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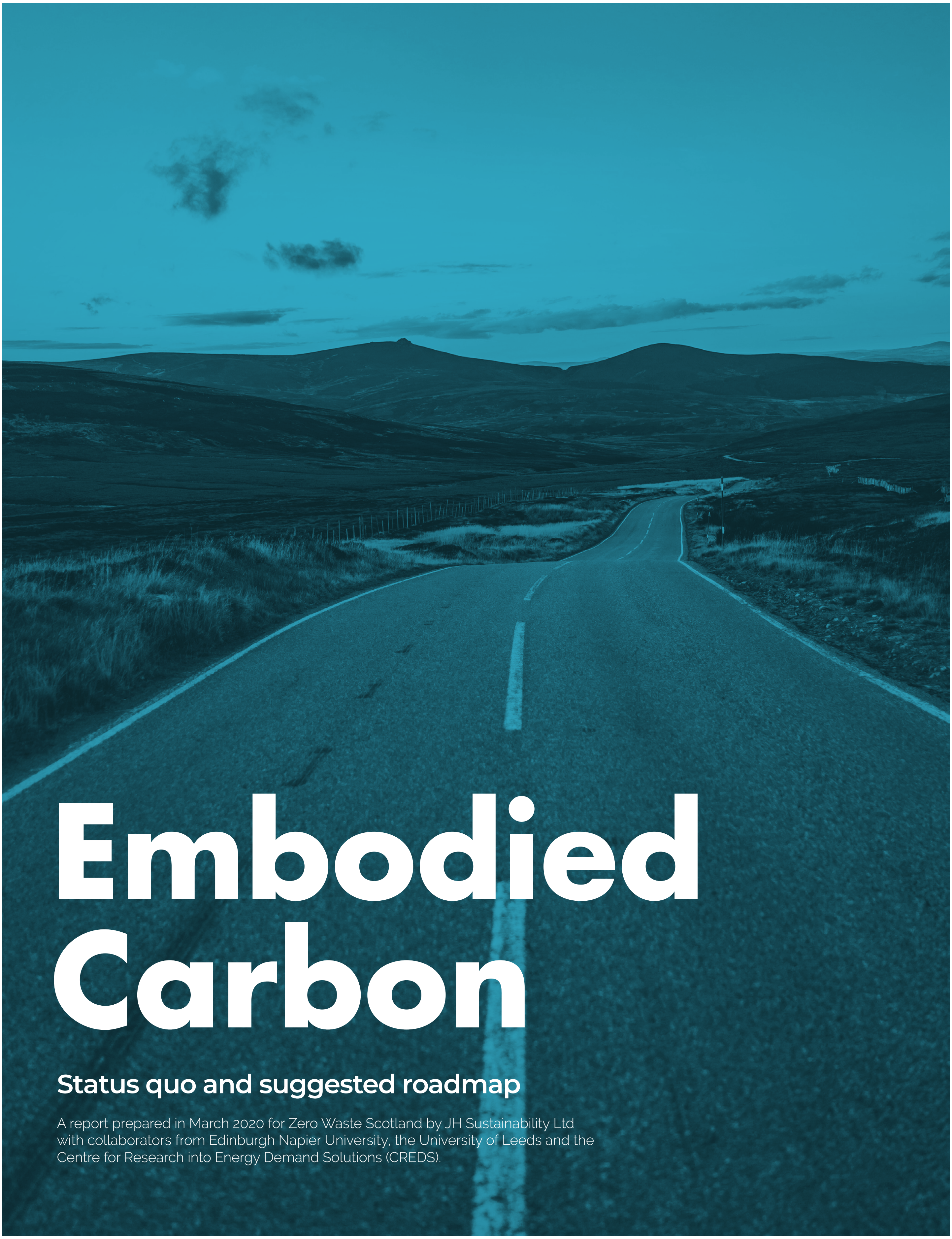

Embodied Carbon

Status quo and suggested roadmap

A report prepared in March 2020 for Zero Waste Scotland by JH Sustainability Ltd with collaborators from Edinburgh Napier University, the University of Leeds and the Centre for Research into Energy Demand Solutions (CREDS).

