

Urban Insight

Urban Insight is a long-term initiative that provides insights about sustainable urban development, seen from a citizen's perspective. The initiative is built on a series of reports, based on facts and research, written by Sweco's experts. The initiative provides society and decision-makers with facts needed to understand and meet current and future challenges.

Carbon Cost in Infrastructure: The Key to the Climate Crisis? is the first in a series of Urban Insight reports from Sweco on the topic Climate Action in which our experts highlight specific data, facts and science that are needed to plan and build safe and resilient future urban environments.

Visit our website: [Swecourbaninsight.com](https://swecourbaninsight.com) to explore the insights

Climate Action 2020

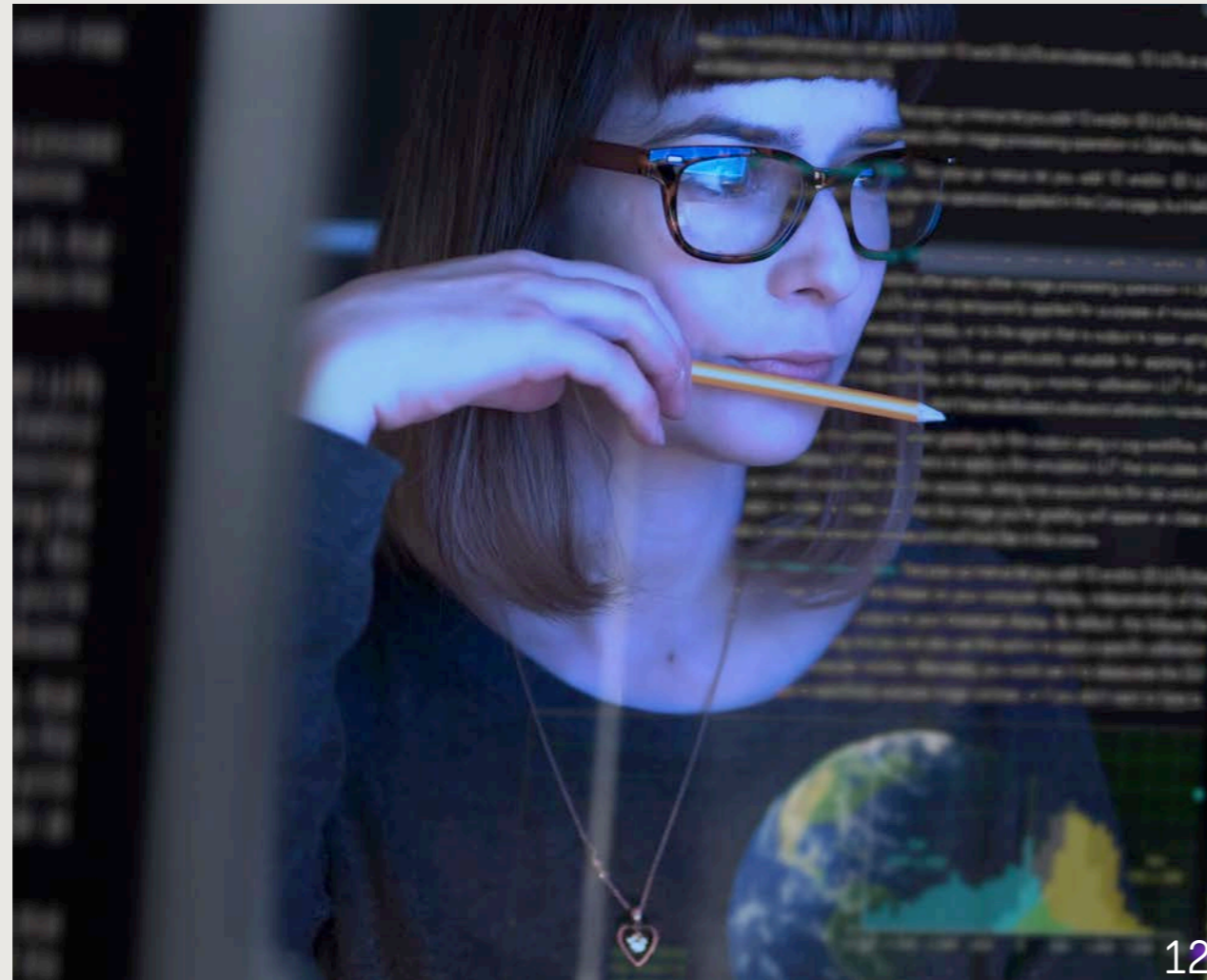
Urban Insight

Carbon Cost in Infrastructure

The Key to the Climate Crisis?

Reducing infrastructure emissions to net zero will require fundamental changes to the way infrastructure is designed, constructed and operated.

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Carbon Cost in Infrastructure *The Key to the Climate Crisis?*

Content

Foreword	4
The Carbon Impact of Infrastructure	6
Carbon and Cost Correlation	8
The Carbon Cost Tipping Point	12
Beyond the Tipping Point	14
Making it Happen	16
Contractual Carbon Reduction	20
Accelerating Change	22
Conclusions	24
About the Authors	26
References	27



1,300+

Climate Emergency Declarations
across 25 countries

Foreword

We understand that there is a relationship between the carbon emissions we produce and the climate change they cause, but we are only beginning to comprehend the urgency of our situation.

Governments, major cities and large organisations around the world are responding by declaring climate emergencies. Over 1,300 local governments and public bodies across 25 countries have made declarations,¹ including the European Union in November 2019. Such declarations are rapidly being followed by pledges for dramatic carbon reduction.

Climate Emergency Declarations are rapidly being followed by pledges for dramatic carbon reduction

The Intergovernmental Panel on Climate Change states that we must reduce global carbon emissions to 'net zero' by 2050 if we hope to limit global warming to 1.5°C above pre-industrial levels, meet the goals of the Paris Agreement and prevent catastrophic climate change.² This has led to the emergence of net zero carbon targets, such as those set by the United Kingdom and Sweden in 2019, with the EU expressing its intention to become the first net zero continent.³

It is estimated that reaching net zero in the UK by 2050 will require spending 1-2% of gross domestic product (GDP) per year,⁴ and the European Commission has suggested that 2.8% of EU GDP will need to be invested annually.⁵

With increasing governmental and public attention on minimising carbon emissions, the construction and operation of infrastructure has been identified as a major issue. However, reducing infrastructure emissions to net zero is a significant challenge that will require fundamental changes to the way infrastructure is designed, constructed and operated.

Using industry-leading research and experience from the UK and Sweden, this Urban Insight report sets out the urgent need to address infrastructure carbon emissions in a new way – through carbon cost management.

The Carbon Impact of Infrastructure

The construction and operation of infrastructure worldwide has significantly contributed to the current climate emergency. UK government analysis of infrastructure emissions concluded that the combined economic sectors of transport, water, waste, energy and communications are responsible for over half of national carbon emissions, a proportion that is expected to increase substantially in the coming decades. The construction, operation and maintenance of these infrastructure assets contributes approximately 16% of total UK carbon emissions. When the use of infrastructure is incorporated, this figure rises to 53%, a proportion that is expected to increase to over 90% in the coming decades.^{6,7}

As our urban population grows, so will the requirement for new and improved infrastructure

Infrastructure emissions are not only a problem for the UK. The situation is the same internationally with existing and planned infrastructure. Asset owners, designers, engineers and their supply chains all have a pivotal role in preventing climate change.

