



BEYOND THE BUILDINGS: **DECARBONISING INFRASTRUCTURE ON MASTERPLANS**

Research Report and Design Guidance
November 2025

CONTENTS

This report presents the results of research into the embodied carbon in masterplanning infrastructure, carried out by Expedition Engineering with support from the Institution of Civil Engineers’ Research and Development Enabling Fund.

The project aimed to provide a greater understanding of where the embodied carbon hotspots are in the ‘enabling infrastructures’ on masterplans, and guidance for early-stage decisions and design principles to avoid “locking in” carbon to those systems, in line with PAS 2080.

The work has been enabled and reviewed by the ICE’s Research and Development group. We would like to thank the ICE for supporting this research and its dissemination.

Cover Image: Meridian Water, © Filippo Bolognese

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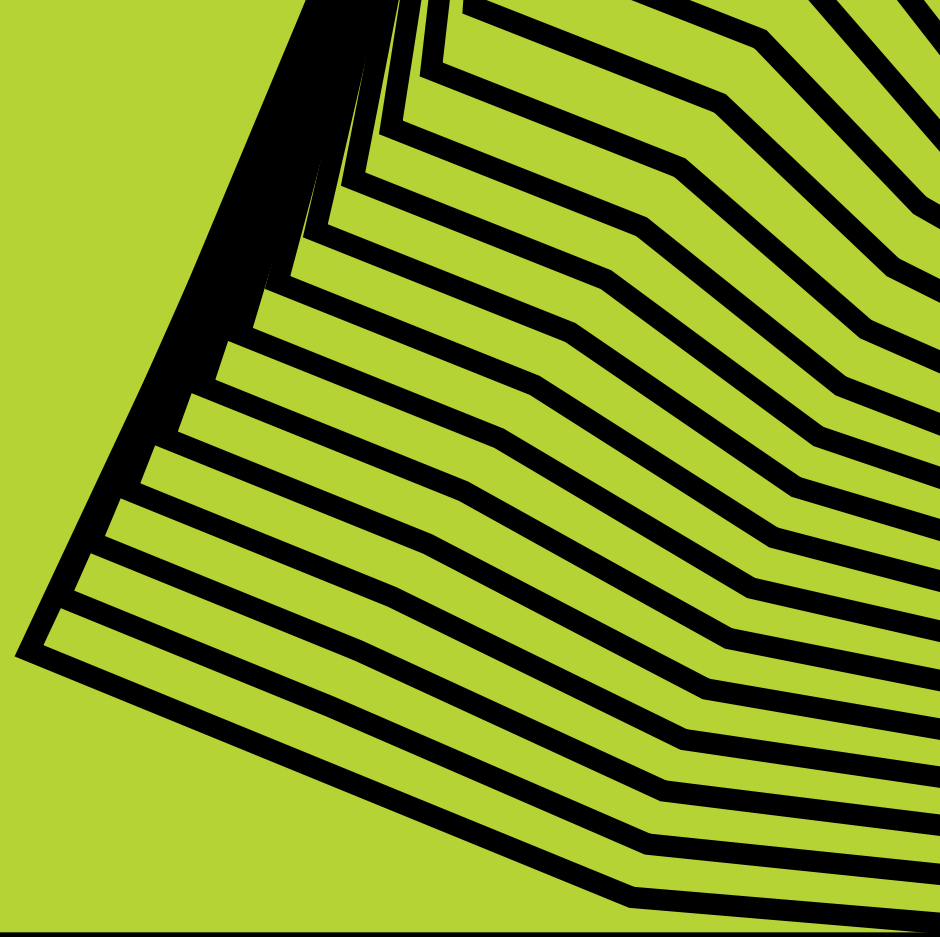
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01



CONTEXT

CONTEXT

THE TWIN CHALLENGE OF DECARBONISATION AND DEVELOPMENT

The UK's construction industry faces a significant twin challenge: to reduce its emissions to help meet the government's legally binding Net Zero target, while delivering 1.5 million new homes (at a rate not achieved so far) in the next five years.

The UK's population is projected to grow by over 4 million people by 2032¹. In parallel with a crisis of housing affordability, driven by historic increases in rents and low rates of new building, the new Labour government has pledged to build 1.5 million more homes over the next five years, enabled by planning reforms, the release of green belt land and housing targets for local authorities².

This requires a significant increase on current housebuilding rates of around 200,000 homes a year³, and in its 2024 budget the government therefore committed £5 billion to be spent on housing between 2025 and 2026⁴.



Image courtesy Kjellander Sjöberg

The UK also faces the challenge of meeting its carbon budget: the Climate Change Act commits the UK government by law to meet its Net Zero target by 2050. The UK's built environment is responsible for 25% of the UK's greenhouse gas emissions⁵, and a 2022 study suggested that delivering this amount of housing using a business-as-usual approach would use up 104% of the UK's cumulative carbon budget by 2050 on its own⁶.

The sector therefore faces a huge challenge to **reduce our emissions while accelerating the amount of housing being delivered.**

Leading organisations in the industry have recognised this challenge (the ICE, IStructE, UKGBC, National Infrastructure Commission, among others) and have started to map approaches to minimising carbon. The initial focus has been on buildings and heavy infrastructure, firstly through operational carbon, but increasingly recognising the significance of embodied carbon in the whole life of an asset. Much of the industry has put its weight behind increasing focus on approaches to governing carbon, including the proposed Part Z amendment to the building regulations, and the UKGBC's Net Zero Carbon Buildings Standard which was published in 2024.

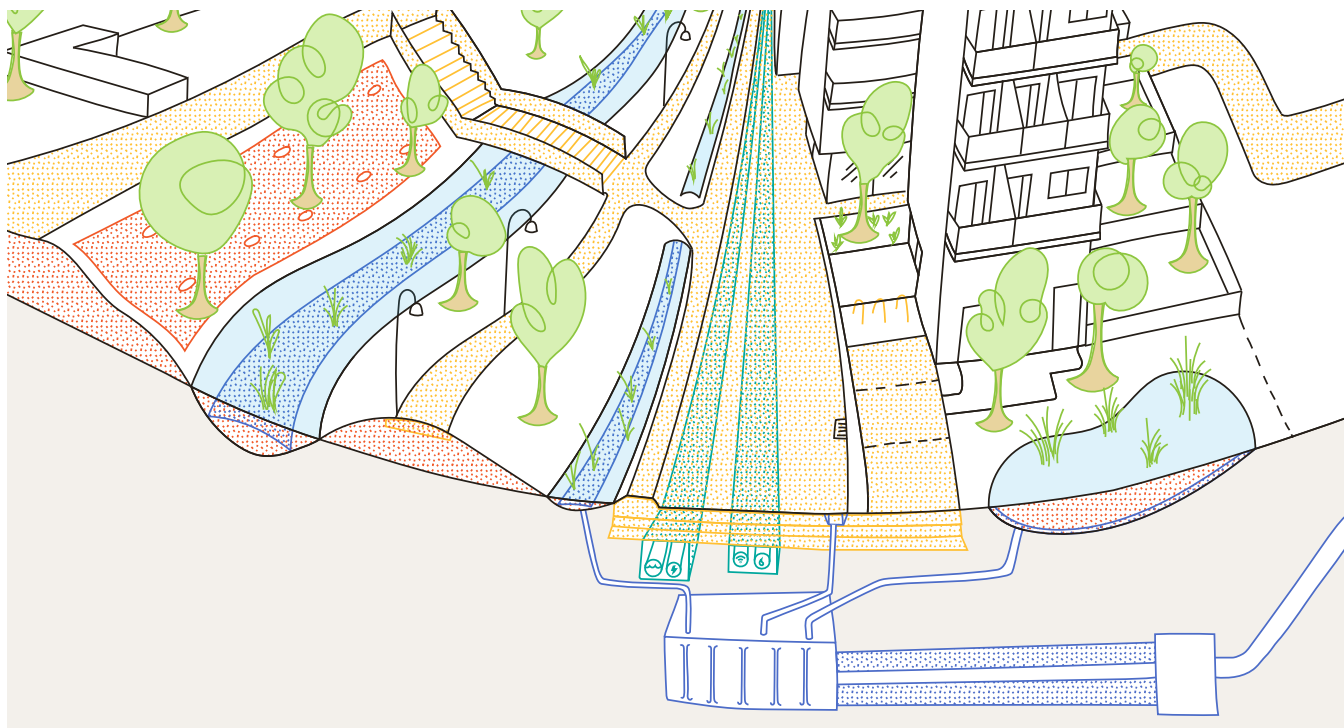
CONTEXT

THE IMPORTANCE OF ENABLING INFRASTRUCTURES

A development – and therefore a community – is not just a set of individual buildings. Homes and buildings do not exist independently; their occupants need clean water, power and light, access to high quality public spaces, shops, green spaces and other areas, and protection from ground instability and flooding.

Those missing links – ‘Enabling Infrastructures’ – are critical to a development, and while the carbon in buildings is increasingly well understood, our experience suggests that the industry’s approach to reducing carbon for these enabling infrastructures is much less mature.

Larger, strategic infrastructure projects such as HS2 and Crossrail have taken pioneering approaches to reducing carbon, but the smaller infrastructure required for this vast scale of development tends to receive much less attention.



EARTHWORKS



UTILITIES



SURFACE WATER DRAINAGE



ACCESS INFRASTRUCTURE



CONTEXT

THE IMPORTANCE OF ENABLING INFRASTRUCTURES

For the purposes of this study, enabling infrastructures have been grouped into four sub-systems: surface water drainage, utilities, access infrastructure, and earthworks. Each of these subsystems is relevant on every development, and all have an impact on embodied carbon.

Note: Landscaping and public realm is an additional element of 'enabling infrastructure'; we recognise that hard landscaping has a material impact and soft landscaping can provide carbon benefits through biogenic storage.

The focus of this research was on between-plot impacts, and as a result landscaping was not included as a subsystem in the scope of this research. Further detail on this reasoning can be found in Appendix B.



SURFACE WATER DRAINAGE

Surface water drainage infrastructure safely conveys rainwater away from properties and other surfaces, to be used in the landscape, elsewhere in the development as greywater, or treated off site.



UTILITIES

Utilities infrastructure delivers electricity, gas, connectivity, water and sewage to the homes and other buildings in a development.



ACCESS INFRASTRUCTURE

Access infrastructure enables people to move safely into and around a development; this includes roads, kerbs, footpaths, cycle paths and the associated infrastructure (lighting, etc.)



EARTHWORKS

Earthworks refers to the movement and treatment of earth required to create the required levels, ensure the stability of slopes, and create trenches and excavations for building foundations and utilities infrastructure.

CONTEXT

RESEARCH METHODOLOGY

This study, co-funded by the Institution of Civil Engineers' Research and Development Enabling Fund and Expedition Engineering, aimed to answer three research questions, set out below.

A mixed-methods approach was taken to answer these questions, taking inputs from published literature, examples of projects and interviews with those leading best practice in the industry.

Research Question	How has industry responded to the need to minimise the embodied carbon in enabling infrastructure?	What might the biggest carbon hotspots be within and between the enabling infrastructure subsystems?			What decisions can clients, designers and others make at an early stage to minimise the carbon in those subsystems?			
	Approach	Literature review of relevant guidance and existing standards	Selection of case study projects	Development of calculation tool	Case study analysis	Collation of best-practice guidance	Interviews with leading practitioners	Review of insights from case studies
REPORT SECTION	SECTION 2: KEY STANDARDS AND PUBLICATIONS		SECTION 3: CASE STUDIES			SECTION 4: GUIDANCE		
	PAS 2080 and other publications		KEY INSIGHTS from the case studies			How to PLAN THE USE OF THE LAND		
	The need for SUBSYSTEM-SPECIFIC GUIDANCE		DETAILED STUDIES			How to SET UP THE PROJECT FOR COLLABORATION		
			 CASE STUDY 1  CASE STUDY 2  CASE STUDY 3			How to DESIGN LOW-CARBON INFRASTRUCTURES:		
						SURFACE WATER DRAINAGE EARTHWORKS UTILITIES ACCESS INFRASTRUCTURE		

CONTEXT

HOW TO READ THIS REPORT

For **clients, designers, developers and others** involved in the creation and delivery of a masterplan:

This report is not a comprehensive design guide, but a ‘critical friend’ to consult in your design process to highlight where decisions can be made to design better lower-carbon infrastructures on new masterplans.

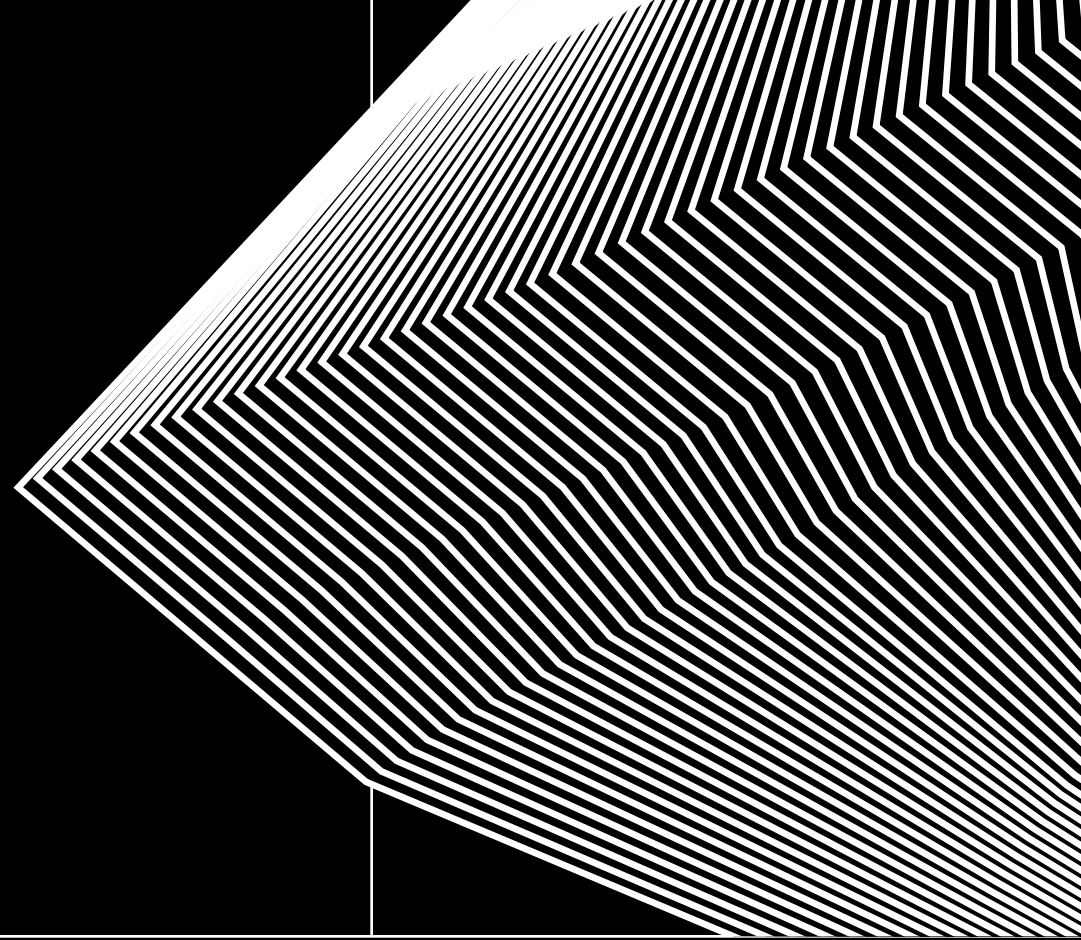
In **SECTION 3** you can read the findings from three case studies, exploring the embodied carbon of enabling infrastructures on masterplans.

You can find guidance for designing low-carbon enabling infrastructures in **SECTION 4**.

For **policy makers and the wider industry**:

This report gives an understanding of the current policies and literature affecting the embodied carbon of infrastructures, as well as the hotspots within different subsystems that need to be addressed.

02



THE INDUSTRY'S RESPONSE

THE INDUSTRY'S RESPONSE

KEY STANDARDS AND GUIDANCE

The industry has started to respond to the need to understand, measure and minimise the embodied carbon of infrastructure, as evidenced in regulations, standards and guidance.

STANDARD: PAS 2080

PAS 2080 is the global standard for Carbon Management in Buildings and Infrastructure, which sets out a standard approach to measuring and managing whole life carbon in the built environment. Whilst the first edition (2016) focused on carbon management for infrastructure projects, the latest revision (2023) encompasses both buildings and infrastructure assets. This highlights the importance of adopting a systems-approach, considering the interdependencies and synergies between assets, networks and systems of the built environment, and the impacts both within and outside the 'red line' boundary of a project.

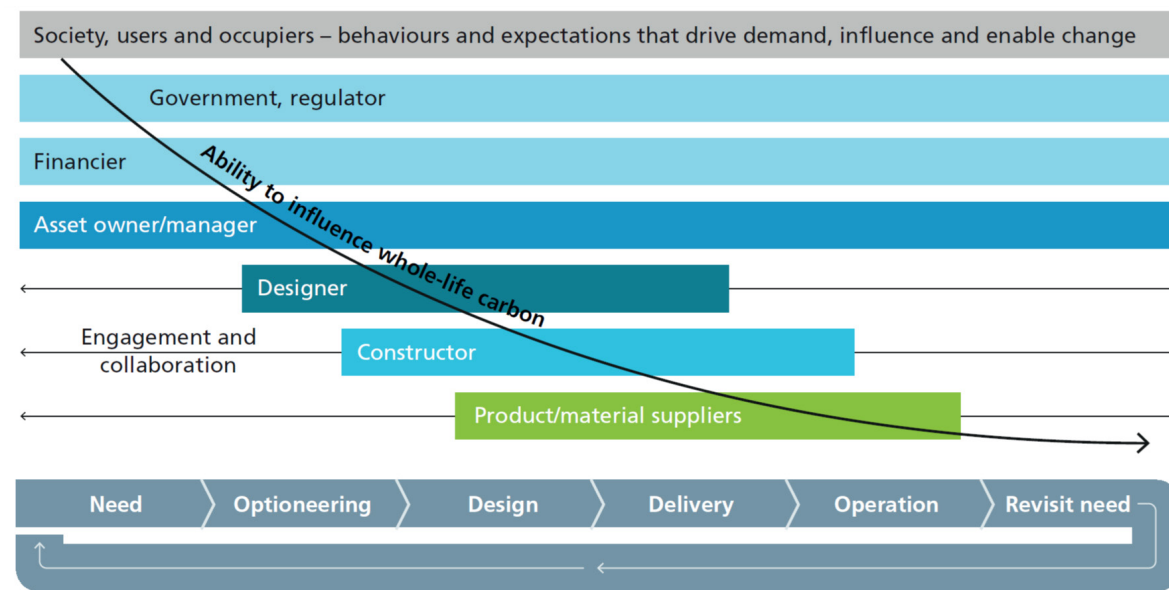
Crucially, PAS 2080 highlights that the greatest potential to influence carbon is at the earliest stages of a project, where strategic decisions are

made about site selection, layout and concept design that 'lock in' carbon, making carbon reduction at later stages much more difficult.

PAS 2080 follows a carbon management hierarchy of **Avoid, Switch, Improve**: avoiding the need for carbon-intensive solutions, switching to a lower-carbon alternative, or improving a necessary solution by reducing its embodied carbon.

Multiple large strategic infrastructure projects and contractors have achieved accreditation with PAS 2080-2016, and some are starting to require their supply chain to implement PAS 2080-accredited systems.

The widespread adoption of PAS 2080, essentially the integration of carbon management in line with the principles of PAS 2080 in projects of all types and scales, is quintessential for the decarbonisation of the built environment.



Value-chain members' ability to accelerate decarbonisation throughout the delivery process, from Guidance Document for PAS 2080, Institution of Civil Engineers, 2023

THE INDUSTRY'S RESPONSE

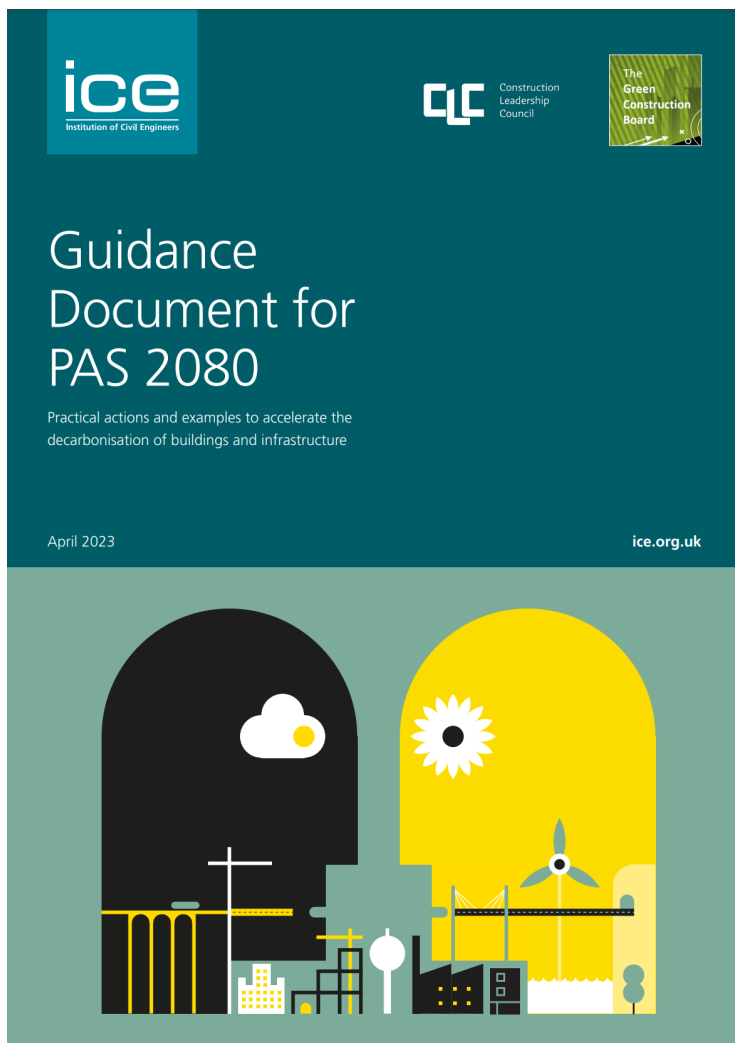
KEY STANDARDS AND GUIDANCE

GUIDANCE: ICE GUIDANCE DOCUMENT FOR PAS 2080

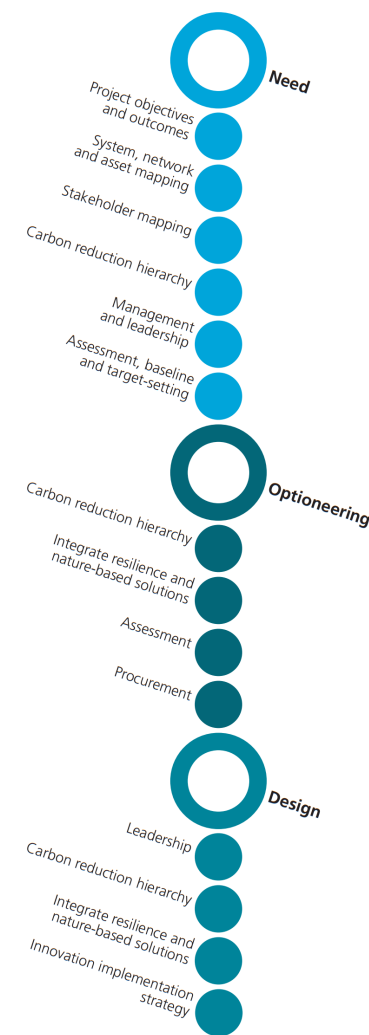
After PAS 2080 was updated in 2023, the ICE published a Guidance Document for applying PAS 2080 to buildings and infrastructure. The document contains practical actions, case studies and worked examples, and specifies the roles and responsibilities of different actors.

The document's 'PAS CITY' worked example gives an example of applying the standard to an industrial regeneration project, throughout the process of the design. Many of the practical actions set out in the worked example apply to 'enabling' infrastructures: understanding existing infrastructure on site to enable reuse, setting a carbon reduction hierarchy aligned with 'Avoid, Switch, Improve', prioritising nature-based solutions, and incentivising carbon reduction in procurement.

We saw a need to develop this type of guidance in more detail, at a technical level for each of the enabling infrastructure subsystems we identified.