Contents

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Highlights

New drivers, such as regulation, are needed to encourage the measurement and targeting of embodied carbon, and this would be welcomed by many actors in the sector.

In parallel with the implementation of such drivers, the need for a standardised methodology to support them should be addressed.

ZWS can support the development of the embodied carbon agenda in the sector through a variety of direct and indirect means, addressing knowledge, skills, and policy.

Support for the development of more Environmental Product Declarations for products manufactured in Scotland would provide impetus for a distinctive Scottish position on low-carbon buildings.

New metrics to chart progress in embodied carbon across the sector in Scotland are required; in the meantime, the most useful metric is based on quantification of construction activities in Scotland and the carbon intensity of those activities aggregated across the UK.

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Introduction

1

Environmental impacts of buildings and infrastructure, including the greenhouse gas (GHG) emissions that contribute to climate change, can be linked to all stages of the lifecycle, from project inception through to demolition and disposal. Extracting raw materials, transforming them into products, transporting them to site, the construction process, use and maintenance, and demolition and disposal activities all demand energy derived from fossil fuels, and therefore such activities are direct drivers of GHG emissions.

For decades, policy and regulations designed to target GHG emissions from construction have been primarily focused on energy demand for heating and powering buildings during their operational lifetimes, and the associated GHG emissions; little attention has been paid to the emissions associated with the materials and processes required to construct, maintain and ultimately decommission the buildings. These are referred to as operational carbon (heat and power) and embodied carbon (everything else) respectively. The term 'embodied carbon' can be interpreted differently depending on perspective and project information and data, but most would fall into one of the following categories:

1. Cradle to gate. GHG emissions associated with extracting and processing materials into construction products.
2. Cradle to site. As 1. Plus transport of the materials to the construction site.
3. Cradle to practical completion. As 2. Plus construction processes.
4. Cradle to grave. As 3. Plus repair and maintenance and, ultimately, demolition and disposal.

Assessment of carbon emissions associated with construction can extend even beyond these boundaries to include, for instance, the impacts on subsequent product systems when materials are recovered at the end of a product's life.

Measures such as the targeting of heat loss through the building envelope, alongside technology improvements such as LED lighting and the increasing role of renewables in electricity production, have made it possible to achieve significantly lower operational carbon figures for a building. Despite progress on waste management, and sustainable procurement, there is little data to support overall progress in the embodied carbon of new construction, and some interventions to target operational carbon can actually increase the embodied carbon. As a result, embodied carbon represents an increasingly significant proportion of the whole-life GHG emissions of new buildings.

Recognition of the increasing relative importance of embodied carbon has led to increasing interest, with data, tools, planning documents, and guidance from professional bodies all being published. This is a new field, however, and there is relatively little experience of embedding assessment of embodied carbon into construction industry decision-making. Accordingly, there has been no clear template for the Scottish industry to follow that accommodates the Scottish context and recent progress. Because of this, this study has been produced for Zero Waste Scotland (ZWS) to help it determine the state of the art in Scotland and beyond, the direction the sector should take, and the support that might be needed from ZWS.

The report includes chapters setting embodied carbon into context in terms of industry and policy, metrics for tracking embodied carbon at the national level, tools and methods for assessment, weaknesses in the state of collective understanding of embodied carbon in theory and practice, mitigation options, industry views, and – ultimately – a roadmap showing the way forward for ZWS.

Context

2

Targets, policies and voluntary initiatives

This chapter outlines the current status of Scotland's construction industry, climate change targets, plans and progress towards achieving them. It then outlines specific policies and standards related to embodied carbon and reviews a range of international precedents. Finally it provides a summary of a number of contemporary voluntary industry initiatives to reduce embodied carbon.