As our population grows, the requirement for new and improved infrastructure is set to continue. We must therefore ensure that the assets we create contribute towards carbon reduction objectives, as part of wider national and international plans for net zero emissions. Reductions are already being made in operational carbon emissions, largely due to recent progress in decarbonising the electricity supply both within the UK⁴ and throughout Europe.⁸ However, as this low-hanging fruit is addressed, the increasing significance of embodied carbon in infrastructure becomes clear.

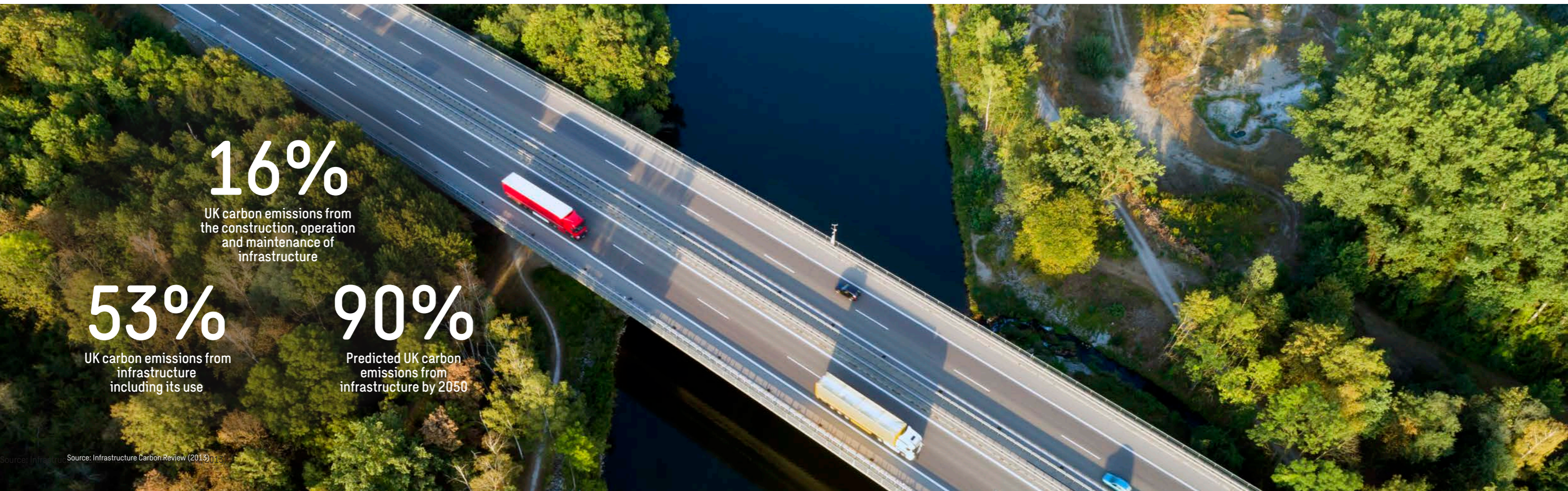
Countries are beginning to recognise the importance of managing infrastructure carbon,⁹ particularly in the context of net zero targets. The UK Green Building Council has recommended that a whole life carbon target be established for the infrastructure industry.¹⁰ Sweden has already taken steps towards action by setting carbon reduction requirements for all infrastructure projects over €5 million.¹¹

Governments worldwide are acknowledging that reducing carbon emissions to net zero will involve investment. Determining the necessary amount of investment requires an understanding of the relationship between carbon and cost in infrastructure.

The infrastructure sector has a major role in achieving carbon reduction targets

CARBON TERMINOLOGY

Carbon:	Shorthand for all greenhouse gases, quantified in tonnes of carbon dioxide equivalent (tCO ₂ e)
Embodied Carbon:	Emissions associated with the creation of an asset
Operational Carbon:	Emissions associated with the operation and maintenance of an asset, quantified in tCO ₂ e/year
Whole Life Carbon:	Emissions associated with the entire life cycle of an asset



16%

UK carbon emissions from the construction, operation and maintenance of infrastructure

53%

UK carbon emissions from infrastructure including its use

90%

Predicted UK carbon emissions from infrastructure by 2050



Carbon and Cost Correlation

There is a strong relationship between carbon and cost in infrastructure. Carbon is a proxy for energy, the use of natural resources and quantities of materials. Reducing carbon therefore usually reduces cost.

“Reduce carbon, reduce cost” is perhaps the principal message from the Infrastructure Carbon Review, a message that was intended to reassure stakeholders who may be concerned that lower carbon solutions will result in reduced levels of service or increased costs. This negative perception of carbon reduction is gradually being addressed as empirical data from infrastructure projects is shared, although there is still a lack of this information across the industry.

The UK government promoted this message in 2013 through the Treasury’s Infrastructure Carbon Review. The report emphasised the importance of addressing carbon at the earliest stage of the design process. As with cost, the greatest potential to reduce carbon exists at the earliest stages of a project when the most influential design decisions are made. Conversely, if left until later in the design process, fewer options remain for both carbon and cost reduction.