Document cover, and *PAS City: managing whole-life carbon across the PAS 2080 delivery stages* – some priorities for the developer and collaborations with the value chain, from Guidance Document for PAS 2080, Institution of Civil Engineers, 2023



THE INDUSTRY'S RESPONSE

KEY STANDARDS AND GUIDANCE

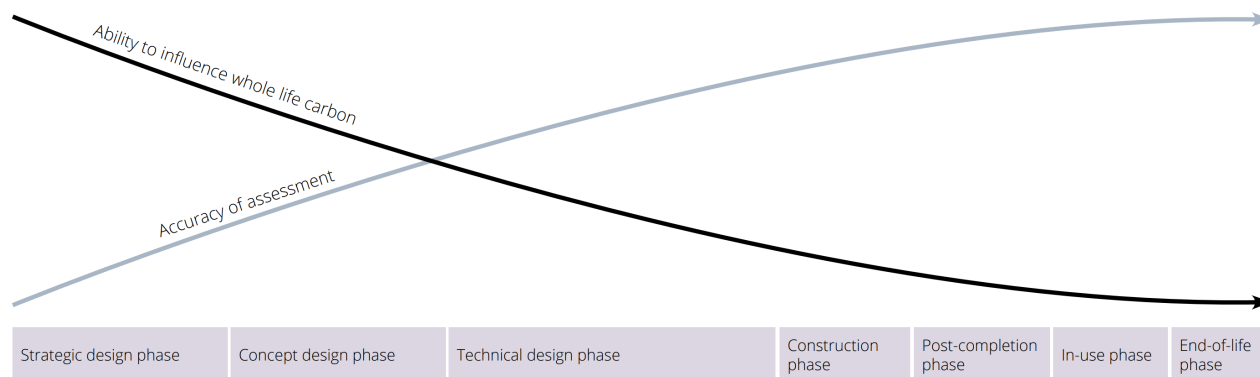
STANDARD: WHOLE LIFE CARBON ASSESSMENT (WLCA) FOR THE BUILT ENVIRONMENT

RICS published a second edition of the standard for Whole life carbon assessment (WLCA) for the built environment in 2024. The standard sets out good practice for undertaking and reporting a WLCA for different types of built environment projects, in alignment with the Greenhouse Gas Protocol.

The standard includes guidance for measuring both building elements and elements for infrastructure assets and civil engineering works.

The second edition includes more detailed guidance on what data should be recorded at each stage, and how to use contingencies and allowances to enable calculations at an early stage on projects where information is likely to be of lower quality.

The standard does not set out a specific approach to reducing whole life carbon (or, specifically, embodied carbon), but, like PAS 2080, emphasises that the greatest opportunity to influence whole life carbon is at the earliest stages of a project.



Document cover, and As the project progresses, the ability to influence whole life carbon decreases but the accuracy of assessment increases, from the RICS Whole life carbon assessment for the built environment standard, second edition.



THE INDUSTRY'S RESPONSE

KEY STANDARDS AND GUIDANCE

PROPOSED REGULATION: PART Z OF THE BUILDING REGS

Proposed Document Z is an industry-proposed amendment to the building regulations, which would legislate mandatory reporting of carbon emissions in the built environment and move towards limiting the embodied carbon emissions on projects.

Part Z has the support of much of the industry, and is aligned with the RICS guidance for assessing whole life carbon in the built environment and similar guidance from RIBA, LETI, IStructE, UKGBC and CIBSE.

GUIDANCE: UKGBC EMBODIED CARBON: DEVELOPING A CLIENT BRIEF

The UKGBC published a guide in 2017 for clients in the built environment to developing briefs for embodied carbon measurements on projects. Recognising the role of the client as “usually the instigator of a project’s sustainability agenda”, the guide gives practical advice to clients on what to ask for and how in a brief for an embodied carbon assessment, and provides an example.

STANDARD: UKGBC NET ZERO BUILDINGS STANDARD

The pilot version of the UK Net Zero Carbon Buildings Standard (NZCBS) was published by an industry-led consortium in September 2024.

It was published in response to the demand for a “clear and unified” definition for a net zero carbon asset in the UK and contains the requirements for different building types to be classified as ‘Net Zero’. The aim is for the standard to be fully compatible with PAS 2080.

The standard does not currently cover infrastructure projects and only requires the measurement of works within the building curtailment. For example, the standard requires the measurement of operational water usage but not the construction of connections to the water grid.

GUIDANCE: RIBA SUSTAINABLE OUTCOMES GUIDE

RIBA’s guide, first published in 2019, defines eight measurable sustainable outcomes for projects. These correspond to the UN Sustainable Development Goals and are appropriate to projects of different scales.

These goals include Net Zero Embodied Carbon and Sustainable Water Cycle, and the guide sets out principles that apply to enabling infrastructures beyond the building envelope. These include providing rainwater recycling, utilising locally-sourced materials and designing for long life. This report aims to support this guide by explaining the early-stage decisions required to enable these principles to be followed throughout the design process.

THE INDUSTRY'S RESPONSE

KEY STANDARDS AND GUIDANCE

GUIDANCE: UKGBC NET ZERO WLC ROADMAP

The UK Green Buildings Council first published a Roadmap to Net Zero Whole Life Carbon for the UK Built Environment in 2021 and it continually reviews progress towards the pathway to Net Zero.

The Roadmap includes a section on infrastructure and highlights the potential for infrastructure to impact reductions in emissions in other ways: for example, by enabling modal shift to reduce transport emissions. The Roadmap recommends a mandate for PAS 2080 implementation across all infrastructure projects by 2025 and highlights the role of Local Authorities in influencing the infrastructure associated with large regeneration projects, introducing policies to support modal shift and ensuring WLC impacts of infrastructure are quantified at planning.

GUIDANCE: LETI CLIMATE EMERGENCY DESIGN GUIDE

In 2020, The London Energy Transformation Initiative published its Climate Emergency Design guide, providing guidance and benchmarks for building designers to reduce the whole life carbon of buildings through five key elements: operational energy, embodied carbon, future of heat, demand responses and data disclosure. The design guide focuses mainly on buildings.

STUDY: UKGBC BUILDING THE CASE FOR NET ZERO: A CASE STUDY FOR LOW CARBON RESIDENTIAL DEVELOPMENTS

In February 2022, the UKGBC's Advancing Net Zero programme published a case study for minimising the embodied carbon associated with a masterplan, using the 750-home Trumpington South development in Cambridgeshire as an example. The study found that a 20% embodied carbon reduction could be made by "simple switches" to the design of the masterplan, simultaneously achieving biodiversity and climate resilience benefits.



Building the Case for Net Zero:

A case study for low carbon residential developments

FEBRUARY 2022

THE INDUSTRY'S RESPONSE

KEY STANDARDS AND GUIDANCE: A MAP

	PROVIDES...				FOR...		OF...		AT A(N)...		
	CASE STUDY/ INFORMATION	GUIDANCE	A STANDARD	REGULATION	MEASURING EMBODIED CARBON	MINIMISING EMBODIED CARBON	BUILDINGS	INFRA- STRUCTURE	INDUSTRY SCALE	PROJECT SCALE	SUB- SYSTEM SCALE
PART Z											
PAS 2080											
ICE PAS 2080 GUIDANCE											
NET ZERO WLC ROADMAP											
UKGBC CASE STUDY											
RIBA SUSTAINABLE OUTCOMES GUIDE											
RICS WLCA STANDARD											
THIS DOCUMENT											

THE AIM OF THIS REPORT

THE NEED FOR SUBSYSTEM GUIDANCE

The existing literature and information provides useful insights into high-level principles for decarbonisation of infrastructure and examples of how those could, and have been, applied at a project scale.

However, often these principles are not adopted consistently in practice or, when they are, the approach might be lacking the systems-thinking and deep collaboration necessary to optimise outcomes within and beyond the site's boundary.

Decisions made at the early strategic definition, brief and concept design stages often 'lock in' carbon, limiting opportunities for best practice in later stages. For example, a designer knows that low-carbon best practice is to switch from standard below-ground stormwater storage to Sustainable Drainage Systems (SuDS), but space has not been allocated on the site. A contractor knows that excess plant usage results in emissions, but utilities excavations have not been coordinated, and so multiple trenches need to be dug.

There are multiple factors driving the current lack of adoption of carbon management and low-carbon design approaches, including a lack of

incentive to do so and a lack of opportunities set out in contracts, as well as systemic barriers.

One significant barrier is the potential lack of key capabilities for those who may already have the opportunity and incentive to minimise carbon on masterplanning projects.

This report, co-funded by the Useful Simple Trust and the Institution of Civil Engineers, seeks to develop three **capabilities**:

- A better appreciation of **how much embodied carbon potentially sits in enabling infrastructures**, and where the likely hotspots (and therefore areas to focus on for decarbonisation) might be
- An understanding of **impactful approaches and decisions to avoiding 'locking in' carbon** at an early stage, and the potential co-benefits of those approaches to project cost, biodiversity and social value
- A **simple source of reference of upfront carbon factors** for key infrastructure specifications and components, to allow for quick, high-level estimates of the carbon impacts of early design decisions

MINIMISING THE EMBODIED CARBON IN THE ENABLING INFRASTRUCTURE ON MASTERPLANS

Capabilities

Knowing how much carbon sits in enabling infrastructures and where the **hotspots** are

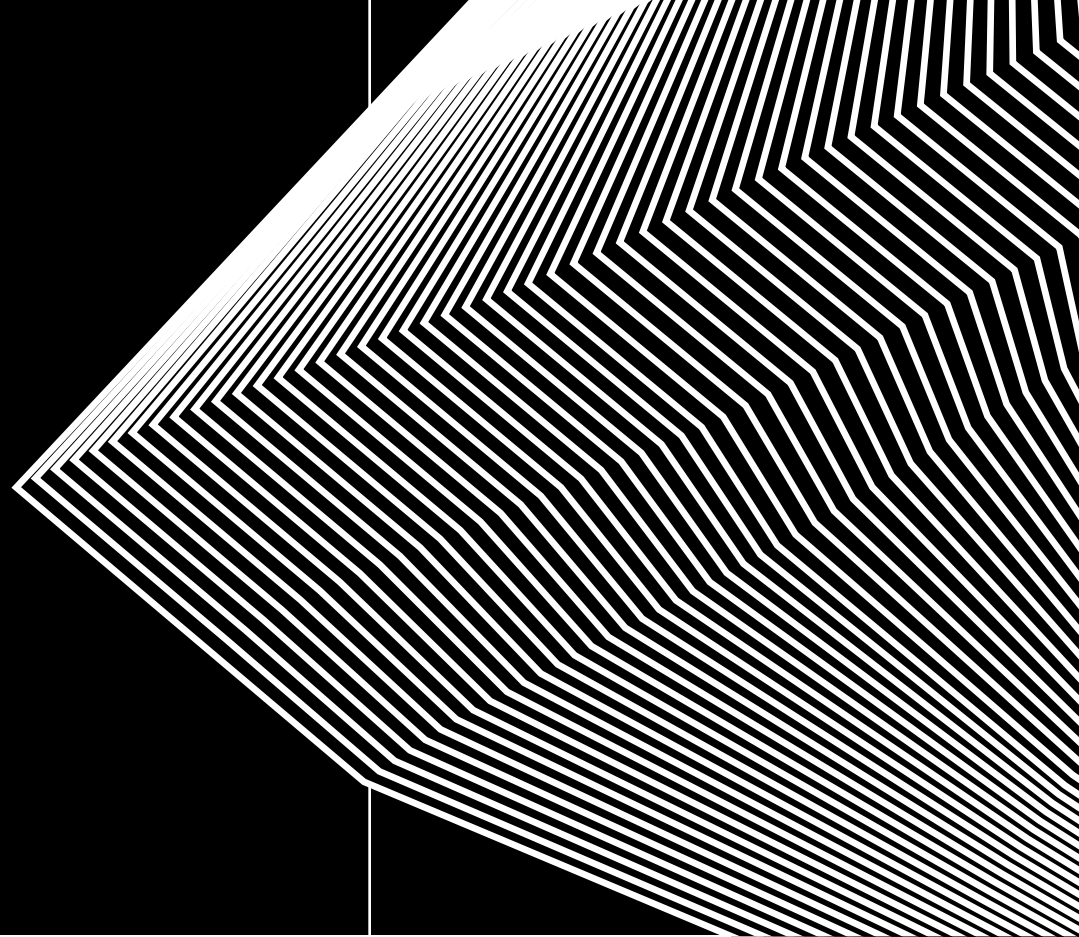
Having simple and easily applicable **ways of calculating** the embodied carbon in enabling infrastructures

Knowing **how to avoid making decisions that 'lock in' carbon** at an early stage in the design process

Opportunities

Motivation

03



CASE
STUDIES

CASE STUDIES

CARBON ASSESSMENT: APPROACH OVERVIEW

The purpose of the case studies is to help us highlight the strategic decisions and early-stage design principles that have the greatest impact on creating low-carbon masterplans.

The upfront carbon impact of enabling infrastructure for a small number of case studies has been assessed with the intention of exploring:

- the relative carbon impact of the different subsystems, i.e. the 'carbon hotspots' and how this might vary between masterplans
- the relationship between existing context and other site-specific characteristics to infrastructure carbon impact.

Simply put, the case studies help us validate the focus areas for infrastructure carbon reduction in early-stage design.

Whilst these focus areas are probably already known amongst the value chain, putting the numbers behind what we know intensifies the message.

Insights from the case studies thus feed into and support the **BEST PRACTICE GUIDANCE** provided in Section 3.

Supplementary to the discussion on carbon hotspots and focus areas for decarbonisation, and in consideration of the potential challenges of carbon assessments, a simple calculation toolkit is provided as an Appendix, to help with high-level upfront carbon estimates at early design stages.

CASE STUDIES

CARBON ASSESSMENT: APPROACH OVERVIEW

CASE STUDY SELECTION

Three new developments have been selected as case studies, spanning actual projects in different geographic locations, contexts and typologies, in an effort to cover some of the diversity of projects found in the UK.

Only one of the three case studies has entered the first phase of construction (CS3), whilst the other two are still in design development (post-planning).

All three case studies are considered ambitious, sustainability-driven masterplans, having achieved optimum outcomes in terms of infrastructure design for one or more subsystems within each site's specific opportunities and constraints.

For the purpose of exploring similarities and differences when it comes to carbon hotspots, the 'performance' (infrastructure carbon impact) of the three projects is discussed in parallel in the pages that follow. However, the intention is not to compare the performance of the three case studies; given their distinct

context and characteristics, such a comparison would be misleading and unfair.

The intention is, rather, to shed light on which infrastructure subsystems can be expected to contribute the largest carbon impact across different contexts and typologies.

Design data have kindly been made available for this research project from collaborators (developers and designers). The case studies have been anonymised in this study to avoid being misread as promotional of individual construction partners.

CASE STUDY 1 (CS1)

A high-density, medium-scale new neighbourhood in a large city, developed on brownfield land. Residential GIA: 98%



SITE AREA:

~ 20 ha

DENSITY:

173 dwellings/ha

2.8 m².GIA/m².site area

CASE STUDY 2 (CS2)

A medium-density, small-scale new neighbourhood in an existing town developed on brownfield land. Residential GIA: 86%



SITE AREA:

~10 ha

DENSITY:

87 dwellings/ha

1.2 m².GIA/m².site area

CASE STUDY 3 (CS3)

A low-density, large-scale strategic urban extension of an existing town, developed on agricultural land. Residential GIA: 99%



SITE AREA:

~150 ha developed

DENSITY:

17 dwellings/ha

0.16 m².GIA/m².site area

CASE STUDIES

CARBON ASSESSMENT: APPROACH OVERVIEW

SCOPE OF THE CARBON ASSESSMENT

The assessments were undertaken based on information available at **RIBA Stage 2 (Concept Design)** and Outline Planning Application Stage, and covered the following elements:

- strategic earthworks
- streets and active travel (vehicle roads, travel pavements, car-parking, pavements)
- surface water drainage (underground pipework, manholes and underground attenuation storage)
- utilities: wastewater (foul) drainage network (pipes and manholes), HV/LV power and telecomms networks (cables and ducts), water supply (pipes and manholes), and gas supply (pipes).

The assessment was limited by the design information available and, therefore, only the primary networks of these packages were captured (i.e. excluding on-plot infrastructure). The estimated carbon impacts encompass the upfront carbon impact alone (i.e. up to construction completion). The duration of construction (i.e. the delivery programme and potential savings from decarbonisation of materials) has not been accounted for.

DISCUSSION ON SCOPE: FOCUSING ON UPFRONT CARBON IMPACTS

- Upfront carbon impacts comprise the majority of embodied carbon emissions in the built environment, with the share of upfront carbon typically being close to, or in excess of, 50% of life cycle embodied carbon impacts in buildings. For infrastructure elements, which are designed for durability and have much longer service lives than building elements, thus requiring little to no replacement over the in-use stage, this share is expected to be much higher.
- Upfront carbon emissions, as opposed to in-use and end-of-life emissions, will occur in the near term and over a small number of years, and we can more accurately estimate their scale in absolute terms. Most importantly, we have confidence that the decisions we take today will have an impact on upfront carbon that we can measure.
- Delivering carbon savings in upfront carbon through the 'avoid' principle delivers savings over the in-use and end-of-life stages.

This is expected to be the case in most other instances as well: i.e. when upfront carbon is reduced through the 'switch' and 'improve' principles, carbon savings are typically also being delivered over the life cycle of the asset/project, although not always.

- Whilst a whole life carbon perspective is important to drive decisions and avoid unintended consequences, the industry is currently lacking widely available in-use data on maintenance, replacement and operational energy requirements of masterplan infrastructure assets.

For all the above, focusing on upfront carbon at the earliest design stages is considered a reasonable approach for infrastructure, especially when design data and time might be limited. Any risks of negating the upfront carbon savings during the in-use stage should/can still be a consideration, to be identified based on designers' experience.

CASE STUDIES

CARBON ASSESSMENT: APPROACH OVERVIEW

NAVIGATING THE CASE STUDIES' MATERIAL

- **Overview of carbon assessment results:** the first pages of the section present the overview of the carbon assessment results for the three case studies
- **Case studies insights:** the next few pages explore the key insights distilled from the three carbon assessments, arranged by theme. A discussion section and recommendations on further research follows after the insights pages.
- **Carbon assessment detailed results:** the insights pages are followed by a detailed presentation of the carbon assessment results for each of the three case studies. The results are arranged over three pages and include an introductory page, a second page that summarises the carbon impact across the infrastructure subsystems, and a third page that presents the elemental and material carbon hotspots for the project.
- **Calculation toolkit:** the Appendix comprises a carbon factors toolkit, providing upfront carbon impact factors (A1–A5*) of basic

infrastructure specifications, elements and materials. The toolkit can be referenced to estimate the upfront carbon impacts and savings associated with early-stage design optioneering, supporting decision-making when more comprehensive assessments and carbon tools are not an option.

CASE STUDIES

CARBON ASSESSMENT - RESULTS OVERVIEW

KEY INSIGHTS

DISCUSSION

FURTHER RESEARCH

CARBON ASSESSMENT - DETAILED RESULTS



CASE STUDY 1



CASE STUDY 2



CASE STUDY 3

APPENDIX

CALCULATION TOOLKIT

The insights sections comprise four elements:

- **Introductory statement** aiming to sketch out how a sustainable, low-carbon masterplan can be defined, in relation to enabling infrastructure.
- **Commentary on upfront carbon impacts**, based on the results of the assessment of the three case studies.
- **A systems perspective on carbon impacts**, discussing some of the interconnections of infrastructure subsystems within the site boundary and beyond. This section is inspired by the 'systems thinking' concept advocated within PAS 2080 as the 'missing link to meaningful decarbonisation'.
- **Beyond carbon:** a final section discussing some of the co-benefits and consequences of the proposed approaches for people, nature, resources and climate resilience.

*Includes A1–A3, A4 and A5.3, excludes A5.2 construction stage emissions.

CASE STUDIES

CARBON ASSESSMENT: RESULTS OVERVIEW

This page provides an overview of the infrastructure upfront carbon impacts for the three case study masterplans assessed.

In both intensity ($\text{kgCO}_2\text{e}/\text{m}^2\text{.GIA}$) and absolute terms (tCO_2e), the highest upfront carbon impact is found for Case Study 3 (Figure 1), which is both the largest masterplan (~280 ha) and the one with the lower density (~9 dwellings/ha). Looking at the contribution of the various infrastructure subsystems (Figure 2), it can be seen that the greatest difference between CS3 and the other two sites' performance is found for earthworks. Site-specific constraints that will be discussed in the insights pages lie behind this difference in scale of impact.

The higher impact of CS3 across all other subsystems (Figure 2) is explained by the large expanse of the site, coupled with low density: infrastructure networks need to span larger distances, whilst serving a smaller number of dwellings.

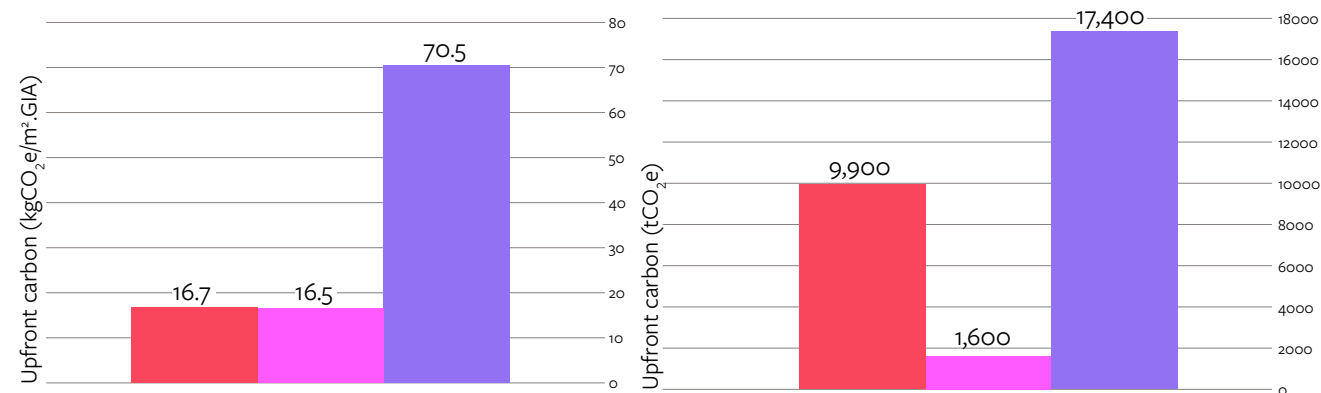
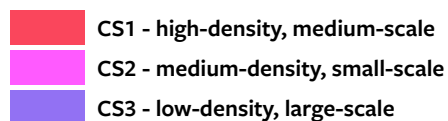


Figure 1. Total upfront carbon impact in absolute terms (left, tCO_2e) and intensity terms (right, $\text{kgCO}_2\text{e}/\text{m}^2\text{.GIA}$) of the three case study masterplans.

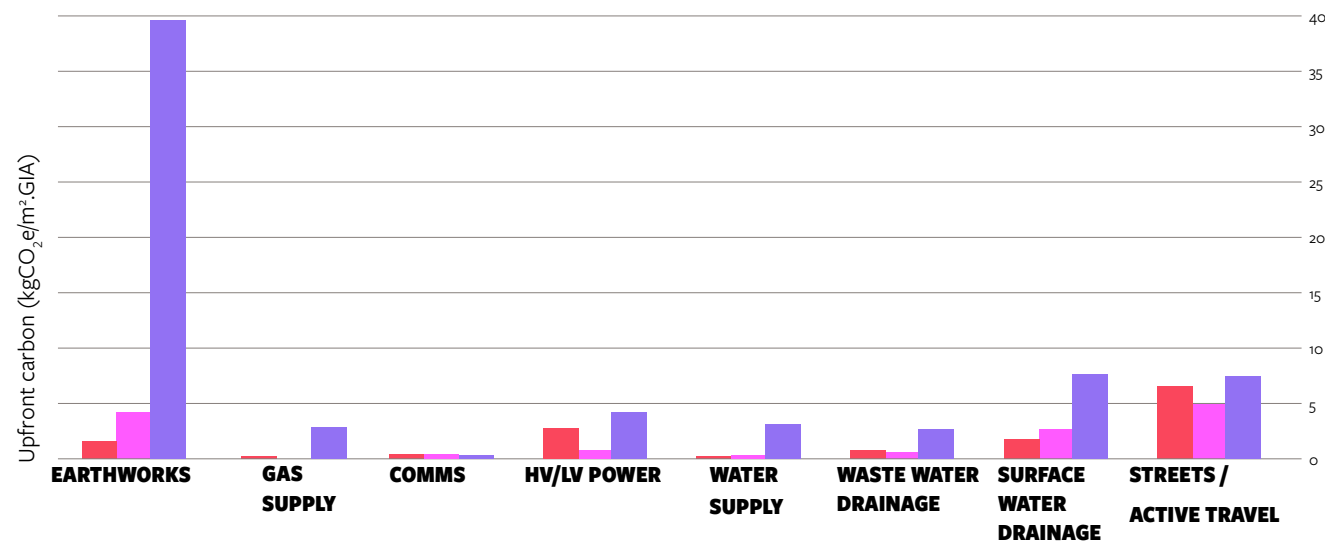


Figure 2. Upfront carbon impacts of infrastructure subsystems for all three case study masterplans, showing vehicle infrastructure (the vast majority of 'streets/active travel') as the major hotspot.