The Scottish construction sector and its supply chains consist of around 46,000 businesses employing approximately 10% of the Scottish workforce (Construction Scotland, 2019). Nine out of ten in the industry are micro-businesses, employing less than 10 people, with only a third of businesses having annual sales in excess of £250,000. Even the largest firms based in Scotland typically only have a few hundred employees (see SQW (2017) for a breakdown of the largest Scottish-based construction firms and UK firms with offices in Scotland, and a profile of the sector). For this reason, the sector is typically characterised as having a high level of fragmentation, with dominant procurement processes resulting in low levels of collaboration. The industry faces significant recruitment challenges, with double the proportion of skills shortage vacancies compared to all industries (ibid), and a workforce with significant imbalances in age and gender. The sector is generally perceived to have relatively low levels of innovation, both compared to other sectors and to construction activity in other European countries. This is despite a wide range of ongoing activity taking place in the country's numerous universities, through Knowledge Technology Partnerships and other initiatives, such as the Construction Scotland Innovation Centre. The sector often faces challenges with access to finance and maintains an understandably risk-averse attitude to innovation.

The industry's output has generally been on an increasing trend over recent decades, barring a substantial decline following the global financial crisis (see Figure 1). Prior to the recession new orders expanded sharply, driven by growth in housing and commercial buildings. Since the recession a recovery in new orders has largely been driven by investment in infrastructure, with more modest increases in private building.

In recent years industry confidence levels have fluctuated substantially in response to external events, such as Brexit. Similarly, many recent changes in industry standards and practice have been driven by a number of unexpected high profile failures, such as the Grenfell Tower fire and the Edinburgh Schools Inquiry. Other trends such as increasing digitisation and more use of modern methods of construction are slowly shaping the industry. The industry's strategy for 2019-2022 (Construction Scotland, 2019) sets out six strategic priorities and outcomes focussed on procurement, skills, quality & standards, planning & building regulations, growth opportunities, and productivity & innovation. Though some of these priorities may indirectly affect embodied carbon, such as "fundamental" changes in procurement practices and systems, there is no explicit consideration of the topic within the strategy.

Built stock

Scotland's current built stock consists of around 2.45 million homes, 200,000 non-domestic buildings and a wide range of infrastructure assets, including some 10,800 km of major roads and a further 60,000 km of minor roads (Department for Transport, 2019; Scottish Government, 2018a). This stock is expected to expand in line with a slow growth in population driven by inward migration. At the same time, delivering reductions in operational carbon emissions and other policy objectives (such as reducing fuel poverty) will necessitate an unprecedented scale of retrofit of the existing building stock. This implies that, without intervention, embodied carbon from new construction, maintenance and retrofit are all set to expand over the coming years.

Figure 1: Construction output and new orders in Scotland. All values are non-seasonally adjusted in £bn current prices. Based on February 2020 ONS data releases on 'Output in the Construction Industry'.

