carbon assessment are most appropriate at different stages. These assessments should inform the management of carbon impacts as part of a PAS2080-aligned carbon management process and provide outputs needed in the development of business cases. Advice on how to prepare carbon assessments (for example how to calculate carbon impacts from traffic modelling or Bills of Quantities) is provided in Chapters 6 - 8.

5.3 As identified in Chapter 2, this guidance does not replace or supersede existing guidance or standards, but is intended to be complementary to existing processes and has been aligned to these where possible, to provide advice on when to assess carbon (i.e. calculating tCO_2e) and how this can support local transport planning.

5.4 Authorities should read this Chapter in conjunction with DfT Transport Business Case Guidance, TAG Unit A3, PAS 2080: 2023 Carbon Management in Buildings and Infrastructure (and associated carbon assessment standards BS EN 15978:2011 and BS EN17472:2022) and the RICS Professional Statement: Whole-life Carbon Assessment for the Built Environment, 2nd edition.

5.5 Whilst this Chapter and Chapters 6 – 8 provide some useful hints on how carbon assessment can support appraisal, and where appraisal methodologies could in turn aid decision making in local transport planning, it is not carbon appraisal or management guidance. DfT TAG Unit A3 and the Green Book should be referred to for appraisal guidance (e.g. guidance on monetisation of carbon impacts) and PAS2080: 2023 for carbon management.

5.6 The design and business case steps referenced in this Chapter have been generalised so that they can be applied across a range of local scheme development and governance processes. Authorities should also apply their own judgement in adapting this carbon analysis advice to their own needs.

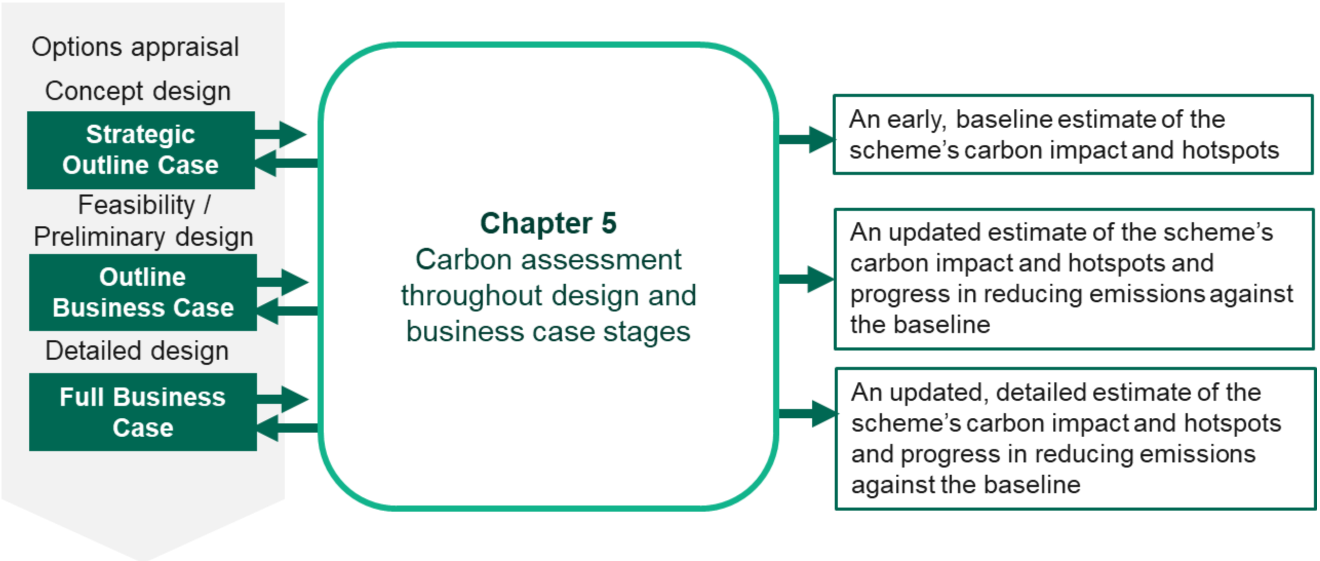
Principles of incorporating carbon assessment into scheme development

5.7 Please refer to Chapter 2 for key principles applicable across this guidance. The following paragraphs provide additional advice on the application of carbon assessment specifically to the scheme development process.

5.8 Undertaking the most detailed carbon assessment possible at the given design stage will allow carbon hotspots to be identified early and maximise carbon reduction opportunities. The greatest ability to influence WLC impacts is at the earliest stages of scheme development, as acknowledged in PAS2080 and DfT Transport Business Case Guidance.

5.9 Figure 5-1 shows the level of assessment and approach typically suitable for each business case stage. This provides an example of a scheme undergoing three design and business case stages which therefore has three corresponding carbon assessments. As acknowledged in paragraph 5.6 however authorities should adapt this advice to their own needs.

Figure 5-1 Example steps in carbon analysis through the scheme development process



5.10 The number of carbon assessments undertaken through the development of a scheme may vary depending on local processes and what is proportionate, but authorities should, wherever possible, undertake a carbon assessment in early stages of scheme development (e.g. in optioneering or on a concept design to inform a Strategic Outline Case).

5.11 The level of detail of carbon assessments should consider both the size of a scheme and the stage of scheme development. Local transport schemes at the earliest stages of the scheme development process (i.e. Strategic Outline Case (SOC) or the Concept design stage) may not be developed to an extent that would enable detailed carbon assessment.

5.12 Where sufficient design information is available however, a more detailed carbon assessment should be produced. This will typically be at Outline Business Case (OBC) or Full Business Case (FBC) stage, and the Preliminary or Detailed design stages, or potentially at SOC stage where sufficient design information is available and a scheme has the potential for a large carbon impact that warrants more accurate evidence. See Chapters 6 – 8 for guidance on assessment methodologies.

Carbon assessment at early stages of scheme development

5.13 This early stage of scheme development involves steps to identify scheme specific objectives, then generate, sift and develop options. This process may be documented in an Option Assessment Report (OAR) with an Appraisal Specification Report (ASR) developed to clarify the approach and scope for further appraisal of better performing options. This stage may then also include development of an SOC where required.

5.14 Proportionate approaches may include (see Chapters 7 and 8 for more details of the approaches):

- Scheme level benchmarking against area-wide user carbon analysis.
- Scheme level simple demand forecasting.
- Scheme level benchmark-based assessment (infrastructure carbon).

5.15 Where a more detailed assessment is required at an early stage, it may be appropriate to use the following approaches (see Chapters 7 and 8 for more details of the approaches):

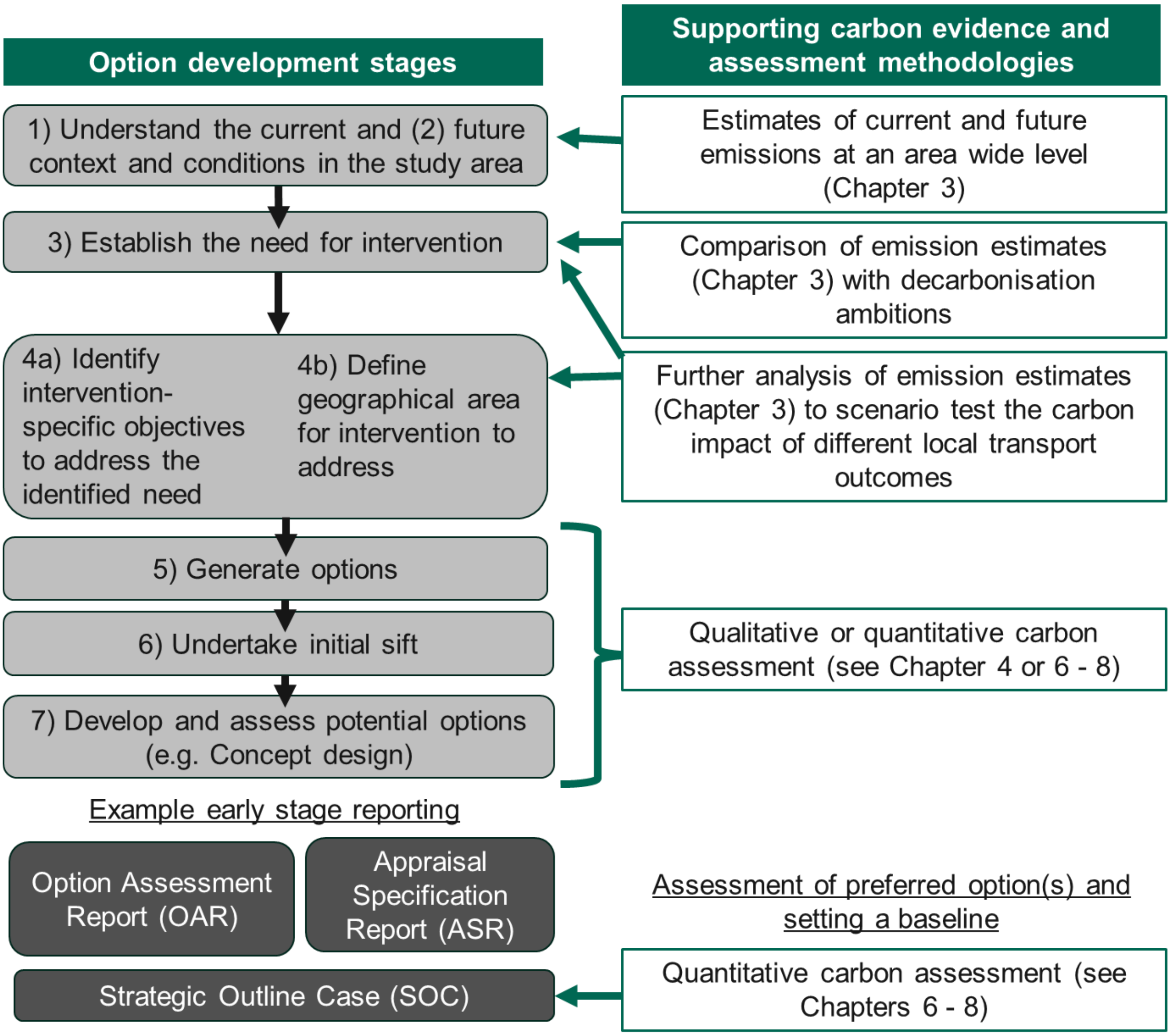
- Scheme level traffic modelling-based assessment.
- Scheme level Bill of Quantities based assessment.
- Scheme level land use change methodologies.

Use of benchmarks

5.16 Benchmarking can be readily applied to estimate the carbon impact of a scheme without specific skills and with a negligible burden of time or cost. Authorities however, should seek to use the best available data and methodologies where appropriate. For example, bottom-up approaches using Bills of Quantities and traffic modelling, where available, should be applied to preferred options as part of assessments reported in a SOC and be used as a carbon baseline for carbon management purposes. However, where this data is not available at the SOC stage, benchmarks may be used.

5.17 Figure 5-2 illustrates how carbon evidence and assessment methodologies could support different stages of early scheme development.

Figure 5-2 Example process of early-stage scheme development and where carbon evidence and assessment methodologies can support this.



Note: where a scheme has been identified through a transport strategy that included the analysis described in Chapters 3 and 4 these steps may not be necessary or can defer to existing analysis.

5.18 While a benchmarking approach may not provide the same degree of accuracy as a bottom-up approach and outputs may not identify a breakdown of emission sources, this method is considered sufficient to inform early-stage decision-making.

5.19 Benchmarks provide an indication of the carbon impact of a scheme against key metrics such as cost or functional unit (length, area etc). Benchmarks are based on high-level sector or industry average data and as such can be considered a 'top-down' method. Benchmarks provide a quick and simple method to estimate impacts with only basic scheme details. This can therefore be an effective way of understanding likely carbon impacts when scheme details are limited or multiple options are under consideration, such as during the option generation and sifting processes, for which a theoretical example is provided in Table 5-1.

Table 5-1 Example of how carbon assessment could be used to inform carbon reduction in option generation & sifting

As part of the transport strategy, it was identified there was a need for new transport infrastructure to provide access to a proposed housing development. In order that the option generation responded to the vision and objectives of the transport strategy, the long-list of options generated to address the identified need included a new bus rapid transit link, bus service improvements, upgrades to local junctions, a 500m new single carriageway and a 2km new dual carriageway. No traffic modelling or demand forecasting was available to quantify the potential user carbon impacts of options, so a qualitative assessment was undertaken, considering compatibility of each option with the transport strategy objectives (reflecting analysis of transport outcomes needed to decarbonise transport). This was scored in a multi-criteria analysis table. To understand the potential infrastructure carbon impact of options, benchmarks were applied to basic scheme characteristics (e.g. length of new road). This provided an initial understanding of the potential scale of infrastructure carbon impacts that was reported in the multi-criteria analysis table. Some options were discarded on poor performance across key viability and acceptability criteria, for which scale of carbon impact, compatibility with outcomes for transport decarbonisation and the PAS2080 carbon reduction hierarchy were a key consideration. For options progressing to further development and appraisal, more detailed analysis was prepared. This included quantitative user carbon assessment using traffic modelling and a bottom-up carbon assessment using Bills of Quantities available from the cost estimation process. Scenario testing was also undertaken to identify how schemes performed under assumptions aligned to the vision and objectives of the transport strategy. Scenario testing also considered reduced vehicular trip rates associated with the new development to understand whether certain options would be more viable if development control or parallel policy measures were implemented to reduce vehicular trip rates and therefore the level of transport capacity needed. All decisions taken through this process to reduce carbon, and where possible the quantified carbon savings, were recorded in the Strategic Outline Case and a Carbon Management Plan.

Setting a Scheme Carbon Baseline

5.20 A scheme carbon baseline is set at an early stage to provide a reference point against which to assess carbon reductions achieved from the carbon management process. The baseline for the scheme should be set at the earliest stage at which there is enough data available to complete a carbon assessment, ideally on the design which wider appraisal as part of a SOC is based on (e.g. concept design). The baseline should be re-evaluated at later stages to ensure it remains representative of the scheme design. An illustrative example is provided in Table 5-2.

Table 5-2 Example of how a quantitative carbon assessment could be used to set a baseline for carbon management

Following an option generation and sifting process, a preferred option for new cycle lane infrastructure was selected on which a SOC would be based and submitted as part of a funding application. A concept design and associated Bill of Quantities was available for this scheme option, as well as an appraisal of active travel benefits using DfT's Active Mode Appraisal Toolkit (AMAT). A quantitative WLC assessment was prepared using the available Bill of Quantities and estimated vehicle km savings as reported within the AMAT. Carbon factors and key assumptions were applied to material quantities to estimate infrastructure carbon impacts, while user carbon savings from the change in vehicle kms were estimated using DfT data on fuel consumption and carbon emissions. This provided annual estimated WLC impacts over a 60-year assessment period. The estimated infrastructure carbon was set as the baseline for carbon management purposes. This was used to represent a 'business-as-usual' design before any carbon reduction measures were applied. A carbon reduction target was also set against that baseline. This was all recorded in a Carbon Management Plan. Carbon assessments at later stages of design monitored progress in achieving this carbon reduction target. For carbon management purposes the baseline for the scheme does not include user carbon impacts because this is not in the direct control of the authority (e.g. national policy relating to ZEV uptake will significantly influence future user carbon impacts). However, the design of the scheme can influence user carbon impacts (for example maximising infrastructure that supports a modal-shift or optimising junctions to reduce delays or re-routeing). The quantified estimate of user carbon was therefore used to inform remaining design decisions.

Qualitative Assessments

5.21 Where suitable benchmarks are not available (i.e. the type of intervention is not available in existing tools or sufficient evidence isn't available to create a benchmark) and sufficient data to produce a bottom-up assessment is also not available, it may be appropriate to use a qualitative analysis to provide a high-level overview of anticipated carbon impacts to support decision-making.

Carbon assessment at later stages of scheme development

5.22 The later stage of scheme development involves further appraisal leading to reporting such as an Outline Business Case (OBC) and Full Business Case (FBC). Scheme designs will be more defined at this stage and more detailed information such as Bills of Quantities and traffic modelling will likely be available.

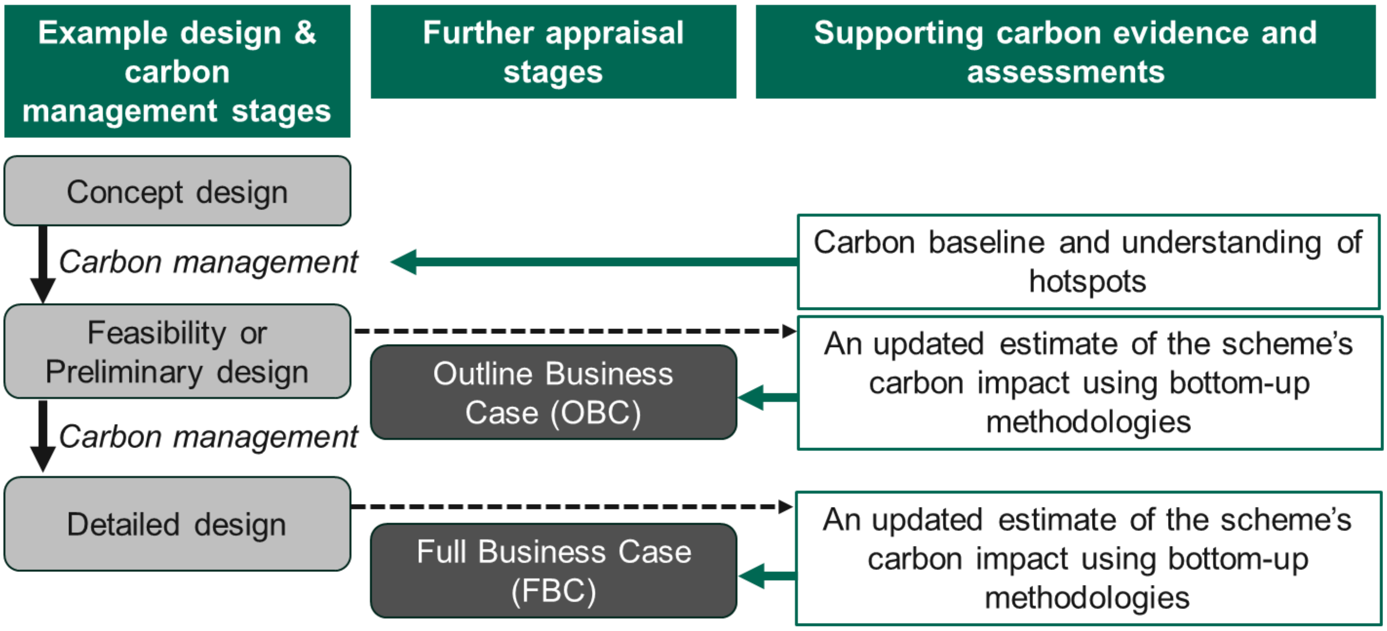
5.23 At these later stages of scheme development, more detailed carbon assessment methodologies should be applied using the best-available data. A wider scope of impacts may also be considered at this stage if relevant and suitable data is available (for example data on land use changes that enable estimation of carbon sequestration impacts).