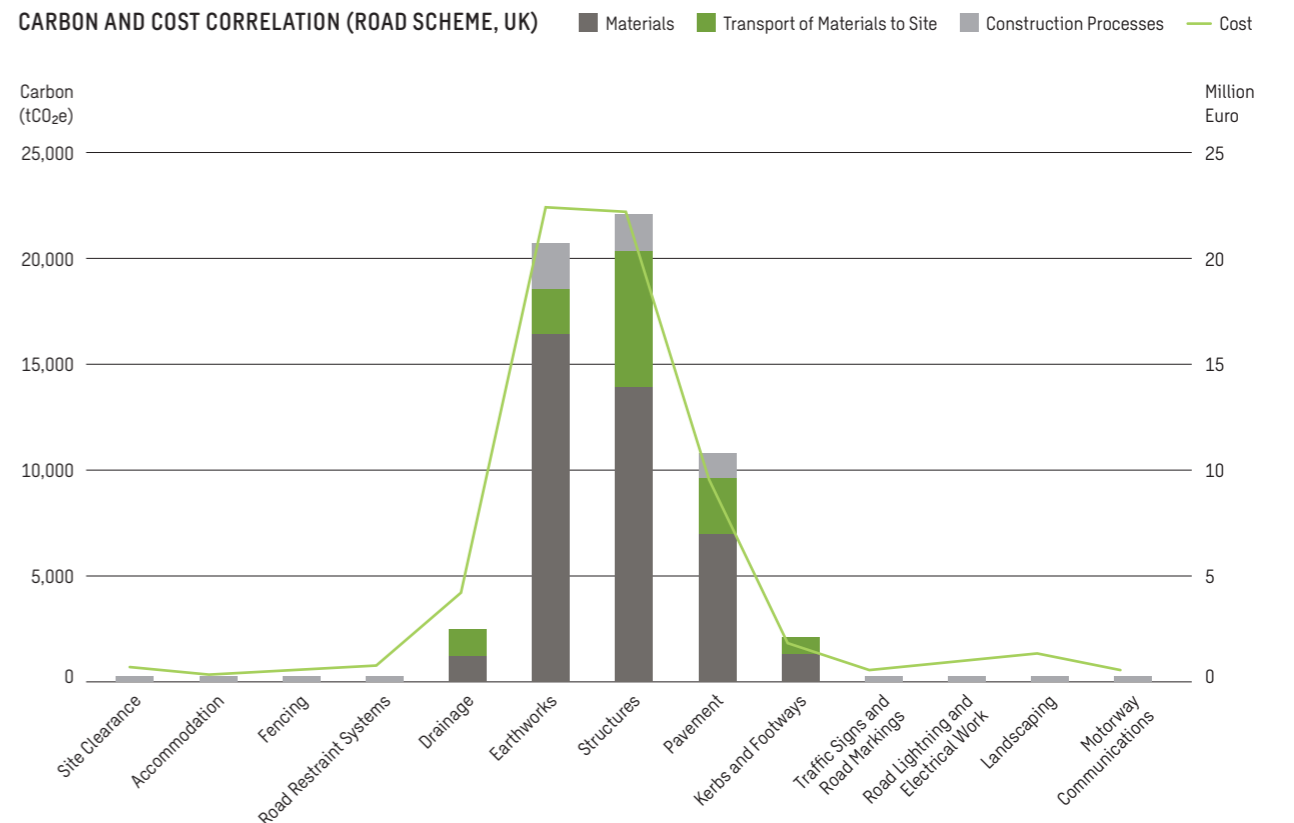
There is a strong relationship between carbon and cost

TACKLE CARBON AND COST EARLY



Source: Infrastructure Carbon Review (2013)

CARBON AND COST CORRELATION (ROAD SCHEME, UK)



Source: Sweco project data

The graphs presented in this chapter illustrate the carbon emissions and costs associated with the construction of recent large road schemes, categorised by key design elements.¹² The alignment between carbon and cost is clear, with the greatest carbon emissions and financial costs usually associated with earthworks, structures, pavements and drainage.

These high carbon and cost categories are consistent throughout most infrastructure projects, and this relationship between carbon and cost has been replicated and reinforced through analysis of several other international schemes.¹³ There is therefore an additional incentive to reduce carbon emissions in infrastructure beyond solely the prevention of climate change: it should also reduce costs. However, there are some important caveats to this approach, as will be explained in the following sections.

CARBON COST INTENSITY

Knowing that there is a relationship between carbon and cost is important, but to practically apply this knowledge requires a deeper level of understanding. For this we can use a metric called Carbon Cost Intensity (CCI).

Similar to the concept of emissions intensity, a measure of the level of carbon emissions per unit of economic output,¹⁴ CCI is a measure of the carbon emitted for each unit of cost

"Reduce carbon, reduce cost" is only the beginning

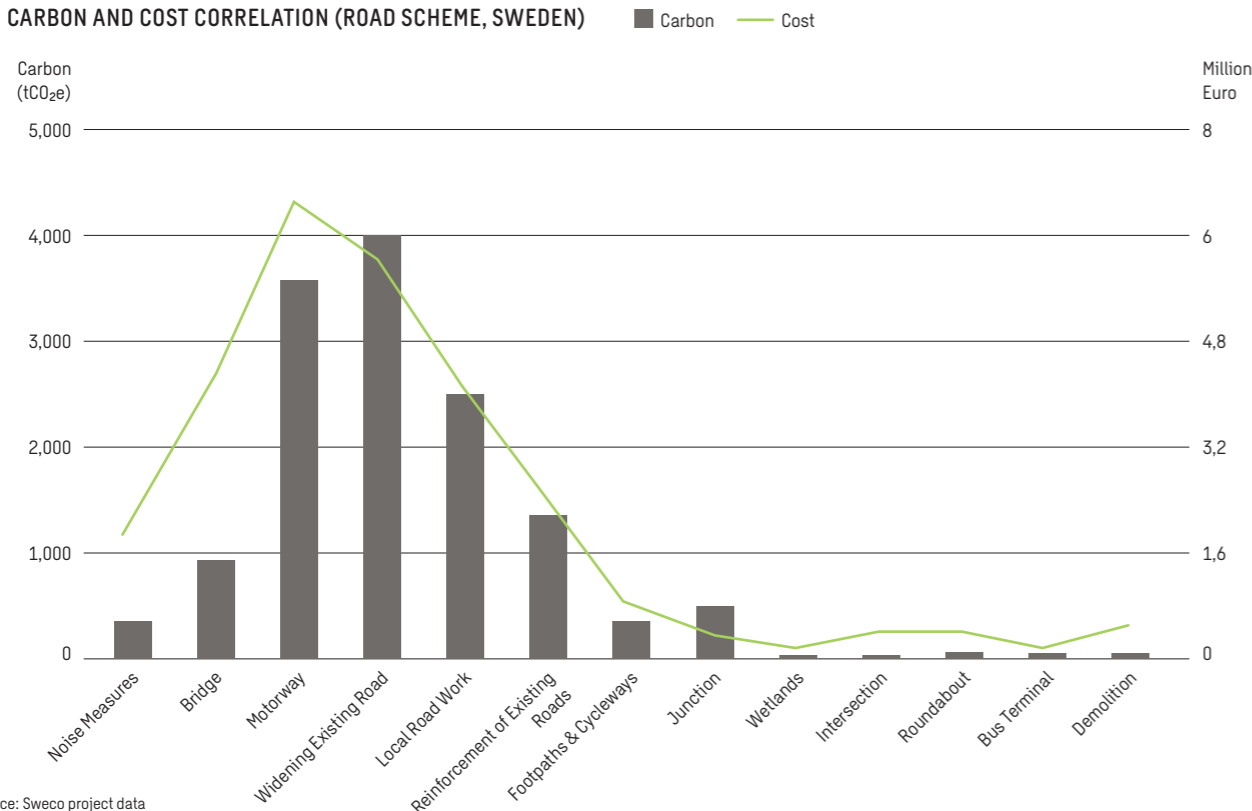
spent, e.g. kilograms of carbon dioxide equivalent per euro (kgCO₂e/€). It can be used to prioritise carbon reduction measures within a fixed budget and identify the most cost-effective carbon reduction options: the best carbon 'bang for your buck'.

Anything can be assessed using CCI: a process, a project, even a journey. Wherever there are a range of solutions to a problem and the goal is to minimise carbon and cost, carbon cost intensity allows both to be brought together simply for comparison.

As the use of the word 'intensity' suggests, the option with the lowest CCI should usually be the preference, i.e. if money is to be spent, it should result in the lowest carbon emissions. CCI is an absolute value that can be used as a starting point for multiple forms of carbon cost assessment.