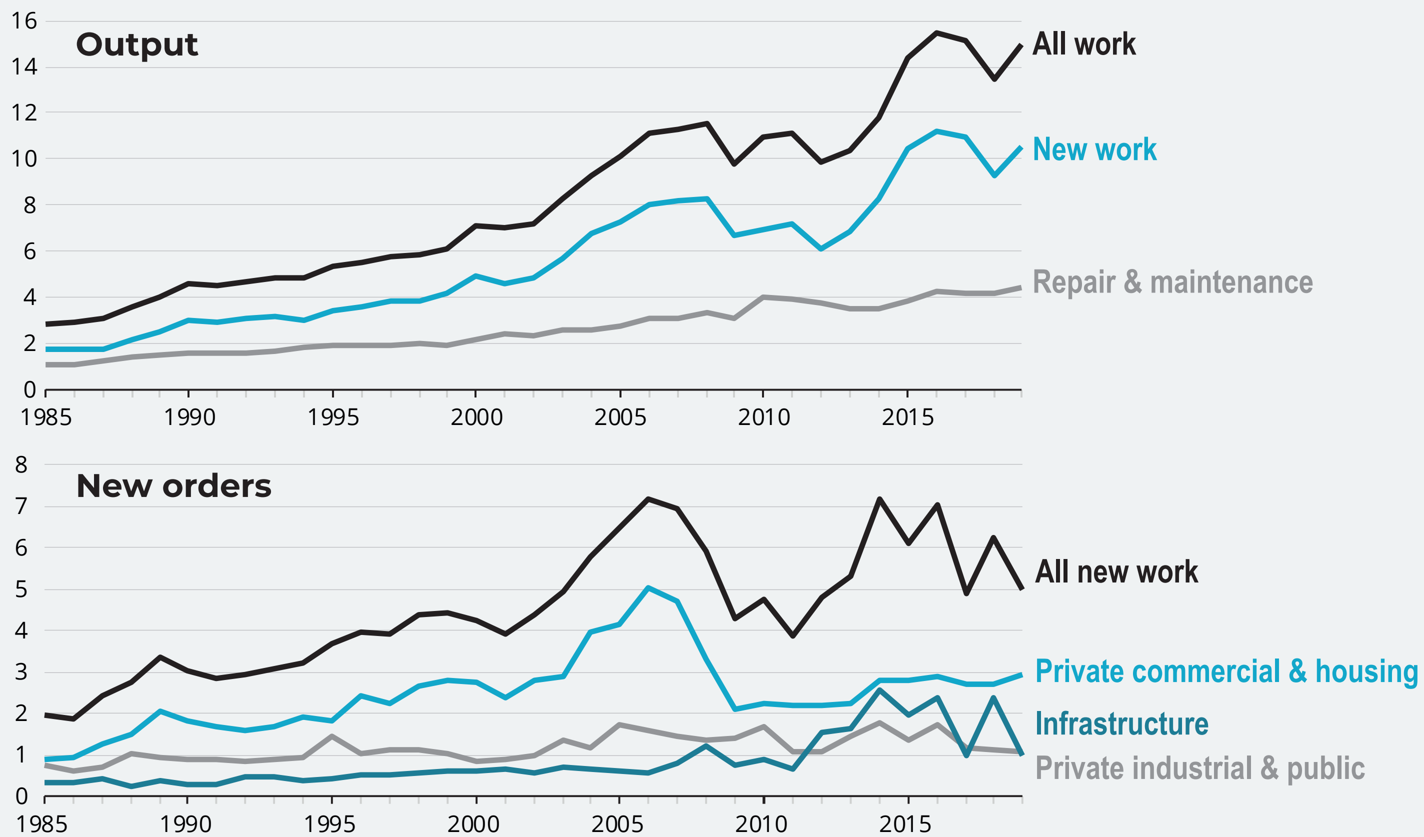
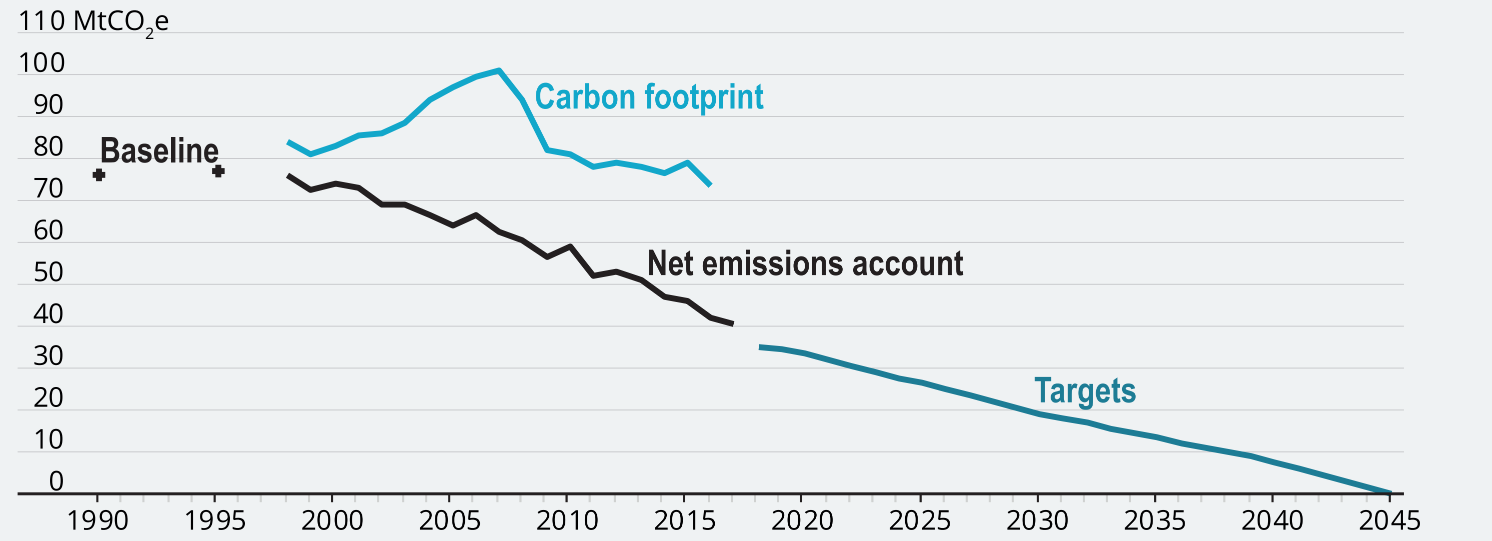