5.24 These approaches may include (see Chapters 8 and 9 for more details of the approaches):

- Scheme level simple demand forecasting.
- Scheme level traffic modelling-based assessment.
- Scheme level Bill of Quantities based assessment.
- Scheme level land use change methodologies.

5.25 Figure 5-3 illustrates how carbon evidence and assessment methodologies could support later stages of scheme development.

Figure 5-3 Example of carbon assessment inputs to later stage scheme development



5.26 During later scheme development stages, the information needed for a detailed assessment will typically be produced as part of wider scheme development activities. For example, traffic modelling is likely to be prepared for a business case and a Bill of Quantities as part of the cost estimation process. Application of carbon factors to this data will provide a more scheme specific and accurate estimate of carbon impacts than is possible with a high-level approach, such as benchmarking. See Chapters 6 – 8 for guidance on the various methodologies.

5.27 Carbon assessments can be used to support carbon management activities with the objective of reducing carbon through design. An example of this is provided in Table 5-3.

Table 5-3 Example of how carbon assessments could be used to inform carbon reduction in design

As part of the development of a SOC a carbon baseline was set using a bottom-up infrastructure carbon calculation based on estimated material quantities. This provided the estimated scale of impact and a breakdown of emission sources by lifecycle stage (e.g. material manufacture, transportation, construction process) and materials (e.g. asphalt, steel). This baseline assessment was used to inform a carbon workshop held at the beginning of feasibility design. An understanding of key ‘carbon hotspots’ informed the targeting of carbon reduction measures where they would have greatest effect. The assessment was also used to test what carbon savings could be achieved through different measures, for example by applying different carbon factors to represent different materials, or by adjusting material quantities. Identified measures were then evaluated for their feasibility and either incorporated into the design, marked as ‘for consideration’ at the next design stage or dismissed. On completion of the feasibility design, an updated carbon assessment was prepared. The infrastructure carbon calculation used the latest Bill of Quantities. This accounted for changes in material quantities and type that were an outcome of the carbon management process. These decisions are reflected as a reduction from the carbon baseline, and the updated assessment was used in the OBC and reported in an updated Carbon Management Plan.

6. Estimating carbon impacts of local transport

Introduction

6.1 This Chapter provides advice on overarching carbon assessment principles and how to scope an assessment (i.e. which impacts to quantify). The advice provided in this Chapter applies across both user carbon and infrastructure carbon.

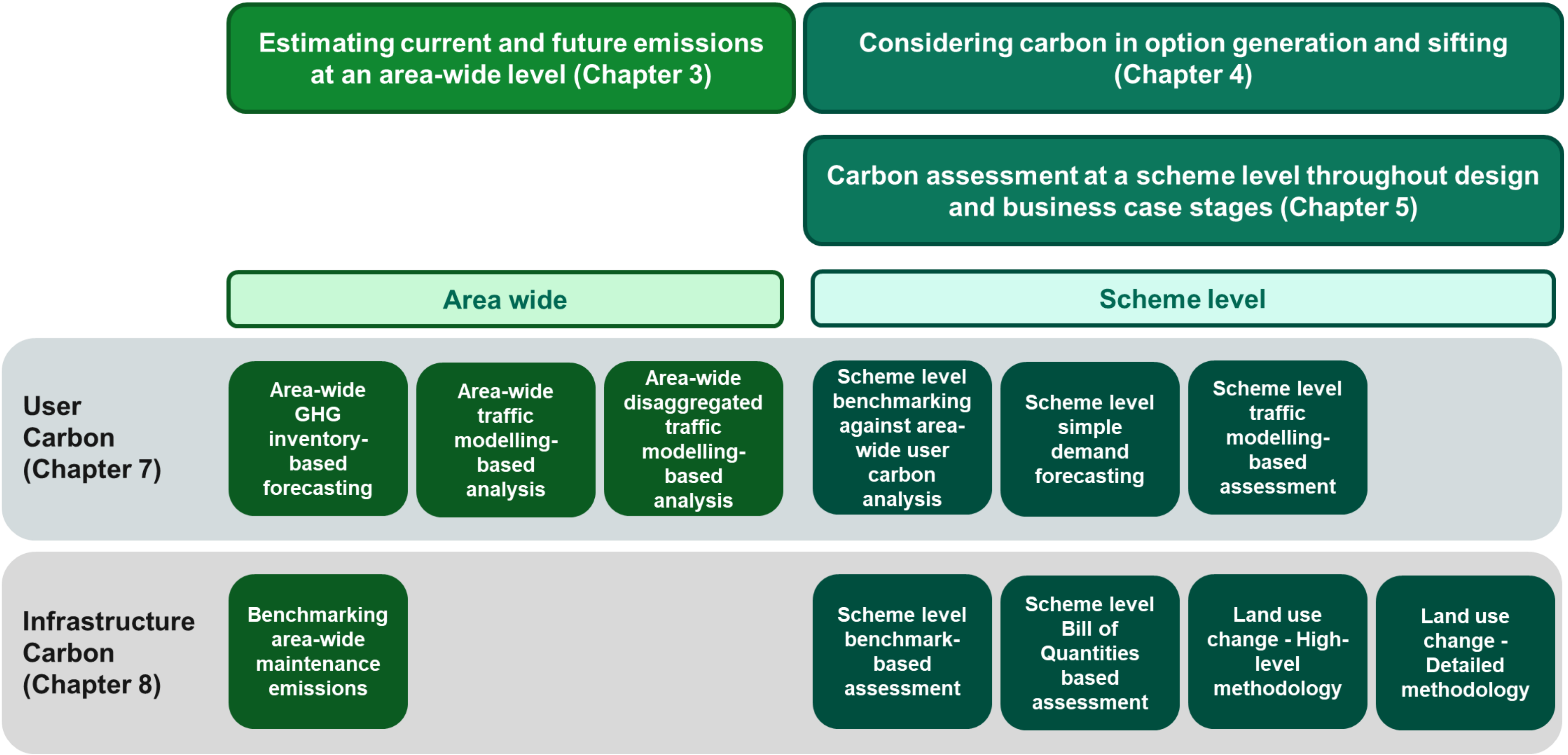
6.2 Chapters 7 and 8 then outline different calculation methods for user carbon and infrastructure carbon (including land use change) respectively. This guidance should support authorities' awareness of the analytical options that can support their decision-making processes and guide practitioners in applying these.

6.3 Chapters 3, 4 and 5 should be referred to for guidance on when carbon analysis should be undertaken, what type of approach might be most appropriate at different stages and how these assessments can support decision-making.

6.4 The methodologies introduced in Figure 6-1 and outlined in Chapters 7 and 8 cover assessment at two different scales:

- **Area-wide analysis** – estimation of emissions across the entirety of a local authority area. For example, estimation of user carbon or maintenance carbon impacts that occur within the geographic boundary of a local authority. This is applicable to developing a transport strategy evidence base as described in Chapter 3.
- **Scheme level** – estimation of the change in emissions that occur as a result of a policy or intervention, such as user carbon impacts a result of intervention or infrastructure carbon impacts from construction. This is applicable to estimation of carbon impacts from schemes identified in transport strategy development (Chapter 4) and in intervention and policy development (Chapter 5).

Figure 6-1 Summary of the methodologies outlined in Chapters 7 – 8



6.5 These methodologies are described further in Table 7-1 in Chapter 7 and Table 8-1 in Chapter 8. As noted in Chapter 2, to support decarbonisation across all emissions sources associated with transport, authorities should consider and account for emissions from the construction and maintenance of infrastructure, as well as user carbon.

Carbon assessment principles and scope

Assessment Period

6.6 Carbon impacts over the lifetime of infrastructure assets should be considered. This will therefore involve estimating 'current' (Do Minimum) emissions and forecasting how these might change in the future. The assessment period used in the analysis should in all cases cover at least up to 2050 (the UK's Net Zero target), and where analysis is part of a business case it should align with the project appraisal period which may be longer than the time to 2050 (e.g. 60 years).

6.7 For strategy level area-wide analysis carbon emissions should be estimated over a suitable timeframe to support decision-making. This should at least cover the period of the transport strategy such analysis is supporting. Given the UK's commitment to Net Zero by 2050 it is suggested 2050 as a minimum is an appropriate timeframe to quantify future emissions to.

6.8 For scheme level carbon assessments, the length of assessment should be aligned to the scheme's appraisal period (as used for wider economic appraisal).

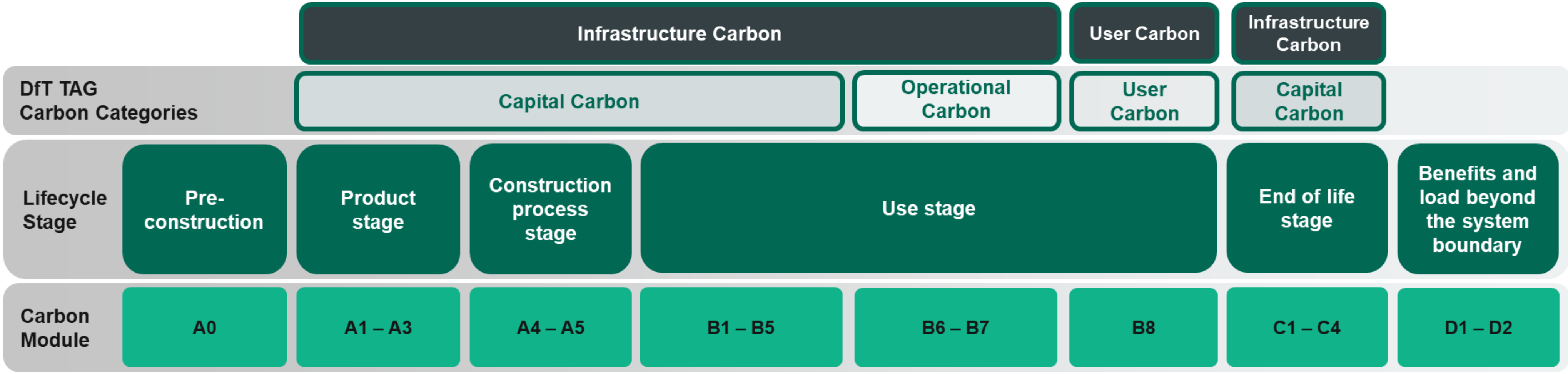
6.9 Where an assessment period or design life has not been set or is not known, authorities should refer to guidance such as TAG, RICS (2023), and DMRB, as appropriate. TAG Unit A1.1 Section 2.3 states "For many transport investments, including most road, rail and airports infrastructure, it is expected that maintenance and renewal will take place when required. This effectively means that the asset life will be indefinite, or at least as long as maintenance and renewal activity is continued. For these projects the core appraisal period should end 60 years after the scheme opens".

Scoping - assessment boundary and methodology

6.10 Scoping is an important step to any carbon assessment. This step identifies the sources of emissions that should be 'scoped in' to the assessment.

6.11 BS EN 17472:2022, RICS WLC assessment for the built environment 2nd Edition, and the Guidance Document for PAS 2080:2023 all provide a useful modular framework to ensure all relevant stages of a project lifecycle are considered. An adapted version of this modular framework and how it aligns with infrastructure carbon (capital and operational, including land use change) and user carbon is shown in Figure 6-2.

Figure 6-2 Adapted modular framework of WLC impacts across lifecycle stages



6.12 Table 6-1 shows common sources of emissions associated with each of these modules. This can be used as a prompt to aid consideration of what should be included in the scope of a WLC assessment.

Table 6-1 Common sources of emissions across the project lifecycle of a typical transport scheme

Carbon module	Common sources of emissions of a typical transport scheme
A0 Pre-construction	**Typically scoped out** of carbon assessments of transport schemes
A1-A3 Raw Material Supply, Transport, and Manufacturing	• Extraction, transportation, and processing of raw materials into materials used in construction, e.g. steel, concrete products, etc
A4 Transport to Site	• Transport of materials (steel, concrete, etc.) to site.
A5 Construction and Installation Process	• Operation of site equipment/plant during construction (emissions from fuel or energy used). • Operation of site facilities. • Waste and waste management, including transportation of waste and disposal / end of life treatment. • Release of stored carbon from vegetation removal and land use change
B1 Use	• Change in carbon storage over the assessment period due to removed / new vegetation and land use change.
B2 Maintenance	• Materials, transport, construction and waste associated with maintenance.
B3 Repair	• Materials, transport, construction and waste associated with repair.
B4 Replacement	• Materials, transport, construction and waste associated with replacing materials at the end of their material service life.
B5 Refurbishment	**Typically scoped out** of carbon assessments of transport schemes; refurbishment projects are not typically planned for at the start of a scheme and would likely be considered a new project in the future which would need its own WLC assessment.
B6 Operational Energy Use	• Fuel and electricity used to operate the asset over its lifecycle, e.g. street lighting, traffic signals.
B7 Operational Water Use	• Water used during the asset's lifecycle, not including that used in maintenance, repair and replacement (**often scoped out** due to immateriality).
B8 (and D) User Carbon	• Changes in emissions associated with users of the affected transport system, e.g.: o Increased / decreased travel demand. o Modal shift. o Changes to general traffic flows (increased/decreased congestion, travel distance, vehicle speed). o Changes to rail traffic.
C1-C4 End of Life	**Typically scoped out** of carbon assessments of transport schemes if the scheme is not expected to be deconstructed within the assessment period.

6.13 Where possible and appropriate, all emissions sources should be scoped into a WLC assessment, however certain life cycle modules may be excluded with justification, for example, if an activity will not materially change the result of the assessment. The Institute of Environmental Management & Assessment (IEMA) Guide to Assessing Greenhouse Gas Emissions and Evaluating their Significance (2nd Edition) suggests this is the case where the emissions from an excluded module are less than 1% of the total emissions, and all excluded emissions are less than 5% of the total emissions. Any sources of emissions that are excluded should be clearly recorded.

6.14 The scope and approach of a WLC assessment of a transport intervention or policy will likely change as it progresses through development stages and as data quality and design detail improve. Advice on how the scope and approach to assessment may typically change between early and later stage assessments is outlined in Table 6-2. As with Table 6-1, the titles of each sub-section in this table can be clicked on to navigate to that text.

Table 6-2 Advice on how the scope of an assessment may typically change between early and later stage scheme assessments

Carbon Module	Strategy stage assessment	Early stage assessment	Later stage assessment
A0 Pre-construction	Typically scoped out	Typically scoped out	Typically scoped out
A1-A3 Raw Material Supply, Transport, and Manufacturing	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate)	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate)	Scheme level Bill of Quantities based assessment
A4 Transport to Site	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate, using transport distance assumptions where required)	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate, using transport distance assumptions where required)	Scheme level Bill of Quantities based assessment (Actual transport distances used, or using transport distance assumptions where required)
A5 Construction and Installation Process	Scheme level benchmark-based assessment, or suitable cost based metric	Scheme level benchmark-based assessment, or suitable cost based metric	Scheme level Bill of Quantities based assessment

Carbon Module	Strategy stage assessment	Early stage assessment	Later stage assessment
Land Use Change (A5 & B1)	Scheme level land use change methodologies- High-level methodology	Scheme level land use change methodologies - High-level methodology	Scheme level land use change methodologies - Detailed methodology
B2 Maintenance	Area-wide maintenance emissions estimation	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate)	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate)
B3 Repair	Area-wide maintenance emissions estimation	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate)	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate)
B4 Replacement	Area-wide maintenance emissions estimation	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate)	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate)
B5 Refurbishment	Typically scoped out	Typically scoped out	Typically scoped out
B6 Operational Energy Use	Area-wide maintenance emissions estimation	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate)	Scheme level Bill of Quantities based assessment

Carbon Module	Strategy stage assessment	Early stage assessment	Later stage assessment
B7 Operational Water Use	Area-wide maintenance emissions estimation	Scheme level benchmark-based assessment (or Scheme level Bill of Quantities based assessment where appropriate and proportionate)	Scheme level Bill of Quantities based assessment
B8 (and D) User Carbon	Area-wide GHG inventory-based forecasting Area-wide traffic modelling-based analysis Area-wide disaggregated traffic modelling-based analysis	Scheme level benchmarking against area-wide user carbon analysis Scheme level traffic modelling-based assessment Scheme level simple demand forecasting	Scheme level traffic modelling-based assessment Scheme level simple demand forecasting
C1-C4 End of Life	Typically scoped out	Typically scoped out	Typically scoped out

Identification of Do Minimum and Do Something Scenarios

6.15 Carbon quantification aims to assess the net change in carbon emissions as a result of the intervention (scheme or package of policies), being implemented.

6.16 Therefore, the impact of the policy or intervention (sometimes referred to as a Do Something Scenario) needs to be compared to the Do Minimum where the intervention and policy development is not implemented:

- **Do Minimum –** This scenario includes only committed interventions and assumes that no additional measures are implemented beyond those already planned or funded.
- **Do Something –** This scenario includes existing committed interventions and the additional proposed intervention(s).
- **Impact -** The comparison between the Do Minimum and Do Something provides an understanding of the impact of the Do Something compared to the Do Minimum.

6.17 When undertaking an assessment, it is important to first identify the Do Minimum scenario to be assessed.

6.18 Area-wide analysis for purposes of a transport strategy evidence-base as described in Chapter 3 does not involve estimating scheme impacts. This will therefore not involve a Do-Something scenario. However as described in Chapter 3 there may be multiple scenarios that are quantified in order to account for uncertainty. For example, Business-as-Usual and accelerated ZEV uptake scenarios.

6.19 At the scheme level, the impact should be calculated as the difference between the two scenarios (Do Minimum and Do Something). See Table 6-3 for a description of the typical Do Minimum and Do Something Scenarios to be assessed for emissions modules A1 to B8 at the scheme level.

Table 6-3 Typical Do Minimum and Do Something Scenarios for each emissions module in a scheme-level assessment.