CCI can be applied at three general levels: granular, mid-range and project. It is a powerful metric for prioritising project options in carbon cost terms, including alternative routes, materials or construction techniques.

CARBON AND COST CORRELATION (ROAD SCHEME, SWEDEN)



Source: Sweco project data

CARBON COST INTENSITY LEVELS

GRANULAR

CCI can be used to assess individual items or processes within a project. This granular level of carbon cost assessment can improve design team awareness and can be used to identify carbon cost anomalies (e.g. if the carbon value seems too low or the cost too high). However, granular assessments must be undertaken carefully to avoid focusing on items that may have a high carbon cost intensity but are relatively insignificant in the wider project context.

Example: assessing concrete mix options, e.g. traditional mix or low-carbon cement replacement.



MID-RANGE

CCI can be used to compare options within a project. For any given specification, the lowest carbon option can be selected within an available budget, or conversely the lowest cost option can be identified for a required level of carbon reduction. Mid-range CCI assessments should be undertaken throughout the design process to ensure that all practicable opportunities for carbon and cost reduction are considered.

Example: assessing options for crossing a river along a transportation route, e.g. bridge or tunnel.



PROJECT

CCI can be used to assess the carbon cost intensity of entire infrastructure projects. This strategic level of analysis will become more valuable over time, once an increasing number of schemes calculate and report on this metric. As a database of project carbon cost intensities grows, potential new projects can be compared with existing carbon cost data. Until then, project level CCI can be used comparatively to assess projects on a relative basis.

Example: assessing the choice of transportation modes, e.g. road or rail.



The Carbon Cost Tipping Point

Efficient design can reduce both carbon and cost in infrastructure to a certain point, usually through reducing material quantities and minimising construction operations. In the past, a low-cost solution that achieved the required performance specification would have been regarded as a success. However, lower carbon solutions exist that currently cost more than traditional options.

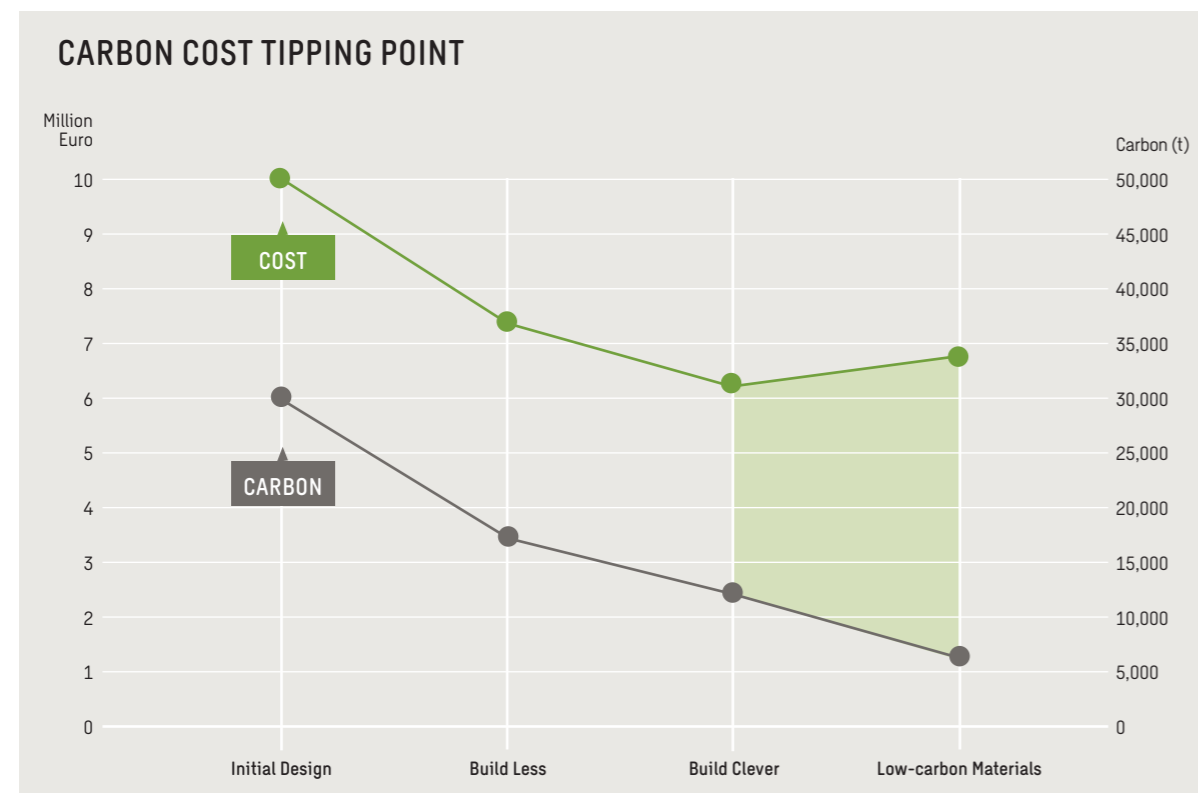
For example, quantities of concrete can be minimised to reduce carbon and cost, but once a minimum volume is established, the lowest carbon concrete is currently more expensive than traditional mixes.

The point at which costs start to increase to reduce carbon further may be defined as the 'carbon cost tipping point'. When the goal is net zero emissions, the carbon cost tipping point is a problem.