Figure 2: Scotland's greenhouse gas emissions and reduction targets.



Scotland's Climate Change Targets, Plan & Progress

The Climate Change (Scotland) Act 2009 set the initial framework for both long term and annual greenhouse gas emission reduction targets in Scotland (Scottish Parliament, 2009). Following the declaration of a climate emergency in 2019, the 2009 Act's targets were amended by the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 (Scottish Parliament, 2019). The 2019 Act set targets to reduce Scotland's emissions of greenhouse gases to net-zero by 2045 at the latest, with interim reduction targets of at least 56% by 2020, 75% by 2030, and 90% by 2040, as well as annual targets based upon equal percentage point changes between the interim targets. Figure 2 illustrates these targets along with progress to date in reducing Scotland's emissions.

The 2019 Act further stipulates that Scottish Ministers must periodically lay a Climate Change Plan before the Scottish Parliament to set out proposals and policies that will contribute to achievement of the targets. This Climate Change Plan is accompanied by annual monitoring reports. The present Climate Change Plan 2018-2032 (Scottish Government, 2018b), published in February 2018 is currently being updated to reflect the increased ambition of the recently introduced targets. The updated plan is due to be published by the end of April 2020. The most recent Monitoring Report (Scottish Government, 2019a), published in December 2019, tracked a series of implementation indicators and policy output indicators. Only 7 of the 29 policy output indicators assessed were on track, with several indicators yet to have sufficient data to yield an assessment of progress. None of the 29 indicators directly address the embodied carbon arising from construction. The four indicators addressing buildings focus exclusively on operational energy and emissions. Meanwhile all industrial production is covered by one energy productivity and one emissions intensity indicator (for which a limited time series of data was available). Other indicators of some relevance to the topic of embodied carbon include: Scottish produced sawn wood and panel boards used in construction; volume of landfilled waste; and a range of the transport indicators (such as average emissions of HGVs per tonne kilometre).

Independent monitoring of progress and advice upon achievement of the long term targets is also offered by the Committee on Climate Change (CCC). Indeed, Scotland's targets were predicated on the advice of the CCC in their May 2019 Net Zero report prepared upon joint request of the Governments of the UK, Wales, and Scotland (CCC, 2019a). The CCC's most recent review of Scotland's progress (CCC, 2019b), published in December 2019, highlighted that aside from substantial progress in reducing emissions from the power sector, progress was minimal in other sectors and that "early and decisive actions to strengthen policy" would be required to deliver upon the 2030 interim target. The progress report did not specifically address embodied carbon arising from construction, referring instead to progress using the CCC's customary sectoral distinctions (buildings, industry, waste etc.). The CCC's advice on buildings focussed upon low-carbon heat, energy efficiency, and fuel poverty.