Module	Typical Do Minimum scenario	Typical Do Something scenario
A1- A3 Raw Material Supply, Transport, and Manufacturing	Where no construction takes place the A1-3 emissions are assumed to be zero	Emissions associated with the manufacturing of materials used in construction of the scheme
A4 Transport to Site	Where no construction takes place the A4 emissions are assumed to be zero	Emissions associated with the fuel used to transport materials to site
A5 Construction and Installation Process	Where no construction takes place the A5 emissions are assumed to be zero.	Emissions associated with construction on site, including fuel use on site through plant and equipment, and waste management
Land Use Change (A5 & B1 Use)	Carbon stored in habitats over the assessment period if the scheme is not constructed	Carbon stored in habitats over the assessment period if the scheme is constructed, including the release of carbon from removal of existing habitats, and carbon stored by newly created habitats
B2-B4 Maintenance, Repair, and Replacement	Where the scheme is newly constructed the Do Minimum for maintenance/ repair/ replacement will likely be zero as there is no existing requirement Where the scheme is an improvement scheme the Do Minimum would be the existing maintenance/ repair/ replacement requirements without the intervention in place	Where the scheme is newly constructed the Do Something will be the new maintenance/ repair/ replacement requirements Where the scheme is an improvement scheme the Do Something would be the total overall maintenance/ repair/ replacement requirements (any existing requirements that remain and any new requirements)
B5 Refurbishment	Usually, scoped out for transport schemes	Usually scoped out for transport schemes

Module	Typical Do Minimum scenario	Typical Do Something scenario
B6 Operational Energy Use	Where the scheme is newly constructed the Do Minimum for operational energy use will likely be zero as there is no existing energy use Where the scheme is an improvement scheme the Do Minimum would be the existing operational energy use without the scheme in place	Where the scheme is newly constructed the Do Something will be the new operational energy use Where the scheme is an improvement scheme the Do Something would be the total overall operational energy use (any existing requirements that remain and any new requirements)
B7 Operational Water Use	Where the scheme is newly constructed the Do Minimum for operational water use will likely be zero as there is no existing water use Where the scheme is an improvement scheme the Do Minimum would be the existing operational water use without the scheme in place	Where the scheme is newly constructed the Do Something will be the new operational water use Where the scheme is an improvement scheme the Do Something would be the total overall operational water use (any existing requirements that remain and any new requirements)
B8 User Carbon	A Do-Minimum scenario as established in traffic modelling i.e. core traffic growth assumptions and movements in the absence of the scheme	A Do-Something scenario as established in traffic modelling i.e. traffic demand, speeds and routeing with the scheme in place

Key considerations when reporting and interpreting results

6.20 Quantified carbon assessments can provide valuable evidence to support decision-making. Carbon assessments however remain an evolving field, and the accuracy of results will be highly dependent on the data on which assessments are based (e.g. traffic modelling, Bills of Quantities) and assumptions made.

6.21 It is important to use the most accurate data available to produce the most representative carbon assessment to inform decision making. It is also important however to acknowledge that with any assessment there is likely to be some degree of uncertainty.

6.22 As acknowledged in PAS2080: 2023, uncertainty will be at its greatest at early stages but should reduce as the scheme design progresses. The ability to reduce carbon associated with a scheme also reduces over time. Uncertainty should therefore not be a reason not to assess and consider carbon early.

6.23 Common causes of uncertainty are outlined in Table 6-4. This will not be an exhaustive list but references common causes that should be considered in reporting and decision-making.

6.24 A DfT review of carbon assessments has shown that many scheme assessments, including of schemes supporting a modal-shift to active and shared modes, indicate schemes will cause a net increase in WLC emissions (i.e. construction stage capital carbon emissions may not be ‘paid back’ by use-stage user carbon reductions (e.g. modal-shift)). When considering such results in decision-making, it is recommended that the ‘strategic fit’ of schemes with the outcomes identified as necessary to decarbonise local transport are considered (as per analysis described in Chapter 4). Quantitative WLC assessments typically consider a scheme’s impact in-isolation and will not account for the potentially larger carbon savings that some schemes might enable, if delivered in-combination with wider policies and interventions. The net-impact of schemes however should not be dismissed; it should be a key consideration in determining carbon management and scheme prioritisation.

6.25 Causes of uncertainty should be identified and reported so that decision-making can take these into account. Quantitative methodologies exist to account for uncertainty, such as RICS WLC assessment for the built environment, 2nd Edition. RICS suggests that WLC assessments should consider contingency based on the uncertainty at the time of the assessment. However, in many cases it will be more proportionate to recognise uncertainty in a qualitative manner as part of carbon assessment reporting outputs.

Table 6-4 Common causes of uncertainty in carbon assessment

Uncertainty type	Description	High uncertainty	Low uncertainty	Examples
Early-stage uncertainty - lack of scheme details or definition	Uncertainty regarding the design, including uncertainty about construction methods, and material types and quantities	Optioneering phase	Detailed Design	At an early scheme stage the full design of a scheme may not be known. There may be elements which are yet to be agreed for incorporation into the design, or there may be multiple options being considered. Quantities such as import and export of material off site is also unlikely to be known
Lack of consideration for scheme-specific features / requirements when using benchmarks	Benchmarks based on functional units (e.g. tCO_2e per length of new road) are generic and do not account for scheme-specific features or requirements, such as extensive earthworks or retaining walls for road building	Benchmarked data used for assessment	Bottom-up (e.g. BoQ) data used for assessment	If a benchmark is used for a new road based on length of the scheme in km, there will be a high level of uncertainty about the actual quantities which would be used for the scheme
Traffic model limitations	Traffic models vary in complexity and outputs only provide insights to variables that are considered in the model	User carbon assessment based on a traffic model with significant limitations in its ability to capture key transport impacts that will influence carbon impact	User carbon assessment based on a traffic model that models all key transport impacts that will influence carbon emissions	If a scheme is reasonably expected to induce demand, a carbon assessment based on traffic forecasts from a model that assumes fixed demand (i.e. not a variable demand model (VDM)) will not provide an accurate representation of future emissions Similarly, if a scheme is expected to encourage modal shift to active travel or public transport, a carbon assessment based on traffic forecasts from a model that does not consider these modes (i.e. only considers motorised traffic) will also not provide an accurate representation of future emissions
Assessment in isolation of other schemes	The user carbon impact of implementing multiple schemes in an area may	No relevant supporting policies or	Sensitivity tests are undertaken to account for	The results of a carbon assessment of a scheme that replaces a traffic lane with a bike lane may show that the scheme produces only a modest user carbon

Uncertainty type	Description	High uncertainty	Low uncertainty	Examples
	differ substantially from the sum of assessment results obtained when assessing the schemes individually	interventions are quantified or acknowledged in the carbon assessment	synergistic effects; or a qualitative narrative is provided that highlights relevant supporting policies and schemes and the potential influence on the scheme's impact in-combination	reduction (or even a user carbon increase) due to increased traffic congestion and only modest modal shift. However, if the scheme is part of a wider package of similar interventions in the area, or coupled with interventions that disincentivise travel by private vehicle, the user carbon reduction could be higher than the sum of impacts of each scheme assessed individually
Generic carbon factors	Uncertainty regarding the representativeness of the carbon factors used, compared to the actual impacts. i.e. If a generic carbon factor is used rather than one that represents the specific product used due to a specific EPD or carbon factor being unavailable	Generic carbon factors are used as the best available match	Specific carbon data for the products are used, e.g. from Environmental Product Declarations (EPDs)	The quantum of steel to be used on the scheme may be assessed with a generic steel carbon factor if a product specific EPD is not available. The generic carbon factor may not be accurate compared to the emissions associated with the steel used. For example, the carbon factor will likely have an assumed percentage of recycled steel included, however this may not be the same as the steel procured for the scheme

Interface of carbon assessment outputs with appraisal calculations within a business case

6.26 A whole-life carbon assessment is a requirement of carbon appraisal (i.e. monetisation). Carbon appraisal is one part of the DfT approach to environmental appraisal detailed in TAG Unit A3. This environmental appraisal is considered alongside economic and social impact appraisal as part of cost benefit analysis and business case.

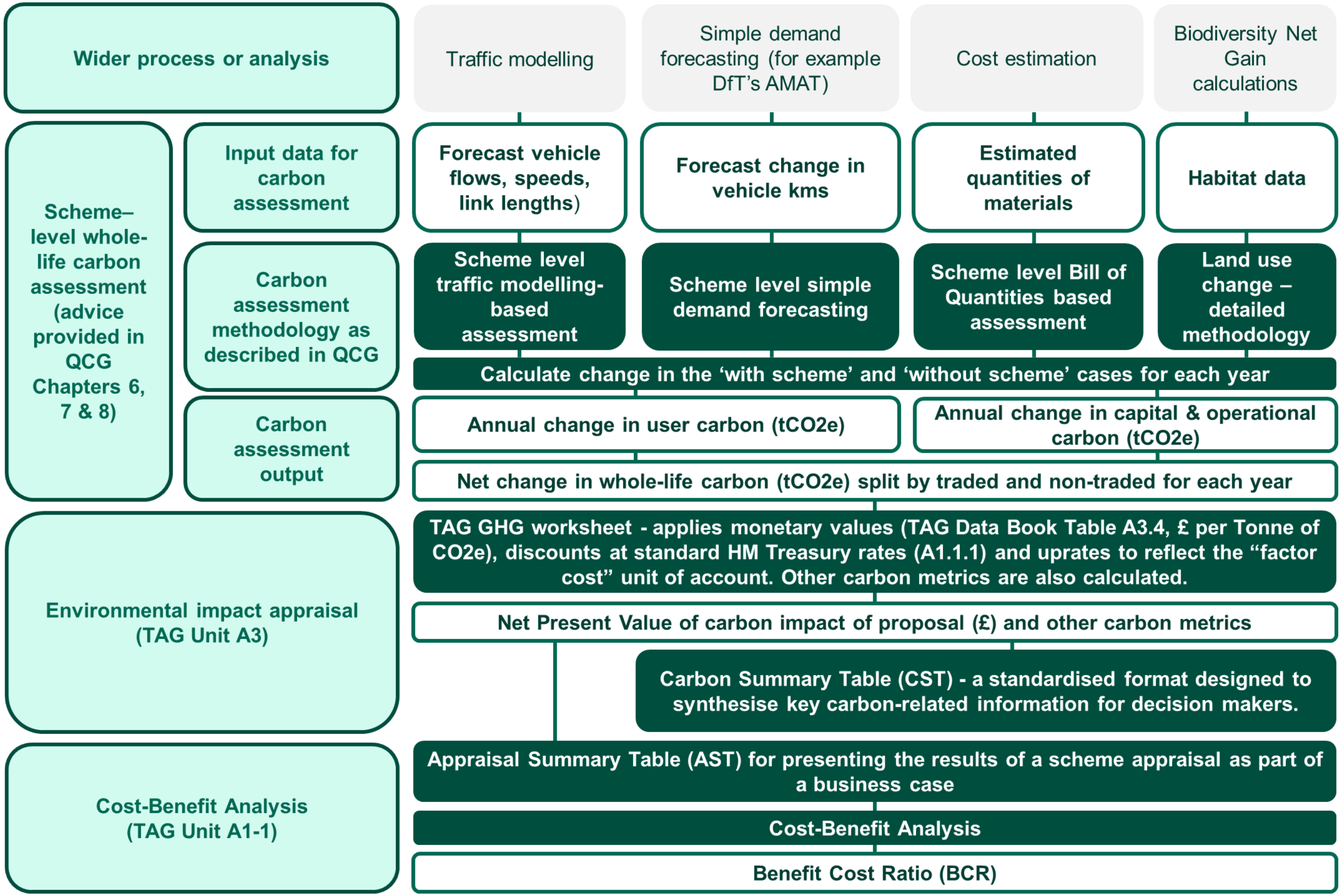
6.27 TAG Unit A3 should be referred to for carbon appraisal guidance. Advice provided in QCG however can support authorities to prepare higher-quality whole-life carbon assessments that improves how carbon impacts are represented as part of appraisal and business cases. Chapters 5 provides advice on how the timing and scope of carbon assessments may differ between business case stages, while Chapters 6, 7 and 8 provides methodological advice for carbon assessment.

6.28 Figure 6-3 illustrates of how carbon assessment provides inputs to carbon appraisal and the calculation of a benefit-cost-ratio (BCR) and business case deliverables.

6.29 When preparing a whole-life carbon assessment to be used in a business case, the following should be considered:

- Estimate carbon impacts in each year of the appraisal period – monetary values for carbon are applied on an annual basis so require annual estimates of carbon impact
- Estimate and report carbon impacts in both the ‘with scheme’ and ‘without scheme’ case – the TAG GHG workbook calculates the difference between these
- Report carbon impacts by ‘user’, ‘capital’ and ‘operational’
- Attribute carbon impacts as ‘traded’ or ‘non-traded’ – an explanation of these is provided in TAG Unit A3.

Figure 6-3 An example whole-life carbon assessment and how this interfaces with other processes/analysis and cost-benefit analysis as part of a business case



7. User carbon methodologies

7.1 This Chapter provides methodological guidance on different quantitative user carbon calculation methods at both an area-wide and scheme-level.

7.2 The ‘key concepts’ section of this Chapter first advises on concepts common across the user carbon methodologies described in this guidance. This Chapter then describes each of the methodologies summarised in Table 7-1. The titles of each sub-section in this table can be clicked on to navigate to that text.

Table 7-1 Summary of User Carbon assessment methodologies outlined in this Chapter

Methodology	Description	Level of detail / complexity	Relevant Chapters
Area-wide GHG inventory-based forecasting	Estimation of future area-wide emissions from a historic estimate provided by the Government’s GHG inventory	Low	3. Estimating current and future emissions at an area-wide level without intervention
Area-wide traffic modelling-based analysis	Estimation of area-wide emissions from link data extracted from a traffic model	Moderate	3. Estimating current and future emissions at an area-wide level without intervention
Area-wide disaggregated traffic modelling-based analysis	Estimation of area-wide emissions from link and matrix data extracted from a traffic model, with additional processing to provide detailed disaggregation of emission sources	High	3. Estimating current and future emissions at an area-wide level without intervention

Methodology	Description	Level of detail / complexity	Relevant Chapters
Scheme level benchmarking against area-wide user carbon analysis	Applying benchmarks or 'impact factors' to area-wide traffic modelling-based user carbon analysis to prepare a high-level estimate of carbon impacts of policies and interventions	Low	4. Considering carbon in option generation and sifting 5. Carbon assessment at a scheme level throughout design and business case stages
Scheme level simple demand forecasting	Calculating carbon emissions from outputs of demand forecasting such as DfT's Active Mode Appraisal Toolkit.	Moderate	4. Considering carbon in option generation and sifting 5. Carbon assessment at a scheme level throughout design and business case stages
Scheme level traffic modelling-based assessment	Extracting link data from a traffic model for both Do-Minimum (i.e. without scheme) and Do-Something (i.e. with scheme) scenarios, applying calculations to estimate carbon emissions, interpolating and extrapolating this over the assessment period and working out the difference between the two scenarios (i.e. the scheme impact)	High	4. Considering carbon in option generation and sifting 5. Carbon assessment at a scheme level throughout design and business case stages

Key concepts

7.3 User carbon on the highway network occurs through (a) burning of fossil fuels in Internal Combustion Engine (ICE) vehicles or (b) use of electricity in electric vehicles (emissions from electricity generation and distribution to the point of charging).

7.4 Current and future user carbon will be influenced by a large number of variables as illustrated below.

Table 7-2 Transport user variables influencing carbon emissions

Transport user variables	Description	Potential changes from an intervention	Potential carbon impacts
Demand	The volume of trips by different modes and vehicle types (e.g. volume of vehicles using a road link in a given timeframe)	The number of vehicle kms could be influenced by interventions that encourage a modal-shift by changes to generalised travel costs for different modes	A change in vehicle kms will change the volume of fuel consumed and therefore carbon emissions
Speed	The speed at which vehicles move over a specific distance	The speed at which vehicles are travelling could be influenced by interventions or policies that influence congestion or alter speed limits	Speed influences engine efficiency and therefore fuel consumption and carbon emissions.
Vehicle routeing and trip length	The route that vehicles take between origin and destination	Traffic routeing and trip length could be influenced by interventions which change the layout of the road network (e.g. a bypass) or alter journey times on existing routes (e.g. by reducing congestion)	Vehicle routeing and trip length influences the speed and duration of vehicle trips which will impact fuel consumption and carbon emissions

7.5 Traffic modelling provides the best data for understanding these variables across the transport network and how they may change in the future, with or without intervention. See DfT guidance for the modelling practitioner (TAG modules M1 to M5) for more information on how traffic modelling is developed.

7.6 Traffic models may not account for all of the variables referenced in paragraph 7.24. For example, many will not include the capability to forecast the modal-shift demand response associated with providing new walking, cycling or public transport infrastructure that makes these modes more attractive. Alternative analysis to quantify scale of modal shift may therefore need to be prepared (e.g. DfT's Active Mode Appraisal Toolkit).

7.7 Regardless of whether it is traffic modelling or alternative analysis (or both) an estimate of carbon emissions can be made where an estimate of demand (e.g. traffic flows or vehicle kms) and speed is available. Other openly available datasets and emission factors can then be used to estimated carbon emissions from demand and speed data. This process is explained in Table 7-3 below.

Table 7-3 Process for estimating carbon emissions from demand and speed data

Parameters from the TAG Data Book can be used to calculate the carbon emissions from vehicles: • Using proportions of vehicle kilometres by vehicle type and fuel type (Table A1.3.9) and fuel consumption parameters (Table A1.3.11) expressed in litres or kWh per km from the TAG Data Book the amount of petrol, diesel and electricity consumed for yearly vkm estimates can be calculated. • Based on the data and information in Table A1.3.11 of the TAG Data Book, the function $L = a/v + b + c.v + d.v^2$ can be used to estimate fuel consumption using average speed data (kms per hour). • Average speed can be obtained from Road Traffic Statistics, GPS derived data or transport model outputs. • Once fuel and electricity consumption is calculated, the associated carbon emissions in tCO_2e can then be calculated using Table A3.3 Carbon dioxide emissions per litre of fuel burnt/kwh used. • If the total emissions from traffic are calculated in the Do Something and Do Minimum scenario, then the net change as a result of the strategy, policy, or intervention can be calculated. When dealing with forecasting across an assessment/appraisal period see Scheme level traffic modelling-based assessment. DfT’s Vehicle Emissions Carbon Tool VECAT (Vehicle Emissions Carbon Tool) can be used to calculate carbon emissions from traffic modelling data using this process.