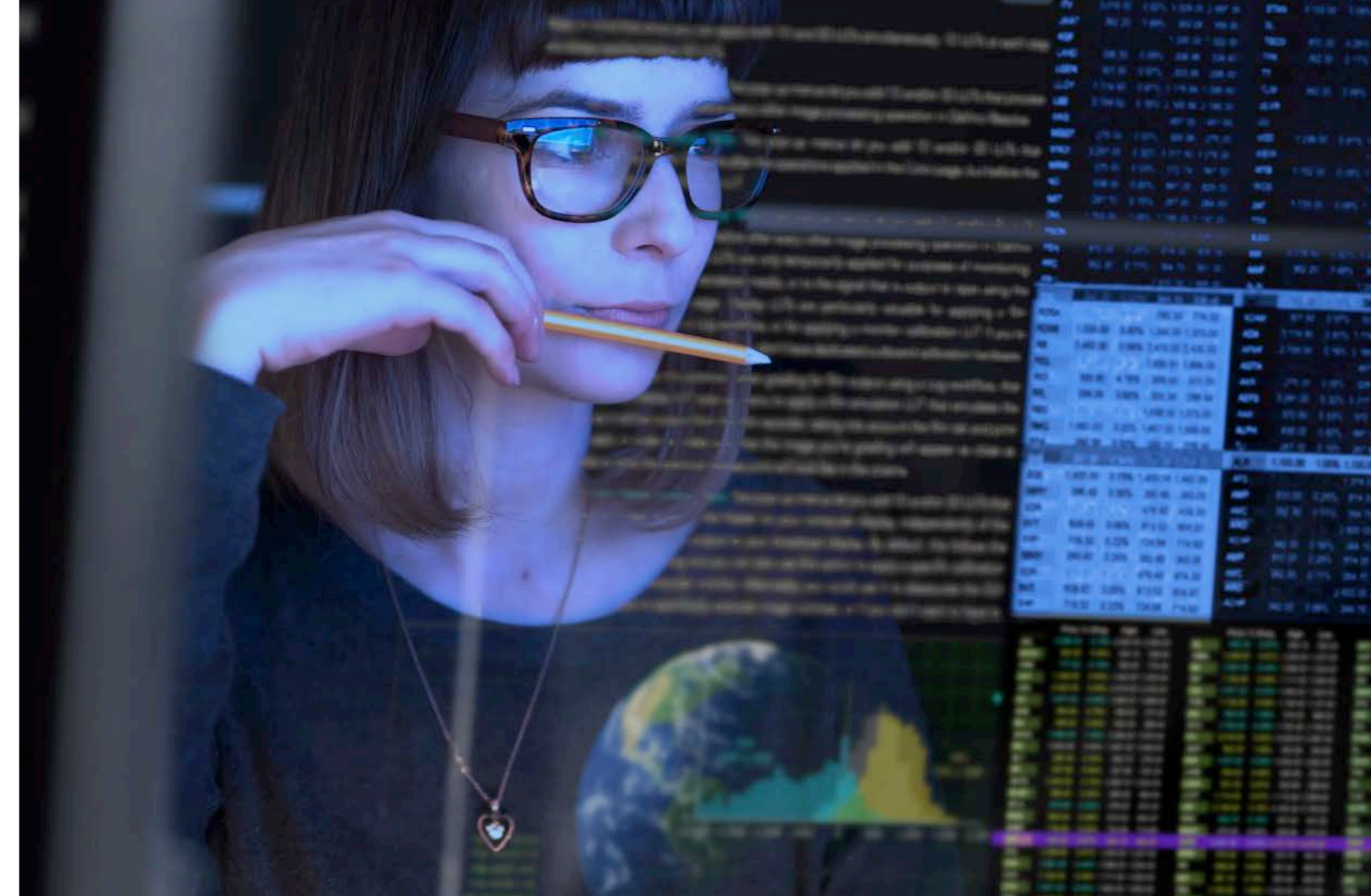
As the market for low carbon materials and construction techniques evolves, the carbon cost tipping point will correspondingly adjust, with higher carbon solutions becoming more expensive. Until then, this tipping point is a financial barrier to net zero carbon.

Tipping points exist, beyond which it currently costs more to reduce carbon

Once we understand the existence of the carbon cost tipping point, we must question the traditional message of "reduce carbon, reduce cost". Firstly, note the order of the statement. It is not "reduce cost, reduce carbon", which might be inferred from demonstrating a strong correlation



Values are for illustrative purposes.



between the two. The intention of the statement is that new opportunities to reduce cost can be created by considering carbon reduction options. Secondly, the statement refers to infrastructure, where carbon emissions are usually 'front-loaded' in the form of large-scale civil engineering operations. "Reduce carbon, reduce cost" is still an excellent rule of thumb, but case by case assessment is required to optimise carbon reduction.

TIPPING POINT TIMING

Carbon cost tipping points will be encountered across various design disciplines at all stages of a project, from inception (e.g. concrete versus wooden structure) to construction (e.g. typical versus low-carbon steel). These options should be considered as far as possible at the outset of the project, enabling a cumulative project carbon cost tipping point to be developed. This is a form of carbon cost benefit analysis, i.e. determining whether the carbon 'spent' on a project will be balanced by the carbon 'saved', either directly or indirectly.

Tipping points in the context of whole life carbon assessments raise an issue that is rarely discussed: is it better to emit carbon now from construction projects that will create carbon savings in the long term? Or is it better to emit less carbon now by maintaining our existing infrastructure, given the urgency of the climate crisis and the requirement to drastically reduce carbon emissions? The answer to these questions lies at a strategic level, with carbon cost assessment at its core.

INNOVATION AND CHALLENGING STANDARDS

Carbon cost tipping points often exist due to the apparent rigidity of existing standards. From the bitumen content in pavements to the cement content in concrete, standards exist that are often unintentionally biased towards higher carbon solutions. This has stifled demand for new low-carbon options and resulted in higher costs at the moment, until these new technologies are able to reach economies of scale.

Carbon cost tipping points need to be identified and assessed to understand the cost of reaching net zero

As the language of carbon cost becomes more prevalent, and problematic tipping points are identified more frequently, there will be greater pressure to drive innovation and challenge standards that put a premium on lower carbon options.

Beyond the Tipping Point

The existence of carbon cost tipping points should not detract from the overarching principle of “reduce carbon, reduce cost”. That message still generally applies, especially for new large-scale infrastructure. However, we cannot rely on carbon reduction to automatically occur through traditional design. We must start to consider our options beyond the tipping point.

It is becoming clear that it will not be possible to achieve national net zero carbon targets through cost saving measures alone. The recently published Leeds City Council carbon strategy¹⁵ set out a series of measures along a pathway to net zero emissions. In the strategy, emissions reduction of 51% is considered possible through “economically viable technologies”, where lowering carbon will bring associated financial savings. Beyond this tipping point, the remaining 49% is likely to require some degree of financial support.

As more governments and local authorities understand the contribution of infrastructure to their total carbon emissions, and awareness spreads that achieving net zero emissions will require investment, what incentives exist to select options beyond the tipping point?

CARBON TAXATION

One mechanism is carbon taxation. A recent report on carbon pricing by the Grantham Research Institute on Climate Change and the London School of Economics¹⁶ included recommendations for proportionate carbon taxation across all key sectors.

The UK Landfill Tax model is referenced as an example of a successful environmental tax that was introduced to shift the industry away from an unsustainable form of waste management. The Landfill Tax started at £7 (€8)/tonne of waste and was increased over a period of twenty years to its current value of over £90 (€106)/tonne. Signs point to a similar approach being adopted soon to encourage the implementation of low-carbon options that were previously economically unviable.

In fact, some forms of carbon taxation have been in place for decades. For example, in 1991 the Swedish government introduced a carbon tax on energy producers set at SEK 250 (€24)/tCO₂e. This has been gradually increased to SEK 1,180 (€114)/tCO₂e in 2019 and has been successful in driving a transition to green energy.¹⁷

Managing carbon and cost becomes increasingly important when carbon taxation is introduced

In 2018, the Greater London Authority introduced taxation on major residential developments through the planning process.¹⁸ Developers must reduce predicted operational carbon emissions as far as possible, then remaining emissions are taxed at £60 (€70)/tCO₂e over a 30-year period, equating to a total contribution of £1,800 (€2,100)/tCO₂e. According to recommendations within the new draft London Plan,¹⁹ this price is set to increase to £2,850 (€3,360)/tCO₂e.

Emissions associated with infrastructure construction have been largely overlooked to date, in favour of operational emission targets. Given that the relative significance of construction emissions is set to increase in coming decades,⁶ any carbon tax introduced to steer a nation towards net zero emissions must incorporate embodied carbon.

DEALING WITH RESIDUAL EMISSIONS

Carbon emissions may be reduced as far as practicable, but if we continue to build new infrastructure, we will continue to emit carbon. With national net zero targets, how do we deal with these remaining emissions?