CASE STUDIES

CARBON ASSESSMENT: RESULTS OVERVIEW

While very different in site size and development density, CS1 and CS2 demonstrate similar carbon intensity for the subsystems assessed (16.7 kgCO₂e/m².GIA for CS1 and 16.5 kgCO₂e/m².GIA for CS2). This is partly to do with the assessment for CS1 assuming a highly ambitious earthworks strategy, as proposed at Stage 2 Design.

The contribution of the different infrastructure subsystems to total upfront impact can be seen in Figure 3, expressed as a percentage of total upfront emissions for the three sites. Whilst percentage figures vary greatly between sites owing to determinant site-specific factors discussed in the following sections, some observations can be drawn regarding orders of magnitude and ranking of carbon hotspots.

The insights that can be drawn from the three assessments are outlined in the pages that follow.

The detailed carbon assessment results per site are presented at the end of the section, along with further commentary.

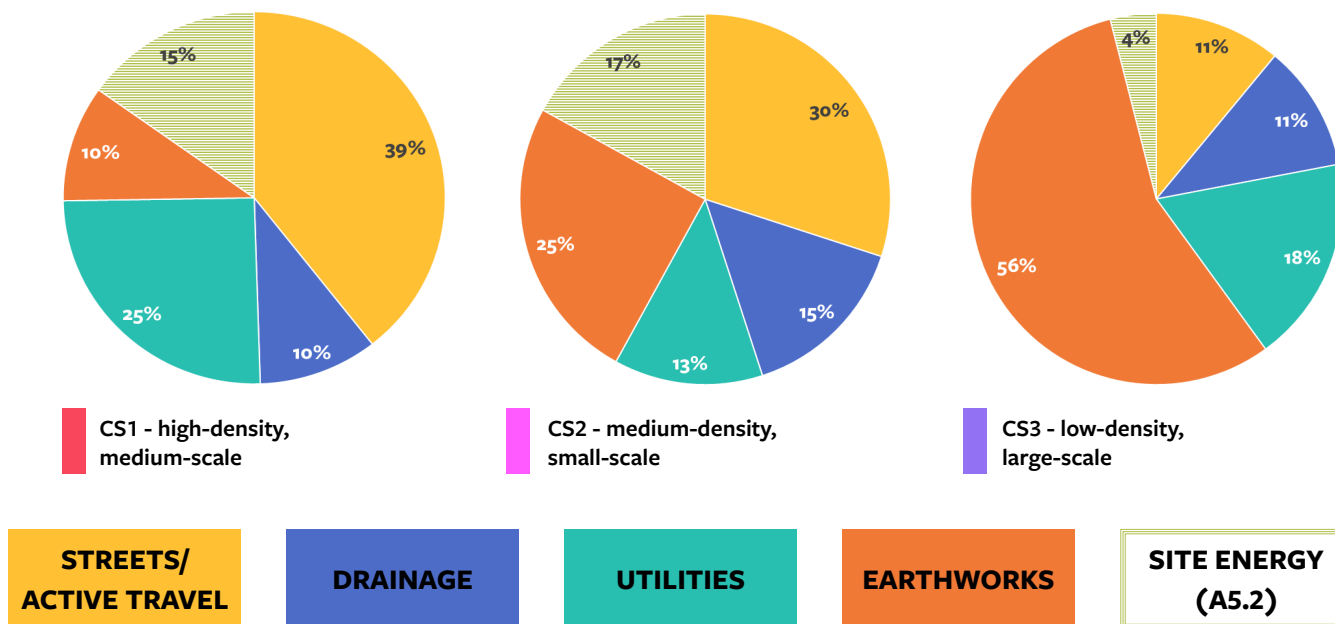


Figure 3. Contribution to total upfront carbon impacts of the different infrastructure subsystems assessed for the three case studies.

CASE STUDIES

INSIGHT #1 - INFRASTRUCTURE FOR VEHICLES

A sustainable, low carbon masterplan is one that **puts people first and minimises the need for car travel** by:

- being well connected to sustainable transport nodes and networks
- being mixed-use and offering access to amenities and facilities within walking distance
- integrating high-quality walking and cycling routes, connecting to or enhancing existing networks off site
- not defining land allocation and plot layout by car usage.

Infrastructure for streets/active travel is a major upfront carbon hotspot across all three sites assessed: in both CS1 and CS2 it is the largest source of emissions out of the subsystems assessed, contributing between **30%–39% of total upfront carbon emissions**; in CS3, this subsystem ranks third in order of magnitude.

The vast majority of this impact is attributed to infrastructure for vehicles: streets and car parking contribute 85%–98% of this impact, with footways/cycleways contributing the remaining.

The three sites have similar impacts in terms of intensity for this subsystem, ranging between 4.9 for CS2 and 7.4 for CS3 (Figure 4).

However, the impacts in CS1 and CS3 are expected to be much higher than those reported here, as the boundary of the assessment does not include mobility hubs in CS1 or on-plot private car parking in CS3.

Vehicle infrastructure can be expected to have a high-carbon impact for masterplans which have poor connections to public transport, rail and amenities, and which do not accommodate mixed uses, thus leading to high reliance on private car ownership for most travel.

High parking ratios in this case become the primary driver of spatial plans, with valuable land taken up for vehicular roads, on-street and off-street car parking*, and/or mobility hubs*.

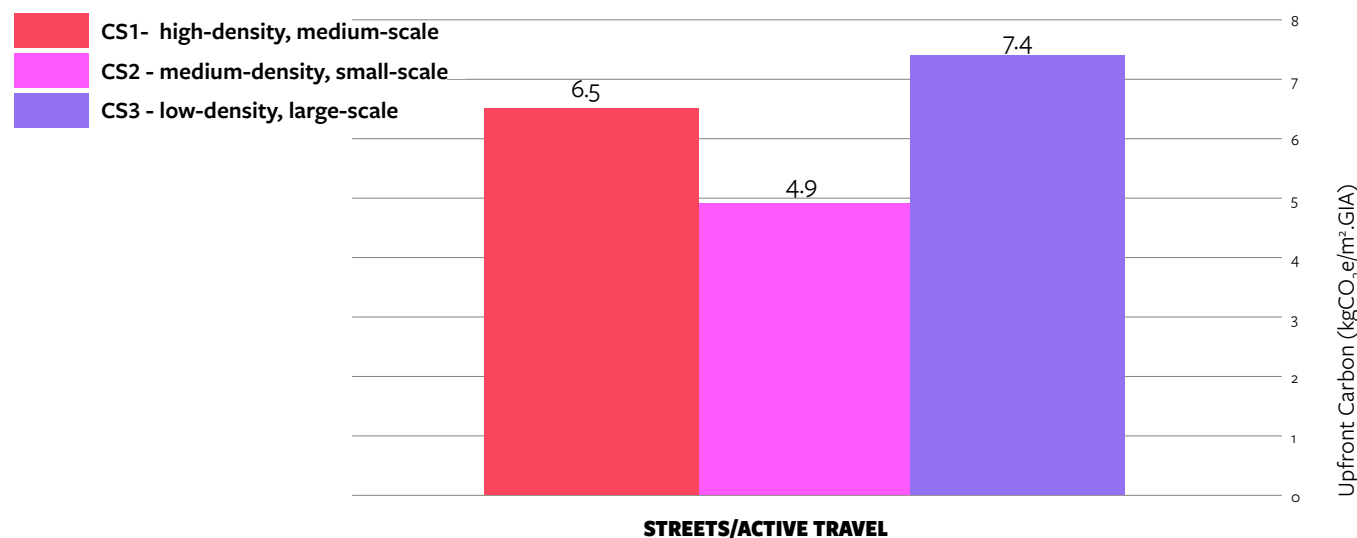


Figure 4. Upfront carbon impact of streets/active travel infrastructure for the three case studies: vast majority of impact from vehicle infrastructure (streets and car parking).

CASE STUDIES

INSIGHT #1 - INFRASTRUCTURE FOR VEHICLES

A SYSTEMS PERSPECTIVE ON CARBON IMPACTS

As shown in Figure 5, the upfront carbon for vehicle infrastructure (roads, etc.) is very small in comparison with the total emissions from car travel during the lifespan of a development. Reducing reliance on private cars is likely to have a greater impact on the life cycle emissions of a development than solely minimising the upfront carbon of the road infrastructure.

Site users' car travel emissions (life cycle module B8, i.e. the carbon emissions from the use of cars for daily activities) can be substantial, even in the case of sites that are well connected and designed to be '5-min' neighbourhoods (Figure 5).

The overall carbon impacts of vehicle infrastructure are therefore strongly determined by the quality of a masterplan's connections to public transport networks and local amenities, and on-site provision of amenities and services, accessible via walking, cycling or public transport routes.

Without these high-quality connections or local services, people will rely on car travel for most trips, justifying high rates of private car ownership and high demand for carbon-intensive parking infrastructure (on-street and off-street car parking* and mobility hubs*).

However, it needs to be acknowledged that this is often much more challenging in rural or suburban locations where regional/local sustainable transport networks are not in place, and it is out of the developer's remit to implement them.

What becomes more important, then, is for developers to make best use of the possibilities offered by the existing site conditions, and for strategic planning of sustainable transport networks to be co-developed with new development planning at regional/local level. This helps to ensure strategic infrastructure is in place to create sustainable outcomes in areas where new development will be mostly concentrated.

SITE 1: COMMERCIAL DEVELOPMENT AND LOGISTICS

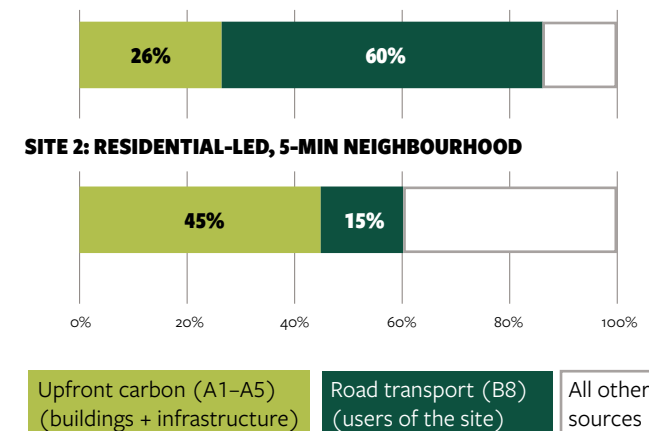


Figure 5. Share of road transport emissions (%) against upfront carbon and the remaining whole life carbon emissions of two masterplans. Data shared from the EIA WLCA of two of Expedition's projects. Even in residential-led sites where car travel is minimised (Site 2), road transport emissions over a 60-year lifespan can comprise 15% of the whole life emissions of the development. The impact of road transport in commercial sites that accommodate logistics is much more substantial (60% of whole life emissions, Site 1).

*Impacts from these elements have been scoped out of the carbon assessment of the case studies due to design data not being readily available. Where possible, these elements should be included in the assessment boundary for completeness. It is noted that car parking provided in basements or multi-storey car parks/mobility hubs are much more carbon intensive - closer to that of buildings - than surface infrastructure.

CASE STUDIES

INSIGHT #1 - INFRASTRUCTURE FOR VEHICLES

BEYOND CARBON

In masterplans where reliance on car travel is high, parking ratios become the primary driver of spatial plans, often driven by local planning policies and/or perceptions of what the local market values. It is important to understand and challenge these 'defaults', as future trends of car use and ownership amongst different demographics are important factors that need to be considered when making the case for a pedestrian-first approach.

While electrification of cars has the potential to reduce carbon emissions, even electric private cars contribute to congestion, particulate air pollution and road safety issues. Provision for electric vehicle infrastructure for car travel only makes sense from a climate mitigation perspective as long as the need for car travel has already been minimised.

SECTION 4 provides best practice guidance for designing streets/travel infrastructure to minimise both operational carbon (by driving modal shift) and embodied carbon.

CASE STUDIES

INSIGHT #2 - EARTHWORKS

A sustainable, low-carbon masterplan is one that **responds to and works with the existing site conditions**, including where:

- the layout aligns with the existing landform to minimise earthworks (cut and fill)
- a cut and fill balance is achieved on site (with no imports or exports of soil)
- the topography guides the integration of nature-based solutions for flood resilience
- the existing topsoil and soft landscape is valued and retained as a resource for biodiversity, food and carbon storage.

Earthworks can be another major source of upfront carbon emissions (from construction plant fuel), in some cases the largest one, outweighing the impacts of all other 'built' infrastructure elements. This is the case for CS3, where earthworks contribute 56% of infrastructure upfront emissions.

This outcome is determined by flood risk management as the CS3 masterplan is bordered by two rivers, with a significant part of the

developable area within Flood Zone 3. The earthworks are needed to raise the residential parts of the development out of the flood plain, and to construct a strategic link road along the southern boundary which is around 2m higher than the existing ground level and acts as a flood defence. The remaining, non-developed area retains its function as a natural flood plain, with increased storage capacity.

This highlights the heavy carbon cost of building on a floodplain and the need to strategically select development sites, avoiding critical

constraints such as floodplains that require carbon-intensive mitigations.

In CS2, earthworks contribute ~25% and in CS1 ~10% of infrastructure upfront emissions. For CS1, this assumes an optimised, **ambitious strategy that reduces emissions of earthworks by 87%** compared with an original non-optimised proposal.

Without this optimisation, the infrastructure upfront emissions of the project (subsystems assessed here) would almost double (1.7x) in scale (Figure 6).

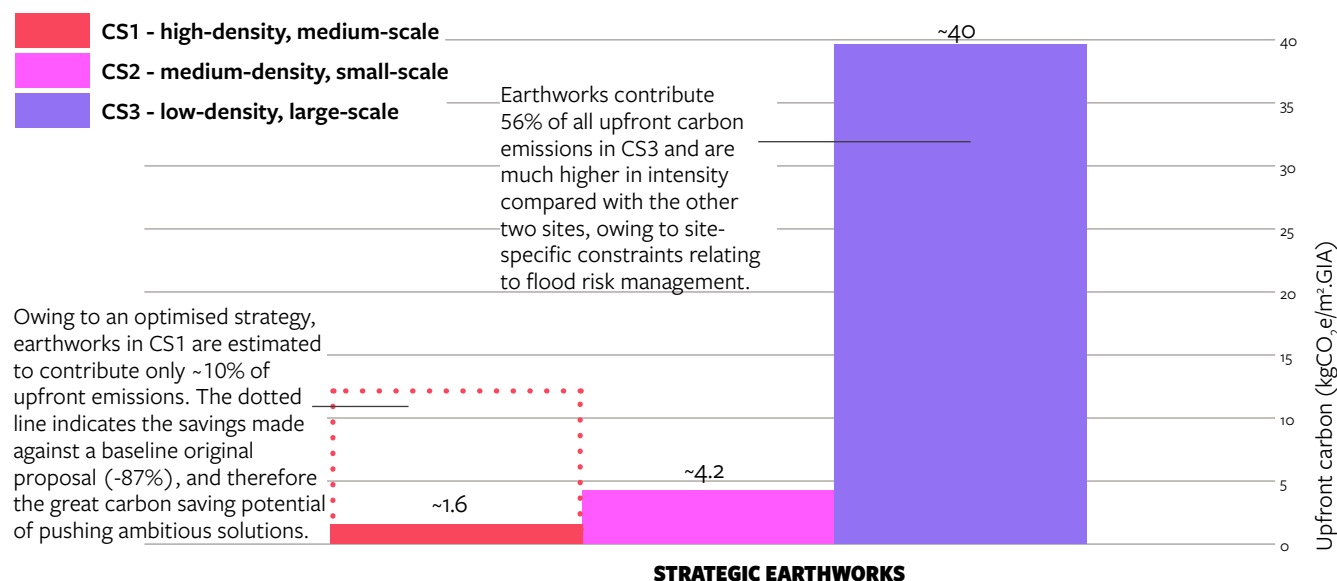


Figure 6. Upfront carbon impacts of earthworks for the three case studies.

CASE STUDIES

INSIGHT #2 - EARTHWORKS

A SYSTEMS PERSPECTIVE ON CARBON IMPACTS

Earthworks are inextricably linked to other key infrastructure: soil is cut and moved to make space for and support the construction of buildings, landscape, roads, utilities and drainage.

Mimimising the interventions by working with existing topography and ecology should be at the forefront of design thinking, and this presents an opportunity to take advantage of existing site character.

The site topography determines where and how water will naturally flow, particularly with regards to drainage. Developing the drainage network in line with the existing landform leads to low-carbon drainage infrastructure and better enables the integration of nature-based solutions.

Whilst the design focus is often on strategic earthworks assessment, the following impacts are often overlooked and are not insignificant:

- deep excavations for foundations and basements of buildings
- trench excavations for road pavements and utilities
- excavations for underground gravity-fed drainage pipes

- soft landscaping works and acoustic barriers (if made of soil);
- (most importantly) the release of carbon and other greenhouse gases stored in the soil when that is disturbed.

BEYOND CARBON

Earthworks can make a significant construction cost, and an optimised strategy can therefore deliver substantial capital project cost savings.

Existing topsoil can be suitable for growing food and trees, and supporting the newly-established landscape.

A culture of valuing the soil and the existing soft landscape that starts from the drawing table comes with significant long-term benefits for nature, climate resilience and the community.

SECTION 4 provides best practice guidance for minimising the carbon associated with earthworks. The need to align layouts with the natural landform of the site is highlighted throughout the subsystem guidance.

CARBON INTENSITY OF EARTHWORKS

There is little to no data on measured emissions from earthworks. In the absence of data, the carbon impact of earthworks was estimated based on CESSM4 figures. Carbon emissions result from burning diesel for construction/excavation plant.

- **General excavation (cut):**
1.2 kgCO₂e/m³.soil [CESSM E3.2.1.01]
- **Soil movement on site:**
1.3 kgCO₂e/m³.soil [CESSM E5.4.2.05]
- **Reuse on site (fill on site):**
1.1 kgCO₂e/m³.soil [CESSM E6.1.1.01]

- **For exports/imports of soil** the carbon impact is estimated based on distance and soil density and is much higher: e.g. for a 20km-export journey of soil with a density of 1,600 kg/m³, the export emissions are ~4.2kgCO₂e/m³ accounting for both the outward and return journey. For a 50km-journey, the impact is 10.4kgCO₂e/m³. This indicates that after minimising cut and fill, it is crucial to both retain soil on site and minimise soil imports.

This may vary significantly, depending on vehicle type, vehicle movement efficiency, etc.

CASE STUDIES

INSIGHT #3 - SURFACE WATER DRAINAGE

A sustainable, low-carbon masterplan is one where **water resources are managed in an integrated way, giving priority to nature-based solutions**, including where:

- flood resilience is achieved primarily with nature-based solutions
- underground attenuation storage is minimised
- the underground drainage pipe network is optimised (for length and diameter of pipes) and laid at shallow depths
- rainfall, mains water and greywater are valued as resources and managed in an integrated way.

The surface water drainage infrastructure can be another significant carbon hotspot in masterplans and one that can vary greatly between projects, dictated by site-specific flood risks and available space for low-carbon, nature-based SuDS.

The higher the demand for 'grey infrastructure' underground networks (comprising pipework and fill materials of trenches), attenuation storage and flood defence structures (typically made of concrete), the higher the carbon impacts.

Across all three case study masterplans, the underground pipe network and underground storage have been reduced to a feasible level, with nature-based SuDS (e.g. large-scale open-water ponds in CS3) integrated in the landscape.

The contribution of surface water drainage to the total infrastructure carbon impact is similar

across all projects, ranging between ~10% (for CS1 and CS3) and 15% (for CS2).

In intensity terms, CS3 exhibits the largest impact (Figure 7), owing to the scale of the site (~280ha) and the resulting much greater expanse of the drainage network.

For CS1, design data were available for both a baseline original proposal and the optimised Stage 2 design. Through optimisation, the underground attenuation volume was reduced by 93%, resulting in a saving of 30% in upfront carbon emissions for this subsystem (Figure 7).

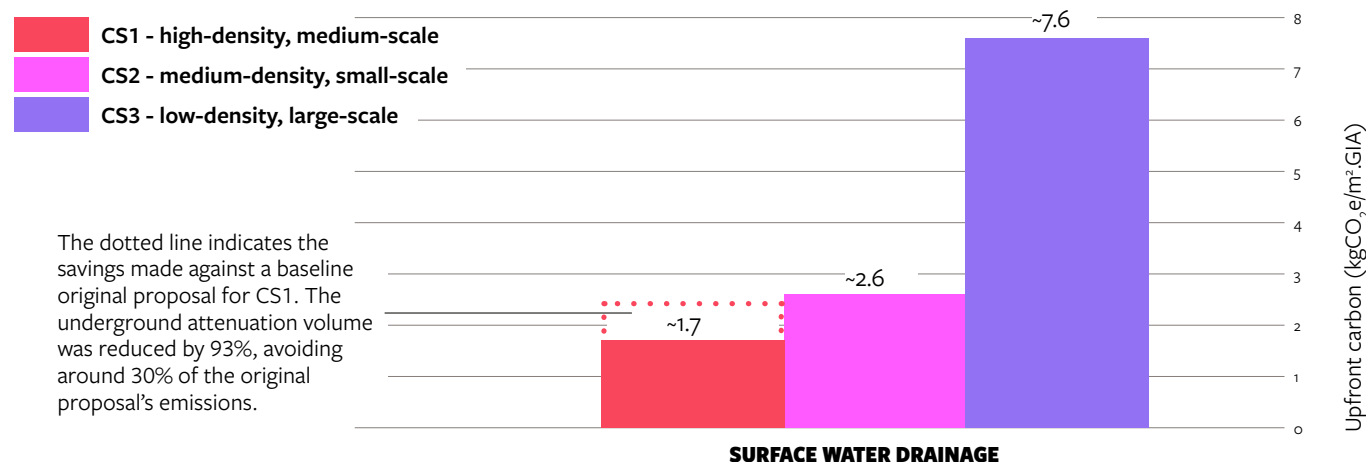


Figure 7. Upfront carbon impacts of surface water drainage across the three sites.

CASE STUDIES

INSIGHT #3 - SURFACE WATER DRAINAGE

A SYSTEMS PERSPECTIVE ON CARBON IMPACTS

An effective flood resilience strategy is the precondition for the function of all other infrastructure services within a site (energy, transport, comms, ecosystems). Its failure has repercussions and incurs 'cost' in materials and carbon emissions* across all other networks both within and well beyond the site, as water knows no red line boundary. This is not so much the case for other infrastructure assets in a masterplan, where impacts of malfunction or failure are typically localised.

Achieving flood resilience within a site through primarily nature-based solutions thus ensures carbon savings, both in the short term (upfront carbon for drainage infrastructure) and longer term across all other infrastructure networks, within and beyond the red line boundary.

Taking into account its significance, working on a nature-based drainage strategy, and following the existing landform and water flow lines, needs to be one of the starting points of masterplan design. A strategy should be co-developed alongside with, if not preceding, spatial layout.

This approach would mark a paradigm shift away from current practice, where drainage often comes as an afterthought to spatial layout and urban design.

BEYOND CARBON

The integration of nature-based solutions for surface water drainage holds **immense potential for delivering co-benefits for nature and people alike, both within and beyond a site's boundary**. Together with the soft landscape of which they are part, they underpin long-term climate and community resilience. These co-benefits are well understood and typically pursued in sustainability-driven masterplans.

Not as yet explored or realised in practice, is the necessary shift towards an integrated management of water resources: a **'water cycle', 'water-sensitive' strategy for sites**, where water (potable, non-potable and rain-/stormwater) is retained, treated (through natural, low-tech means) and reused to alleviate demand for fresh water supply. Fresh water is a resource that will become ever more scarce as the climate crisis intensifies, making integrated water management a fundamental component of climate resilience.

SECTION 4 provides best practice guidance for minimising the carbon associated with drainage and earthworks.

A METRIC FOR UTILISING NATURE-BASED SOLUTIONS FOR FLOOD RESILIENCE

Taken from TfL's metric-driven Sustainable Development Framework (SDF), Climate Resilience metric CR5 can be adopted to compare how well different sites manage rainfall at source.

CR5 Metric: percentage of rainwater discharged via stages 1–3 of the London Plan Hierarchy

Stages 1–3 comprise:

- Stage 1: rainwater use as a resource
- Stage 2: rainwater infiltration to ground at, or close to, source
- Stage 3: rainwater attenuation in green infrastructure features for gradual release.

CASE STUDIES

DISCUSSION - ON DENSITY

In the context of the climate emergency and the drastically increasing urban population globally, the question of optimal density of development becomes key for sustainable urbanism.

While a level of densification can be expected to deliver material efficiencies and carbon savings for infrastructure in masterplans and for the wider urban infrastructure networks*, too much density can come at the detriment to liveability, climate resilience, health and wellbeing.

Furthermore, the potential for densification is essentially location-dependent, responding to an existing built environment, historic and cultural context, and the current and future needs of the community.