Area-wide GHG inventory-based forecasting

7.8 Table 7-4 summarises key characteristics of this method.

Table 7-4 Key characteristics of Area-wide GHG inventory-based forecasting

Variable	Definition
Summary description	This method involves forecasting future emissions from existing carbon estimates in the Government's GHG inventory
Relevant stage and QCG chapter	Transport strategy evidence-base - Chapter 3
Applicable scale	Area-wide
When to use	This can be a quick way to estimate future user carbon but it will not capture local variations in demand and other variables. It should therefore only be used where traffic modelling based forecasts are not available or a suitable traffic model is not available to develop such analysis
Input data	• The Government's GHG inventory data • Openly available data including TAG Data Book
Output	Estimated current and future annual user carbon. These estimates can be disaggregated by road type categories used in the GHG Inventory

7.9 Inventories of historic GHG emissions at a sub-national level have been prepared by The Department for Energy Security and Net Zero (DESNZ) and predecessor departments since 2005. The dataset provides total emissions by authority across sectors. For surface transport, emissions are split by DESNZ default road type classification (Motorways, A Roads and Minor Roads).

7.10 The methodology used in developing the GHG Inventory can be found in this detailed technical methodology report. This method offers a comprehensive and nationally consistent estimate of local transport emissions; a dataset that when aggregated is used to monitor changes in emissions over time and informs national policy. The DESNZ GHG Inventory can therefore be used as a reliable estimate of current (recent) emissions. Estimates of current emissions from modelling-based methods (network based estimation) should be compared with the DESNZ GHG Inventory to understand any differences.

Table 7-5 Estimating current authority transport emission estimates from the DESNZ GHG inventory

To identify an estimate of current (recent) transport emissions at an authority scale the following steps can be taken: • Access the dataset on GOV.UK: UK local authority and regional greenhouse gas emissions statistics • Download the 'UK local and regional greenhouse gas emissions - data Tables' file in Excel. • Table 1.1 in the dataset provides a breakdown of authority GHG emissions 2005-2022. This includes all GHGs influenced by transport and that contribute to climate change. This data table can be filtered by authority, year and sector. For each year in each authority, it provides total transport emissions and a breakdown by road type classifications. • Table 2.1 in the dataset provides a dataset of CO_2 emissions within the scope of influence of authorities; defined for transport in this dataset as excluding motorways and diesel railways. These CO_2 estimates for road transport on A-roads and minor roads however may include through-trips (for example a trip on an A-road that has no origin or destination in that authority). It should also be noted that the exclusion of motorway CO_2 emissions may exclude trips that take place on a motorway but have an origin or destination in that authority and can therefore be influenced by that authority. Table 2.1 does not include transport influenced GHGs such as nitrous oxide: only CO_2. To understand total greenhouse gas emissions ($MtCO_2e$) authorities should therefore use Table 1.1. This dataset has also been visualised by the National Atmospheric Emissions Inventory as an interactive map available here: **Local Authority GHG Map**

7.11 The DESNZ GHG Inventory only provides estimates of historic emissions, but it is possible to prepare forecasts of future emissions from the DESNZ GHG Inventory and other datasets. For example, the methodology described in Table 7-5 can be applied in reverse to 'reverse engineer' Government tCO_2e estimates to vehicle kms from which growth factors and forecast data can be applied to estimate future emissions. Where modelling-based methods are not yet available to authorities this can provide a preliminary understanding of how emissions might change up to 2050, without the need for specialist skills or modelling data.

Area-wide traffic modelling-based analysis

7.12 Table 7-6 summarises key characteristics of this method.

Table 7-6 Key characteristics of area-wide traffic modelling-based user carbon analysis.

Variable	Definition
Summary description	This method involves quantifying carbon emissions from traffic model data
Relevant stage and QCG chapter	Transport strategy evidence-base - Chapter 3
Applicable scale	Area-wide
When to use	Authorities may choose to use this method when suitable local or regional strategic models are available, but a disaggregated traffic modelling-based user carbon calculation is not readily available
Input data	• Link data extracted from a suitable local or regional strategic traffic model(s) that covers the required geography of the transport strategy • Openly available data including TAG Data Book.
Output	Estimated current and future annual user carbon. These estimates can be disaggregated by variables such as vehicle type or road type where calculations are specified to do so

7.13 This is the simplest form of a modelling-based approach using a suitable traffic model covering the local authority area. A traffic model can provide network-based outputs including:

- Link traffic flow by vehicle type, time period and journey purpose.
- Link distances.
- Average link speeds.

7.14 Using model outputs this method calculates vehicle kms travelled on a link-by-link basis. This can be processed to calculate vehicle kms travelled across the relevant network. Vehicle km values can be converted to carbon emissions using the process described in Table 7-6 to understand current and future emissions within the modelled geography.

7.15 The process for estimating vehicle kms and resulting emissions from traffic model outputs can be summarised into three key steps:

1. Extract traffic flow by vehicle type / journey purpose, link length and speeds from traffic model network for each modelled period;

2. Calculate vehicle kms (vkms) (traffic flows * link length) average speeds for each link;

3. Split adjusted vkms by fuel type using TAG Data Book Table A1.3.9 and HGV category from local count data or DfT TRA3105; and

4. Using TAG Data Book Tables A1.3.11 and A3.3, convert the average speed into an average fuel consumption (litres per km per vehicle) then carbon emissions.

7.16 In order to disaggregate emissions by variables such as time period, vehicle type, journey purpose and road type, the process above can be used. Links within the model will need to be classified by these variables. For example, in order to understand emissions by road type (for example motorway, A road, B road, SRN or local) links within the model networks will need to be classified by these road type categories.

7.17 A modelling practitioner will need to assess the suitability of the model and may need to undertake additional processing tasks to derive an accurate emissions estimate from this approach. The following paragraphs should be taken into consideration.

7.18 If the model used does not cover all traffic within the desired geography a factoring approach using DfT transport statistics might be applied. For example, to account for vehicle kms within the full in-scope geography where the model does not cover that full geography.

7.19 TAG advice needs to be considered to take a view on the appropriateness of the model base year and forecast years. A modelling practitioner will need to assess if an appropriate base year and forecast year horizon can be derived by interpolation of existing model runs or whether additional runs will be required to feed into the baseline forecast. The reason behind the approach chosen, along with the issues considered, should be documented.

7.20 In order to quantify emissions on a yearly basis (for example report total emissions in 2019, 2030 and up to 2050) vehicle kms will need to be annualised. This can be done using data from local traffic counts. The annualisation and other adjustment factors can be assumed to remain constant over the forecast period, unless there is clear reason to change (which should be documented). Further information on annualisation can be found in VECAT guidance. Emissions can be derived for years not represented by the traffic model by interpolation and extrapolation. Extrapolation outside the range of the available modelled years is best based on the trend determined by interpolating between the two closest modelled years.

7.21 To prepare emission estimates under accelerated ZEV uptake scenarios as described in Chapter 3, authorities will need to update the fleet mix in a consistent format to TAG Data Book Table A1.3.9.

7.22 In addition to the core outputs provided by the transport model and TAG data, supplementary data sources can also be applied for more detailed disaggregation and insight. For example, National Travel Survey (NTS) data can be used to apply to apply pro rata splits to the data to indicate journey purpose proportions to the results (for example emissions by retail trips). Where pro rata data splits are used it is important to make sure the results are reasonable given the context of the area. All assumptions applied should be clearly and transparently reported alongside any results.

Area-wide disaggregated traffic modelling-based analysis

7.23 Table 7-7 summarises key characteristics of this method.

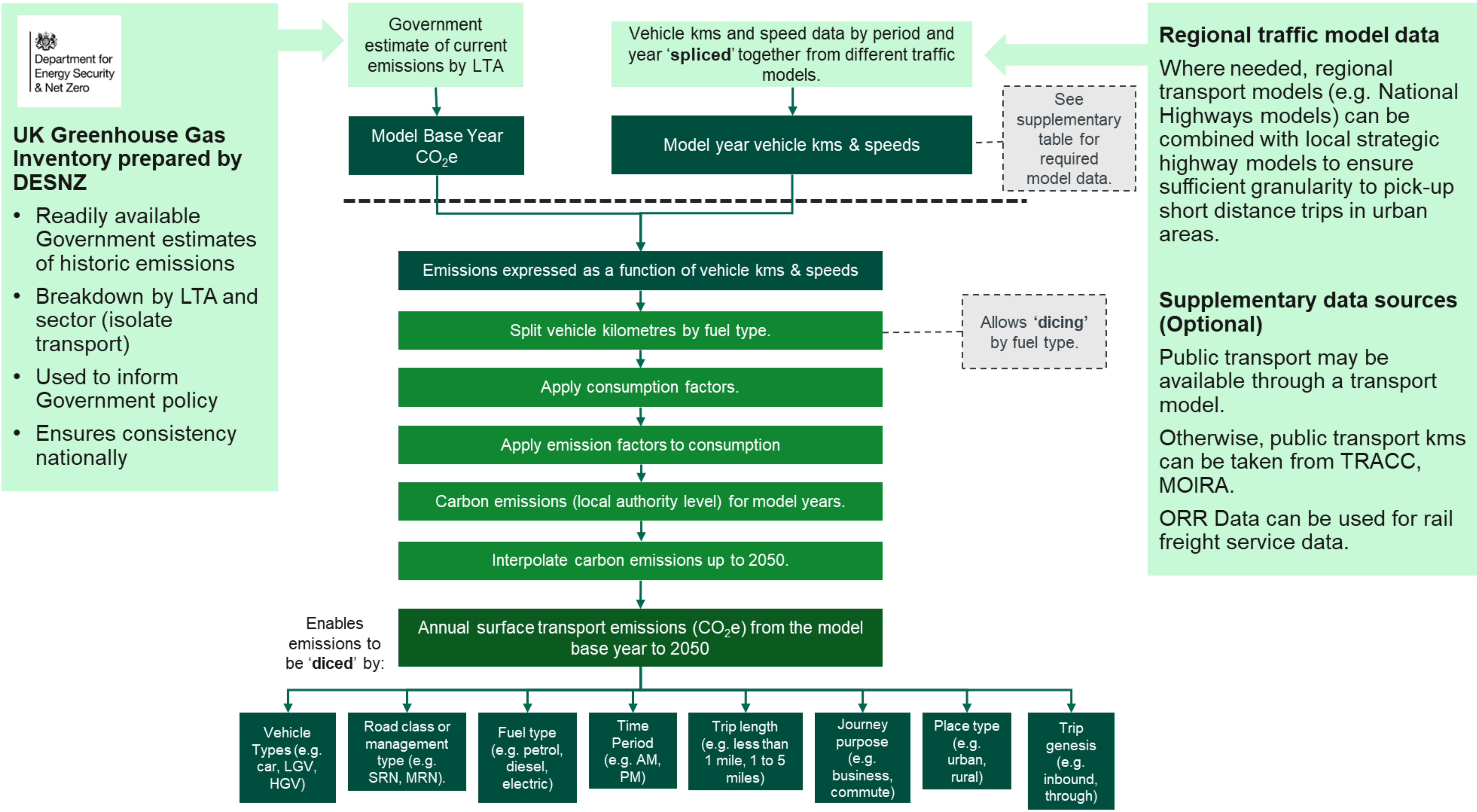
Table 7-7 Key characteristics of disaggregated traffic modelling-based user carbon analysis

Variable	Definition
Summary description	This method involves quantifying carbon emissions from traffic model data but uses additional data sources and data processing to provide detailed disaggregation of emission sources. In most regions, this analysis has already been prepared at a regional level with outputs provided in a carbon tool with advanced functionality to interrogate and test the data
Relevant stage and QCG chapter	Transport strategy evidence-base - Chapter 3
Applicable scale	Area-wide
When to use	Where already available this method will provide the most accurate and detailed analysis of current and future emissions. Outputs (and the tool they are available within) can readily provide evidence and analysis to support processes described in Chapters 3 and 4. This includes additional insights such emissions from segments of demand that local authorities may not have control over (for example through-trips or emissions generated on the SRN). Authorities should utilise the results of this method wherever available from existing analysis or at the earliest opportunity that they can be obtained
Input data	• Link and matrix data extracted from a suitable local or regional strategic traffic model(s) that covers the required geography of the transport strategy • Openly available data including TAG Data Book
Output	Estimated current and future annual user carbon. These estimates will be disaggregated by vehicle type, fuel type, trip purpose, time period, road class or management type (e.g. SRN, MRN or local), trip length, origin and destination, place type and potentially also by public transport types

7.24 This method uses additional data sources, data processing and a more advanced carbon tool than the simple network-based estimation. Where prepared at a regional level this analysis has typically used modelling outputs which take account of the full extent of journeys (from origin to destination) and optionally other modes (for example rail, bus and coach) while disaggregating emissions to constituent local authorities.

7.25 An example of this disaggregated method is shown in Figure 7-1 below. The method has the capacity to provide a breakdown of emissions by a more extensive range of variables than is possible with the network-based estimation. This includes variables such as place type, journey length and distribution (for example whether a vehicle trip is outbound, inbound, internal or through an authority), owing to the use of model time, distance, and demand matrices. Such additional insight about where emissions come from can be used by authorities to make better informed decisions in their transport strategy.

Figure 7-1 An example workflow of a disaggregated network-based user carbon calculation.



7.26 Table 7-8 details the traffic model data that can be used as an input to this methodology and which variables it enables emissions to be disaggregated (or 'diced') by.

Table 7-8 Traffic model data that can be used as an input to this methodology and the variables it enables vehicle kms, and therefore emissions, to be disaggregated (or 'diced') by.

Traffic model data required	Enables emissions to be disaggregated by:
Link flows, distances and speeds	Road class Vehicle type Time period Journey purpose
Time, distance and demand matrices from network cordon around LTA	Trip distribution (may be referred to as trip genesis) Vehicle type Time period Journey purpose
Trip routeing (origin node, destination node, and intermediate nodes) – flow, distance and speed along trip routes between nodes	Broken down per trip by node pair: Place type Trip length Vehicle type Time period Journey purpose

Table 7-9 Disaggregation by Place Type.

Trip routeing outputs allow the user to see the specific origin and destination nodes / zones of each trip, or aggregated trips. These model zones can then be equivalenced to LTA boundaries, geographies used in the census such as Medium or Lower layer Super Output Areas (MSOA or LSOA) boundaries, or so on.

Zone equivalencing can be done by overlaying model zones with LTA / MSOA / LSOA boundaries and assigning a proportion of trips to each LTA / MSOA / LSOA. In some instances, the model zone may be based on an existing boundary and therefore all trips would be assigned to the LTA/MSOA/LSOA. Once the zones have been assigned a geographical area, it can help the user understand the place type they are looking at, for example, rural town and fringe place types.

Understanding the origin and / or destination place type of a trip can inform an understanding of transport emissions within the influence of a local authority and which interventions are likely to have the greatest impact.

The place type would be categorised as rural or urban as a minimum but can be disaggregated further if desired. Place types can be defined using DfT's National Trip End Model (NTEM), a variation on NTEM, or an alternative credible source.

Table 7-10 Truncating emissions explainer.

When reporting emissions, it is important to specify the boundary of the area covered. It is recommended, as a minimum, that an LTA reports emissions captured wholly within the authority boundaries. For variables such as trip distribution (whether a vehicle trip is outbound, inbound, internal or through an authority), this is the most straightforward way to capture emissions. Figure 3-1 provides a visual example of how trip genesis emissions can be truncated to the LTA boundary. The solid lines in Figure 3-1 represent parts of the trips which are quantified as part of the LTA's carbon emissions, and the dashed lines are omitted and will be captured as part of the neighbouring LTA's baseline. The benefit of capturing emissions in this way is that it only quantifies emissions that are wholly within the LTA area. However, when looking at emissions from an origin or destination-based perspective, an LTA may want to see the full extent of emissions up to a regional boundary, or even to an external authority. The benefit of quantifying emissions past the LTA boundary is it can help understand the full impact of any interventions applied, such as, introducing a workplace parking levy is likely to reduce inbound trips, and therefore emissions, before they even reach the LTA (i.e. the sum of the dashed and solid line for the inbound movement in Figure 3-1. It can also help identify where trips are going to / coming from and encourage collaborative working across LTAs to target cross-boundary emissions. When reporting these numbers, it should be clear which area / proportion of the trip is being quantified.

7.27 The evidence from this method can also be used to understand future emission trends and identify the influence that future interventions might have. As with the network-based estimation, in order to forecast the accelerated ZEV uptake scenario, authorities will need update the fleet mix. This adjustment should be consistent with the format of TAG Data Book Table A1.3.9.

7.28 Since this method allows for emissions to be disaggregated by a larger number of variables than the 'network-based estimation', more extensive and detailed scenario testing can be undertaken. For example, the expected impact of different transport outcomes or interventions can be tested by adjusting vehicle kilometres for specific segments of emissions (such as, emissions for trips under a certain distance, or trips starting in a specific authority). This can enable scenario testing of different transport outcomes as alluded to in Chapter 4, and the 'scheme level benchmarking against area-wide user carbon analysis' as described next in Chapter 7.

7.29 The disaggregated method has the flexibility to use inputs from a wide range of sources, for example a combination of local and regional traffic models to improve the representation of both short distance and long-distance traffic and speeds.

7.30 Scheme level benchmarking against area-wide user carbon analysis Table 7-11 summarises key characteristics of this method.

Table 7-11 Key characteristics of benchmarking against area-wide user carbon analysis

Variable	Definition
Summary description	This method involves applying benchmarks or 'impact factors' to area-wide traffic modelling-based user carbon analysis to prepare a high-level estimate of carbon impacts of policies and interventions
Relevant stage and QCG chapter	• Considering carbon in option generating and sifting (Chapter 4) • Carbon assessment throughout design and business case stages (Chapter 5)
Applicable scale	Scheme-level
When to use	When more detailed analysis is not possible (e.g. lack of data) or proportionate (e.g. too many schemes) but a quick, high-level understanding of the potential scale of carbon impacts from different policies and interventions is needed
Input data	• Disaggregated area-wide user carbon analysis • Basic assumptions on policy or intervention details such as location, scale and timing • Benchmarks / impact factors
Output	Estimated user carbon impact (tCO_2e) of proposed policies and interventions. This may also provide a disaggregation of which 'segments' of transport emissions this intervention is targeting (e.g. impact by vehicle type or place type)

7.31 Of the transport variables and changes referenced in Table 7-11, those typically assessed using traffic modelling (i.e. speeds and routeing) cannot reliably be assessed using benchmarks. Such impacts will be too dependent on local circumstances such as road network geography, design and traffic volumes to be easily or reliably benchmarked based on scheme cost or functional units such as scheme length.