In addition to addressing territorial emissions of greenhouse gases, the 2019 Act stipulates that the Climate Change Plan must also set out Scottish Ministers' "proposals and policies for taking action to reduce emissions of greenhouse gases (whether in Scotland or elsewhere) which are produced by, or otherwise associated with, the consumption and use of goods and services in Scotland". To this end, the Scottish Government also publishes an annual set of consumption-based emissions accounts, known as Scotland's Carbon Footprint (Scottish Government, 2019b). Progress in reducing consumption-based emissions has been slower than that for territorial emissions, as shown in Figure 2. Territorial emissions have declined by 45% since 1998, compared to a 12% decline in consumption-based emissions. At present Scotland's targets refer exclusively to the net Scottish emissions account (i.e. on a territorial basis with several minor adjustments e.g. for shipping and aviation). As the Scottish construction sector imports around £2bn worth of goods and services (SQW, 2017), including a high proportion of construction materials, reductions in embodied carbon are likely to drive deeper carbon reductions when measured on a consumption basis. However, only reductions incurred within Scotland will contribute to the achievement of national targets.

In response to strengthened targets the Scottish Government has launched a wide array of new consultations and policy initiatives. The following sections outline current and proposed policies and legislation. This includes a review of national buildings standards, local requirements, and a comparison with international precedents.

Policy & standards

Building Standards

The Building (Scotland) Act 2003, which came into force in 2005, is the primary legislation under which Scotland's building standards system operates. Since 2005, the standards have been repeatedly strengthened through a series of amendments[1] requiring, amongst other changes, significantly reduced operational carbon emissions and the introduction of sustainability labelling. The standards are accompanied by a pair of technical handbooks for domestic (Scottish Government Building Standards Division, 2019a) and non-domestic buildings (Scottish Government Building Standards Division, 2019b) – the most recent versions of which were published in September 2019. The standards do not place any requirements upon the assessment or mitigation of embodied carbon, instead focusing on other aspects of sustainability such as energy efficiency. Although there is no requirement to assess embodied carbon, the topic is noted in both technical handbooks.

Section 7 of the Domestic handbook notes that:

"There are areas considered inappropriate for inclusion in the optional upper levels for domestic buildings due to the complexity of some subjects related to building design such as material sourcing and embodied energy...This standard can respond in due course to the growing relative importance of embodied energy as the performance of new buildings improves further."

The handbook subsequently highlights some resources to refer to, and

1 See https://www.gov.scot/publications/building-standards-legislation/ for a full list

indicates that the area has been *"flagged up"* for future review. A similar note is presented in the Non-domestic handbook. Despite the lack of direct requirements, some aspects required to achieve the highest sustainability levels will indirectly impact upon whole life carbon emissions. For instance, to achieve the Gold Sustainability Level for domestic buildings one of a number of approaches to design for deconstruction must be adopted (Scottish Government Building Standards Division, 2019a, p. 394). The next set of standards and guidance will be introduced in October 2021 with changes being published one year in advance. A consultation on potential changes concluded in September 2018.

Though embodied carbon is not addressed through current building standards, awareness of the topic, and proposals to include it, have a long history. As far back as 2007 the Sullivan Report set out recommendations on how the building standards system could be improved to combat climate change (Scottish Building Standards Agency, 2007). These recommendations included an ambition of *"total-life zero carbon buildings by 2030"* and considered the possibility of covering embodied energy in building products. At the time, the panel recommended that the issue be set aside until the European Commission had re-examined the Construction Products Directive. Embodied carbon received little attention in the 2013 update (Scottish Government Building Standards Division, 2013) following a reconvening of the panel, as the industry was still deeply impacted by the recession and more focussed upon agreeing a deliverable definition of zero-carbon for operational emissions. The debate at that time focussed upon the role of Allowable Solutions within any zero-carbon definition and the resultant recommendations were for a generally more moderate pace of change. Shortly thereafter in response to the then prospective UK requirements for Zero Carbon Homes, a self-assembled industry task force advocated for the inclusion of embodied carbon as an Allowable Solution – publishing a series of detailed proposals in 2014 (Battle, 2014). Unfortunately the long heralded UK requirements were subsequently dropped in July 2015 by a newly elected Government in order to *"reduce net regulation on housebuilders"* (HM Treasury, 2015).