The IPCC states that to keep global warming below 1.5°C, negative emissions technology will be required,² such as direct air capture. Although such technology is emerging, it would need to be deployed at a national scale, demanding



unprecedented energy resources. For instance, a recent study estimated that the annual energy required to capture sufficient carbon from the atmosphere to balance carbon emitted by 2100 would be 300 exajoules, equivalent to the current annual energy demand of China, the US, the EU and Japan combined.²⁰

A natural form of atmospheric carbon dioxide removal exists in the form of trees. Trees absorb carbon and have added biodiversity benefits. However, their carbon absorption is slow, difficult to predict and unlikely to be sufficient to balance residual infrastructure emissions. Many carbon offsetting schemes involve tree planting, but offsetting should be regarded as a last resort, not a licence to emit.

The relative costs of carbon taxation and carbon reduction need to be closely monitored to identify the most economical and meaningful options beyond the tipping point.

What costs may be required to reach net zero?

Consider an infrastructure project with a capital cost of €100,000,000 and associated carbon emissions of 50,000 tonnes. Using an example carbon tax range of €50 to €100 per tonne, the tax bill would range from €2,500,000 to €5,000,000, an increase of between 2.5% and 5% to the total project cost.

Tree planting

€20+ / tCO₂e

Assumes carbon adsorption of 0.5 tonnes over the lifetime of a tree.

Direct air capture

€200+ / tCO₂e

Negative emissions technologies will be required to reach net zero¹⁶

National taxation

€60+ / tCO₂e

Likely minimum price required to reach net zero by 2050¹⁶

Taxation through local planning

€2,100 / tCO₂e

Greater London Authority Offset Fund, based on a 30-year operational period¹⁸

Making it Happen

Carbon emissions need to be minimised to protect the global environment. However, carbon emissions reduction is not just an issue for environmentalists. It needs to be understood and acted upon by decision-makers, including project managers, clients and governments. But how can this be practically applied in infrastructure projects?

In recent years, there has been a gradual shift from carbon accounting to carbon management. Carbon accounting is a passive approach with little bearing on the design process. We will not achieve national net zero carbon targets through carbon accounting alone.

Conversely, carbon management is an active process where options for reduction are considered and integrated into the design process. However, even the carbon management process will have limited success if the costs of reduction options are not also considered.

The next level is carbon cost management. This process involves all the aspects of good carbon management, but it also includes costing of all carbon reduction options. It elevates carbon reduction from purely an environmental discipline and places it into the realm of value engineering.

PAS 2080: CARBON MANAGEMENT IN INFRASTRUCTURE

An internationally relevant specification exists to ensure the minimisation of carbon on major infrastructure projects: 'PAS 2080 – Carbon Management in Infrastructure'. Published by The British Standards Institution in 2016, its central aim is to promote whole life cost reductions through whole life carbon reduction. While it does not provide guidance on how to manage whole life costs, with minimal adaptation it can be used to apply carbon cost management to any construction project.

We will not achieve national net zero carbon targets through carbon accounting alone

PAS 2080 is compatible with relevant existing international standards and guidance. Specifying that a project should follow PAS 2080 ensures the accuracy, transparency, consistency, and relevance of the carbon management process. Requirements across the supply chain are clearly set out, from clients and asset managers, through to designers, contractors and material suppliers.

OPTIONS SELECTION

With the PAS 2080 process in place, the review of carbon and cost reduction options becomes a standard process. At the earliest stage of a project, an estimate of carbon emissions is made to identify key carbon hotspots. This leads to design team workshops where carbon and cost reduction opportunities are reviewed. Where viable options are identified, their relative carbon and cost benefits are considered, with the outcomes recorded for reference in a final report that documents all decisions made with an influence on carbon emissions.

Short-term carbon savings should not result in an increase in overall emissions throughout a project. Therefore, whole life carbon emissions must be considered in carbon cost options assessments. Some materials may have lower embodied carbon emissions due to their components, production method or source. However, if the material would require more frequent replacement or lessen recyclability, then it may not be the better option from a whole life carbon or cost perspective.

Carbon cost assessment should form part of the options selection process from the earliest concept stage. This should include critical analysis of the overall goals of the project at its inception and whether they can be achieved through the use of existing infrastructure.

Considering carbon with cost enables best value reductions

CARBON COST MANAGEMENT

Carbon cost management is a new area of expertise, involving science, engineering and project management. Knowledge and experience of carbon coefficients, tools and processes is necessary, combined with pragmatic engineering expertise across all relevant disciplines.

As specifications such as PAS 2080 are implemented more frequently, the role of the carbon cost manager will formalise. Until then, a basic principle is that they should be included on design teams and be party to any key decisions that may influence carbon or cost.

Carbon cost management will eventually become a standard project process, just as has the consideration of health and safety.



GLASGOW AIRPORT INVESTMENT AREA

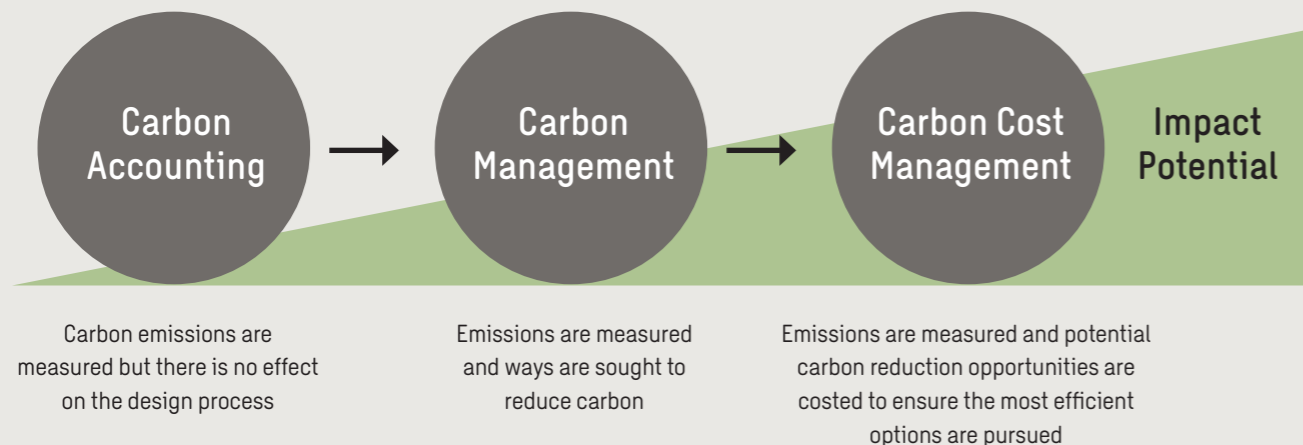
Carbon cost management and PAS 2080 were used on this major infrastructure project for Renfrewshire Council to great effect.