7.32 Benchmarks or impact factors for demand responses such as modal shift however can be prepared and provide a high-level indication of the potential scale of behavioural response from different types of intervention. For example, if a segregated cycle scheme in a suburban area was observed or estimated (using detailed methods) to lead to an 1.2% annual reduction in car kms it could be inferred that a similar type of scheme in a similar place could result in a similar demand response.

7.33 These type of 'intervention impact factors' or benchmarks can be used to adjust trip data and therefore carbon emission calculations in Area-wide disaggregated traffic modelling-based analysis . This type of analysis can be automated through tools so that users only need to enter basic policy package details (e.g. type of intervention, scale, location) to quickly estimate user carbon impacts.

Scheme level simple demand forecasting

7.34 Table 7-12 summarises key characteristics of this method.

Table 7-12 Key characteristics of simple demand-forecasting assessment

Variable	**Definition**
Summary description	This method involves calculating carbon emissions from outputs of demand forecasting such as DfT's Active Mode Appraisal Toolkit
Relevant stage and QCG chapter	• Considering carbon in option generating and sifting (Chapter 4) • Carbon assessment throughout design and business case stages (Chapter 5)
Applicable scale	Scheme-level
When to use	For carbon assessment of schemes expected to result in a modal-shift yet this demand response is not captured in available traffic modelling
Input data	• Annual change in vehicle kms extracted from tools such as AMAT or bespoke demand forecasting • Emission factors or data on fuel consumption and carbon emissions (e.g. as available in the TAG Data Book)
Output	Estimated annual user carbon impact (tCO_2e) associated with modal-shift of proposed schemes

7.35 For schemes that result in a change in vehicle demand/use (e.g. through modal-shift or changing private vehicle occupancy) the impact on carbon emissions can in high-level terms be quantified using the four-phase process illustrated below:

1. Phase 1 – Estimate demand (without intervention)
2. Phase 2 – Estimate Demand (with intervention)
3. Phase 3 – Quantify change in Vehicle km (annual)
4. Phase 4 – Convert change in vehicle km to carbon emissions (tCO_2e)

7.36 Whether through the use of existing tools (e.g. AMAT) or bespoke calculations these four phases can offer a proportionate approach to estimate carbon impacts resulting from modal-shift or changes in vehicle occupancy without the need for traffic modelling.

Scheme level traffic modelling-based assessment

7.37 Table 7-13 summarises key characteristics of this method.

Table 7-13 Key characteristics of scheme traffic modelling-based assessment

Variable	Definition
Summary description	This method involves extracting link data from a traffic model for both Do-Minimum (i.e. without scheme) and Do-Something (i.e. with scheme) scenarios, applying calculations to estimate carbon emissions, interpolating and extrapolating this over the assessment period and working out the difference between the two scenarios (i.e. the scheme impact)
Relevant stage and QCG chapter	• Considering carbon in option generating and sifting (Chapter 4) • Carbon assessment throughout design and business case stages (Chapter 5)
Applicable scale	Scheme-level
When to use	When suitable traffic modelling data is available to support a WLC assessment. This typically will be in intervention and policy development stages when traffic modelling is prepared anyway for economic analysis, such as SOC, OBC and FBC
Input data	• Link data extracted from a traffic model with flows, speed and link length. Data is needed for both a Do-Minimum and Do-Something scenario in each modelled year • Emission factors or data on fuel consumption and carbon emissions (e.g. as available in the TAG Data Book)
Output	Estimated annual user carbon impact (tCO_2e) of proposed schemes

7.38 This methodology is not specific to any particular type of scheme; any intervention that affects the highway may result in a carbon impact from changing fuel consumption and energy use as influenced by changes in the variables referenced in Table 7-12. For example, this method could be used to estimate the change in user carbon emissions from an intervention that traffic models forecast will lead to changes in vehicle speed, trip distances and demand.

7.39 There are various types of traffic model that can be used to assess the potential impact a scheme will have on general traffic. This includes simple junction models, reassignment models and variable demand models. Each has different characteristics that should be understood to determine which approach is most suitable and/or any limitations from the model used.

7.40 When an intervention is coded into a traffic model its impact can be quantified in terms of changing traffic flows, speeds and fleet composition on different highway links. In the same way as for economic assessment, model runs for different scenarios and years will need to be prepared to derive the change over time.

7.41 To convert model outputs to carbon, the most robust approaches are link-based approaches (i.e. emissions are calculated on a link-by-link basis). VECAT, available upon request, uses the data available in the TAG Data Book and a link-based approach. There are also matrix based approaches that provide outputs in terms of carbon emissions. More detail on the difference between matrix- and link-based approaches can be found in Annex A: Key Concept Explainers.

7.42 The process of running a link-based assessment using a tool such as VECAT will typically involve the following steps for the model year data:

1. Extract link data from a traffic model for each modelled year in both Do-Minimum and Do-Something scenarios. Each link should be attributed with link ID, link length, speed, and traffic flow (in vehicles) (ideally split by vehicle type: car, LGV, HGV, PSV)
2. Use a tool such as VECAT to calculate carbon emissions on each link for each modelled year in both the Do-Minimum and Do-Something scenarios. This could involve applying carbon factors or using fuel consumption and carbon factors by fuel type based on fleet composition data.
3. Sum the estimated carbon emissions on each link to obtain total carbon emissions in each modelled year in both scenarios.
4. Annualise the total carbon emissions for each modelled year using appropriate factors.
5. Calculate the annual differences in estimated carbon emissions between the Do-Minimum and Do-Something scenarios for each modelled year.

7.43 To then calculate the annual emissions across the whole scheme assessment period, the data should be interpolated (linear interpolation is usually sufficient) between the model years. The following two approaches should be considered, with differing levels of detail.

- At the lowest level of detail, the total carbon emissions (summed over all links) for each appraisal year can be linearly interpolated / extrapolated from the total carbon emissions for each modelled year.
- At the highest level of detail, the link-by-link traffic flows and speeds for each modelled year can be interpolated / extrapolated over the assessment period and carbon emissions calculated for each appraisal year.

7.44 In both cases the interpolation should be done by vehicle type. Wherever possible the highest level of detail should be used.

7.45 When extrapolating either carbon emissions or link-by-link traffic flows and speeds for appraisal years before the first modelled year (i.e. to extrapolate back to an earlier opening year), this can usually be done by linearly extrapolating from the first and second forecast modelled years. Interpolation using the base year would not usually be appropriate given its lack of Do Something scheme links, and it is important to retain consistency in approach between the Do Minimum and Do Something.

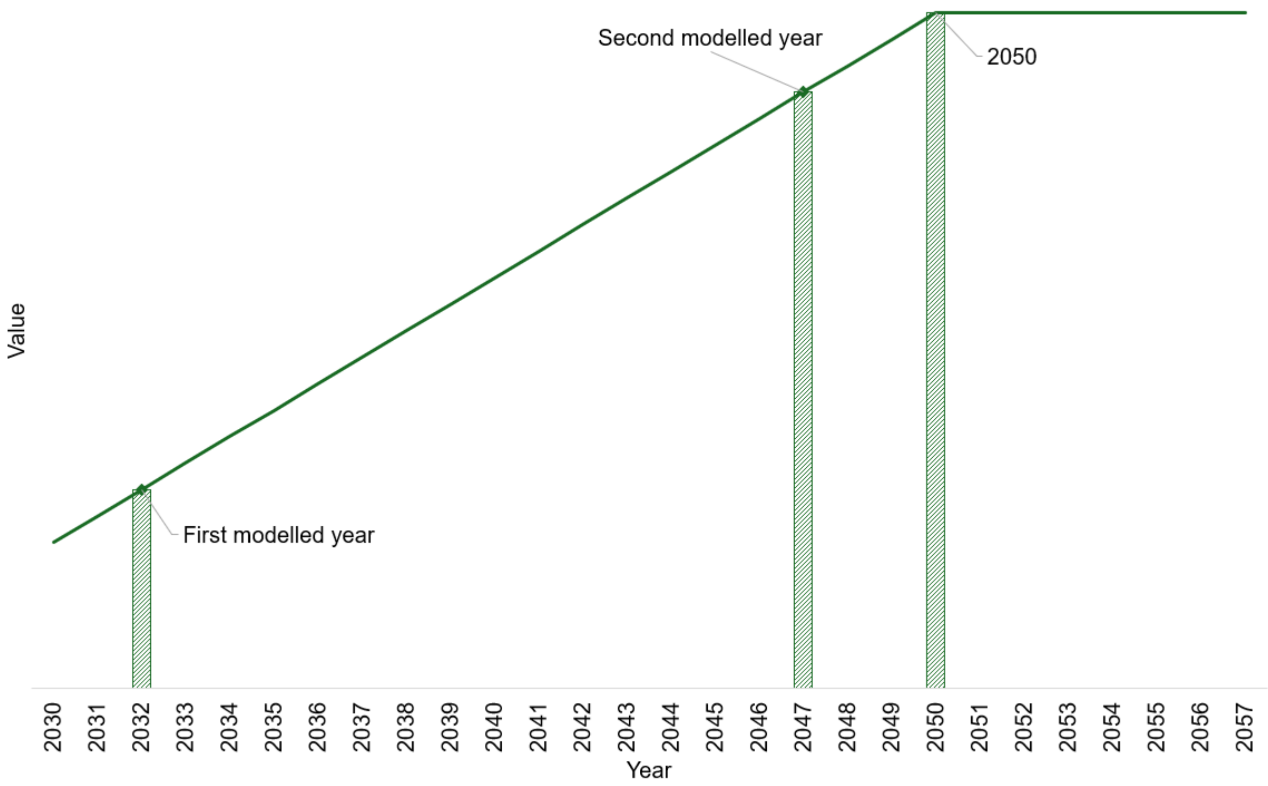
7.46 If the last modelled year is a long time (for example more than 5 years) from 2050, then a 2050 estimate for link flow and speeds should be produced by extrapolating the last modelled year's data and TAG Data Book 2050 data to capture the full extent of fleet composition changes published in the TAG Data Book. As the last modelled year is the basis of subsequent years up to what is likely to be a 60 year appraisal period, it has a significant influence on total impacts, especially those impacts such as carbon emissions in terms of tCO_2e that are not subject to discounting.

7.47 Data for appraisal years beyond 2050 can be held constant up to the end of the assessment period (extrapolated horizontally). This is illustrated in Figure 7-2. Alternatively, the annual change between the final two modelled years could be applied beyond the final modelled year if considered appropriate.

7.48 The annual differences in estimated carbon emissions between scenarios can then be calculated for all years across the assessment period to calculate the full scheme impact.

7.49 Interpolation between modelled years and extrapolation beyond the last modelled year are illustrated in Figure 7-2.

Figure 7-2 Interpolation between modelled years and extrapolation from second modelled year onwards, and extrapolation back to the scheme opening year.



7.50 When using either method it is important that impacts are considered in all time periods and on all affected parts of the highway network. See TAG Unit M2-1.

8. Infrastructure carbon methodologies

8.1 This Chapter provides methodological guidance on different quantitative infrastructure carbon calculation methods at both an area-wide and scheme-level.

8.2 The 'key concepts' section of this Chapter first advises on concepts common across the infrastructure carbon methodologies described in this guidance. This Chapter then describes each of the methodologies summarised in Table 8-1. The titles of each sub-section in this table can be clicked on to navigate to that text.

Table 8-1 Summary of Infrastructure Carbon assessment methodologies outlined in this Chapter

Methodology	Description	Level of detail / complexity	Relevant Chapters
Area-wide maintenance emissions estimation	Applying benchmarks to asset inventory data (e.g. m^2 of carriageway, number of potholes filled annually) to prepare a high-level estimate of carbon emissions from maintenance, replacement, repair and operational energy consumption (e.g. highways lighting). From this estimate of current/historic emissions assumptions of future carbon intensities of activities can be applied to forecast future emissions under different scenarios	Low	3. Estimating current and future emissions at an area-wide level without intervention

Methodology	Description	Level of detail / complexity	Relevant Chapters
Scheme level benchmark-based assessment	Applying benchmarks to basic scheme details (e.g. length of cycle lane) to estimate construction-stage capital carbon emissions. Assumptions can also be made (e.g. frequency of resurfacing) to estimate maintenance, repair, and replacement emissions	Low	4. Considering carbon in option generation and sifting 5. Carbon assessment at a scheme level throughout design and business case stages
Scheme level Bill of Quantities based assessment	Applying carbon factors to material quantities and other data such as assumed transportation distances and construction cost, to estimate construction-stage capital carbon emissions. Assumptions can also be made (e.g. frequency of resurfacing) to estimate maintenance, repair, and replacement emissions	High	4. Considering carbon in option generation and sifting 5. Carbon assessment at a scheme level throughout design and business case stages
Land use change - High-level methodology	Applying carbon factors to habitat areas (areas of a particular habitat type usually in hectares) for both Do-Minimum (i.e. without scheme) and Do-Something (i.e. with scheme) scenarios and working out the difference between the two scenarios (i.e. the scheme impact)	Low	4. Considering carbon in option generation and sifting 5. Carbon assessment at a scheme level throughout design and business case stages
Land use change - Detailed methodology	Applying carbon factors to habitat areas (areas of a particular habitat type usually in hectares) for both Do-Minimum (i.e. without scheme) and Do-Something (i.e. with scheme) scenarios and working out the difference between the two scenarios (i.e. the scheme impact)	High	4. Considering carbon in option generation and sifting 5. Carbon assessment at a scheme level throughout design and business case stages

Key Concepts

8.3 Infrastructure carbon impacts occur as a result of the relevant activities referenced in Figure 6-2 and Table 6-1 (i.e. all BS EN 17474 modules but user carbon).

8.4 Estimates of infrastructure carbon impacts can be made by applying carbon factors to data such as material quantities. Carbon factors specific to materials, transport, fuel and electricity use may be available for translating activity data (e.g. material quantities or transportation distances) into estimates of carbon emissions.

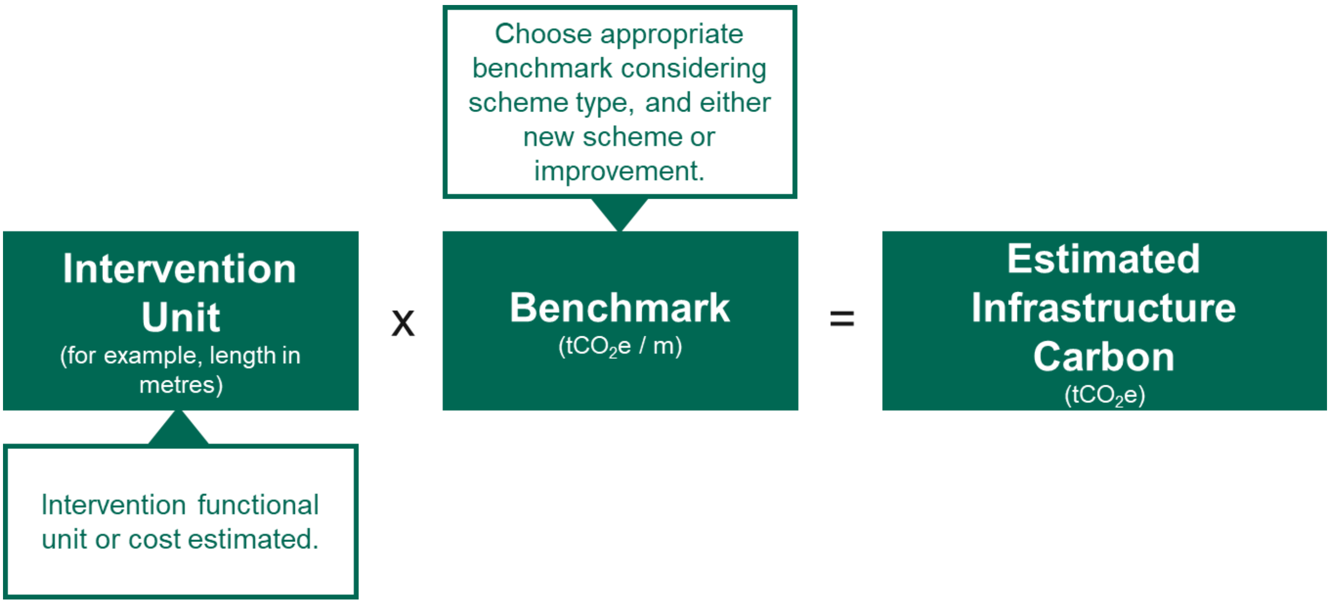
8.5 Where detailed data such as material quantities are not available then carbon benchmarks are likely to be most suitable. Benchmarking involves application of benchmarks or impact factors to basic scheme details such as functional units (e.g., 100m of cycle lane) or scheme cost. This provides a quick, high-level assessment that will be most appropriate as part of transport strategy or early intervention and policy development. Calculations based on benchmarks will be less accurate than methodologies that use detailed activity data (e.g. a Bill of Quantities) but may make carbon assessment possible where it would otherwise not be due to lack of data or proportionality.

8.6 Carbon benchmarks can be available in different metrics such as:

- Functional unit-based metric: tCO_2e/km of road, cycle lane etc.
- Cost-based metric: tCO_2e/£100,000 construction cost.

8.7 As illustrated in Figure 8-1, the process for applying benchmarks involves multiplying the benchmark value by the scheme unit (functional unit or cost) to provide an estimate of the infrastructure carbon impact.

Figure 8-1 Illustrative process for applying infrastructure carbon benchmarks



8.8 During strategy development, or at very early stages of intervention and policy development, schemes may be poorly defined. Where this is the case, the precautionary principle should be adopted by applying a reasonable worst-case assumption (i.e. maximum likely carbon emissions). Any such assumptions should be clearly documented.

8.9 Best practice guidance when developing benchmarks for carbon metrics is published by the Infrastructure and Projects Authority “Best Practice in Benchmarking”.

8.10 The scope of benchmarking metrics such as those listed above can vary. For example, a benchmark may cover only construction stage capital carbon or may cover WLC impacts.

8.11 Authorities should use the most appropriate benchmark available (functional unit-based metric, or cost-based metric) considering geographic location, type of scheme, and other constraining factors such as inflation. Generally, it is advisable to use a functional unit-based metric (e.g., length by scheme type, such as km of road, or number of specific items, such as number of bus stops), rather than a cost-based metric. In most scenarios, a functional unit-based metric provides a more accurate representation of a scheme and avoids issues related to inflation or factors that affect costs, such as changes to the supply chain and/or allowances made for contingencies/risk.