In the intervening years, numerous calls have been made to introduce requirements around embodied carbon into building standards. For instance, in their 2013 Low Carbon Routemap for the Built Environment, the Green Construction Board advocated for measurement of whole life carbon on public buildings by 2017 and for all buildings by 2022 (GCB, 2013). The UKGBC have repeatedly called for requirements, including most recently as part of their response to the Ministry of Housing and Local Government's (MHCLG) consultation on the Future Homes Standard (UKGBC, 2020). Their recommended approach is to phase in requirements for assessment of whole life carbon, starting with larger developments in 2020. By 2025 requirements to assess and disclose whole life carbon impacts would be extended to cover all developments, and reduction targets would be phased in for larger developments. By 2030, these whole life carbon targets would cover all developments. This phased approach to the introduction of assessments and targets across development scales echoes that set out by others, including in the proposals for a Green New Deal for Housing prepared for the UK Labour Party (Brown, 2019) and other plans (e.g. Roelich and Giesekam (2019)).

In 2018, the CCC joined in calls for the introduction of a new approach, starting with their report on the role of Biomass in a Low Carbon Economy (CCC, 2018). The report called for *"a new mechanism...to incentivise and drive whole-life carbon savings for new buildings"* and *"policies to support a substantial increase in the use of wood in construction"*. The CCC recommended that *"over the next 3-5 years, Government and industry should lay the groundwork to support assessment and benchmarking of whole-life carbon. This should include developing a standardised approach to carbon quantification (making use of consistent methodologies over comparable scopes), development of databases for lifecycle assessments and environmental product declarations (including on a national basis where needed), and steps to drive skills development. Initial roll-out could be driven by public procurement, planning requirements and through evolution and consolidation of a voluntary framework which supports developers to develop their design and materials sourcing strategies in anticipation of mandatory implementation at a clearly specified future date. This groundwork should inform a decision on a mandatory regulatory framework in the 2020s that drives whole-life carbon savings. An effective framework would need to cover all construction systems through technology and material neutral standards that ratchet up over time to drive innovation, best practice and ongoing decarbonisation of industrial sectors."* The CCC also commissioned AECOM to prepare a report outlining options for incorporating embodied and sequestered carbon into the UK building standards framework (AECOM, 2019). The AECOM authors presented 3 broad options summarised in Figure 3.

Related messages were reiterated by the CCC in subsequent Housing (CCC, 2019c) and Net Zero (CCC, 2019a) reports and technical annexes.

At the beginning of 2019, the Building Standards Futures Board was established to strategically advise and direct a broad programme of work aimed at improving the performance and sustainability of the Scottish building standards framework. The Board operates through a number of Work Streams, amongst which the Technical Strategy Work Stream would be most likely to consider the topic of embodied carbon. Though the Board has undertaken some work related to other aspects of sustainability, minutes from meetings do not suggest any recent consideration of embodied or whole life carbon[2].

Local Requirements

In the wake of the UK and Scottish Governments' declarations of a climate emergency and announcement of net zero targets, many local authorities have reassessed their climate goals. At the time of writing, two thirds of UK District, County, Unitary and Metropolitan Councils have declared a Climate Emergency, including 17 in Scotland[3]. Many of these local authorities have subsequently set new emissions reduction targets that are typically more ambitious than national goals. These include targets set by Scotland's two most populous council areas, Glasgow City Council and the City of Edinburgh Council, for the cities to be carbon neutral by 2030. Although Edinburgh City Council's current Local Development Plan (The City of Edinburgh Council, 2016) and Design Guidance (The City of Edinburgh Council, 2018) make references to the use of sustainable materials, they do not place any requirements upon assessment or mitigation of embodied carbon. Likewise, Glasgow's City Development Plan and Supplementary Guidance (Glasgow City Council, 2017) encourage developers to *"demonstrate the highest standards of sustainable design and construction"* but do not include any requirements around embodied carbon.