- Improved cycling and walking infrastructure
- New road bridge across the White Cart Water
- Road realignment and improved connections

Total carbon savings of over
8,000 tCO₂e

Total cost savings of over
€14,000,000

THE EVOLUTION OF CARBON MANAGEMENT



Carbon cost management should be applied at the route selection stage

EARLY CARBON COST OPTIMISATION

A preconception exists that carbon can only begin to be considered as designs become detailed. However, knowledge of the carbon cost relationship allows us to estimate carbon emissions at any stage that cost can be considered. The ability to assess carbon at the earliest project stages is essential, as this is where the greatest reduction potential exists.

An innovative GIS-based tool – Geokalkyl – enables designers and asset managers to estimate carbon and cost associated with infrastructure schemes at the highest level. Developed on behalf of the Swedish Transport Administration (Trafikverket), Geokalkyl applies a visual approach to assessing both the carbon and cost impacts of alternative routes.

For transportation infrastructure projects, initial route selection has a significant bearing on both carbon and cost, e.g. due to ground conditions which require varied earthworks or geotechnical solutions.

Geokalkyl quickly enables the interpretation of ground conditions by generating carbon and cost estimates associated with building along each alternative route. As a result, key hotspots are identified, highlighting areas where both carbon and cost are likely to be high, so that these factors can be considered together in the options selection process.

This approach can be taken at the start of any infrastructure project without the need for detailed design information.

Contractual Carbon Reduction

If carbon reduction in infrastructure was purely voluntary, we would be unlikely to prevent catastrophic climate change. We need integrated and collaborative solutions throughout the supply chain, achieved through procurement processes and national legislation. We are now seeing the creation of tendering mechanisms which demand carbon reduction, encourage innovation and ensure a carbon focus is maintained from project start to finish.

Steps can be taken to reduce carbon throughout design stages (process reductions) or between them (procurement reductions). Procurement reductions are particularly important as they present the opportunity for a step change: for carbon to become a differentiating factor in tenderer selection.

Carbon reduction should be contractual, not just coincidental

If the carbon management process has been in place from the outset of a project, a carbon baseline will be available at the start of each stage against which reductions can be targeted and measured. Within the procurement process, tenderers can be challenged to demonstrate their capability to reduce carbon associated with an existing design. Submissions can be evaluated by those with relevant expertise to confirm that proposed reductions are feasible in the context of the project and its objectives. During the construction tender stage alone, carbon reductions of over 30% have been realised through this process, and even more is possible if incorporated earlier.²¹

Procedural carbon management requirements are of equal importance in support of reduction targets. For instance, requiring that an individual responsible for carbon management be appointed and implementing a regular reporting schedule should supplement quantitative requirements to ensure accountability.

The supply chain is ready to be challenged on carbon. Best practice is emerging in this area, and procurement mechanisms can be designed strategically to incentivise carbon reduction, encourage innovation and deliver optimal solutions in the context of net zero targets.

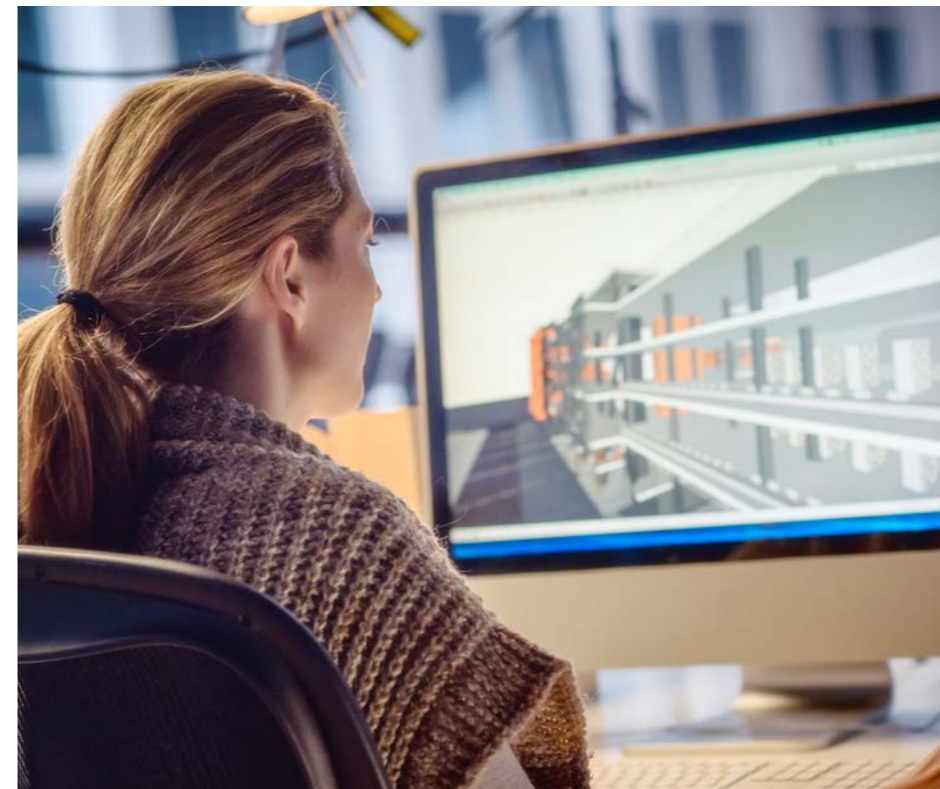
A SWEDISH APPROACH

The Swedish Transport Administration, Trafikverket, is the government agency responsible for Sweden's infrastructure planning for transport, including road, rail, shipping and aviation. In response to Sweden's national net zero aspirations, Trafikverket established a long-term goal for infrastructure to reach carbon neutrality by 2045. In 2016 they acted by introducing contractual climate requirements, in the form of carbon reduction targets, for major infrastructure schemes exceeding €5 million in value.¹¹

Acknowledging the carbon cost relationship and the benefits that can arise by focusing on carbon reduction, Trafikverket also provides a financial incentive for minimising carbon on its contracts. Bonuses can be offered to organisations that achieve carbon reduction beyond the required target.

By mandating the use of their own carbon tool – Klimatkalkyl – Trafikverket ensures that a consistent calculation methodology is applied both throughout design stages and across projects. A baseline year is also specified within the tool to enable transparent assessment of any claimed reductions. Reductions must also be directly related to the scope of works (e.g. scheme design, materials used, construction fuel use, etc.) and cannot be purchased as offsets.²²

Through this approach, Trafikverket has not only facilitated carbon reduction, but they have also seen the emergence of new and innovative solutions which push the boundaries of traditional infrastructure design.



Carbon reduction can be improved by using software to visualise carbon cost hotspots

Accelerating Change

Given the urgency of our situation and the knowledge that carbon cost management is critical in preventing catastrophic climate change, we must immediately accelerate the work in this field.

Although cost management is well understood, carbon remains a relatively abstract concept to many, including stakeholders with significant influence in its reduction. To rapidly deploy carbon cost management in infrastructure, a combination of digitalisation and education is required.

DIGITALISATION

Civil engineering has been evolving through the development of digital techniques for decades. It is time for carbon cost management to join this process. We quickly need to reach the point where the impact of design decisions on both carbon and cost can be instantly assessed.

The innovative use of software and carbon databases is making this possible, helping to build awareness amongst key decision-makers and enabling them to influence designs most efficiently.