8.12 Authorities are encouraged to contact the DfT for guidance about available carbon factors and benchmarks. In instances where existing benchmarks are not available and/or appropriate, existing designs or, ideally, a Bill of Quantifies (BoQ) from a similar scheme can be used to develop a benchmark using a bottom-up approach.

8.13 There is a high-level of inaccuracy to using generalised benchmarks to estimate infrastructure carbon impact. Reasons for this may include:

- The design of the proposed scheme differs substantially from the benchmarked scheme. For instance, the benchmark may include road widening that is not expected to be necessary for the proposed scheme being assessed, resulting in an overestimate of material quantities and associated emissions from manufacturing and transportation. Alternatively, a proposed scheme may require significant earthworks, requiring the transportation of large quantities of materials off-site and generating emissions that may not be reflected in the benchmark used.
- The benchmark does not consider any carbon management interventions employed in the delivery of the proposed intervention, such as the use of alternative materials. Additionally, the benchmark may have a lower carbon impact due to non-standard design choices that the proposed intervention does not adhere to.

Area-wide maintenance emissions estimation

8.14 Table 8-2 summarises key characteristics of this method.

Table 8-2 Key characteristics of benchmarking area-wide maintenance emissions

Variable	Definition
Summary description	This method involves applying benchmarks to asset inventory data (e.g. m^2 of carriageway, number of potholes filled annually) to prepare a high-level estimate of carbon emissions from maintenance, replacement, repair and operational energy consumption (e.g. highways lighting). From this estimate of current/historic emissions assumptions of future carbon intensities of activities can be applied to forecast future emissions under different scenarios
Relevant stage and QCG chapter	Transport strategy evidence-base - Chapter 3
Applicable scale	Area-wide
When to use	This can be a quick way to estimate area-wide maintenance emissions as part of a transport strategy evidence-base
Input data	• Asset inventory data such as surface area of carriageway surfacing. See Table 8-3. • Carbon benchmarks (or emission factors for more detailed assessment) • Decarbonisation factors for use in forecasting future emission scenarios
Output	Estimated current and future annual maintenance emissions. These estimates can be disaggregated by different activities and material types

8.15 A top-down estimate for the maintenance, replacement and operational emissions of an asset can be calculated using asset inventory totals (e.g. km carriageway, no. gullies) and benchmark carbon factors.

8.16 Table 8-3 presents example asset inventory and carbon benchmark data and how this might be calculated across the total assessment period.

Table 8-3 Example asset inventory and carbon benchmarks for a top-down assessment

Example asset inventory	Example carbon Benchmark
Surface area of carriageway requiring resurfacing (m^2)	tCO_2e per m^2 carriageway resurfacing
Surface area of carriageway requiring surface treatment (m^2)	tCO_2e per m^2 carriageway surface treatment
Metres of kerbing replaced (m)	tCO_2e per m kerbing
Potholes repaired (no.)	tCO_2e per pothole repair
Gullies emptied/cleaned (no.)	tCO_2e per gully cleaned
Streetlighting columns replaced (no.)	tCO_2e per streetlighting column
Number of lanterns (no.)	tCO_2e per lantern

8.17 Authorities are encouraged to estimate emissions from as many sources within the asset management groupings as is reasonably practical given the asset inventories, maintenance and replacement scenarios and carbon data available.

8.18 If a more detailed assessment is needed, this could be prepared using activity data and/or consider maintenance and replacement frequency of different assets. This might include collecting real data (e.g. specific materials used in carriageway resurfacing or road signage replacements, and fuel used to enable gully cleaning) and applying carbon factors to calculate emissions more accurately. This more detailed, activity data based methodology can provide a more disaggregated insight into maintenance, replacement and operational energy consumption emissions. However, it will be resource intensive and time consuming to complete so a benchmarking based assessment is likely to be more appropriate in most cases.

8.19 Once current or historical maintenance emissions have been estimated a simple forecast can be produced by assuming annual maintenance activities remain constant and emissions fall as a result of background decarbonisation scenarios described in Chapter 3. Table 8-4 provides an example of how this approach could be applied. This provides a quick way of forecasting future operational maintenance emissions and understanding how background trends may influence these.

8.20 Further assumptions could be applied to produce a more accurate forecast reflective of local circumstances that influence annual asset management activities. This however will be more resource and time consuming to prepare.

Table 8-4 Illustrative example of development decarbonisation scenarios for estimates of highways infrastructure carbon

A Local Highways Authority's maintenance emissions were estimated at 10,000 tCO_2e in 2024. 87.5% of this is from replacement (resurfacing), 2.5% from repair (e.g. potholes) and 10% from maintenance. If this level of highways maintenance emissions stayed constant (a no change scenario) 260,000 tCO_2e would be emitted by 2050 (26 years cumulative emissions).

In a Business-as-Usual (BaU) scenario it is assumed that the level of material use and activities continue at current levels in future years. No local measures (either by the LHA or their contractor e.g. switching materials, electric plant) to reduce these emissions are committed so no such measures are included in a BaU scenario. The only influence on future emissions accounted for in a BaU scenario is therefore firm and funded trends of energy and materials decarbonisation. This is modelled using assumptions in RICS 'firm and funded decarbonisation' scenario, which suggests 50% decarbonisation of B2-B4 impacts over a 120 year Reference Service Period. This equates to 0.42% a year. In the BaU scenario maintenance emissions in year 1 (in this example 2025) are therefore reduced by 0.42%, in year 2 (2026) are reduced by 0.84% (from 2024 levels) and so on. Under this scenario annual emissions are 11% lower in 2050 (8,917 tCO_2e in 2050) and cumulative emissions emitted by 2050 (26 years) are 245,375 tCO_2e.

A scenario of more ambitious background decarbonisation of infrastructure emissions is also tested to understand how national policies may influence local infrastructure carbon emissions. For this 'accelerated industrial decarbonisation' scenario the CCC's Seventh Carbon Budget balanced pathway for industry is used. This provides annual reductions for the industrial sector that are advised by the CCC to achieve carbon budgets and Net Zero by 2050. The reduction between the CCC industry pathway and industry baseline year on year are applied to the 'no change' scenario to estimate annual highway maintenance emissions. Under this scenario annual emissions are 94% lower in 2050 (637 tCO_2e in 2050) and cumulative emissions emitted by 2050 (26 years) are 98923 tCO_2e.

Scheme level benchmark-based assessment

8.21 Table 8-5 summarises key characteristics of this method.

Table 8-5 Key characteristics of scheme level benchmark-based assessment

Variable	Definition
Summary description	This method involves applying benchmarks to basic scheme details (e.g. length of cycle lane) to estimate construction-stage capital carbon emissions. Assumptions can also be made (e.g. frequency of resurfacing) to estimate maintenance, repair, or replacement emissions
Relevant stage and QCG chapter	• Considering carbon in option generating and sifting (Chapter 4) • Carbon assessment throughout design and business case stages (Chapter 5)
Applicable scale	Scheme-level
When to use	Typically at early stages when detailed data such as material quantities is not available or detailed assessments are not proportionate. Benchmarking can provide a quick way of estimating infrastructure carbon impacts but will have a high degree of uncertainty so should not be used at later stages
Input data	• Intervention unit (e.g. number of bus stops or length of cycle lane) • Carbon benchmarks (e.g. $XtCO_2e/100m$) • Assumptions on maintenance or replacement frequency (for operational carbon estimates)
Output	Estimated infrastructure carbon impact (tCO_2e) of proposed schemes. This can also provide limited disaggregation of emission sources (e.g. proportion of impact by lifecycle module and material)

8.22 This method involves applying carbon benchmarks using a similar process to that outlined in Figure 8-1. The relevant intervention units and benchmarks however will vary for different carbon modules as shown in Table 8-6.

Table 8-6 Examples of how benchmarks can be applied for infrastructure carbon modules

Module	Description	Example intervention unit	Example benchmark
A1-A3	Emissions associated with the manufacturing of materials used in construction, from the raw material supply to the point it leaves the manufacturing supplier	Cycleway length (metres)	tCO_2e per metre of cycleway
A4	Emissions associated with the fuel used to transport materials to site	Cycleway length (metres)	tCO_2e per metre of cycleway
A5	Emissions associated construction on site, including fuel use on site through plant and equipment, and waste management	Construction cost (£)	tCO_2e per £1000 of construction cost
B2	Emissions from the routine maintenance of the asset in operation. This could include material use, energy consumption, and water consumption	Cycleway length (metres)	tCO_2e per metre of cycleway OR 1% of A1-A5 emissions (RICS, 2023)
B3	Emissions from the repair of the asset in operation. This could include material use, energy consumption, and water consumption	Cycleway length (metres)	tCO_2e per metre of cycleway OR 25% of B2 maintenance impacts for the relevant items, except for Mechanical, Electrical, and Plumbing (MEP), where 10% of A1–A3 impacts should be assumed (RICS, 2023)
B4	Emissions from the replacement activities for an asset in operation, for example resurfacing of a road. This could include material use, energy consumption, and water consumption	Cycleway length (metres)	tCO_2e per metre of cycleway

Module	Description	Example intervention unit	Example benchmark
B6	Emissions from energy used over the lifetime of the asset, for example for street lighting	Lighting columns (number of columns)	tCO_2e per year per lighting column
B7	Emissions from the water used and its treatment (pre- and post-use) by the civil engineering works during its normal operation	Bus station water use (m^2 Gross Internal Area)	tCO_2e per m2

8.23 Table 8-7 presents case studies demonstrating how capital carbon benchmarks can be used for carbon assessments of different types of transport scheme.

Table 8-7 Worked examples of using different types capital carbon benchmarks in practice

Scheme A – cycle improvements on a highway corridor This scheme involves the delivery of a fully segregated cycle lane along a 2km-long stretch of road. There is an available functional unit benchmark of 0.07 tCO_2e / m of segregated cycle lane. This is applied to the 2km length (i.e. 0.07 multiplied by 2,000) to give an estimated capital carbon impact of 140 tCO_2e.
Scheme B – multi-modal improvements on a highway corridor The objective of this scheme is to improve cycle safety, bus journey times and reliability, and to upgrade a key junction to reduce congestion for general traffic. No optioneering or design has yet taken place, but the scheme is likely to include a mix of signal improvements, kerb line adjustments, some road space reallocation, and some highway widening. As this scheme is made up of many components, it is unlikely that a single functional unit benchmark will provide an accurate estimate of capital carbon impacts. Some possible solutions include: • using a combination of several functional unit benchmarks (if sufficient detail is known about each component, e.g. type and length of cycle safety improvements, type and length or extent of bus infrastructure, and the approximate size and design of the junction improvement) • benchmarking by comparison with a comparable scheme for which a carbon assessment has already been completed (if such an assessment of a sufficiently similar scheme is available), with comment as to how the proposed scheme may differ (• Table 8-8) • using a cost-based benchmark (if a cost-based benchmark of a sufficiently similar scheme is available, noting that costs can vary considerably across scheme type and scale, and may not account for changes to costs, due to supply issues or inflation).

8.24 Table 8-8 provides an example of how a benchmark can be created using data from comparable schemes.

Table 8-8 Example of creating a length-based capital carbon benchmark using data from comparable projects to quantify capital carbon of a new road

During an early-stage assessment for the construction of a new highway scheme including tunnelled sections, a length-based benchmark (tCO_2e/km of carriageway) was developed from comparable schemes to estimate capital carbon impacts. To determine these metrics the following tasks were undertaken: • A literature review was conducted and found several similar schemes. • The information associated with these schemes was used to generate average benchmarks (tCO_2e/km of carriageway and tCO_2e/km of tunnel). • These rates were applied to the distances of scheme elements resulting in emissions estimates for them.

8.25 It should be noted that in cases where new benchmarks are developed, these should be shared with DfT for inclusion in available benchmarking tools where appropriate, to support and promote knowledge sharing.

Scheme level Bill of Quantities based assessment

8.26 Table 8-9 summarises key characteristics of this method.

Table 8-9 Key characteristics of Scheme level Bill of Quantities based assessment

Variable	Definition
Summary description	This method involves applying carbon factors to material quantities and other data such as assumed transportation distances and construction cost
Relevant stage and QCG chapter	• Considering carbon in option generating and sifting (Chapter 4) • Carbon assessment throughout design and business case stages (Chapter 5)
Applicable scale	Scheme-level
When to use	When a Bill of Quantities is available and it is proportionate to prepare an assessment of this (which can be time consuming). This may be as early as SOC stage but should wherever possible be undertaken at OBC and FBC stages
Input data	• Material quantities (typically sourced from a Bill of Quantities prepared as part of a cost estimate) (A1-3) • Assumptions on transportation distances (A4) • Construction cost or activity data (A5)

Variable	Definition
	• Carbon factors (e.g. the Inventory of Carbon and Energy (ICE) database)
Output	Estimated infrastructure carbon impact (tCO_2e) of proposed schemes. This can also provide disaggregation of emission sources (e.g. proportion of impact by lifecycle module and material)

8.27 A bottom-up calculation of capital carbon typically involves applying emission factors to material quantities (usually from a Bill of Quantities (BoQ)) and to other variables such as construction activities (e.g. transportation distances).

8.28 The key steps of this process are:

1. Review the BoQ data: To ensure compatibility with carbon quantification tools or emission factors, it is necessary to obtain and format material estimates into the appropriate input format, e.g. units. Generally, quantities should be provided in cubic meters (m^3) or tonnes, although there may be exceptions for specific materials or items. Other key inputs including cost may also be required. If project specific information is not available, apply assumptions to set transportation distances for materials and waste, and fuel and electricity use for construction plant and equipment use. RICS WLC Assessment for the Built Environment guidance (2nd edition) sets out relevant assumptions which can be used.
2. The material estimates and any other data are then inputted to the chosen tool or multiplied by appropriate emission factors if a tool is not being used, to calculate an estimate for carbon emissions.
3. To produce a complete infrastructure carbon assessment, this process of applying emission factors should be applied to each material estimate or activity. The sum of these results will provide the infrastructure carbon total for the scheme.

8.29 A summary of how a bottom-up approach could be used for each of the modules within infrastructure carbon (excluding land use change emissions which are covered from 8.41) is shown in Table 8-10.

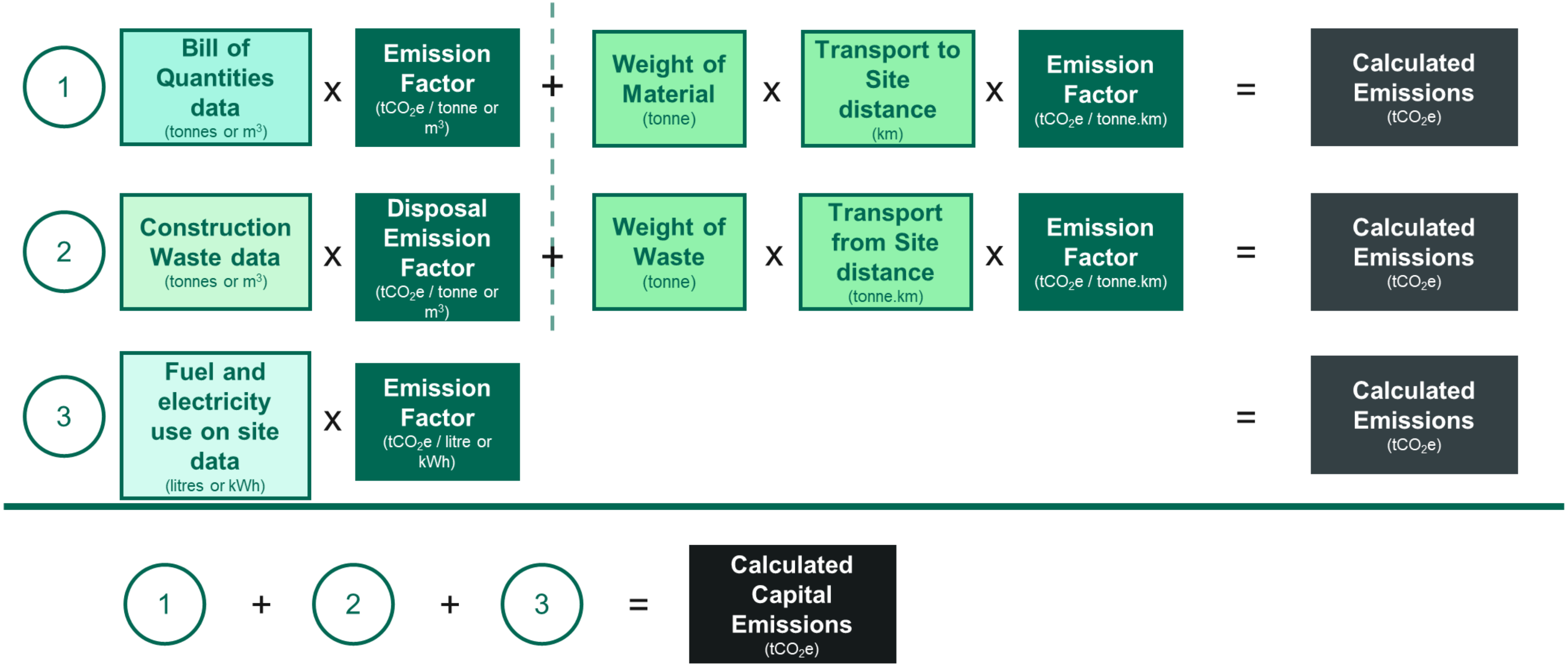
Table 8-10 Examples of how a bottom-up approach can be applied for infrastructure carbon modules

Module	Description	Example data	Example emission factor
A1-A3	Emissions associated with the manufacturing of materials used in construction, from the raw material supply to the point it leaves the manufacturing supplier	Tonnes of concrete	tCO_2e per tonne

Module	Description	Example data	Example emission factor
A4	Emissions associated with the fuel used to transport materials to site	Mass of concrete and distance transported to site (tonne.km)	tCO_2e per tonne.km
A5	Emissions associated with construction on site, including fuel use on site through plant and equipment, and waste management	Diesel used (litres)	tCO_2e per litre
B2-4	Emissions from the routine maintenance (B2), repair (B3), and replacement (B4) of the asset in operation. This could include material use, energy consumption, and water consumption	Tonnes of concrete Diesel use in litres	tCO_2e per tonne tCO_2e per litre
B6	Emissions from energy used over the lifetime of the asset, for example for street lighting	Electrical energy usage in kWh	tCO_2e per kWh
B7	Emissions from the water used and its treatment (pre- and post-use) by the civil engineering works during its normal operation.	Annual litres consumed and annual litres of waste water produced	tCO_2e per litre used tCO_2e per litre of wastewater produced

8.30 Figure 8-2 illustrates how a bottom-up approach can be applied to modules A1-A5 (capital carbon).

Figure 8-2 Illustrative process for applying a bottom-up approach for capital carbon



8.31 For maintenance (B2) emissions, RICS (2023) suggests that reasonable maintenance scenarios should be developed based on facilities management and maintenance strategy reports, facade access and maintenance strategies, life cycle cost reports, operations and maintenance manuals. Where available, relevant carbon data from Environmental Product Declarations (EPDs) should be adjusted according to the scheme-specific maintenance scenario.