A sustainable, low-carbon masterplan is therefore one that balances development density with quality placemaking and best practice urban design strategies, ensuring the density reflects the existing context, and supports rather than hinders positive environmental and social outcomes.

*This is because infrastructure networks need to 'cover' larger areas. In order to build and operate such infrastructure networks, more land, materials and energy are required, to enable them to deliver their service to a site's or city's population (if this population is more scattered).

**Urban LCA studies and material flow analyses demonstrate the inherent correlation between infrastructure stock and urban density, with more dispersed settings having a higher share of impacts. The research paper 'Embodied climate impacts in urban development: a neighbourhood case study' cross-references some of these studies.

It falls outside of our scope to explore the relationship between density, carbon impacts and broader environmental and social outcomes in new development, but the question of optimal density for the various typologies of development in the UK context lends itself to future/further research**.

In this brief section, we aim to open the discussion about density and the need to consider carbon 'expenditure' for infrastructure in both absolute and intensity terms (e.g. $\text{kgCO}_2\text{e}/\text{population}$ or $\text{kgCO}_2\text{e}/\text{dwelling}$) when making strategic development decisions and aiming to manage the remaining carbon budget of the built environment responsibly.

ON A CARBON EXPENDITURE METRIC

The density of a development can be measured in different ways:

- In more 'traditional', residential-led developments where non-residential uses form a very small part of the development, **dwelling/hectare** lends itself as a metric of density.
- In mixed-use masterplans where a significant element of non-residential floorspace is being delivered together with new homes, density can also be measured using the floor area ratio: **$\text{m}^2.\text{GIA}/\text{m}^2.\text{site area}$** .
- Perhaps the metric that best links us back to the purpose of development (delivering a service for people) is density expressed in **population/ha**.

The estimated **carbon expenditure per dwelling, per floor area or population in a masterplan ($\text{kgCO}_2\text{e}/\text{m}^2.\text{GIA}$, $\text{kgCO}_2\text{e}/\text{dwelling}$, $\text{kgCO}_2\text{e}/\text{population}$) thus becomes a valuable metric** for comparing sites, driving strategic site selection and design optimisation.

CASE STUDIES

DISCUSSION - ON DENSITY

Based on a limited dataset (comprising the three case studies assessed here and six more sites of low density similar to CS3), we note that lower-density developments (< 15–20 dwellings / ha) result in a higher infrastructure upfront carbon intensity per dwelling or per floor area ($\text{kgCO}_2\text{e/dwelling}$ or $\text{kgCO}_2\text{e/m}^2\text{.GIA}$) compared with higher densities (Figure 8).

The difference appears to drop off after densities of 20–25 dwellings/ha (Figure 5). However, the data set is too small for observations to be in any way conclusive. It also lacks a wide spectrum of densities and includes sites not representative of standard design practice.

A higher carbon intensity per dwelling may not necessarily reflect inefficiencies in infrastructure design but, rather, the limitations that come with the specific site and context (as is the case with CS3, Figure 8), as each site holds a unique potential to accommodate higher densities alongside sustainable outcomes. In other words, infrastructure carbon intensity is grounded on context and pre-existing conditions, reinforcing the significance of site selection and strategic development planning.

UPFRONT CARBON IMPACT OF ENABLING INFRASTRUCTURE ACROSS SITES OF DIFFERENT DENSITY

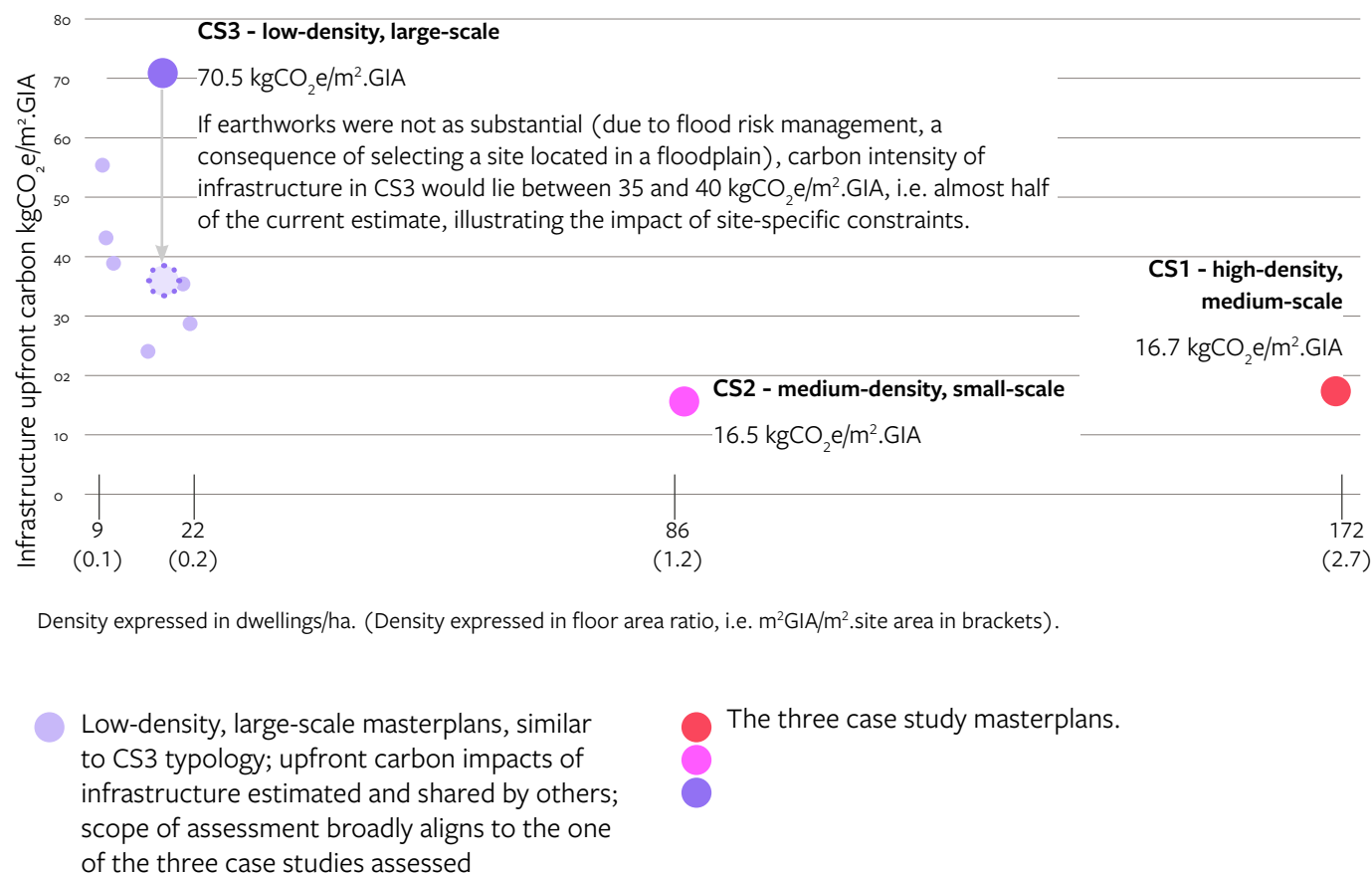


Figure 8. Upfront carbon impacts of infrastructure plotted against masterplan density (x-axis) for the three case studies and six more low-density masterplans (assessed by others and kindly shared with us).

CASE STUDIES

DISCUSSION - ON BUILDINGS VERSUS INFRASTRUCTURE IMPACTS

For the three case studies assessed, upfront carbon impacts of key enabling infrastructure subsystems was found to lie between 16.5 and 70.5 kgCO₂e/m².GIA. This is not considered to represent current standard practice, as all three masterplans integrate sustainable design principles and are considered sustainability-driven.

Furthermore, the assessments do not cover all enabling infrastructure* and the results, therefore, do not depict the full scale of infrastructure upfront carbon impacts. Assuming the impact of landscaping (soft and hard) was also to be added to those of enabling infrastructure, the carbon impact of all elements outside of the buildings in a masterplan would rise further.

As a point of reference, a previous study for one neighbourhood in Denmark identified 78% of total embodied carbon impacts to be attributed to buildings, with the remaining 22% to be attributed to all elements outside of buildings (12% of which were from car-parking facilities).

*Exclusions include on-plot infrastructure subsystems, power/energy generation plant, mechanical/electrical equipment, mobility hubs/multi-storey or underground car parking, and specialist structures such as retaining walls and bridges.

Whilst embodied carbon impacts of elements outside of buildings in a masterplan (enabling infrastructure, soft and hard landscaping) can be expected to be comparatively less than those of buildings, this does not imply they are insignificant or not worthy of the same attention.

In absolute terms, enabling infrastructure for masterplans forms a significant share of the construction industry's carbon budget. Furthermore, as stricter limits start to apply to the embodied carbon impacts of buildings, this share will be rising in the absence of

decarbonisation targets for infrastructure (Figure 9).

In the context of the climate and biodiversity crisis, the decarbonisation of infrastructure is as much a priority as the decarbonisation of buildings.

The rate of decarbonisation can also prove much quicker for infrastructure compared with buildings, as material and carbon savings (through the most effective 'avoid' decarbonisation principle) are simpler to achieve and go hand-in-hand with savings in both capital and operational expenditure.

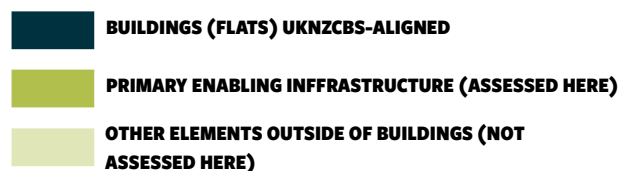
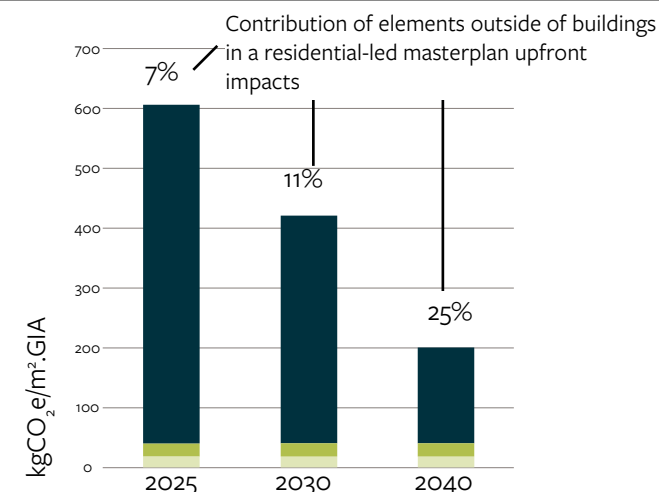


Figure 9. For illustrative purposes only: contribution of buildings versus elements outside of buildings in a residential-led masterplan's total upfront carbon in years 2025, 2030 and 2040. Buildings assumed to comply with UK NZCBS targets for flats (565 in year 2025, 380 in year 2030, 160 kgCO₂e/m².GIA in year 2040); primary enabling infrastructure assumed to be 20 kgCO₂e/m².GIA considered representative of more urban density masterplans; another 20 kgCO₂e/m².GIA is assumed to cover all other impacts not assessed here, bringing total upfront impacts of infrastructure, hard and soft landscaping to 40 kgCO₂e/m².GIA.



CASE STUDIES

FUTURE RESEARCH

The following topics/study areas have been identified for future research:

- **Development of benchmarks and/or simplified approaches to estimate on-site energy use and carbon emissions during the construction of infrastructure assets and earthworks (module A5.2):** there is currently a gap in the industry, making design-stage estimates of construction emissions problematic, leading to potential underestimation of construction emissions*.
- **Study of the embodied and whole life carbon intensity (i.e. kgCO₂e per population, per dwelling, per floorspace) of the infrastructure within a set of archetypal neighbourhoods** representing current and emerging urban development patterns in the UK: this exploration can help drive the discussion relating to density and sustainable outcomes, help inform local authorities' policies, planning requirements and strategic development plans, and allocate a carbon budget to new development infrastructure. It may also help explore

whether it is possible to draw ranges of allowable decarbonisation-aligned carbon intensity benchmarks for infrastructure within a set of neighbourhood typologies, similar to the approach we take for buildings.

- **Study of the embodied and whole life carbon, embodied biodiversity and social impacts of different strategies for energy generation and energy distribution networks:** optioneering and optimisation assessments such as these are best carried out in the context of neighbourhoods and local authorities, rather than undertaken for individual sites in isolation, although valuable insights might come from assessments at masterplan level. The optimised strategies at neighbourhood or city scale could then inform and supplement the site-specific assessments and strategies.

- **Study of the embodied and whole life carbon, embodied biodiversity and social impacts of the electrification of car travel for various modal shift scenarios:** the carbon impacts associated with the construction and operation of the infrastructure that supports electric vehicles (increase in power generation capacity, extra distribution networks, EV charging points, electric vehicles manufacturing), are not widely understood and are often overlooked. These carbon impacts could represent a significant portion of the remaining carbon budget for the energy and transport sectors. The increase in demand for materials, particularly for rare metals, is also likely to have substantial embodied biodiversity and embodied social impacts.

*For this research we have relied on CESMM benchmarks for earthworks emissions and two data sets of actual construction emissions, monitored and shared by contractors. The A5.2 carbon impact reported in the case studies is therefore not a reliable estimate.

**The research paper 'Embodied climate impacts in urban development: a neighbourhood case study'⁷, undertaken for one archetypal neighbourhood in Denmark, makes a good reference point for such a study, as it proposes a replicable methodology.

CASE STUDY 1 - HIGH-DENSITY, MEDIUM-SCALE CARBON ASSESSMENT: DETAILED RESULTS

PROJECT OVERVIEW

The project proposal is to deliver a new neighbourhood of over 3,000 new homes, on brownfield land in a large city in the UK. The new neighbourhood will complement an existing town centre and comprise over 20 hectares of public realm and parkland, a hub of social infrastructure and a mixed-use community centre.

Nature and biodiversity are central to the proposals, with new wetlands, parkland and meadows being delivered.

Proposals also include rejuvenated walkways, cycle paths, walking trails and footbridge connections to an existing park.

It is noted that the carbon assessment does not factor in the improvements in design and specifications that would be expected over the project's delivery programme, or the decarbonisation of construction materials within that time.



CASE STUDY 1 - HIGH-DENSITY, MEDIUM-SCALE CARBON ASSESSMENT: DETAILED RESULTS

CARBON IMPACT SUMMARY

9,900	tCO ₂ e
16.7	kgCO ₂ e/m ² .GIA
2.6	tCO ₂ e/dwelling

KEY PROJECT INFO

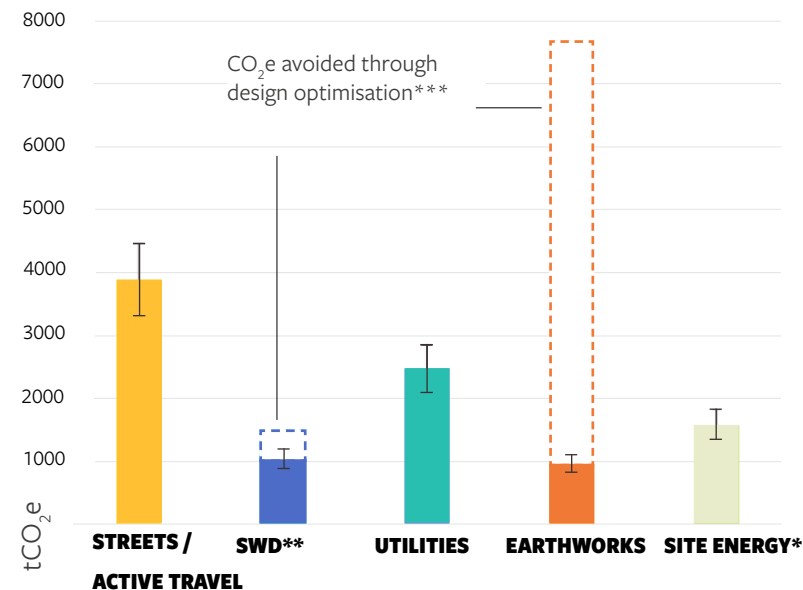
SITE AREA	21.7 ha
DENSITY	3,750 dwellings 173 dwellings/ha
	593,700 m ² .GIA (98% residential)
	2.8 m ² .GIA/m ² .site area

CARBON HOTSPOTS OVERVIEW

ELEMENT	%	kgCO ₂ e/m ² .GIA
STREETS/ACTIVE TRAVEL	39%	6.5
UTILITIES	25%	4.2
SITE ENERGY*	16%	2.7
EARTHWORKS	10%	1.6
DRAINAGE**	10%	1.7

*Estimated emissions from energy use during construction (module A5.2 as per RICS v2.0), excluding general site earthworks, which is covered under 'Earthworks'; highly speculative estimate, based on construction data from two projects.

**Surface water drainage (SWD)



***CO₂e savings quantified against a baseline (original) proposal; savings were estimated based on available design information and do not cover all potential savings of the project.

CARBON MANAGEMENT - KEY OUTCOMES

SURFACE WATER DRAINAGE

- Carbon savings achieved through nature-based solutions (including multi-function wetland) and introduction of SuDS alongside streets and on plots.
- Greenfield run-off rate increased in consultation with LLFA and EA to better reflect site hydrology.
- Attenuation storage reduced from 4,400m³ in the original proposals to 320m³ (93% saving), accommodated through low-carbon Hydrorock modular units.

EARTHWORKS

- Starting from a baseline of 440,000m³ of estimated soil exports, an options appraisal and optimisation exercise resulted in a solution that is almost perfectly balanced, with an export volume of 27,000m³, comprising contaminated piling and other arisings that cannot be balanced on site (94% volume of soil exports avoided).

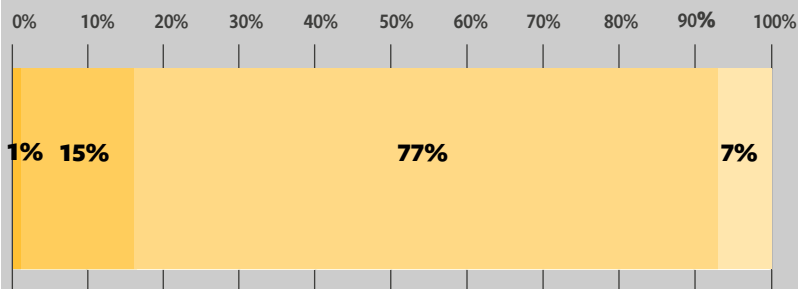
CARBON AVOIDED - DRAINAGE 360 tCO₂e

CARBON AVOIDED - EARTHWORKS 6,680 tCO₂e

CASE STUDY 1 - HIGH-DENSITY, MEDIUM-SCALE CARBON ASSESSMENT: DETAILED RESULTS

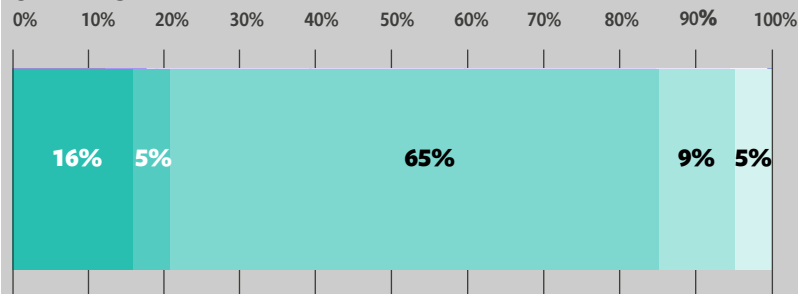
ELEMENTAL HOTSPOTS

ACCESS



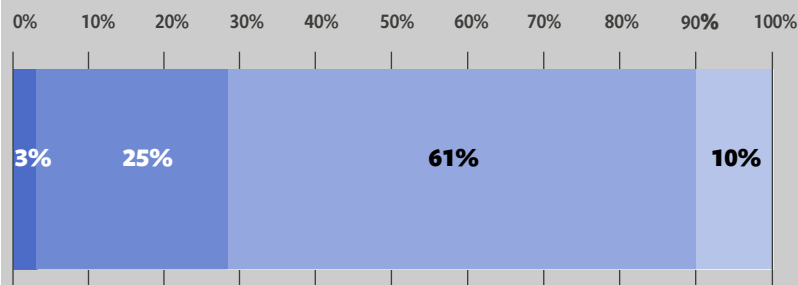
Element	Average carbon intensity
Car park	36 kgCO ₂ e/m ² .spec
Foot/cycle paths	27 kgCO ₂ e/m ² .spec
Vehicular roads	66 kgCO ₂ e/m ² .spec
Kerbs	24 kgCO ₂ e/m.kerb

UTILITIES



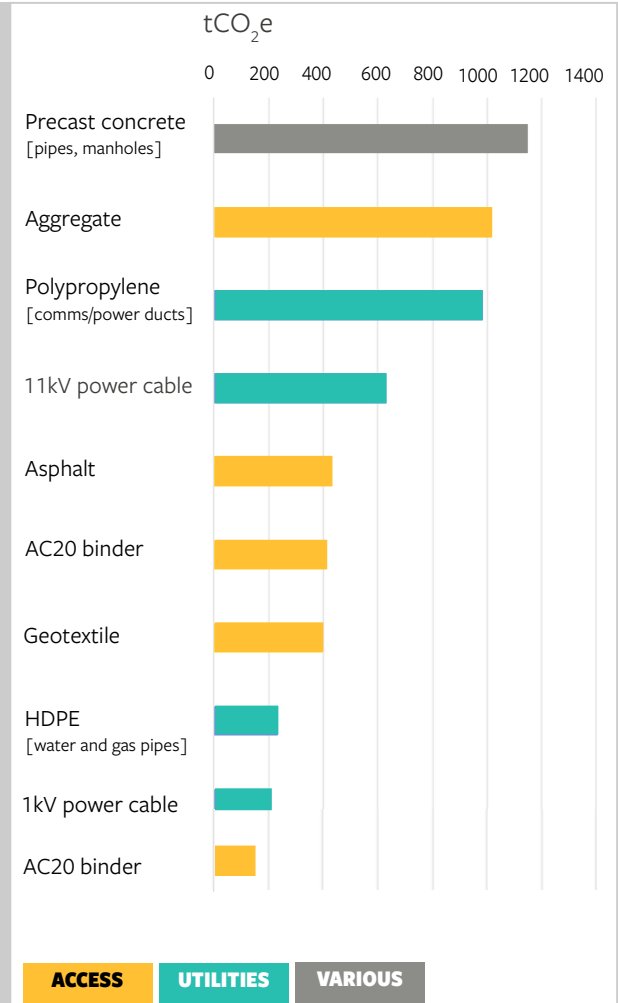
Element	Average carbon intensity*
Waste water drainage	56 kgCO ₂ e/m.pipe
Water supply	19 kgCO ₂ e/m.pipe
Power	29 kgCO ₂ e/m.cable
Comms	8 kgCO ₂ e/m.cable
Gas	17 kgCO ₂ e/m.pipe

SURFACE WATER DRAINAGE



Element	Average carbon intensity
Attenuation	-
Manholes	1,111 kgCO ₂ e/#
Pipe material	118 kgCO ₂ e/m
Pipe surround	20 kgCO ₂ e/m

MATERIAL HOTSPOTS (ALL INFRASTRUCTURE)



*The average carbon intensity for utilities in kgCO₂e per metre of pipe or cable is not an appropriate metric for comparing projects, as values are highly dependent on the density of the masterplan, the length and total runs of pipes and cables laid in trenches and, in the case of power, on the energy efficiency and energy strategy of the site. Values of power and comms are also informed by high-level assumptions and rules of thumb in the absence of available design data. Values should be treated as informative only, not to be used as indicative of performance for other projects or for comparing different projects.

CASE STUDY 2 - MEDIUM-DENSITY, SMALL-SCALE CARBON ASSESSMENT: DETAILED RESULTS

PROJECT OVERVIEW

The project comprises the mixed-use redevelopment of over five hectares of brownfield land to deliver over 500 homes (around a third of which are affordable), community spaces, pedestrian walking routes, a health centre and a mobility hub hosting car parking, shared mobility services, shuttle bus and last-mile delivery services.

At the heart of the neighbourhood will be a series of public squares connecting to a community canteen, event hall, fitness centre, workspace and makerspaces, much of which will be housed within repurposed industrial structures.

It is noted that the carbon assessment does not factor in the improvements in design and specifications that would be expected over the project's delivery programme, or the decarbonisation of construction materials within that time.