The incorporation of carbon criteria within the design process can be accelerated by embedding it within existing programmes and procedures. Engineers already use digital design tools such as GIS, AutoCAD and Revit, all of which have the potential to incorporate carbon as a variable. 3D models can then be augmented to show the relative carbon intensity of specific design elements.

The visual assessment of carbon hotspots is a useful communication tool to help identify and convey opportunities for carbon and cost reduction. With experience, engineers can raise their carbon awareness on a discipline-specific level and understand their important role in preventing climate change. The potential to educate through emerging digital techniques extends to all stakeholders involved.

Developments in artificial intelligence are such that carbon and cost will soon be optimised automatically through generative design. Sweco is currently developing techniques using parametric design, a process whereby computer

algorithms are used to generate solutions to satisfy a set of specified design parameters, using machine learning to identify the optimal carbon cost solution.²³

It will soon be possible to use machine learning to enable the rapid optimisation of carbon and cost for any design problem. In the meantime, we must integrate carbon cost assessment and reduction into our processes from the outset. Digitalisation will be part of the solution to climate change, but we cannot wait until it is perfected before we urgently tackle our situation.

Civil engineering has been evolving through the development of digital techniques for decades. It is time for carbon cost management to join this process.

EDUCATION

Technological advancements will help to improve carbon cost management, but fundamentally this is a new area of understanding that will require education and training at all levels.

The next generation of policy makers, clients, designers and contractors are already motivated by climate change. In March 2019, 1.6 million students from 125 countries took part in school strikes to demand action from global leaders.²⁴ Beyond training current designers and engineers, the next generation is eager to contribute to the climate change solution and we must ensure they have the necessary knowledge and skills to do so.

Climate change is a complex global problem with political, economic and behavioural components, and tackling it will require a truly multidisciplinary approach. The relevance of STEM subjects (science, technology, engineering and maths) is clear. It is important to inspire the next generation to pursue these areas by demonstrating the impact they can have.

Conclusions

To prevent catastrophic climate change, we must tackle the carbon emissions associated with national infrastructure. Globally significant quantities of carbon are emitted through its construction; however, these emissions are often overlooked in favour of carbon from its use. To understand the whole picture we must consider whole life carbon, just as we consider whole life cost.

CARBON, COST AND THE TIPPING POINT

There is a close relationship between carbon and cost in the infrastructure sector. In most cases the relationship is approximately proportionate - if carbon is reduced, so is cost. There are therefore both environmental and financial incentives to ensure carbon emissions are minimised.

Although 'reduce carbon, reduce cost' is a simple general principle in infrastructure, there are many instances where the lowest carbon solution is not the least expensive. There

are carbon cost tipping points that need to be assessed to provide the most worthwhile carbon reduction. It has become clear that if governments intend to reach net zero carbon emissions, detailed assessment of these tipping points is required.

MANAGING INFRASTRUCTURE CARBON

The minimisation of carbon emissions in infrastructure is not only an environmental discipline – it is of much wider relevance when our overarching goal is sustainable development. To most effectively reduce carbon, we need to integrate carbon and cost reduction across all design disciplines from the outset and at the highest level. There is a necessary evolution for carbon reduction in infrastructure: from carbon accounting, to carbon management, to carbon cost management. It is only through carbon cost management that we can minimise carbon as efficiently as possible.



To be most effective, carbon cost management must be integrated into the design process. From the outset and at every decision point, carbon emissions and associated cost should be considered. Carbon must become a natural part of the value engineering process and considered alongside cost to enable best-value reductions.

Carbon cost management can be mandated at a strategic level through the application of a specification such as PAS 2080. This is internationally relevant and ensures a consistent focus on carbon and cost reduction.

MAKING CARBON REDUCTION CONTRACTUAL

The procurement process is key to carbon cost management. From the inception of a project and at each procurement stage, carbon reduction should be a differentiating metric. Innovations in procurement can incentivise carbon reduction and accelerate a variety of low-carbon solutions. Carbon reduction in the procurement process should not only be qualitative input to a sustainability assessment – it should be a fundamental and measurable contractual requirement.

LEADERSHIP

Without strong leadership, carbon reduction is, at best, a passive environmental aspect that has no bearing on a design. With strong leadership, proactive carbon cost management occurs at every design decision point. The client is aware of all carbon reduction opportunities: which will save money, which will cost money, which are affordable, which are most worthwhile. Carbon and cost are presented on the same page.

While the focus of this report has been on infrastructure carbon cost management, this assessment approach is equally applicable to every aspect of the built environment. In fact, carbon cost assessment is applicable to decisions we all face in our daily lives, from the best way to visit relatives over the holidays to your choice of meal this evening.

Everything with a financial cost has an associated carbon value. Understanding these carbon cost relationships gives us the knowledge to help us most efficiently reduce carbon and prevent climate change.



We all have a role to play in reducing carbon emissions, but the greatest impact requires decisive leadership at all levels.

POLICY MAKERS

Enable the appropriate market framework and regulations to encourage carbon cost management.

CLIENTS

Recognise your role in establishing carbon reduction as a key contractual metric across your supply chain.

ENGINEERS

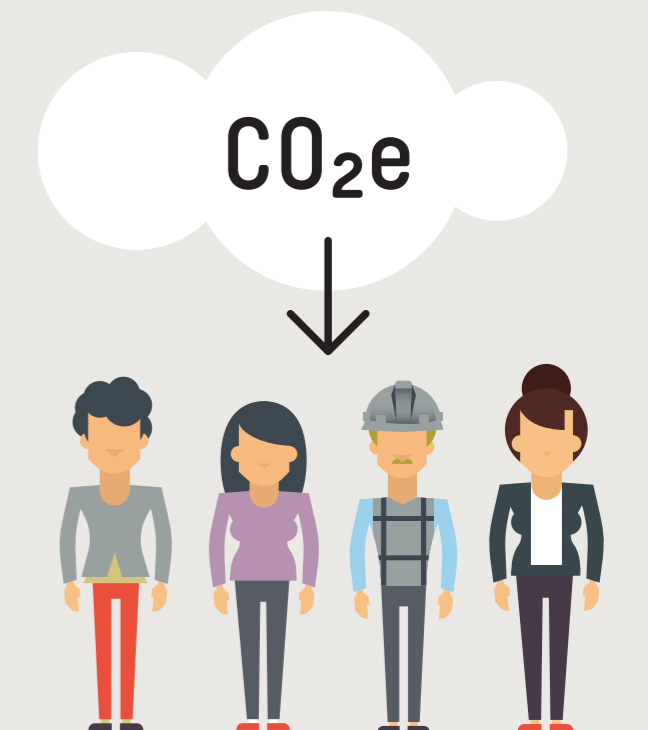
Consider both the carbon and cost impacts of your decisions and present these together.

CONTRACTORS

Promote low-carbon innovations either side of the carbon cost tipping point.

EDUCATORS

Prepare the next generation of carbon cost experts through science, technology, engineering and mathematics.



About the Authors

Do you have questions about Carbon Cost Management?
Don't hesitate to contact us.

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