8.32 A similar approach can be taken for B3, using data from facilities management/maintenance strategy reports, life cycle cost reports, operations and maintenance manuals, and other professional guidance to develop scenarios for repair.

8.33 Table 8-13 presents a case study demonstrating how a bottom-up approach to modelling B4 (replacement emissions) can be used for a carbon assessment of resurfacing.

8.34 Operational energy consumption from electricity use in the operation of a scheme, e.g. from lighting can be calculated used annual electricity data (kWh) and UK Government emission factors which project the change in emissions associated with UK grid electricity over time. For a scheme level assessment the long-run marginal consumption based electricity emission factors should be used (Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal - GOV.UK).

8.35 To assess changes in emissions from rail schemes, first the change in energy consumption needs to be calculated. DfT has developed recommended energy consumption rates (by stock type) for use in appraisal of rail schemes. These can be accessed by contacting the Department.

8.36 The fuel/electricity consumption estimated should be converted into carbon dioxide equivalent (CO_2e) emissions. TAG Data Book Table A3.3 can be referred to for carbon factors per litre of fuel burnt/kWh used. It should be noted that emission factors for electricity will reduce over time as the electricity grid is projected to decarbonise. Please see TAG Unit A3 Guidance for more information on carbon assessments and appraisal for rail schemes.

8.37 Table 8-11 presents a case study demonstrating how a bottom-up approach of a construction (A1-A5) assessment for a road scheme could be approached.

Table 8-11 Example of bottom-up approach for a construction (A1-A5) assessment for a road scheme

The construction of new road has the following data: - 700 tonnes of concrete - 1,500 tonnes of aggregate - 6,700 tonnes of base course asphalt - 2,000 tonnes of binder course asphalt - 1,500 tonnes of surface course asphalt - 300 tonnes of steel The concrete, aggregate, and asphalt will be transported 50km to site. The steel will be transported 300km. 9,000 litres of diesel will be used during the construction, and 2,000 kWh of electricity.

8.38 Table 8-12 presents the calculations for calculating the emissions for A1-5 for the example described in Table 8-11.

Table 8-12 Example calculations for calculating the emissions for A1-5

Item	Quantity	Emission Factor	Carbon Emissions	Transport distance	Tonne.km	Transport Emission Factor	Carbon Emissions (assuming two-way journey)	Total Carbon Emissions
Concrete (C32/40)	700 tonnes	0.138 tCO_2e/t	966 tCO_2e	50km	35000	0.0000913 tCO_2e/tonne.km	6 tCO_2e	972 tCO_2e
Aggregate	1500 tonnes	0.007 tCO_2e/t	11 tCO_2e	50km	75000	0.0000913 tCO_2e/tonne.km	14 tCO_2e	24 tCO_2e
Base course asphalt	6700 tonnes	0.055 tCO_2e/t	369 tCO_2e	50km	335000	0.0000913 tCO_2e/tonne.km	61 tCO_2e	430 tCO_2e
Binder course asphalt	2000 tonnes	0.055 tCO_2e/t	110 tCO_2e		100000	0.0000913 tCO_2e/tonne.km	18 tCO_2e	128 tCO_2e
Surface course asphalt	1500 tonnes	0.055 tCO_2e/t	83 tCO_2e	50km	75000	0.0000913 tCO_2e/tonne.km	14 tCO_2e	96 tCO_2e
Steel	300 tonnes	1.550 tCO_2e/t	465 tCO_2e	300km	90000	0.0000913 tCO_2e/tonne.km	16 tCO_2e	481 tCO_2e
Diesel	9000 litres	0.002512 tCO_2e/l	23 tCO_2e	n/a	n/a	n/a	n/a	23 tCO_2e
Electricity	2000 kWh	0.000207 tCO_2e/kWh	<1 tCO_2e	n/a	n/a	n/a	n/a	<1 tCO_2e
Total	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	**2155 tCO_2e**

8.39 Table 8-13 presents a case study demonstrating how a bottom-up approach of a resurfacing emissions (B4) assessment for a road scheme could be approached. Readers are advised to check for the latest carbon factors rather than using this data.

Table 8-13 Example of a bottom-up approach for a road resurfacing

Based on the example in Table 8-12, this example shows how resurfacing emissions can be calculated for module B4 for a scheme. This example is limited to the materials and transport of materials emissions associated with replacement; however, fuel use and any other emissions should be assessed for these activities where appropriate. The binder course will be replaced every 30 years. The surface course will be replaced every 15 years. The scheme assessment period is 60 years long. Therefore the binder course will be replaced twice and the surface course will be replaced 4 times. In the absence of any expected replacement %, it will be assumed that the whole course will be replaced. It is assumed the base course won't be replaced in the scheme lifetime. Binder course: 2000 tonnes × 2 = 4000 tonnes in total over the assessment period of the scheme. Surface course: 1500 tonnes × 4= 6000 tonnes in total over the assessment period of the scheme.

8.40 Table 8-14 presents the calculations for calculating the emissions for B4 for the example described in Table 8-13.

Table 8-14 Example calculations for calculating the emissions for B4

Item	Quantity	Emission Factor	tCO_2e	Transport distance	Tonne.km	Transport Emission Factor	tCO_2e (assuming two-way journey)	Total tCO_2e
Binder course asphalt	4,000 tonnes	0.055 tCO_2e/t	220	50km	200,000	0.0000913 tCO_2e/tonne. km	36	256
Surface course asphalt	6,000 tonnes	0.055 tCO_2e/t	330	50km	300,000	0.0000913 tCO_2e/tonne. km	55	385
Total	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	641

Scheme level land use change methodologies

8.41 Table 8-15 summarises key characteristics of this method.

Table 8-15 Key characteristics of land use change methodologies

Variable	**Definition**
Summary description	This method involves applying carbon factors to habitat areas for both Do-Minimum (i.e. without scheme) and Do-Something (i.e. with scheme) scenarios and working out the difference between the two scenarios (i.e. the scheme impact)
Relevant stage and QCG chapter	• Considering carbon in option generating and sifting (Chapter 4) • Carbon assessment throughout design and business case stages (Chapter 5)
Applicable scale	Scheme-level
When to use	When a scheme is expected to lead to a change in land use that is of a scale to warrant an assessment and suitable habitat data is available to enable this. This typically will be in later intervention and policy development stages (e.g. OBC and FBC) when habitat assessments (e.g. for Biodiversity Net Gain calculations) have been prepared anyway for planning purposes
Input data	• Habitat data (e.g. as would be prepared for Biodiversity Net Gain calculations) • Carbon factors
Output	Estimated land use change carbon emission impact (tCO_2e) of proposed scheme across scheme lifespan

8.42 Significant amounts of carbon are stored in vegetation and soil. Where a proposed scheme requires the removal of existing vegetation or soil, stored carbon is released to the atmosphere. Additionally, wherever land is converted from one use or vegetation type to another, the rate at which it sequesters (or releases) carbon over time is altered.

8.43 One way of determining the amount of carbon *released or sequestered* (i.e. the carbon *impact*) due to land use change over the scheme assessment period is to compare the amount of carbon *stored* in the land (vegetation and soil) at the end of the assessment period between the Do Minimum (DM) and Do Something (DS) scenarios.

8.44 To determine the change in carbon *storage* as a result of implementing the scheme, the amount of carbon stored in the land at the end of the assessment period in the DM scenario can be subtracted from the amount of carbon stored in the land at the end of the assessment period in the DS scenario. The net carbon *impact* of implementing the scheme is the opposite of this as any reduction in stored carbon is assumed to be released to the atmosphere, and any increase in stored carbon is assumed to be removed from the atmosphere, as demonstrated in the example illustrated in Table 8-16 and Figure 8-3.

Table 8-16 Example approach to estimating land use change carbon impacts

A scheme is proposed on a site that has 10,000 tCO_2e stored in existing vegetation and soil.

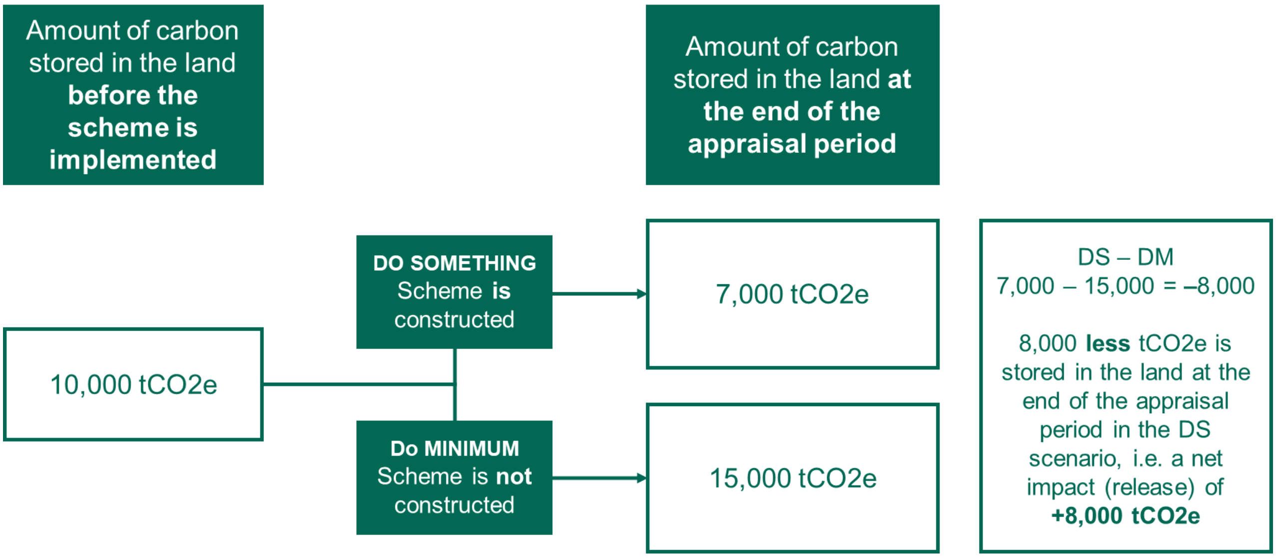
- If the scheme is not constructed (the Do Minimum scenario), the existing vegetation continues to sequester carbon and at the end of the assessment period there is 15,000 tCO_2e stored in vegetation and soil on the site.
- If the scheme is constructed (the Do Something scenario), some of the stored carbon is released due to removal of existing vegetation or soil in some areas. These areas of land are repurposed (or 'changed') to another 'use' such as a road, or to a different vegetation type, altering the sequestration rate of the land. At the end of the assessment period, there is 7,000 tCO_2e stored in vegetation and soil on the site.

The difference in carbon *stored* in the vegetation and soil between the two scenarios is therefore 8,000 tCO_2e (i.e. 8,000 less tCO_2e is *stored* at the end of the assessment period in the Do Something compared with the Do Nothing scenario – see Figure 8-3*)*.

It can therefore be assumed that an additional 8,000 tCO_2e is *released* if the scheme is constructed, i.e. a net *impact* of +8,000 tCO_2e.

Important: Subtracting the carbon storage figure (at the end of the assessment period) for the Do Minimum scenario from the Do Something scenario gives the change in carbon *storage,* i.e. 7,000 – 15,000 = –8,000 tCO_2e. The net carbon *impact* (release) is the opposite of this, i.e. +8,000 tCO_2e.

Figure 8-3 Example approach to estimating land use change carbon impacts



8.45 A key principle to consider in this assessment is that for any area (e.g. any square m) the habitat can change from one type to another (e.g. grassland to woodland) but it cannot be removed (i.e. if woodland is felled and a sealed urban surface is created, then that area has changed from woodland to sealed surface). Thinking about land use change in this way allows the net change in carbon storage at the end of the scheme lifecycle to be calculated.

8.46 Unlike other sources of carbon, it is not typical to use benchmarks to estimate land use change carbon impacts. The level of assessment detail however should be proportionate to the stage of intervention and policy development. A high-level and detailed methodology are described below.

8.47 Distinct areas of land that differ by land use type or vegetation type are referred to as "habitats".

8.48 While this guidance refers specifically to carbon analysis of land use changes there are wider considerations and values placed on any changes to natural assets. Further information can be found in the Government's Enabling a Natural Capital Approach guidance.

High-level methodology

8.49 At the early stages of intervention and policy development, it is unlikely that a detailed understanding of land use change (e.g. a habitat assessment for both the Do Minimum and Do Something scenarios) will be available. In this case, a high-level methodology considering only the key habitat changes is appropriate.

8.50 Key habitats should ideally include any habitats that represent a significant proportion of the site, and any habitats that store large amounts of carbon by area (e.g. woodland, peatland, or wetland).

8.51 A high-level understanding of key habitats and how they may change if the scheme is implemented can be obtained by undertaking desktop analysis of the site (e.g. "satellite view") and by referring to any available scheme drawings.

8.52 The approximate area of key habitats can be multiplied by suitable "carbon storage values" (i.e. tC per hectare, for each habitat) to determine the carbon stored at the end of the assessment period in each of the Do Minimum and Do Something scenarios. The difference in carbon storage between the two scenarios can therefore be obtained by subtracting the Do Minimum result from the Do Something result (i.e. DS – DM).

8.53 A key guidance document to consider is Natural England, (2021), Carbon Storage and Sequestration by Habitat (2nd) (Natural England, 2021). Appendix 1 of the Natural England guidance presents carbon storage values per habitat per hectare.

8.54 It should be noted that carbon storage values are typically in units of tonnes of carbon per hectare (tC/ha). To determine the amount of carbon dioxide equivalent (tCO_2e) that would be associated with this storage, it is necessary to multiply by 44/12, i.e. 100 tonnes of carbon (tC) stored in a hectare of land is equivalent to 100 x (44/12) = 367 tCO_2e if released to the atmosphere. Conversely, if 1 ha of land sequesters 367 tCO_2e from the atmosphere, it would be stored as 100 tC.

8.55 The carbon impact of the scheme is the opposite of the difference in carbon storage between the two scenarios. If the difference in carbon storage is negative (-) (as with the example in Table 8-17), less carbon is stored in the Do Something scenario, which implies the net impact of the scheme is to release carbon (+).

8.56 Conversely, if the difference in carbon storage is positive (+), more carbon is stored in the Do Something scenario, which implies the net impact of the scheme is to sequester carbon (-).

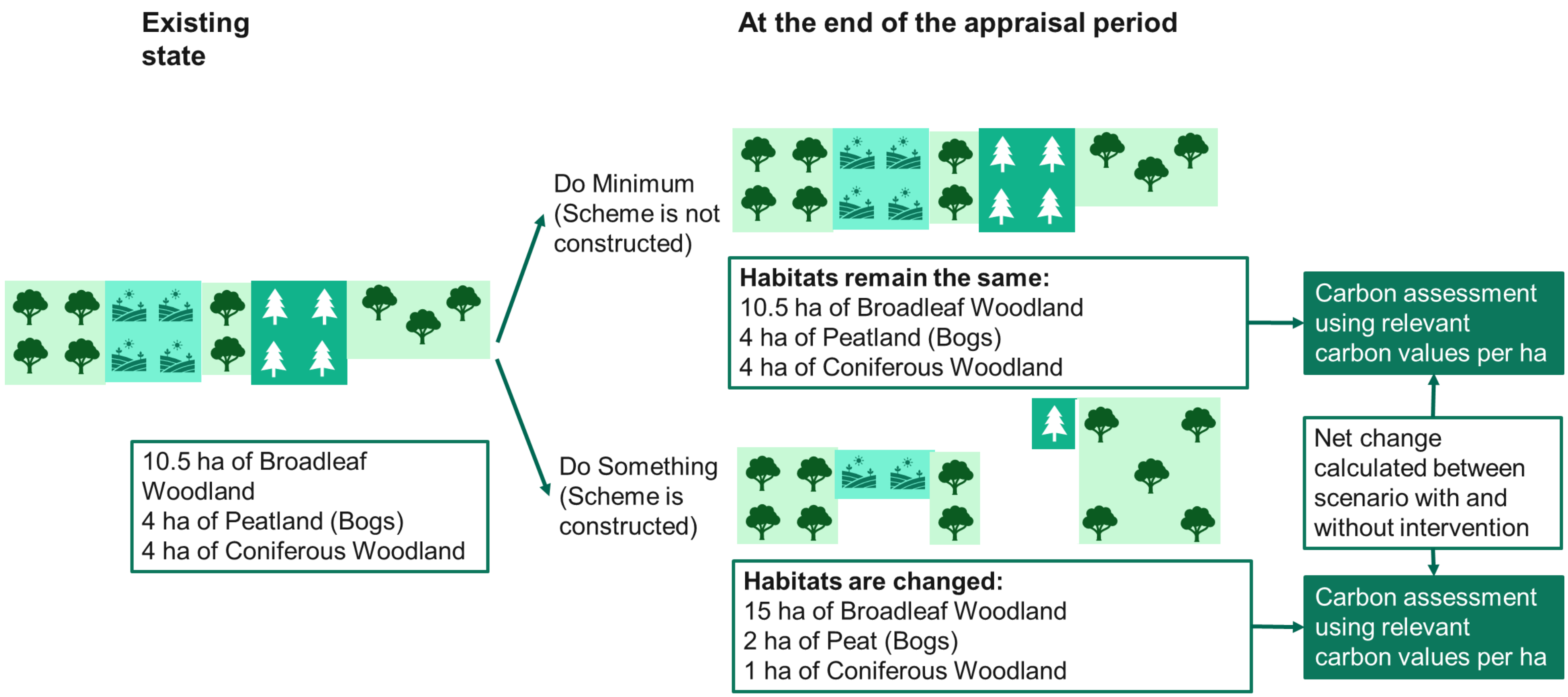
8.57 An example of this methodology in practice is provided in Table 8-17.