CASE STUDY 2 - MEDIUM-DENSITY, SMALL-SCALE CARBON ASSESSMENT: DETAILED RESULTS

CARBON IMPACT SUMMARY

1,600	tCO ₂ e
16.5	kgCO ₂ e/m ² .GIA
2.3	tCO ₂ e/dwelling

KEY PROJECT INFO

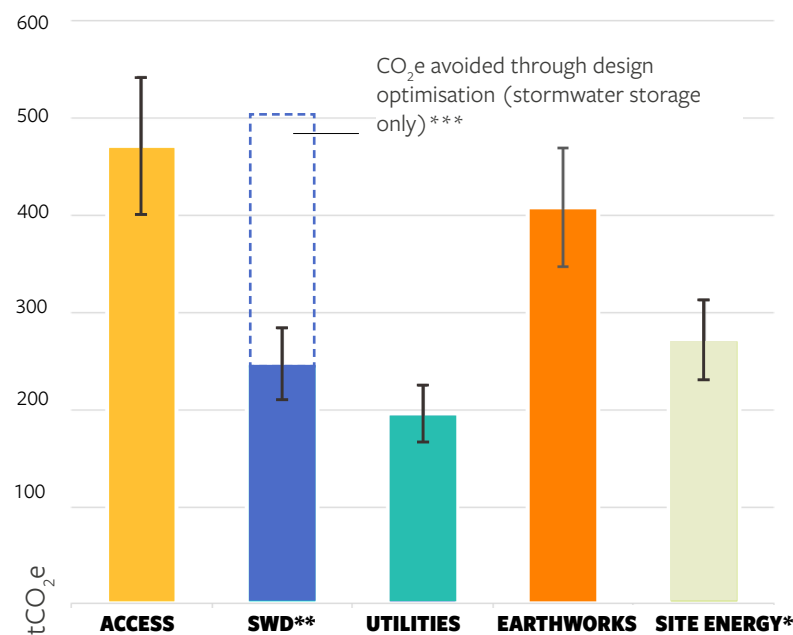
SITE AREA	7.9 ha
DENSITY	685 dwellings 87 dwellings/ha
	96,700 m ² .GIA (86% residential)
	1.2 m ² .GIA/m ² .site

CARBON HOTSPOTS OVERVIEW

ELEMENT	%	kgCO ₂ e/m ² .GIA
ACCESS	30%	4.9
UTILITIES	13%	2.0
SITE ENERGY*	17%	2.8
EARTHWORKS	25%	4.2
DRAINAGE**	15%	2.6

*Estimated emissions from energy use during construction (module A5.2 as per RICS v2.0), excluding general site earthworks, which is covered under 'Earthworks'; highly speculative estimate, based on construction data from two projects.

**Surface water drainage (SWD)



***CO₂e savings only capture savings in stormwater storage features and do not reflect all potential savings of the drainage strategy and flood defence proposals of the project; savings associated with utilities and earthworks systems have not been included in these calculations.

CARBON MANAGEMENT - KEY OUTCOMES SURFACE WATER DRAINAGE

- Lean flood defence design but constrained by the need to retain the existing river wall and create an ecological shelf.
- Stormwater storage volumes were reduced to less than a fifth through a review of local hydrology, combination of storm, fluvial and tidal events, and use of back-up stormwater pumps. This was therefore achieved by using open water storage features integrated with the green infrastructure, developed in close consultation with EA and LLFA.

UTILITIES

- Implementation of exemplary smart rainwater harvesting system, alongside the drainage strategy, to achieve reduced water consumption and significant reduction in embodied carbon compared with conventional systems with bespoke tanks.

EARTHWORKS

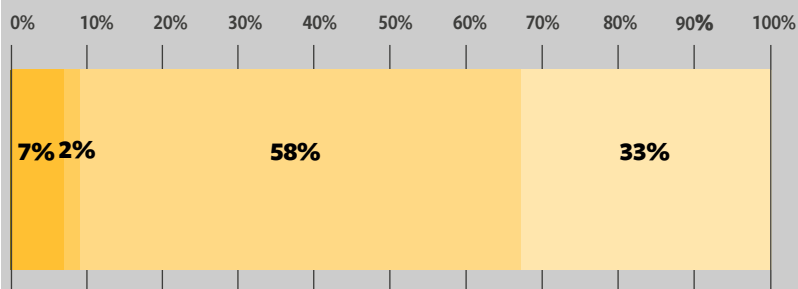
- Optimised balance of earthworks, considering reuse of demolition material from industrial buildings and alignment with surface water drainage strategy.

CARBON AVOIDED - DRAINAGE
(STORMWATER STORAGE ONLY) 255 tCO₂e

CASE STUDY 2 - MEDIUM-DENSITY, SMALL-SCALE CARBON ASSESSMENT: DETAILED RESULTS

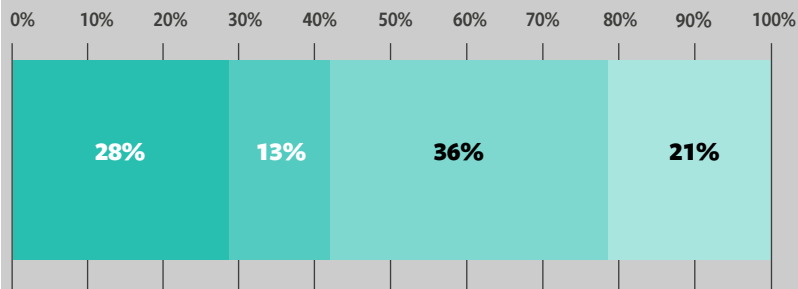
ELEMENTAL HOTSPOTS

ACCESS ELEMENTAL HOTSPOTS



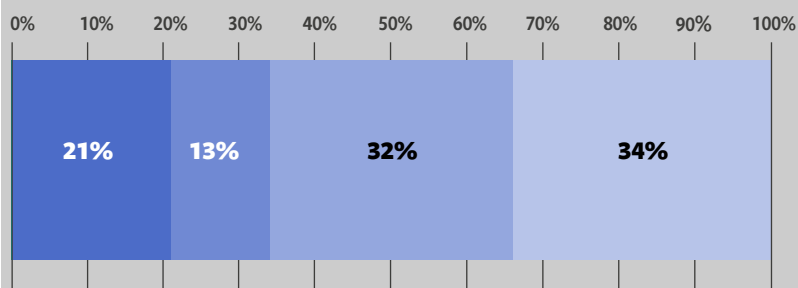
Element	Average carbon intensity	
Car park	36	kgCO ₂ e/m ² .spec
Foot/cycle paths	17	kgCO ₂ e/m ² .spec
Vehicular roads	30	kgCO ₂ e/m ² .spec
Kerbs	42	kgCO ₂ e/m.kerb

UTILITIES ELEMENTAL HOTSPOTS



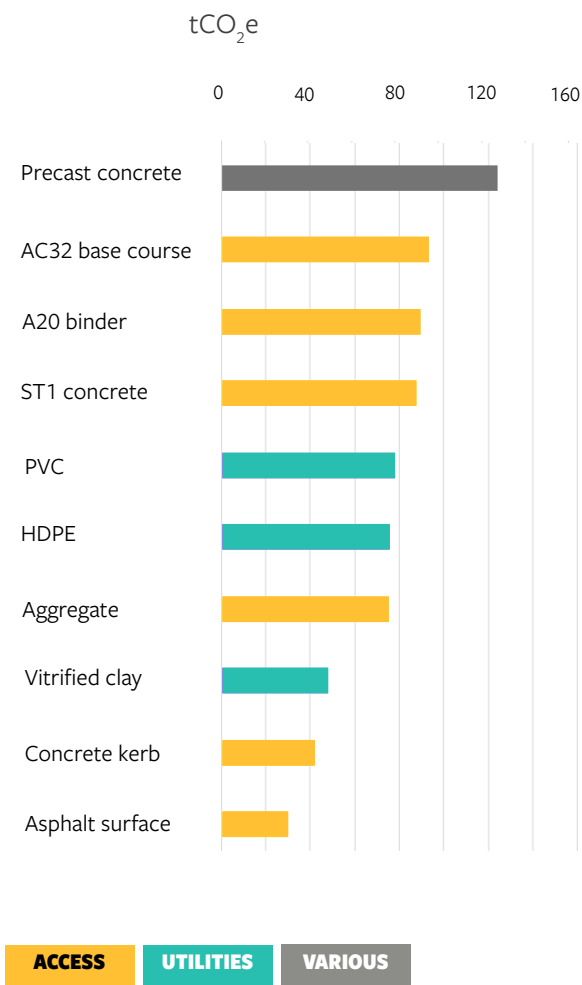
Element	Average carbon intensity*	
Waste water drainage	51	kgCO ₂ e/m.pipe
Water supply	18	kgCO ₂ e/m.pipe
Power*	49	kgCO ₂ e/m.cable
Comms*	7	kgCO ₂ e/m.cable
Gas	N/A	

SURFACE WATER DRAINAGE ELEMENTAL HOTSPOTS



Element	Average carbon intensity	
Attenuation	3	kgCO ₂ e/kg
Manholes	963	kgCO ₂ e/#
Pipe material	75	kgCO ₂ e/m
Pipe surround	81	kgCO ₂ e/m

MATERIAL HOTSPOTS (ALL INFRASTRUCTURE)



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CASE STUDY 3 - LOW-DENSITY, LARGE-SCALE CARBON ASSESSMENT: DETAILED RESULTS

PROJECT OVERVIEW

The project comprises a 500+ acre urban extension of an existing town. The project has a delivery programme of around 25 years and, once complete, will deliver around 2,500 detached/semi-detached homes, and significant green infrastructure (including a park and walkways), alongside community and commercial infrastructure (including a primary school, café, care home, and fitness hub). Out of the total site area, around a quarter will be undeveloped, comprising nature conservation areas, watercourses and nature-based large-scale SuDS. Significant highways improvements, links to the National Cycle Network and the construction of a relief road are also supporting the development.

Key sustainability measures include compliance with Flood Zone regulations, strategic earthworks to mitigate flood risks, and the promotion of active travel through pedestrian and cycle-friendly infrastructure.

It is noted that the carbon assessment does not factor in the improvements in design and specifications that would be expected over the long delivery programme, or the decarbonisation of construction materials within that time. The carbon impact reported here is, therefore, an overestimate based on outline planning-stage design information for all phases.



CASE STUDY 3 - LOW-DENSITY, LARGE-SCALE CARBON ASSESSMENT: DETAILED RESULTS

CARBON IMPACT SUMMARY

17,400	tCO ₂ e
70.5	kgCO ₂ e/m ² .GIA
6.6	tCO ₂ e/dwelling

KEY PROJECT INFO

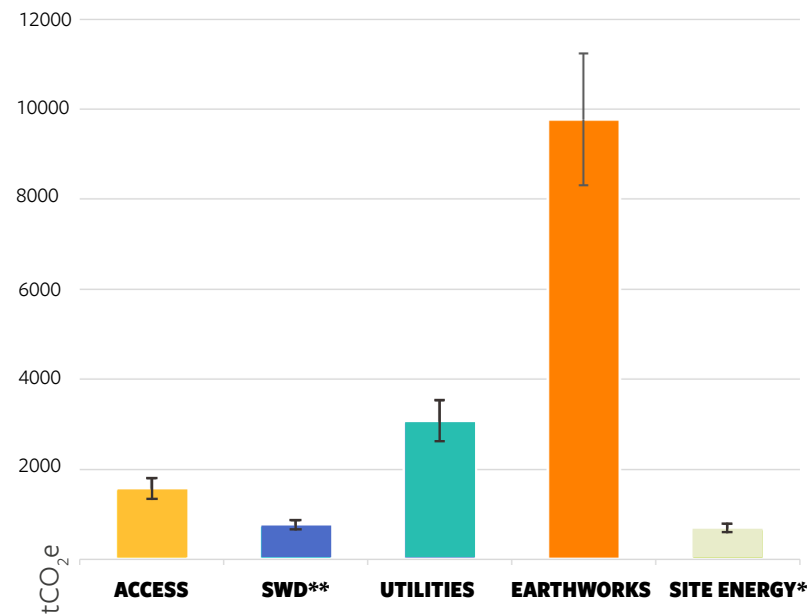
SITE AREA	280 ha (151 ha developed)
DENSITY	2,650 dwellings 17 dwellings/ha
	246,510 m ² .GIA (99% residential)
	0.16 m ² .GIA/m ² .site area

CARBON HOTSPOTS OVERVIEW

ELEMENT	%	kgCO ₂ e/m ² .GIA
ACCESS	11%	7.4
UTILITIES	18%	13.1
SITE ENERGY*	4%	2.8
EARTHWORKS	56%	39.5
DRAINAGE**	11%	7.6

*Estimated emissions from energy use during construction (module A5.2 as per RICS v2.0), excluding general site earthworks, which is covered under 'Earthworks'; highly speculative estimate, based on construction data from two projects.

**Surface water drainage (SWD)



CARBON MANAGEMENT - KEY OUTCOMES

EARTHWORKS AND SURFACE WATER DRAINAGE

- A cut and fill balance has been achieved on site. However, the extent of earthworks is substantial as the residential plots of the site are located in Flood Zone 3, requiring that the ground level across this area be lifted to enable development.
- The flood zone is therefore moved to the southern boundary of the site, with stormwater managed within the country-park area through water SuDS features (wetlands and ponds), thus minimising the extent of grey infrastructure for drainage. No underground storage is needed to manage stormwater.

ACCESS

- Access infrastructure is driven by Highways design standards, requiring tarmac-surfaced cycleways on both sides of roads and large widths for vehicle pavements.

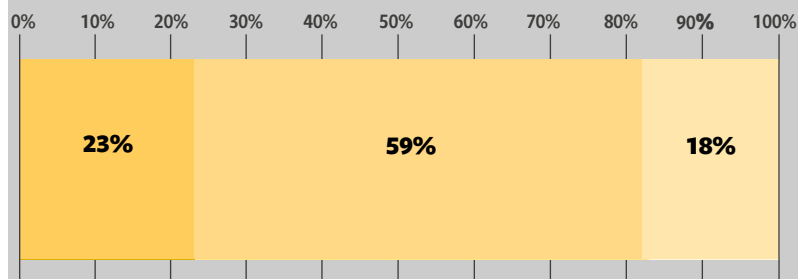
CARBON AVOIDED

Not quantified (no baseline proposal available)

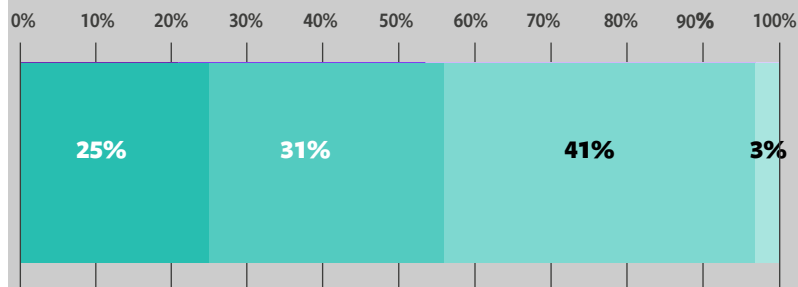
CASE STUDY 3 - LOW-DENSITY, LARGE-SCALE CARBON ASSESSMENT: DETAILED RESULTS

ELEMENTAL HOTSPOTS

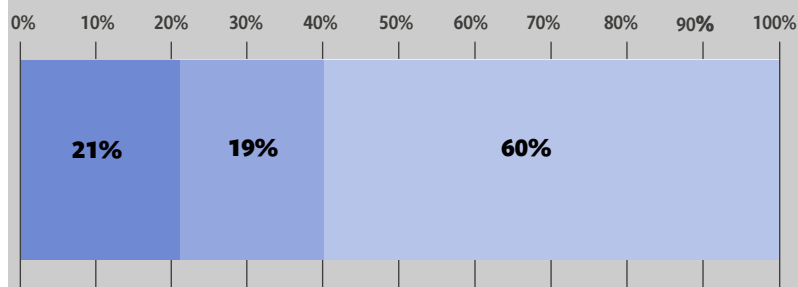
ACCESS ELEMENTAL HOTSPOTS



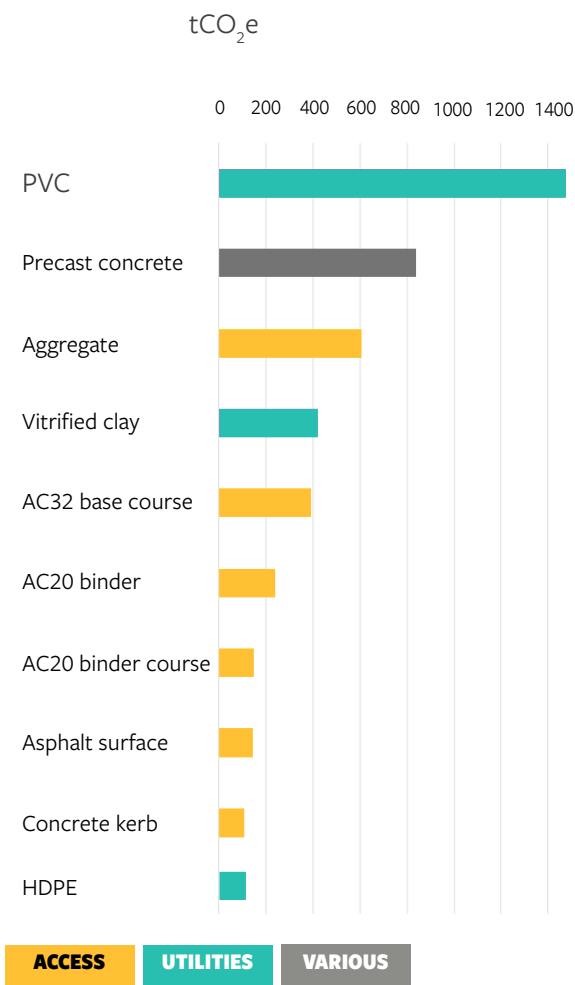
UTILITIES ELEMENTAL HOTSPOTS



SURFACE WATER DRAINAGE ELEMENTAL HOTSPOTS



MATERIAL HOTSPOTS (ALL INFRASTRUCTURE)



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CARBON MANAGEMENT IN PRACTICE

LESSONS LEARNED - THE CASE OF A MASTER DEVELOPER

A leading master developer has started integrating carbon management in line with PAS 2080 in its business decision-making and design development of its portfolio as of 2019, when it commissioned the first 'pilot' embodied carbon assessment for one of its projects.

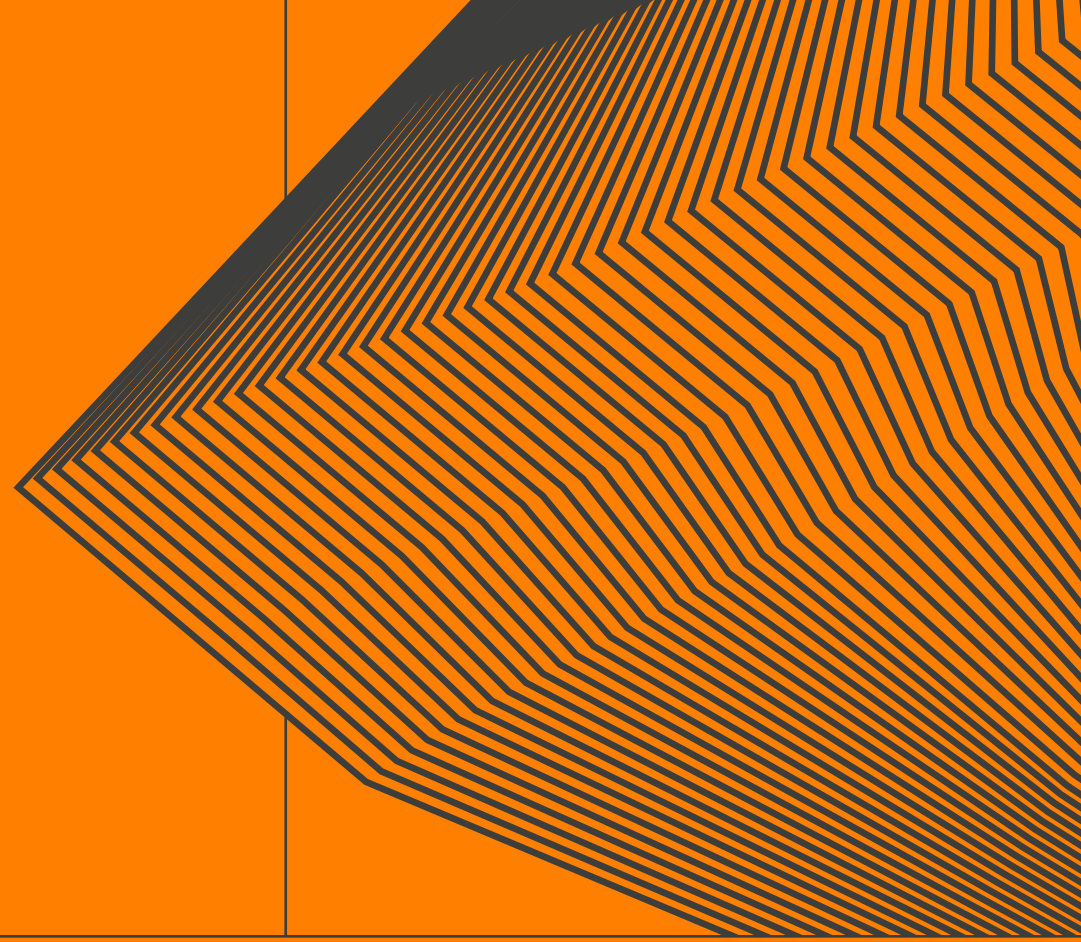
Embodied carbon targets for key enabling infrastructure are now included in project briefs, and sustainable design and construction credentials are a key consideration at tender stage.

Five years into implementing carbon management, the developer's key learnings include the following:

- **Having processes in place that support and empower people to make the right decisions in their role is fundamental in driving change.** Addressing barriers other than technical expertise is key. The in-house sustainability team commissioned a behavioural-focused study that explored the attitudes, skills, confidence and autonomy of the developer's team in delivering sustainable outcomes and the developer says this study provided invaluable insights it 'wouldn't really think of', helping it find new ways to support and unlock the full potential of its team.

- **Having carbon targets for the project set from the start helps drive best practice design.** However for infrastructure elements, best practice is primarily driven by other key factors (e.g. cost, quality placemaking, biodiversity, active travel, SuDS).
- **Carbon savings are being delivered as a result of sustainability-driven masterplans,** even if not necessarily quantified, and even if carbon is not (yet) as central in the designers' arguments.
- **Change is realised through simple messaging, engagement and consistent collaboration internally and across the value chain.** Having the discussions and providing continuous support is what builds awareness and inspires others to act. Bite-size case studies for sharing lessons learned, attending designers' team meetings and visiting site to engage with contractors' teams are some of the ways the developer's sustainability team engages and collaborates within and outside the organisation.
- **Data collection from contractors and reliable carbon calculations remain a challenge, but things are improving, albeit at various paces.** There are still large discrepancies among contractors with regards to data collection and reporting, but some really take on the challenge (e.g. one contractor developed a bespoke in-house tool). Simpler, automated processes for ease of reporting is the developer's next step on this front.

04



GUIDANCE AND DESIGN PRINCIPLES

GUIDANCE AND DESIGN PRINCIPLES

STRUCTURE OF THIS SECTION

PAS 2080 states that the greatest opportunity to reduce embodied carbon is in the early stages of a design, where we can avoid taking decisions that 'lock in' carbon.

This section provides guidance for clients, designers, engineers and others. It aims with decision-making and provides principles to follow at an early stage on masterplan projects, in order to minimise the carbon in the enabling infrastructure systems.

As the case studies highlighted, the embodied carbon of these systems depends heavily on the type of development, its location and geographic context, and the needs of its users. Many of the principles in the following section reflect the need to take a systems approach and think critically about trade-offs and compromise.

This guidance has been collated from:

- **interviews** with leading industry experts
- **case studies** of successful, sustainable masterplans
- **published best practices and guides;** these are **referenced and linked** where relevant.

1. How to **PLAN THE USE OF THE LAND**

2. How to **ENABLE LOW-CARBON DESIGN THROUGH PROCUREMENT**

3. How to **DESIGN LOW-CARBON INFRASTRUCTURES**

SURFACE WATER DRAINAGE



EARTHWORKS



UTILITIES



ACCESS INFRASTRUCTURE



4. Areas and principles that require **COLLABORATION**

5. Considerations **BEYOND EMBODIED CARBON**

1. PLANNING FOR LAND USE

Lifetime carbon impacts are locked in by decisions made when planning the layout of the site.

On large-scale masterplans, many of the factors influencing the design of the subsystems are decided in the course of initial massing and laying-out of specific community assets.

This page presents four principles for planning the use of land on the site, to enable low-carbon design options at a later date. These principles align with PAS 2080's 'avoid' principle - avoiding the need for earth movement, pumping rainwater, decontamination of earth, stormwater run-off capacity, and hard paving for access infrastructure.

Some of these decisions and influences emerge in the guidance for the sub-sections, but some are wider considerations that need to be made at an earlier stage (before appointing a design team) to avoid 'locking in' carbon to a design.

Work with the site's contours

Design around the **natural contours of a site**, to minimise the need for earth movement where possible and take advantage of gravity.

The energy and carbon associated with pumping in drainage should be minimised by **laying out the site so that attenuation drainage uses gravity, to avoid the need for pumping infrastructure**.

'Levelling' the site to accommodate a layout should not be the default. The **land use should respond to the existing topography** of the site, not only to achieve a cut and fill balance, but also to minimise earth movement. This also helps to retain existing habitats, making it easier to deliver Biodiversity Net Gain.

Allow space for sustainable infrastructure

Make **space for sustainable infrastructure**, and find opportunities for secondary benefits of that infrastructure.

Nature-based attenuation solutions such as **ponds and swales need land area**. The land-use planning should allocate space to these in the landscape, where they can also add amenity and biodiversity value.

If earth movement is needed, **make space for bunds** in the plan and use them as noise barriers or to provide visual interest in the landscape.

Place assets in suitable locations

Strategically place assets to **utilise the existing conditions and infrastructure** (where it exists) on the site.

Soil disturbance, earth movement, and cut and fill imbalance (all of which cause emissions through the use of plant) can be minimised at an early stage by **placing assets in areas where the ground conditions are likely to be suitable**.

Minimise the need for installing new utilities by **locating buildings adjacent or nearby to existing utilities corridors** (on or off the site).

Avoid sites located on floodplains, as this will require carbon-intensive earthworks to raise levels and minimise flood risk for the majority of asset types.

Minimise hard-landscaped areas

Use density to **reduce the area of hardstanding**.

Aim for **higher densities, compact building forms and layouts to reduce the footprint of access infrastructure** and make active travel more appealing, and reduce utility and servicing runs.

Reduce hardstanding to **enable slower infiltration and minimise stormwater run-off at source**. The latter will reduce the requirements of the drainage infrastructure.

2. PROCUREMENT AND COLLABORATION

There is a key role for a client in setting a vision for low-carbon infrastructure in a masterplan. However, translating this vision into reality in the design does not always take place. There is therefore a need to consider how the opportunities for minimising carbon are created through the procurement process.

The construction supply chain operates on low margins and takes on a lot of risk. Much of the guidance in the following selections requires standards and norms to be challenged in order to achieve lower carbon. This comes with risk, and the capacity to take on that risk should be accounted for in the procurement process.

The **LETI Low Embodied Carbon Specification and Procurement Guide** provides helpful guidance for procurement for low-carbon buildings; similar principles can be applied to the infrastructure on masterplans.

Set a clear vision across the design team

Set clear requirements for measuring and minimising carbon in scopes, requests for proposals and construction contracts. Carbon management requires extra resource and, unless it is set as a project requirement, it will not be priced into a contract.

Define a routemap for minimising carbon in the project and identify the role of enabling infrastructure within that.

Use consistent and clear terminology for embodied carbon, whole life carbon and other key terms.

Include KPIs for whole life carbon and waste management considerations, and make the boundaries of these very clear.

Consider approaches to incentivising design teams to avoid overspecification and overordering (and addressing the root causes of these).

Engage early with the supply chain

The vision and ambition of the design team should be feasible to deliver. This feasibility should be tested with the supply chain at an early stage.

Engage with potential suppliers and product suppliers at an early stage to test the feasibility of the ambition being set out from a technical perspective.

Account for the extra cost of challenging the default

Accommodate the extra work and cost likely to be required to challenge standard requirements and designs and, therefore, avoid overdesign.

A theme across all subsystems is challenging over-conservative or unnecessary standard requirements for run-off, parking spaces, hardstanding, etc.

Challenging these requirements can require significant extra time for the design teams in engaging with local authorities, utilities providers and others. This extra time and the costs should be accounted for.

Set a clear approach to monitoring carbon at the outset of the project

At an early stage, define an approach to monitoring and measuring carbon (and any other related KPIs) so the delivery teams know what their commitments will be measured against.

Make the boundaries of any KPIs and measurement regime very clear.

Develop and specify the approach to monitoring these KPIs at an early stage, and share this with project teams.

Make sure the sustainability commitments made by the teams have been communicated to the relevant contract/asset managers, to ensure they are followed through.

3. GUIDANCE FOR DECARBONISING SUBSYSTEMS

HOW TO READ THIS GUIDANCE

The following pages present guidance specific to each of the four subsystems:

Surface water drainage

Earthworks

Utilities

Access infrastructure

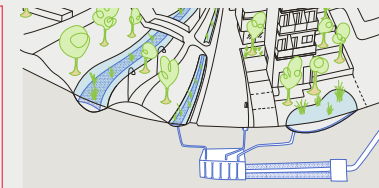
Each is designed to be read as a stand-alone section, so some of the guidance reiterates principles set out in the land-use and procurement sections.

1. A **summary of the subsystem** components (and the hotspots found in the case studies), and the key principles for low-carbon design.

KEY PRINCIPLES



EARLY LOCK-INS



2. A series of **key actions throughout the RIBA stages 0-2**: all of these follow a similar pattern, as shown on the right. These are not technical pieces of advice, but a suggested process to follow in the early stages of a project, to avoid adding carbon and enable 'switch' and 'improve' actions later in the design process.

RIBA 0: Strategic definition

Set a **clear ambition** to reduce carbon

Set the **right design criteria**, and **challenge conservative defaults**

RIBA 1: Prep and briefing

Understand **the needs and characteristics of the site** and its occupants

Establish a **clear design hierarchy** to prioritise low-carbon options

RIBA 2: Concept design

Reuse what's on site, and develop a design that **works with the site's characteristics**

Align the design with other relevant infrastructures



Biodiversity and nature



Cost saving



Amenity value



Check-in point

3. A series of **technical principles and references** for low-carbon design, and prompts to challenge standard approaches. Some additional case study examples are included here, where these principles have been applied.

Key principle

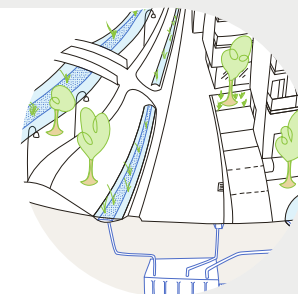
How the principle should be applied in practice

What needs to happen and why it is important for decarbonisation

Prompts, technical details and **references**

Case study

Example of a principle (or multiple) being applied in practice



SURFACE WATER DRAINAGE OVERVIEW



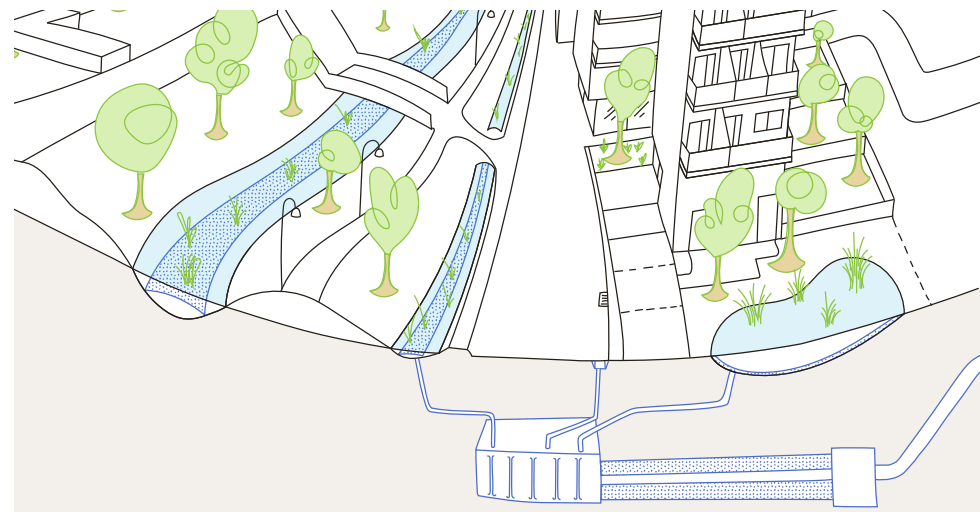
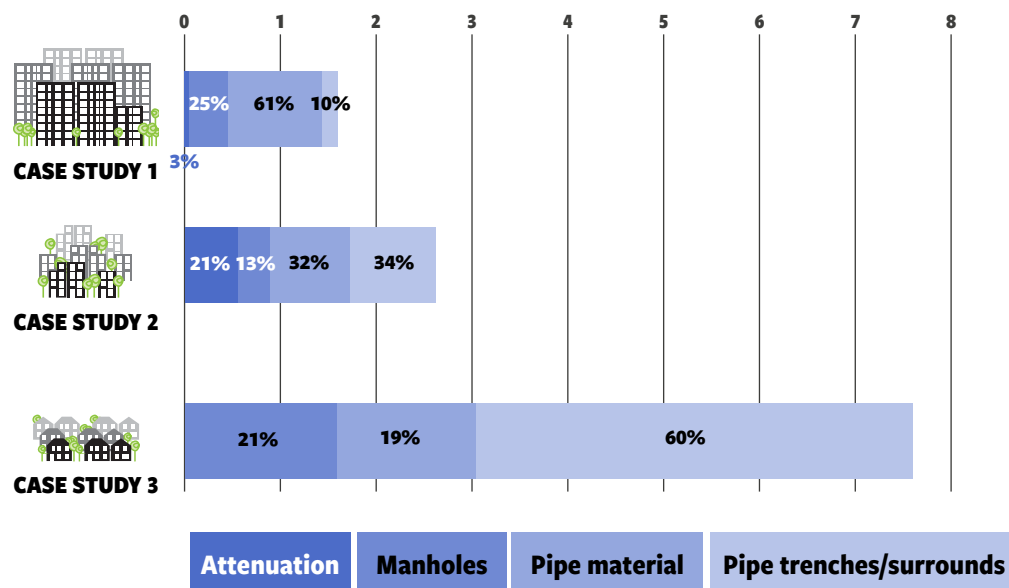
Surface water drainage infrastructure protects a development from flooding by conveying rainwater into the landscape and away from the site, to be treated.

In the **CASE STUDIES**, surface water drainage infrastructure accounted for between 5% and 10% of the total enabling infrastructure carbon:

the **smallest or second-smallest proportion of carbon** of all the subsystems. The most significant hotspots were in pipes and manholes.

On CS2, optimising the design by reducing the underground attenuation volume enabled a saving of around 30% of the emissions from this infrastructure.

BREAKDOWN OF SURFACE WATER DRAINAGE CARBON (kgCO₂e/m².GIA)



KEY PRINCIPLES

Minimise run-off **at source**

Reuse existing assets

Prioritise **nature-based** solutions

Use the site **contours**

Refine contingencies **over time**

Set the right levels of **flood protection**

Adapt **discharge rates**

Specify low-carbon **details**



EARLY LOCK-INS

Not making space for SuDS

Working **against the site contours**

Setting **overly conservative protection**

SURFACE WATER DRAINAGE

APPROACH TO MINIMISING CARBON



Set a **clear ambition to minimise carbon** in the surface water drainage system

Define national and local policy requirements for carbon reduction.

Test the feasibility of your ambition by engaging early on with designers and contractors.

Establish **appropriate design criteria** and **challenge defaults**

For each asset, define the level of protection required as a return period, and challenge overly conservative defaults. For example, the 100-year event should not need to be contained within the network design.

Challenge whether combined conservative safety factors reflect realistic scenarios and, if not, establish and agree less onerous factors of safety. Work with the LLFA to define realistic characteristics. 

Design for exceedance in order to ensure departures from conservative defaults are not introducing risk: for example, ensure building thresholds, access and egress routes are fully protected.

RIBA 0: Strategic definition

Get a good, **accurate understanding of the existing surface water drainage** on the site and at its boundaries

Understand existing drainage infrastructure, including:

- the age and condition of existing sewers
- the capacity of receiving sewers
- end-of-pipe surcharge conditions, under different storm events.

Understand **existing hydrological conditions**

Understand existing hydrological conditions, including:

- the location and levels of groundwater and its seasonal variations
- the condition of potential receiving watercourses, including water levels under different storm events.

Understand **existing discharge rates**

Understand existing discharge rates, by seeking:

- selection of soil characteristics
 - catchment lengths and time of concentration.
- Model the discharge conditions based on this information.

RIBA 1: Prep and briefing

STOP!

Before proceeding to concept design, have you **reviewed your design criteria based on the site conditions?**
Narrow down safety factors based on your findings.

Establish a design hierarchy to **prioritise the use of existing infrastructure**, followed by low-carbon nature-based solutions

Maximise soft-landscaped area by compacting the development, to minimise run-off and make space for nature-based solutions.

Minimise the use of engineered solutions such as crates and concrete tanks.

Make reuse the starting point: explore opportunities to reuse what is already on site

Use the capacity of existing drainage infrastructure before designing in new assets. 

Design the drainage system to use uncontaminated site arisings from earthworks activities, such as in sub-base or pipe surrounds. 

Design to **make use of the topography** of the site

Design the drainage system to take advantage of the natural contours of the site to control the flow of surface water.

Integrate the drainage design with the **provision of utilities**

Design the system to harvest stormwater for non-potable use where possible, to minimise the demand for water drawn from the grid.

Integrate nature-based drainage solutions into the landscaping strategy, as low-carbon opportunities to provide extra visual delight, amenity and habitats to improve biodiversity and appeal. 

RIBA 2: Concept design

SURFACE WATER DRAINAGE

TECHNICAL PRINCIPLES AND REFERENCES



Set levels of protection

The level of protection (design return period), considering climate change, should be adapted to the vulnerability of each asset.

Challenge the use of default, overly conservative design criteria ('this is what we always do'), or blanket application of a conservative design criteria to all parts of a development ('to make modelling simpler'). Work with the LLFA to agree realistic characteristics.

Consider whether low-sensitivity assets could be allowed to flood in a controlled manner in extreme events, to minimise stormwater attenuation storage and associated carbon. Could your car park flood in the 1:100-year event, or the green amenity space in the 1:10-year event?

BS EN 752 provides guidance on design return periods for land-use types.

There is a requirement to ensure that stormwater does not overflow onto adjacent sites for the 1:100-year event, allowing for climate change, and that buildings and sensitive infrastructure are not at risk of flooding, but there is no requirement for the 1:100-year storm to be contained below ground.



GURNELL LEISURE CENTRE

The redevelopment of Gurnell Leisure Centre is on a site partly occupied by an active floodplain of the River Brent.

The surface water drainage strategy utilises the existing pipes and outfalls, and the land in the floodplain has been designed to accommodate parkland as a low-sensitivity area which can store water in extreme flood events. This required challenging the default approach. Run-off will be controlled at source by utilising multi-function open-water bodies in wetlands closely integrated into the landscape, which also add biodiversity and amenity value.

Image sourced from Architects' Journal

Refine contingencies

Design contingencies should be adapted at each design stage, taking into account the cumulative effect of multiple factors.

Design 'bagginess' is a key contributor to carbon emissions. Whilst contingencies may be justified at early stages to deal with uncertainties, they should be refined as the design progresses. The cumulative effect of contingencies and safety factors on several design parameters can lead to significant overdesign for unrealistic scenarios. Designers often adopt worst-case parameters (such as infiltration rates) without considering that this overdesign can add unnecessary embodied carbon.

Safety factors to reduce infiltration rates when designing soakaways (for uncertainty on long-term performance) should be adapted to the risk of degradation, taking into account the design life, and type and size of drainage catchment, in line with **the SuDS Manual (CIRIA C753)**.

Review the 'default' suggested freeboard of 300mm (which is often adopted to set the top of a bank above the design water level) as this can result in a significant and unnecessary increase in the size of a pond or SuDS feature, with poor utilisation of the potential capacity.

Minimise run-off at source

Run-off should be minimised at source and drainage catchment characteristics should not be overly conservative.

Overestimating the extent of impermeable surfaces results in over-specifying drainage pipework and attenuation storage, adding unnecessary embodied carbon. Best practice is to maximise soft-landscaped areas, permeable pavement and green roofs (where appropriate) for their benefit of reduced run-off rates, and co-benefits such as pollution control, biodiversity and amenity, to minimise impermeable area.

Lined permeable pavement systems will still generate inflows into the drainage network, but with a significant delay, and the designer should ensure that the storage capacity is fully utilised.

Run-off coefficients are often conservatively estimated, leading to significant overdesign and added carbon. Choosing 90% impermeable area rather than 80% is down to designer judgement, but it increases flows by 10%.

The benefits of source control measures should consider reduction in pipe sizes, attenuation storage capacity and proprietary treatment solutions.

SURFACE WATER DRAINAGE

TECHNICAL PRINCIPLES AND REFERENCES



LEA VALLEY ICE CENTRE

The Lea Valley Ice Centre in East London features an innovative, low-carbon approach to minimising water consumption and enabling resilience. A constructed wetland system filters and treats the meltwater from the ice rink, using a gravel filter medium and a rich mix of aquatic plants, before it is conveyed into two ponds in front of the building. This solution removes the need for an engineered, carbon-intensive tank system, reduces the carbon associated with pumping, and enhances biodiversity and the landscape of the development by means of the reed ponds.

Image © Benedict Luxmoore

Use nature-based solutions

Maximise opportunities for nature-based solutions, with their reduced carbon footprint and co-benefits.

Nature-based solutions (including swales, raingardens, ponds and wetlands) collect, convey, clean and attenuate stormwater run-off, and generally have a lower carbon footprint than pipes, manholes, hydrocarbon interceptors and in-ground tanks. They also bring co-benefits to the landscape and biodiversity, potentially reducing carbon associated with other systems, and are generally more cost-effective than in-ground solutions.

The UKGBC's **Principles For Delivering Urban Nature Based Solutions** report provides a guide to designing, delivering and operating nature-based solutions in an urban context.

For constrained sites, nature-based solutions include rain gardens that can be integrated with seating, and tree planters in the run-off systems.

Maximising the co-benefits of nature-based solutions in line with best practice from **The SuDS Manual** can bring significant value to a scheme's visual character and help achieve net gains. These opportunities are often missed and features are designed surrounded by fencing.

Adapt discharge rates

Peak discharge rates should be adapted to the site, its context and history, and should respond to local policy to avoid an increase in off-site flooding.

Peak discharge rates have a direct impact on attenuation storage requirements and the associated carbon impact of tanks, ponds, etc. Challenge the adoption of default, simplified peak discharge rates, which may not account for the specific hydrology or ground conditions of the site, or which exceed policy requirements without a clear need to do so.

Many local policies now require discharge to be limited to greenfield run-off rates and volumes. An accepted simplified approach is to limit all discharge to the very low Qbar greenfield rate. Implementing a more sophisticated flow control system, and assessing historical discharge volumes while taking into account the history of the site, generally results in smaller attenuation volumes and, therefore, lower carbon associated with storage.

Default soil characteristics in the **Greenfield runoff rate estimation** tool should be carefully checked against site ground-condition data, as they tend to lead to underestimating greenfield rates, and hence overestimating storage volumes.

When discharging to a river near the downstream end of its catchment, it is often acceptable not to limit peak discharge, removing the need for attenuation storage and associated carbon impacts.

SURFACE WATER DRAINAGE

TECHNICAL PRINCIPLES AND REFERENCES



Reuse existing assets

Reuse parts of an existing drainage system where possible, including existing infrastructure and materials.

The lowest-carbon option generally comes with the reuse of a system that is already built on the site. However, when taking this approach, it is also important to consider the condition and maintenance requirements over the design life of the system. A holistic approach is needed to consider the associated impacts on other construction works.

Drainage outfalls, nearby hydrocarbon interceptors or other proprietary pollution control systems, as well as connections to sewers, are all generally good candidates for reuse, even when the site drainage system is mostly replaced.

Reuse is not always the answer, as there are often trade-offs depending on the site itself: it may be more carbon-efficient to resurface an existing car park, reusing its existing sub-base, and to introduce linear swales to intercept and mitigate the run-off, than to replace all surfacing and sub-base with a permeable pavement system.

Use levels in drainage

Closely integrate the drainage system with existing and proposed levels, to minimise the depth of the system and the need for pumping, and to integrate better with the landscape.

Deep drainage systems require deeper excavations, temporary support and larger manholes, all of which increase embodied carbon. The need to minimise pumping and its operational carbon emissions is well understood, but the response to levels should also focus on minimising the system depth and the carbon associated with deep construction; for example, having a pond in the wrong place requiring significant earthworks and impacting the landscape.

Ponds and wetlands should respond to ground contours. Nature-based solutions are beneficial, but ponds are often located in a way that requires significant excavations and embankments, which can have significant carbon impacts.

The carbon impact of pumping beyond the site boundary should also be considered. It may be better to pump and lift water a few metres on site to the river, rather than to discharge to a combined sewer where water will be pumped higher off site to a treatment works, and then pumped again to the river.

Specify low-carbon details

Specify low-carbon materials and construction methods when detailing the system.

The choice of pipe materials, components, storage units and systems, including their surround and bedding, have a significant impact on upfront embodied carbon emissions. The design life, robustness, maintenance cycles and end-of-life disposal should also be carefully considered in assessing whole life carbon impacts.

Clay pipes generally have a lower carbon footprint than PVC or plastic pipes. When assessing the carbon implications of material choices, the whole system needs to be considered holistically. For example, when pipe materials are selected, the surround and bedding should be considered.

Modular stormwater attenuation systems have very varied embodied carbon footprints, and use of virgin materials. This should be carefully considered when selecting a product, and all parts of the system should be taken into account.

Drainage systems offer good opportunities for the use of recycled aggregates or low-carbon concrete for the surround of components.

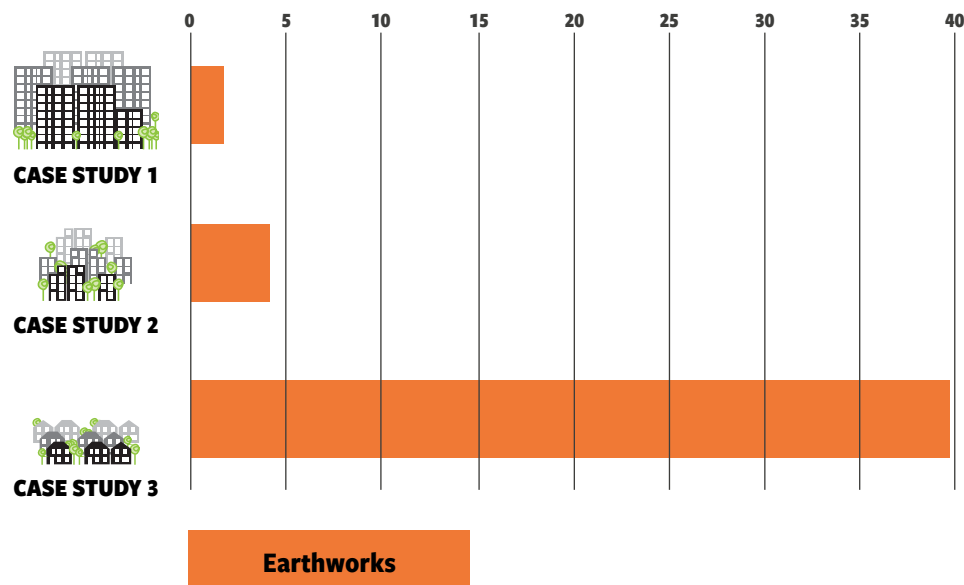
EARTHWORKS OVERVIEW

Earthworks are required to create the levels for buildings, to construct basements, foundations and utilities trenches, and to stabilise steep slopes. Unlike the other subsystems, the emissions associated with earthworks are largely process-driven, comprising the use of plant, as opposed to A1–A3.

In the three **CASE STUDIES**, earthworks accounted for between 10% and 61% of the total enabling infrastructure carbon and had the greatest impact on two of the case studies.

The low value of 10% on CS1 was achieved by optimising the earthworks strategy.

BREAKDOWN OF EARTHWORKS CARBON (kgCO₂e/m².GIA)



KEY PRINCIPLES

Work with the **site's contours**

Optimise levels early on

Align with the **construction phasing**

Do ground investigations early, in two phases

Minimise earth disturbance

Use plant **efficiently**



EARLY LOCK-INS

Locating assets on of unstable ground, which requires deep foundations

Locating **sensitive assets in areas likely to be contaminated**

Not challenging **over-conservative ground movement limits**

EARTHWORKS

APPROACH TO MINIMISING CARBON



Set a clear ambition to minimise carbon in the earthworks process

Define national and local policy requirements for carbon reduction.

Test the feasibility of your ambition by engaging early on with designers and contractors.

Establish appropriate design criteria, based on the needs of the masterplan

Understand what assets are required on the site, and challenge standard, conservative requirements for ground movements for each asset.

For each asset, understand the geotechnical and geoenvironmental ground conditions needed to enable its delivery.

Identify any assets which are particularly sensitive to ground conditions: contamination, settlement, etc.

Adopt a two-phased approach to ground investigation



Phase 1:

Perform an initial high-level ground investigation to identify any risk areas.

Complete an initial light investigation to understand the presence of leaching, contamination or other issues.