Table 8-17 Example high-level assessment of land use change carbon impacts based on approximate areas of key habitats

- A scheme is proposed on a site that currently features 4 ha of woodland. Available feasibility stage scheme drawings show that approximately 1 ha will remain in place and the other 3 ha will be cleared. The cleared land will be converted to a road.
- Through research, a suitable carbon storage value of 100 tC/ha is sourced for the woodland.
- Multiplying the existing area of woodland by this value provides an estimate of carbon stored in the Do Minimum scenario,
  i.e. 4 (ha) x 100 (tC/ha) = 400 tC.
- Multiplying the area of woodland remaining after the scheme is implemented by this value provides an estimate of carbon stored in the Do Something scenario,
  i.e. 1 (ha) x 100 (tC/ha) = 100 tC.
- The difference in carbon storage is obtained by subtracting the Do Minimum result from the Do Something result,
  i.e. 100 – 400 = –300 tC (300 less tC stored in the Do Something scenario).
- The total change in tonnes of carbon should be converted to tCO_2e to allow it to be factored into a WLC assessment with other emissions impacts.
  i.e. -300 x 44/12 = -1,100 tCO_2e
- The net carbon impact of the scheme is the opposite of this as any reduction in stored carbon is assumed to be released to the atmosphere.
  i.e. +1,100 tCO_2e; this is the net land use change carbon impact of the scheme.

8.58 The same high-level methodology can be used where multiple key habitats are considered, as shown in Figure 8-4.

Figure 8-4 High-level assessment of land use change carbon impacts



8.59 There are tools available which can support with the calculation of carbon stored in habitats. Please reach out to DfT for further information.

Detailed methodology

8.60 At later stages of intervention and policy development, it is likely that a more detailed understanding of land use change (e.g. a habitat assessment for both the Do Minimum and Do Something scenarios) can be obtained. In this case, a more detailed methodology considering all affected habitats is appropriate.

8.61 As part of a detailed assessment of land use change carbon impacts, in addition to vegetation type, consideration should also be given to vegetation age, as this influences the amount of carbon vegetation can store.

8.62 In practice, this means different carbon storage values (tC/ha) should be used even if the vegetation type in a particular habitat remains unchanged, to account for the additional carbon it will sequester over time. In other respects, the detailed methodology is similar to the high-level methodology explained above.

8.63 An example of this methodology in practice is provided in Table 8-18.

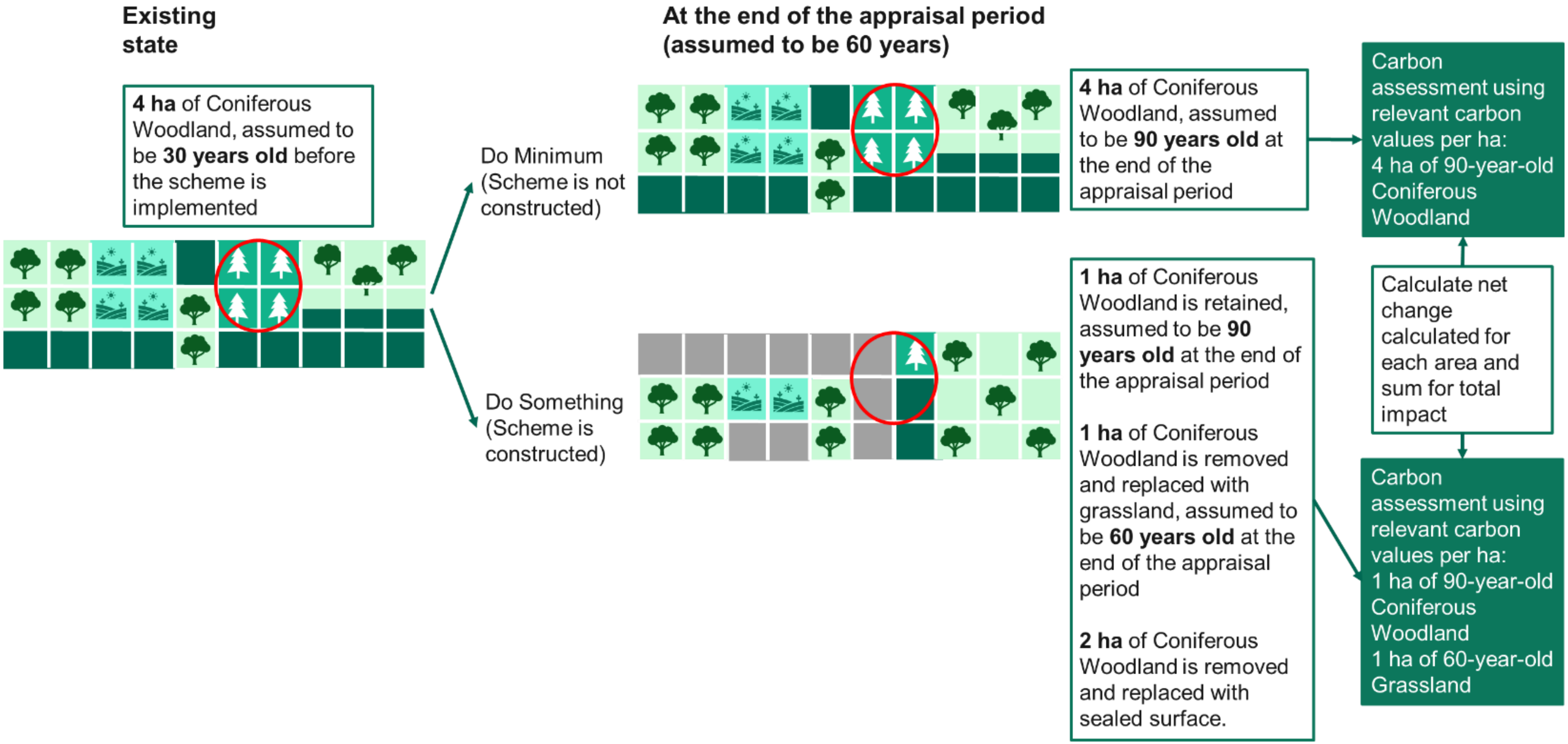
Table 8-18 Example detailed assessment of land use change carbon impacts, accounting for vegetation age

- A scheme is proposed on a site that currently features 4 ha of woodland. Available feasibility stage scheme drawings show that approximately 1 ha will be retained and the other 3 ha will be cleared. 2 ha of the cleared land will be converted to a road, and new woodland will be established on the other 1 ha.
- It is determined that the existing 4 ha of woodland is 30 years old.
- The assessment period of the scheme is 60 years. As such, in the Do Minimum scenario, the 4 ha of woodland would be 90 years old at the end of the assessment period. Through research, a suitable carbon storage value of 100 tC/ha is sourced for the 90-year-old woodland.
- Multiplying the area of woodland by this value provides an estimate of carbon stored in the Do Minimum scenario,
  i.e. 4 (ha) x 100 (tC/ha) = 400 tC.
- In the Do Something Scenario, only 1 ha of existing woodland is retained and will be 90 years old at the end of the assessment period,
  i.e. 1 (ha) x 100 (tC/ha) = 100 tC
- 3 ha of woodland will be cleared, and new woodland will be established on 1 ha of this area. This hectare of new woodland however will only be 60 years old at the end of the assessment period, and therefore has not sequestered as much carbon as 90-year-old woodland would.
- A suitable carbon storage value of 90 tC/ha is sourced for the 60-year-old woodland. Multiplying the area of woodland by this value provides an estimate of carbon stored,
  i.e. 1 (ha) x 90 (tC/ha) = 90 tC
- The remaining 2 ha is converted to a road and does not store any carbon. Therefore at the end of the assessment period, 190 tC is stored in the land in the Do Something scenario,
  i.e. 100 (tC) + 90 (tC) = 190 tC.
- The difference in carbon storage is obtained by subtracting the Do Minimum result from the Do Something result,
  i.e. 190 – 400 = –210 tC (210 less tC stored in the Do Something scenario).

- The total change in tonnes of carbon should be converted to tCO_2e to allow it to be factored into a WLC assessment with other emissions impacts.
  i.e. -210 x 44/12 = -770 tCO_2e
- The net carbon impact of the scheme is the opposite of this as any reduction in stored carbon is assumed to be released to the atmosphere.
  i.e. +770 tCO_2e*; this is the net land use change carbon impact of the scheme.*

8.64 Figure 8-5 provides an illustration of how this approach would be applied.

Figure 8-5 Detailed assessment of land use change carbon impacts



9. Carbon Impact Evaluation

Introduction

9.1 Evaluation can inform thinking before, during and after an intervention's implementation. To support learning and provide accountability evaluation can answer questions such as 'did the intervention work?' and 'by how much?'. Further guidance on how evaluation can be found in the HM Treasury Magenta Book.

9.2 Evaluation of carbon impacts can provide learnings that will improve consideration of carbon in future strategic planning and scheme development. This chapter focuses only on the evaluation of carbon impacts, not broader scheme impacts covered in the HM Treasury Magenta Book, or DfT Evaluation Guidance. It can improve the evidence used in transport planning tasks, such as the preparation of transport strategy evidence-base or carbon evidence used to inform optioneering. This can enable decision-makers to learn from past projects and improve future transport strategies and schemes.

9.3 Carbon impact evaluation however is challenging. Unlike air quality impacts which can be measured locally, carbon impacts from transport occur at dispersed locations. It therefore cannot be measured directly for the purposes of transport evaluation; concentrations of greenhouse gases in the atmosphere are only monitored at a few locations globally.

9.4 Estimates of carbon impacts however can be made through the use of proxy observed data such as traffic counts and bus patronage data. By using observed data in place of the estimates used prior to scheme delivery, insights can be gained as to how actual carbon impacts might be different to estimated impacts.

9.5 Calculation methodologies used in carbon impact evaluation will be very similar to those used in carbon assessment. The methodologies described in Chapters 6 – 8 can be adapted for use with observed data. There is however likely to be an absence of observed data for many of the variables used in a carbon impact evaluation calculation; where this is the case the same datasets used in assessment may be used. For example, observed traffic flows may be used in place of flows forecast in a traffic model, but the TAG Data Book assumptions might be used for the proportion of vehicles by fuel type.

9.6 This Chapter only provides high-level advice on key principles and concepts of carbon impact evaluation. For detailed guidance on how to undertake carbon impact evaluation authorities should refer to the Local Authority Major Schemes Benefits Management and Evaluation Framework. Overarching guidance on transport related evaluation can be found in TAG unit E-1.

Key principles and concepts of carbon impact evaluation

9.7 Evaluation is a systematic assessment of the design, implementation, and outcomes of an intervention. This can include what difference it has made (impact evaluation), whether its benefits justified its costs (value-for-money evaluation), and how it was delivered (process evaluation). This Chapter only covers how carbon can be calculated for the purposes of impact evaluation.

9.8 When considering carbon impacts, the impact evaluation key steps are likely to include:

- Conduct data collection at appropriate timepoints, including at the baseline (i.e. before the scheme), one year post-opening, and three years' post-opening. Typically, the data collected for other purposes (e.g. traffic counts or demand data) can be used for carbon evaluation.
- Analyse the data to answer the impact evaluation questions (e.g. produce carbon estimates from outturn data) and write up the findings.
- Share findings and lessons learnt with relevant stakeholders, including programme staff, funders, and community members.
- Where appropriate, compare evaluation data against ex-ante appraisal findings and use the evaluation findings to inform future scheme design.

9.9 Analysis of the data (e.g. traffic counts, demand data) to answer a carbon impact evaluation question would involve similar calculations to those described in Chapter 7 for carbon assessment using forecast data.

9.10 The recommended approach to impact evaluation is to conduct a before versus after comparison for selected measures, with some counterfactual comparisons where appropriate to provide context. Establishing a credible counterfactual (i.e. estimates of what would have happened in the absence of the scheme) is important. This should draw on approaches used as part of a wider evaluation.

9.11 The scope of carbon impact evaluation is likely to focus on user carbon impacts. Infrastructure carbon impacts are likely to be approached differently, reflecting that construction stage capital carbon impacts will have been already emitted in ex-post evaluation but maintenance would be ongoing. Monitoring and evaluation of infrastructure carbon impacts may be required through the carbon management process, for example to evaluate whether carbon reduction targets set against an early baseline have been met. This process of monitoring infrastructure carbon impacts should be established within a Carbon Management Plan.

Annex A: Key Concept Explainers

A.1 Explainer 1 - Units used in carbon assessment

Tonnes of carbon dioxide equivalent (tCO_2e) is the unit of measurement which includes all seven GHGs, as defined in the Kyoto Protocol. This unit provides a way to account for the impact of all the GHGs in terms of the equivalent amount of carbon dioxide.

This is based on the Global Warming Potential (GWP) of different greenhouse gases. GWP is a measure of how much different greenhouse gases trap heat in the atmosphere over a specific period, relative to carbon dioxide (CO_2). Carbon dioxide has a GWP of 1 and the other gases are measured in comparison to this.

For example, the GWP of methane is 27-30 over a 100-year period, which means it will trap 27-30 times as much heat as the same mass of carbon dioxide in that time.

Quantities in tCO_2e may be presented in different magnitudes, e.g. kilotonnes of carbon dioxide equivalent ($ktCO_2e$). The table below explains how to convert between these magnitudes.

Annex A Table 1 Units used in carbon assessment

Unit	Conversion from tCO_2e
1 gram (gCO_2e)	Multiply by 1,000,000
1 kilogram ($kgCO_2e$)	Multiply by 1,000
1 tonne (tCO_2e)	1
1 kilotonne ($ktCO_2e$)	Divide by 1,000
1 megatonnes ($MtCO_2e$)	Divide by 1,000,000
1 gigatonne ($GtCO_2e$)	Divide by 1,000,000,000

A.2 Explainer 2 - How do WLC emissions relate to the GHG Protocol's scope 1, 2 and 3 categories?

Scope 1, 2 and 3 categorises emissions are based on the level of control an organisation has over them. The definitions of Scope 1-3 emissions are based on the Greenhouse Gas Protocol ('GHG Protocol') standards, which are the globally accepted greenhouse gas accounting standards, published by the World Resource Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The categorisation of which emissions fall in which scope often varies depending on who is the subject. For example, a different scope may be used depending on whether a local authority is focused solely on its own organisational footprint or that of the geographical area it covers.

This QCG approach and advice is focused on emissions within the influence of transport strategies and schemes rather than organisational footprints. Carbon impacts described in this guidance are therefore not categorised by the GHG Protocol's scope 1, 2 and 3 categorisation. WLC emissions quantified in the analysis described in this guidance will primarily fall within scope 3 of the GHG Protocol for organisational emissions (e.g. supply chain emissions from highways construction and maintenance). Some WLC emissions however may contribute to organisational scope 1 and 2 commitments, such as energy consumption from highway lighting (scope 2).

Likely to be of most relevance to authorities in the development of transport strategies is the approach adopted in the 'Global Protocol for Community-Scale Greenhouse Gas Inventories: An Accounting and Reporting Standard for Cities Version 1.1'. This is a standard which sets out a framework for cities and local governments to 'identify, calculate, and report on city greenhouse gas emissions'.

The 'GHG Protocol for Community-Scale Greenhouse Gas Inventories' sets out the definitions of Scope 1, 2, and 3 emissions based on geographical boundary. This is different to the Scope 1, 2, and 3 emissions definitions used for companies and organisations; an outline of the differences can be found in Table A.1 of the 'GHG Protocol for Community-Scale Greenhouse Gas Inventories'.

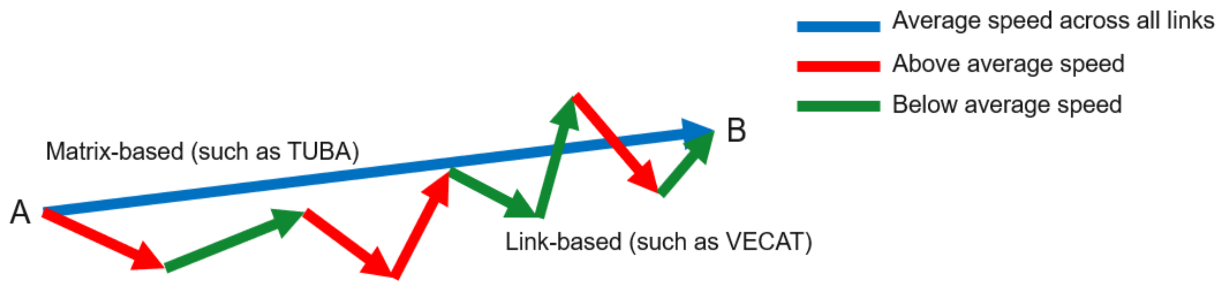
Under these city-scale definitions of scope 1, 2 and 3 emissions all emissions from the use of fuel on the transport network, as well as manufacturing and construction fuel use within a Local Authority's boundary would sit within Scope 1 emissions. Electricity used in the transport network (e.g., EV car charging and road lighting) would sit in Scope 2 emissions. Infrastructure carbon emissions associated with construction or maintenance materials produced outside of the city boundary would be Scope 3.

Whilst these GHG Protocol categorisations provide a useful framework for identifying all potential emissions sources which are in a Local Authority's direct and indirect control or influence, for the purpose of QCG analysis, authorities are encouraged to understand all the emissions sources which they have influence over. Area-wide and scheme-level analysis referred to in QCG relates to all carbon emissions that are created by activity in a local authority or through their policies or interventions, irrespective of whether those emissions occur in the geographic boundary of that authority or not.

A.3 **Explainer 3 - How does a link-based approach differ to a matrix-based approach when calculating emissions?**

Matrix based approaches, such as TUBA, consider data on an overall trip basis rather than link-by-link. This means one average speed is assumed across a whole trip between its given origin and destination, rather than by each link that makes up the journey. The carbon impact is then calculated using the average speed and TAG assumptions such as mileage split by fuel type and fuel efficiency. This gives a single rate of fuel consumption for the whole length of the journey and cannot therefore differentiate between a trip that travels at a steady speed and one that travels at varying speeds. In comparison, link-based approaches average the speed on each individual link; combining this with the link length and flow to estimate emissions on a link-by-link basis. This is illustrated in Annex A Figure 1. The blue line in Annex A Figure 1 represents the whole trip between A and B assumed by a matrix-based approach with a steady speed, whereas the red and green lines are the individual links between A and B which are each treated separately in a link-based approach.

Annex A Figure 1 Illustration of matrix and link-based approaches



Matrix based approaches such as TUBA may therefore over or under-estimate emission rates, while link-based approaches such as TAG-based calculations, e.g. VECAT, are likely to be more accurate and should be used wherever possible.