Complete an initial desk study to review the findings and understand potential sources, pathways and receptors (SPRs) on the site, and where those might affect sensitive assets.

Identify high risk areas of the site, based on initial findings.

Phase 2:

Perform a targeted ground investigation focused on risk areas, to provide more certainty about those risks.

Select and tailor further tests performed to further investigate and validate what was found in Phase 1, reflecting the needs of the site.

Carry out a geotechnical investigation to understand soil conditions in more detail in problem areas or near sensitive assets.

Map the extent of contaminated or problem soil.

Establish a clear design hierarchy to minimise soil movement and plant emissions

Define clear criteria for site-won soils to be reused on site, taking into account the factors set out in the ICE's *"Earthworks: a guide"*.

Avoid excavating where possible.

Use site-won soils rather than importing, either for other purposes (fill, etc.) or in landscaping bunds to minimise haulage emissions.



Adapt the design to the ground conditions present

Locate sensitive assets away from unstable ground to avoid the need for reinforcement or earth movement.

Locate sensitive assets away from contaminated soil to avoid the need for decontamination.

Coordinate with the other subsystems to align them to the site topography

Minimise the need for ground movement by aligning levels and access infrastructure with the existing site topography.

Identify opportunities to reuse or achieve co-benefits through site arisings

Reuse arisings for landscape bunds or to create visual interest in the landscape.

Identify nearby uses for site-won soils if reuse on site is not possible.

Plan in advance for storage of soils where required, for future uses.

RIBA 0: Strategic definition

RIBA 1: Prep and briefing

RIBA 2: Concept design

EARTHWORKS

TECHNICAL PRINCIPLES AND REFERENCES



Work with the site's contours

Minimise the overall quantity of bulk earthworks activities by working with the natural contours of a site. Balance cut and fill, and maximise the use of site-won materials, where possible.

Generally minimise the changes to levels needed for the development site, and try to work with natural landforms and topography. Reduce the quantity of earth imported to, and exported from, the site, and seek to balance cut and fill.

Avoid the use of deep basement solutions.

Optimise foundation systems for different building typologies, to reduce the depth to formation level and excavation arisings.

Consider the use of site-won materials as engineered fill, even when they sit outside the standard specification categories.

Consider using soil modifications or stabilisation techniques (e.g. lime stabilisation) over the import of engineered fill.

Use any excess material available for construction of landscape features, ecology corridors or noise attenuation bunds.



LITTLE HALDENS, GOMM VALLEY

Gomm Valley is a prime example of planning a site around the existing landscape character. The roads align with the existing contours of the site, reducing the need to move earth excessively for the sake of the site access. Instead, the existing topography was used to inform the site, both reducing carbon in the earthworks strategy, and appreciating and embracing the natural characteristics of the land.

Image courtesy of Periscope

Do GI early, in two phases

Undertake site investigations early and take a two-phased, efficient approach, to inform geotechnical design.

Carrying out ground investigation early can inform the placement of assets where the conditions are suitable, minimising the requirement for stabilisation, remediation or other works later in the design process.

Instead of carrying out extensive investigations on the entire site, ground investigations can be made more efficient (saving both cost and carbon) by carrying out a first phase to identify areas of risk and then a second, more intensive phase to validate those risks.

Use less conservative design parameters when developing earthworks design. Using a more detailed account of the actual ground conditions, specific geotechnical design parameters and performance requirements will lead to a reduction in overall material requirements and resulting carbon savings.

Encourage the use of mobile or pop-up site laboratories to improve the rate at which information about soils is processed and made available for decision-making.

In the first phase, carry out a light investigation informed by desk research to identify potential sources of contamination (including sources, pathways and receptors) and areas of potentially poor ground conditions.

Use this information to inform the second phase of investigation, selecting and tailoring tests to validate the suggested risks from the first phase. Use this information to map with more certainty the extent of contaminated or problem soil.

EARTHWORKS

TECHNICAL PRINCIPLES AND REFERENCES



Optimise levels early on

Coordinate earthworks design with masterplan platform levels, access and drainage strategy.

Optimise earthworks levels across the site by considering the interaction of building levels, highways access and drainage. Iterate a number of times to validate the proposed levels, and fix these constraints before developing detailed design. Leaving this until late in the design process risks setting building levels which have negative knock-on consequences.

Optimise earthworks section geometry and use natural slopes where possible. Reduce the need for geosynthetic and hydrocarbon-based slope strengthening technologies, both of which have high associated embodied carbon.

Where it is not possible to use natural slopes, consider more naturalised embankment systems (for example, Tensar GreenSlope) over traditional, higher-carbon retaining wall technologies.

Undertake a number of iterations of earthworks options testing early in the masterplanning stage, before parameters and levels are fixed.

Where it results in significant excavation, challenge the design team to push against 'nice-to-have' level and slope geometry, e.g. very low-gradient cycling routes.

Report: Decarbonising Infrastructure on Masterplans

Align the construction phasing

Consider the phasing and construction sequencing when developing the earthworks strategy, to prevent the need for material export or storage.

Plan the earthworks activities so that they can be undertaken considering the phasing of the construction of the development. Ensure that, at each stage, a surplus of material is available, but which should not need to be stored for a significant period of time.

Sequence the works to reduce mass-haul distances.

Consider seasonal working and restrictions within the phasing planning.

Minimise the longer-term storage of earthworks materials to ensure they do not degrade over time (as this will require the import of new materials, which adds carbon due to mass-haul).

Align and coordinate all excavation activities, including utilities corridors and creation of ponds and swales, to avoid double-digging.

Consider the opportunities for undertaking earthworks early in the construction sequence, to gain the advantage of longer-term settlement and compaction.

Minimise earth disturbance

Minimise the impact of earthworks activities on ecological networks, habitats and biomass, as all of these 'secondary' benefits contribute to the soil's value as a carbon store.

The ground represents a significant sequestered carbon store, and undertaking earthworks activities intervenes with these natural cycles. Reduce damage to natural systems from earthworks activities, which can cause harm to ecological networks, habitats and biomass.

Protect existing water courses and natural geomorphology. For example, do not block existing water courses and overland flooding routes.

Mitigate against the erosion of fines through surface water run-off, which can have knock-on effects on local environmental receptors.

Where materials from off site are required, consider options for sourcing them from near to the development site, and use low-carbon mass-haul technologies.

Develop the earthworks strategy to minimise the clearance of existing vegetation, mature hedgerows and high-value trees.

Use plant efficiently

Maximise the efficiency of plant (minimising the emissions associated with its use on earthworks) by optimising construction operations.

A significant proportion of the emissions associated with earthworks are from the use of plant for excavation and soil movement. Take steps to reduce carbon during on-site activities (A4–A5) by encouraging industrialised and efficient plant operations, making best use of electrified/hybrid plant, digital twins and construction-sequencing technologies.

Require the use of alternative fuel types (e.g. hybrid and electrified) to reduce carbon emissions in comparison with hydrocarbon-fuelled plant. This can also improve air quality and noise pollution levels on site.

Explore the use of emerging ground improvement techniques including, for example, bioengineering and electrokinetic dewatering.

Incentivise accurate and real-time monitoring and data capture of earthworks activities, combined with the use of connected and autonomous (CAP) plant technologies.

Implement plant tracking and monitoring to assess mass-haulage efficiency and productivity rates.

UTILITIES OVERVIEW



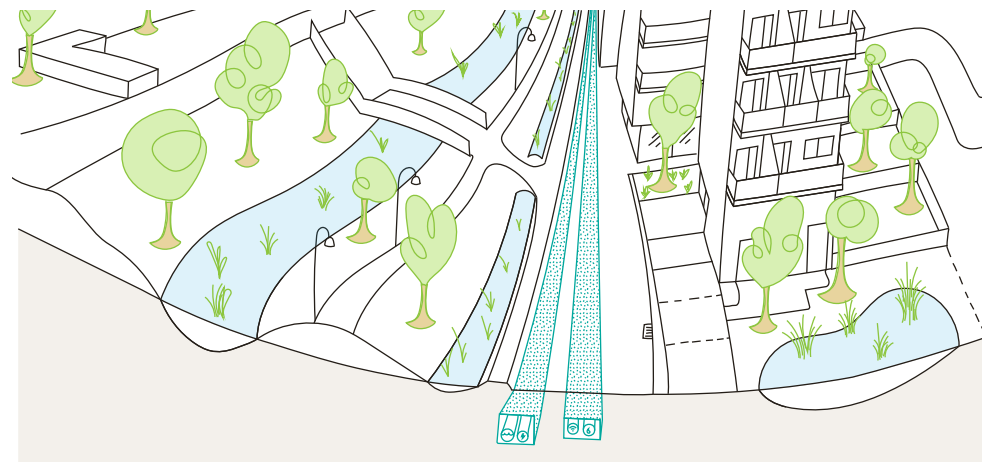
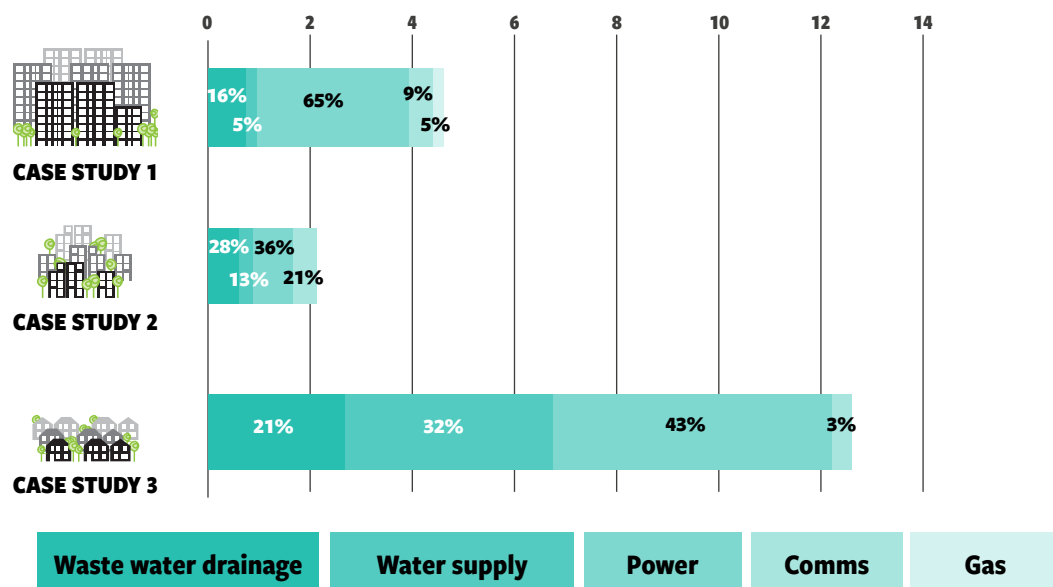
Utilities infrastructure provides power, gas and connectivity to buildings, either to local generation or through connection to the grid.

In the three **CASE STUDIES**, utilities infrastructure accounted for between 16% and 25% of the total enabling infrastructure carbon.

The power infrastructure (particularly cables) was the main hotspot, as were the waste water drainage and water supply (which comprised largely PVC pipes).

This element of the case studies was subject to many assumptions and should therefore be addressed carefully.

BREAKDOWN OF UTILITIES INFRASTRUCTURE CARBON (kgCO₂e/m².GIA)



KEY PRINCIPLES

Understand the **existing network on site**

Reuse existing networks

Align installations with other works

Coordinate services early on

Sequence the works to meet phasing needs

Specify **low-carbon materials**

Keep accurate records of installation



EARLY LOCK-INS

Not aligning installation and maintenance schedules with project phases (double digs)

Missing opportunities to reuse by **not understanding existing infrastructure**

UTILITIES

APPROACH TO MINIMISING CARBON



Set a clear ambition to minimise carbon in the utilities

Define national and local policy requirements for carbon reduction.

Test the feasibility of your ambition by engaging early on with designers and contractors.

Understand the **changing needs of the site in its phases**

Define a plan for the provision of utilities that reflects the project's phases and builds in resilience to future expansion.

Consider the **proximity of the site to utility providers and existing connections/corridors** when selecting a site

Define a plan for utilities provision that reflects the proximity to existing utilities providers, corridors and connections, and identify possible links.

Form a **dedicated team to coordinate the design and installation** of utilities

Build relationships with third-party utility providers, regulatory agencies and impacted stakeholders early on.

Understand how the design of other subsystems impacts the utility design: for example, if stormwater can be stored in areas of low sensitivity, do not overprovide attenuation.

Understand the **capacity and condition of existing on-site utilities** and connections

Locate utility records within the project boundary.

Where possible, use GIS and GPS-obtained data to make sure information is accurate, and consider the reliability of as-built information.

Perform investigations on existing ducts and capacity to understand possibility for reuse.

Make reuse the priority: explore opportunities to reuse what is already on site

Reuse existing pipework and foul water connections where possible.

Define a **proactive operational maintenance schedule**

Make access permissions and responsibilities clear.

Establish a proactive inspection schedule and methodology.

Minimise the need for repeated access to utilities trenches and disruption to related infrastructures

Establish a clear utility-installation programme.

Plan the delivery and installation of utilities so they align with other scheduled works, particularly earthworks and access infrastructure.

Proactively share installation timelines externally with service providers, as well as within the team.

Maintain a shared register of utility installation and repairs to ensure as-built information is clear.

RIBA 0: Strategic definition

RIBA 1: Prep and briefing

RIBA 2: Concept design

UTILITIES

TECHNICAL PRINCIPLES AND REFERENCES



Understand existing infrastructure

Obtain up-to-date and accurate records of existing infrastructure early, to inform the design of new services, including spatial coordination of design proposals.

Understanding the existing utilities infrastructure and layout on the site enables the design to make the most of existing capacity, and minimises the risk of unexpected issues (and carbon-intensive solutions) late on in design or construction.

Do not rely on statutory utilities mapping; this is often indicative, and easements allow for some uncertainty in asset locations. This can lead to conservative, more carbon-intensive approaches.

Identify statutory utility providers and other information holders for the site area, and obtain relevant asset information from them, as well as from site owners and occupiers.

Clearly identify and acknowledge gaps in the information gained, and carry out further surveys (such as GPR and trial holes) to establish the exact locations of existing infrastructure. This may make it possible to reduce easements, enabling more efficient design and, therefore, reducing excess carbon.

Consider using the **National Underground Asset Register (NUAR)** (a digital map of underground pipes and cables) to assist with more comprehensive and coherent searches. As of publication of this report, a Beta version of the NUAR is available in England, Northern Ireland and Wales.

Coordinate services early

Carry out a services coordination exercise early on, to establish 'utilities corridors' and identify any potential service clashes.

Using combined utilities corridors offers one of the greatest opportunities to reduce embodied carbon in utilities, by keeping excavations to a minimum and reducing the need for multiple trenches. To achieve this, the layout should be planned early and a coordinated approach should be taken across the service disciplines.

Use the **NJUG guidance** for 3-D coordination of services, to identify minimum trench widths, shortest below-ground routes and opportunities to utilise combined trenches, based on the services required.

Coordinate the route and depth of services, and optimise the layout, to minimise the width and depth of trenches required, reducing emissions from excavation and trench materials.

Identify appropriate corridors at an early stage, to reduce the carbon impact of installation and future maintenance. Corridors within footpaths can be shallower than in carriageways, requiring less excavation, and replacing the surfacing for future maintenance may have a lower carbon impact.

Align installations where possible

Engage with asset providers, local authorities and nearby developers (where appropriate) to understand other planned works in the area, and coordinate the installation of utilities, to avoid double-digging.

There may be opportunities to combine proposals for new infrastructure with other planned works, to minimise the extent of works being carried out and the risk of excavation of newly installed infrastructure (and unnecessary carbon associated with installation).

Adjacent and nearby sites may be planning to carry out utilities works, which could impact on the infrastructure for the site. Engage with statutory utilities companies and local developers of nearby sites to find opportunities to coordinate upgrade works. This could enable multiple installations to take place at the same time, reducing the carbon associated with multiple excavations.

The **Local Plan for the area** may provide information on upcoming public infrastructure upgrades within the area, which could be combined with infrastructure installations for the site.

UTILITIES

TECHNICAL PRINCIPLES AND REFERENCES



Reuse existing networks

Reuse part or all of the existing utilities networks in situ where possible, but also consider the reuse of redundant pipework, cabling ducting and surround materials elsewhere on the site.

Similarly to surface water drainage, the lowest-carbon option for utilities is usually to reuse the system (or components thereof) that is already built on site. Reuse should take into account the condition and maintenance requirements over the design life of the system. A holistic approach is needed when considering the associated impacts on other construction works.

Use existing ductwork for additional cables if there is sufficient space, rather than excavating to lay new ductwork.

Design for the reuse on site (where possible) of existing pipes or cables that are no longer required. If this is not possible, ensure that these are recycled or made available for reuse off site.

Depending on their condition and capacity, reuse existing utilities connections where possible.

Plan for phasing

Review phasing of infrastructure and consider potential future needs.

Re-excavation of trenches to install infrastructure for later phases, or future increases in demand, can have a high carbon impact. Consider the phasing and installation of infrastructure required to serve future phases while excavations are open. This can also make the development resilient to future increases in demand. Balance this with the need to avoid overprovision and consider the likelihood of future increases in demand, particularly in terms of energy usage.

Plan and sequence the works to reduce the need for multiple trenches being dug at different times during the build. Where services are required for later phases, avoid multiple installations by ensuring that these services are installed in earlier phases.

Where possible, permanent infrastructure should be installed at the outset, to minimise the requirements for additional temporary works during construction or to accommodate phasing.

Consider installing additional ducts for future use while trenches are open, to avoid the need to reexcavate to serve future demand. Be careful, however, not to specify unnecessary materials if demand is not likely to increase.

Specify low-carbon materials

Specify low-carbon materials and construction methods when detailing the system.

The choice of materials for pipework, ductwork, cabling and associated protection, insulation and bedding/surround has a significant impact on upfront embodied carbon emissions. The design life, robustness, maintenance cycles and end-of-life disposal should also be carefully considered in assessing whole life carbon impacts.

Do not assume the need for armoured cables by default; armoured cables have a higher carbon footprint than standard cables. Consider whether additional investigations and a better understanding of the environmental factors could mitigate the need for armoured cables.

Use infrastructure networks as a low-sensitivity opportunity to use recycled aggregates or low-carbon concrete for surround to pipework and ductwork.

Keep accurate records of installation

Accurately record all utilities infrastructure installed and ensure digital records are held in the building information management (BIM) system.

The quality of record information available for utilities networks is critical for efficiently and effectively managing their future operation, maintenance, modification and decommissioning.

Poor knowledge of the type and location of assets can cause future carbon impacts: for example, new services may be installed unnecessarily if there is not good information about existing services.

Reidentification of services at a later date, (for example, using trial holes) to determine exact locations also results in unnecessary emissions.

Make sure accurate as-built information is produced and provided in the health and safety file and shared with all relevant parties at the end of the project.

Wider adoption of the NUAR is likely to present easier opportunities to record and share information about utilities networks as they are installed.

ACCESS INFRASTRUCTURE OVERVIEW

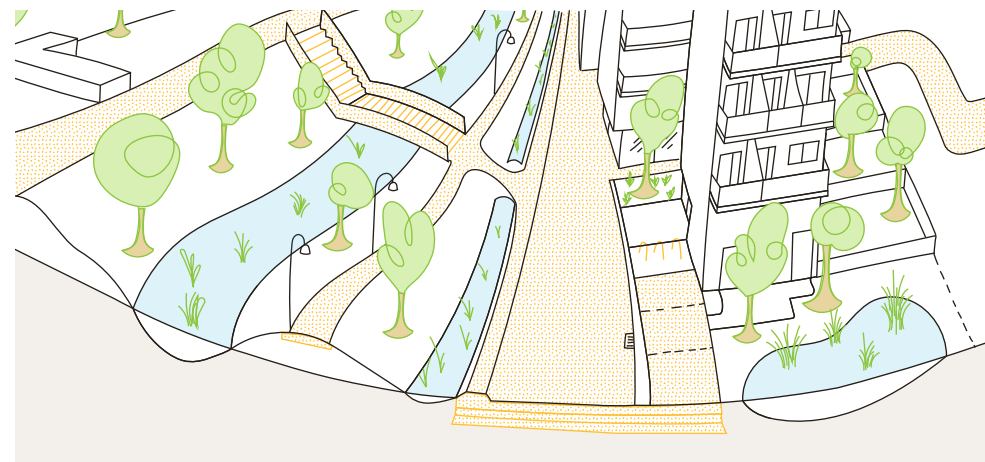
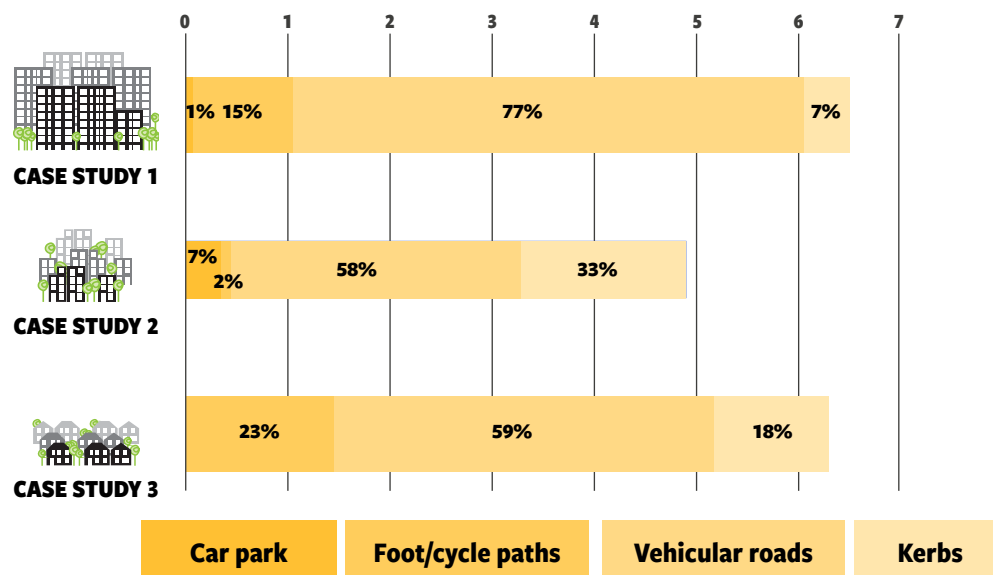


Access infrastructure enables people and goods to move to, from and around a development: on foot, by rolling, by public transport, by car or any other mode.

In the **CASE STUDIES**, access infrastructure represented the largest source of emissions in CS1/CS2, and the second largest in CS3.

In all the case studies, the vast majority of the embodied carbon in the access infrastructure was attributed to the vehicular roads and kerbs. The constituent materials (concrete, asphalt, binders, and aggregate) were some of the most embodied carbon-intensive on the projects.

BREAKDOWN OF ACCESS INFRASTRUCTURE CARBON (kgCO₂e/m².GIA)



KEY PRINCIPLES

Vision-led planning: design for people first

Reduce the land take for grey infrastructure

Slower streets = safer streets
Move roads down the **movement hierarchy**

Integrate streets **with homes**

Green and blue infrastructure

Design for **maintenance and adaptability**

Use low-carbon **materials**



EARLY LOCK-INS

High default parking ratios
driving plot layouts, and hence also road layouts

Lack of flexible provision for changing mode split over time

ACCESS INFRASTRUCTURE APPROACH TO MINIMISING CARBON



Set a clear ambition to minimise carbon in the access infrastructure

Define national and local policy requirements for carbon reduction.

Test the feasibility of your ambition by engaging early on with designers and contractors.

Understand the needs of the community

Perform travel planning analysis, or engage with a travel planner.

Gather data on existing or local car ownership.

Understand the access requirements of the target demographics.

Define minimum access requirements for freight, deliveries, emergency, etc.

Gather accurate information on existing access infrastructure and site conditions

Understand the location, condition and current usage of existing access infrastructure.

Understand existing topography and ground information.

Coordinate with earthworks to understand possible arisings from site excavation.

Establish a design hierarchy that prioritises active travel and low-speed roads, and reuse of existing infrastructure and site materials

Minimise the need for high-speed roads where possible, as these can require more intensive build-ups (in addition to contributing to air pollution).

Prioritise the use of existing access infrastructure provision on or near to the site, including public transport networks.

STOP!

Before proceeding to concept design, have you **challenged the default** provision for parking, and tailored the design to the specific needs of the community?

Incorporate phasing into the access strategy to account for the changing needs of the community

Challenge statutory requirements for parking spaces, based on the community's needs.

Plan to collect evidence from early phases to make the case for changes (such as provision of active travel infrastructure or changing use of parking provision) at later phases.

Consider the implications of phasing on the maintenance strategy and utilities renewals.

Explore opportunities to **reuse site-won material** for access infrastructure build-ups and surfacing

Utilise site arisings for access infrastructure build-ups where possible.

Coordinate the design and delivery of access infrastructure with the earthworks and utilities strategies

Design active travel routes in line with the site topography, to balance the need for earthworks with accessibility.

Align the delivery with the installation of utilities, to minimise the emissions associated with repeat excavations.

Prioritise **design for adaptability and flexibility** of access infrastructure

Design access infrastructure to be adaptable to different uses as needs change and mode split changes, to avoid having to deconstruct/demolish infrastructure as it is no longer needed.

Explore opportunities for access infrastructure to be multifunctional, such as by using green paving for emergency access.

Design space for shared mobility schemes and electric vehicle charging.

RIBA 0: Strategic definition

RIBA 1: Prep and briefing

RIBA 2: Concept design

ACCESS INFRASTRUCTURE

TECHNICAL PRINCIPLES AND REFERENCES



The new National Planning Policy Framework (updated December 2024) directs planners and designers towards a ‘vision-led’ approach to transport planning, rather than designing to meet projected, future capacity requirements. A vision-led approach is defined as one ‘based on setting outcomes for a development based on achieving well-designed, sustainable and popular places, and providing the transport solutions to deliver those outcomes, as opposed to predicting future demand to provide capacity (often referred to as ‘predict and provide’)’.

The NPPF also sets out ‘Golden Rules’ for developing housing on land released from Green Belt, including the requirement that residents should have access to good-quality green spaces within a short walk of their homes.

More so than any of the other subsystems, the provision of access infrastructure has a huge impact on the operational carbon of the development and the wellbeing of its occupants, due to its role in driving modal shift.

The technical principles for access infrastructure are therefore divided into two themes: the first relates to designing to enable modal shift while meeting the needs of a community’s residents (and being resilient to those changing needs), while the second specifically focuses on the embodied carbon of the access infrastructure itself.



Image: Bailrigg Garden Village, courtesy of JTP

Vision-led transport planning: design for people first

Design access infrastructure to enable a modal shift away from reliance on private cars, while considering the changing needs of residents.

New communities must be designed to facilitate and encourage a modal shift away from reliance on the private car. The environmental benefits of this extend to potentially significant reductions in grey infrastructure, more space for green infrastructure and correspondingly significant reductions in embodied carbon.

Designs should be coordinated from early stages between urban designers, transport planners, landscape architects and highways engineers, to maximise efficiency in the layout while focusing on street character, usability and placemaking.

Where vehicular routes will pass through new development, designers should set out to create people-friendly streets, not car-first roads.

Seek to maximise the amount of development served by grey infrastructure by increasing densities, while also minimising road length and area.

Vision-led planning should mean that assessment of future capacity does not result in ‘over-delivery’ of road infrastructure from Day 1: for example, through the inclusion of additional turning lanes and segregation of routes, catering for a potential scenario 5, 10 or 20 years from Day 1.

When designing streets and active travel routes, focus should be on lean design principles. Where possible, layouts should be straightforward (but without encouraging car-use as a result of their convenience), and prioritise pedestrians, cyclists and public-transport users.

Locate services locally, to minimise the distance people need to travel to reach shops, pharmacies, green spaces and other amenities.

ACCESS INFRASTRUCTURE

TECHNICAL PRINCIPLES AND REFERENCES - FOR MODAL SHIFT



Reduce the land take for grey infrastructure

Design the streets around the needs of those using the community, and use density to minimise the amount of grey infrastructure and hardstanding.

Road infrastructure accounts for a significant proportion of the embodied carbon attributable to any large development that includes new movement/vehicular infrastructure. Every design decision that adds to the land-take of roads, footpaths and cycle paths therefore adds to the embodied carbon impacts. Ultimately 'building less' is a key component of reducing embodied carbon in the delivery of new streets and active travel routes. Roads are necessary, but should not be principal determinants of the character or structure of a new community.

Segregated footpaths and cycle paths can increase pedestrian and cyclist safety, and encourage active travel where they are provided. However, the problem should first be tackled at source: wherever possible, traffic speeds and volumes should be reduced substantially by design, such that risks to non-motorised users are substantially reduced and their status as users of the street is elevated.

Test first whether segregation is necessary: with its benefits can come challenges, not least in permeability for people moving at 90 degrees to the direction of the main route and needing to cross it, and in the added embodied carbon of additional lanes and paths.

Segregation reduces enclosure and increases land-take (and, therefore, embodied carbon) in the infrastructure required to cross segregated components of a street: verges, cycle paths, footpaths. Designs should factor this into decision-making about segregation and roadside SuDS.

Challenge expectations of primary routes connecting only to secondary routes, which then connect to tertiary routes: it is possible to move quickly from a higher tier route on the network into a finer grain of tertiary streets.

Move roads down the movement hierarchy

Prioritise car-free, lower-tier streets and do not default to these as a starting point.

Roads and paths should be commensurate with the scale of development that they will serve. If a planned route is not connecting settlements or destinations with a catchment wider than the development it is passing through, then its non-strategic role should be reflected in its design. Lower traffic volumes should be accommodated via people-friendly streets, not via roads with excess capacity.

Rather than adopting a primary/secondary/tertiary approach to street hierarchy, start with the lower tier, car-free or low-speed streets, and only introduce higher tiers where necessary.

Do not default at the outset to the terminology of 'primary streets' or 'primary roads': this sets expectations for a road format that may not be appropriate, nor required.

Only add extra carriageway width/lanes to corridors when the intensity of use fundamentally demands it: i.e. where narrower routes or fewer lanes could not support a reasonably maintained movement of traffic.



GOLDSMITH STREET

Goldsmith Street is a high-density social housing scheme in Norwich. The scheme was delivered affordably, while also creating an attractive, pedestrian-priority street network, where every home has car-free access.

Where a typical UK housing scheme allocates 40% of space to vehicles (roads and parking), careful design of the streets and parking areas reduced this to 15% on the scheme, allowing 25% of the site to be given over to shared green spaces, gardens and biodiverse areas.

Images and text provided by Mikhail Riches Architecture

ACCESS INFRASTRUCTURE

TECHNICAL PRINCIPLES AND REFERENCES - FOR MODAL SHIFT



Integrate streets with homes

Create streets at a scale that suits the surrounding homes.

Shared drives or access roads parallel to a principal route can add more than 50% extra embodied carbon to a movement corridor. Corridor width (when measured as the building 'front-to-front' dimension across a route) can be the equivalent to an eight-lane motorway when drives or access roads serving properties are included either side of the main route. Unless lined by buildings of six or more storeys, a sense of enclosure is lost, while the primacy of the central carriageway is emphasised, perpetuating 'car-first' environments that create severance and encourage speed.

Test opportunities for direct plot access to building plots and how the main route serving these can be designed and delivered to allow it.

Design flexibility for points of access from main routes into development parcels where possible, so that implementation of that route does not prohibit multiple points of direct plot access when the design and delivery of that parcel comes forward.

Where car parking is located to the rear of buildings, minimise the length of access routes connecting to it.

Explore opportunities for off-plot car parking in areas initially used for housing, but on land that could be repurposed in the future.



LEEDS CLIMATE INNOVATION DISTRICT

Leeds CID is a car-free development. Emergency access is enabled by a 'functional landscape' which provides green space and enables attenuation, while providing a suitable surface for emergency vehicles to access homes, if needed.

Image sourced from New London Architecture

Green and blue infrastructure

Integrate green and blue infrastructure into the design of access infrastructure and movement corridors.

By reducing grey infrastructure and integrating green and blue infrastructure within movement corridors, designers can reduce the carbon associated with paving, as well as reducing capacity requirements for surface water drainage. Planting and SuDS features can also provide added value in terms of improved climate resilience, by reducing urban heat island effects, and helping to create streets that facilitate walkable neighbourhoods. This encourages a modal shift away from private car use for short journeys.

Green infrastructure should be considered as integrated, rather than segregated, in the design of movement corridors.

Designers must work early on, with developers and local authorities (including LLFAs) to understand how planting and SuDS features within movement corridors will be maintained, and the implications of adoption, if they are to be adopted.

Slower streets = safer streets

Streets should be designed to reduce speed, improving safety and air quality, and minimising surfacing emissions.

The size, alignment and character of roads directly influences driver behaviour, with corresponding impacts on safety, emissions and road wear-and-tear/maintenance requirements. Greater carriageway and corridor widths encourage greater vehicular speeds and often lead to the implementation of retrofitted traffic calming measures, in an attempt to solve a problem created by the design of the road.

Start with the objective of 'cars as guests' in residential and built-up areas.

Use enclosure and 'side friction' (achieved through proximity and scale of built form next to vehicular routes) for traffic calming on roads.

Articulate the wider benefits of designing for lower speeds: reduced vehicle carbon emissions, improved air quality and reduced need for carbon-intensive, high-friction surfacing.

Integrate narrowings and priority passing-places, green infrastructure and lateral deflection into carriageway alignment in order to slow vehicle speeds and improve safety for pedestrians.

ACCESS INFRASTRUCTURE

TECHNICAL PRINCIPLES AND REFERENCES - FOR INFRASTRUCTURE



Design for maintenance

Design to minimise the carbon associated with maintenance throughout the life cycle of the access network.

Roads are notoriously difficult to maintain, causing strain on the surrounding network, frustration for local stakeholders and additional embodied carbon due to repairs and reworking. This can be improved on by designing carefully for maintenance and operation, taking into account material durability, future growth and safety.

Prioritise material durability to extend the lifespan of asphalt surfaces and reduce resurfacing frequency, patching/haunching and associated material use.

Consider how to meet the needs of everyone using the development, while also minimising the use of unnecessary street clutter (including signage and signalling systems), which can add upfront carbon.

Check unusual vehicle access scenarios and ensure sufficient space is provided to undertake routine and emergency maintenance safely. Additionally, explore opportunities for secondary use of paved areas and hardstanding for vehicle access.

Design for adaptability

Consider adaptability, decommissioning and circular economy principles.

The design of the road should consider future adaptation, future demand and decommissioning, to ensure that the on-site network is resilient to changes in mode and demand, and to ensure that the materials used in highways and paving can be reused or recycled at end of life.

Coordinate with the local authority to understand the future plans for the local transport context and how these might change use patterns on the site.

When designing for streets, consider how the site network could be adapted for future developments in transport technologies, including autonomous vehicles and rapid transit systems.

Design streets to be climate resilient: where asphalt is needed, specify mixes to withstand increased temperatures.

Provide accurate and detailed as-built records of the materials used, to be maintained by the adopting authority and operator, in order to enable future reuse and/or recycling of materials.

Reduce the number of joints (for example, through echelon paving) to enable deconstruction and reuse where possible.

Use low-carbon materials

Where hardstanding is required, reduce the need for high-carbon materials and plant as much as possible.

A large proportion of the embodied carbon of a pavement is in the pavement build-up of a road and, in particular, the surfacing layer. Every tonne of asphalt that is laid emits an average of 70kgCO₂e. Designers should consider low-carbon pavement specifications and contractors should employ emerging construction technologies that reduce the carbon associated with plant.

Specify warm-mix asphalt over hot mix products, and consider emerging biobinder products as a greener alternative to conventional neat asphalt binders

Use available pavement embodied carbon footprint tools such as asPECT, which are broadly compatible with PAS 2050.

Improve the durability of asphalt by using bitumen modifiers, or improve joint sealants to change the balance of stiffness and crack resistance.

Use permeable pavement techniques, which will improve drainage and reduce embodied carbon associated with below-ground plastic attenuation crates.

Use reclaimed material and recycled asphalt pavement (RAP), where possible: this helps to save costs associated with transport and disposal of materials.

Source materials such as asphalt, concrete and aggregate from plants and facilities which use low-carbon energy sources and minimise water consumption.

Source materials from as close as possible to the site, to minimise emissions from mass haul.

Where concrete is needed (for example, in maintenance, ancillary structures, bridges and foundations), specify low-carbon concrete alternatives (for example, transition from GGBS to limestone cements or ternary blends with lower GGBS contents).

Reduce aggregate moisture content to reduce energy demand during batching.

GUIDANCE AND DESIGN PRINCIPLES

COLLABORATIVE GOALS

Collaboration, the need for trade-offs and the potential for cobenefits is a common thread for much of this guidance.

This page summarises some of the key areas for collaboration and shared benefits/compromises between each of the subsystems.

As a client or designer, seeking these out, and working with teams who are leading other packages, can help to minimise carbon and save cost.

SURFACE WATER DRAINAGE



Prioritise source control to minimise the combined load of stormwater and foul water drainage.
Harvest stormwater/surface water run-off for greywater use on site, minimising the need for utilities infrastructure to provide water drawn from the grid.
 Develop an installation/maintenance plan where **drainage and utilities infrastructure is installed and maintained at the same time**, minimising the need for repeated excavations.



Minimise paved areas, and therefore run-off, to reduce the additional load on the drainage system. Maximise the permeability of access infrastructure surfaces (roads, paths and cycle lanes) by **utilising permeable paving or grass pavers** to minimise the additional run-off.
Challenge the standard flood protection required for access infrastructure and develop a strategy for safely using non-critical assets for floodwater storage for 1:100-year events.



Design the **drainage strategy to utilise the existing topography on site**, minimising the need for (and emissions associated with) soil movement or pumping. If soil movement is needed for remediation, geotechnical or other reasons, **utilise any cut arisings for drainage matrix or pipe surrounds** before importing new material.
 Use **permeable earthworks approaches** to minimise additional run-off and strain on the drainage system.

EARTHWORKS



Align excavation schedules when developing an installation plan, to enable the digging of trenches to take place at a similar time to drainage excavations and general earthworks activities.

Ensure coordination happens at an early stage, to minimise the risk of earthworks unintentionally damaging existing utilities corridors on site.

Align roads, paths and cycle tracks to utilise the contours of the site (and consider how travel infrastructure is set out) to minimise the need for earthworks, levelling for cycle paths and active travel gradients, and slope stabilisation.

Where possible, **use site arisings for road and path construction** (in the base or sub-base layers), before importing fill.

ACCESS INFRASTRUCTURE

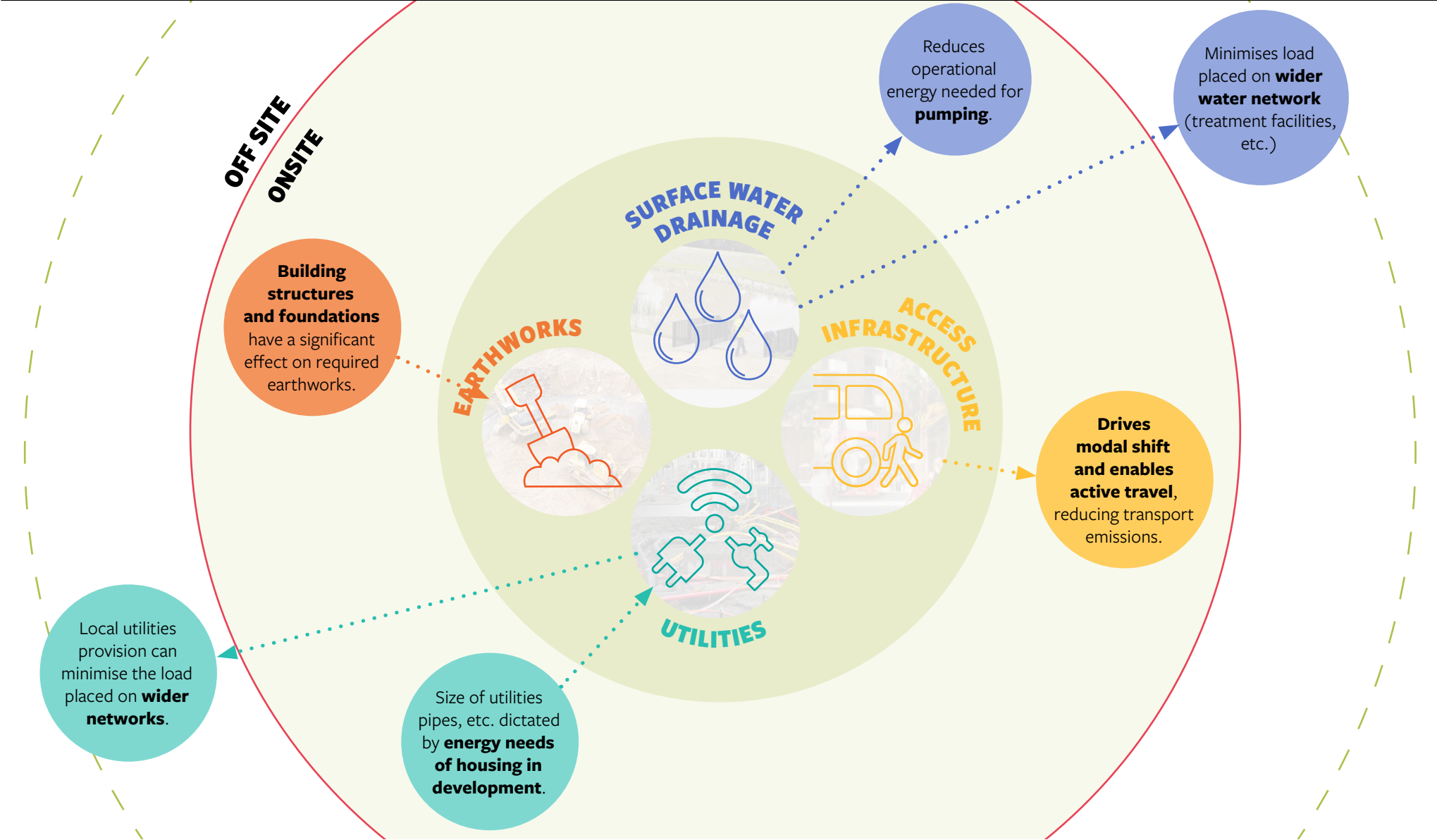


Where possible, **iterate the utilities alignment to prioritise placing corridors under pavements** (as less excavation is likely to be required and replacement of the surfacing may be less carbon-intensive compared with a highway).

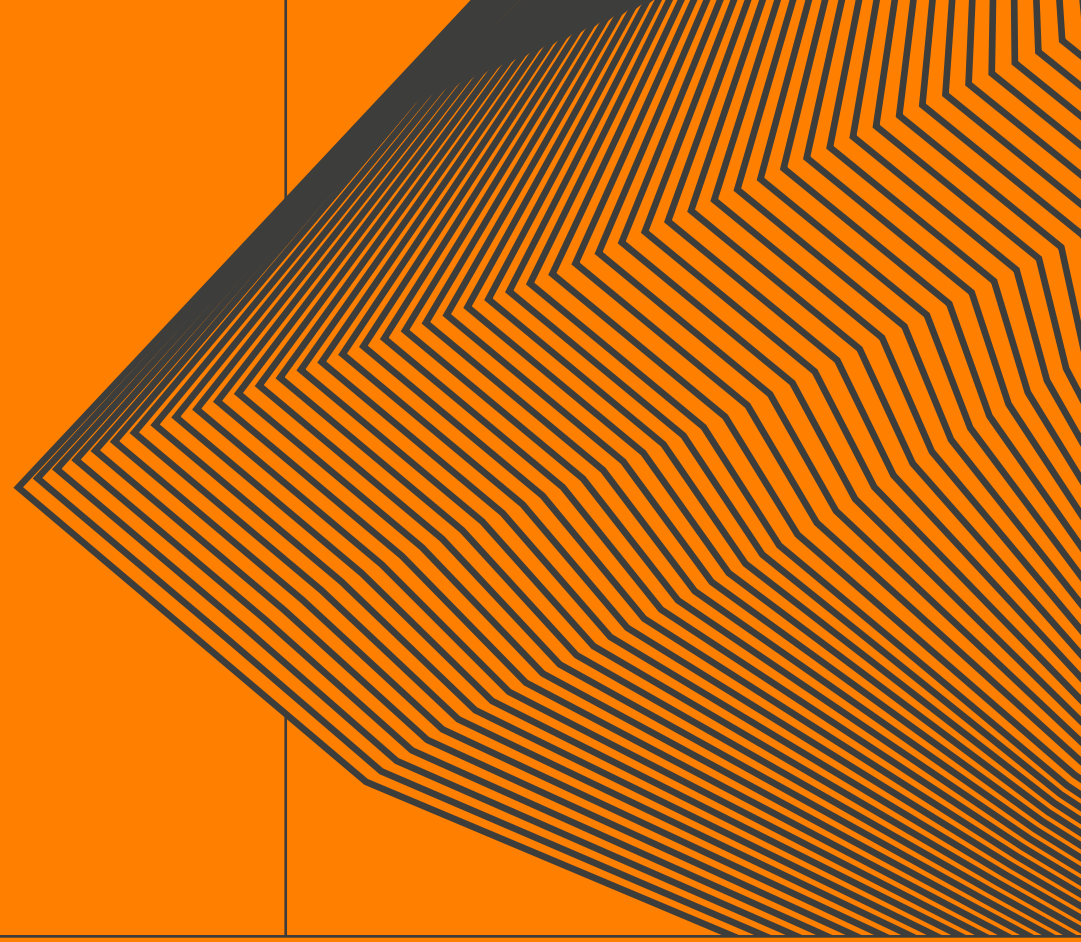
Align maintenance schedules for access infrastructure with utilities to prevent repeated excavations.

OTHER CONSIDERATIONS

IMPACTS ON BUILDING AND OPERATIONAL CARBON



05



RECOMMENDATIONS

RECOMMENDATIONS TO THOSE WORKING ON MASTERPLANS

As set out by PAS 2080, clients, designers and others can have the greatest impact on creating a sustainable, low-carbon masterplan at the early stages: in the selection of a site, the planning of how the land is used, and in developing the brief and concept.

A sustainable, low-carbon masterplan is one that:

- puts people first
- enables car-free lifestyles
- responds to and works with the existing site conditions
- prioritises nature-based solutions to manage water resources and flooding in an integrated way.

Use the principles set out in this guide (summarised here) to inform how you set up a project, plan the use of a site, and design each of these subsystems.

When planning the **LAND USE:**

Work with the site's contours

Minimise hard-landscaped areas

Allow space for sustainable infrastructure

Place assets in suitable locations

When setting up the **PROJECT TEAM:**

Set a clear vision across the design team

Account for the extra cost of challenging the default

Set a clear approach to monitoring carbon at the outset of the project

Engage early with the supply chain

At the early stages of designing each of the **SUBSYSTEMS:**



RIBA 0: Strategic definition

Set a **clear ambition** to reduce carbon

Set the **right design criteria** and **challenge conservative defaults**

RIBA 1: Prep and briefing

Understand **the needs and characteristics of the site** and its occupants

Establish a **clear design hierarchy** to prioritise low-carbon options

RIBA 2: Concept design

Reuse what's on site and develop a design that **works with the site's characteristics**

Align the design with other relevant infrastructures

Consider **TRADE-OFFS** and **IMPACTS BEYOND EMBODIED CARBON**

RECOMMENDATIONS TO THOSE DRIVING CHANGE IN THE INDUSTRY

Minimising the carbon associated with infrastructure on masterplans is critical to ensuring that the delivery of housing in the UK does not compromise the Net Zero target.

The case studies in this research demonstrate initial insights into the embodied carbon hotspots within enabling infrastructure in masterplans. However, they highlight a number of challenges to carrying out these calculations and the current reliance on assumptions.

This research has highlighted the need for the following areas of further work:

1 THE IMPLEMENTATION GAP

Interviews suggested that very few organisations are measuring infrastructure carbon in masterplans or driving its reduction.

Recommendations:

- 1.1 Engagement, to understand the level of adoption of embodied carbon measurement and reduction of infrastructure, and the barriers to adoption.
- 1.2 Testing of the guidance principles set out in this document with practitioners, to understand barriers to adoption.

2 BENCHMARKS AND A COMMON APPROACH TO REPORTING

A common approach to reporting and benchmarks for good practice are needed: currently, there is little evidence of what 'good' looks like, nor is there a standard approach or scope for carbon calculation for masterplan infrastructure.

Recommendations:

- 2.1 Development of benchmarks and/or simplified approaches to estimate on-site development of benchmarks for energy use and carbon emissions during the construction of infrastructure assets and earthworks (module A5.2)
- 2.2 Development of guidance for minimising the carbon associated with hard and soft landscaping.

3 THE IMPLICATIONS OF DENSITY

The three case studies provided initial insights into how densities and development types affect infrastructure carbon, but these are a small sample from which to draw broad conclusions.

Recommendation:

- 3.1 Study of the infrastructure's embodied and whole life carbon intensity (i.e. per population, per dwelling, per floorspace) of a set of archetypal neighbourhoods, representing current and emerging urban development patterns in the UK.

4 DATA GAPS

The carbon impacts of landscaping, energy systems and soils were not considered in this research, but may carry embodied carbon implications or present opportunities for capture.

Recommendations:

- 4.1 Study of the embodied carbon impacts of existing and emerging energy system infrastructure.
- 4.2 Study of carbon impacts and storage opportunities through soils.

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