By contrast, the Greater London Authority is currently in the process of introducing requirements to assess embodied carbon in the city's largest category of developments. The August 2018 Draft London Plan (GLA, 2018) includes a new policy SI2 DB which states: *"Development proposals referable to the Mayor should calculate whole-life cycle carbon emissions through a nationally recognised Whole Life-Cycle Carbon Assessment and demonstrate actions taken to reduce life-cycle carbon emissions."* This is expanded upon in new 9.2.9A section and included in the energy strategy requirements. A contract for design of the policy detail was awarded in October 2019 with the final guidance due for imminent publication at the time of writing this report. The final version of the London Plan is expected to be published shortly. Since the GLA introduced these proposals a number of other local authorities have come forward with draft interventions.

The Greater Manchester Combined Authority has introduced a similar requirement into the new Greater Manchester Spatial Framework (Greater Manchester Combined Authority, 2019). This includes Policy GM-S 2: *"an expectation that new development will be net zero carbon from 2028"* and that all developments will *"include a carbon assessment to demonstrate how the design and layout of the development sought to maximize reductions in whole life CO_2 equivalent carbon emissions"*. The precise definition of zero carbon has yet to be determined at the time of writing.

Other local authorities, such as Bristol City Council, have announced an ambition that by 2025 it will be *"standard practice for major developments in Bristol to be carbon neutral"* and by 2030 it will be *"standard practice that major developments in Bristol are net carbon negative"* (Bristol City Council, 2019). However, the policy detail to support these ambitions has yet to be forthcoming.

A further 11 UK local authorities have made prior enquiries or set requirements around reporting of embodied energy or carbon in some form (Giesekam, 2016). For instance, in 2011 Brighton and Hove County Council introduced an assessment of embodied carbon as part of its required sustainability checklist for all new build residential applications. This is supported by a free online tool for estimating the embodied carbon of building materials. No limit is set, but the policy was simply designed to encourage the use of low carbon materials through the act of encouraging assessment and reporting.

2 Available from https://www.gov.scot/groups/building-standards-futures-board/

3 See https://www.climateemergency.uk/scotland/ for a summary of declarations.

Figure 3: Summary of options and indicative timeframes for driving down lifecycle carbon (including embodied and sequestered carbon) in new buildings based on Figure 1 from (AECOM, 2019).

Time-scale	Common	Voluntary action led by Government procurement	Building regulations whole- life carbon intensity targets	
			Elemental	Whole building
	Groundwork	Option 1	Option 2	Option 3
Decision-point	Commence groundwork and Option 1 as low-regret actions			
2019	National product/material & building LCA/EPD database Standard, simplified LCA for new buildings	Develop overall and sectoral strategies Monitor sectoral carbon intensity targets Lobby for mandatory LCA in BREEAM & HQM		
Decision-point		Require government funded projects to consider and minimise the contribution of embodied and sequestered carbon to lifecycle carbon impacts (e.g. by making relevant BREEAM & HQM credits mandatory)	Opt for Option 2 or Option 3 as the preferred option	
2020	Build professional & industry capacity Expand building LCA database & benchmark across archetypes		Establish targeted elemental method Develop regulatory methods and tools Develop regulatory (e.g. building control) capacity Introduce elemental carbon intensity targets	Establish whole building method and scope
2021				
2022	Maintain LCA / EPD		Progressively tighten intensity targets	Develop regulatory methods and tools Develop regulatory (e.g. building control) capacity Introduce whole building carbon intensity targets
2023				
Onwards			Potentially introduce whole building targets	Progressively tighten intensity targets

Legend: LCA = lifecycle analysis; EPD = Environmental Product Declaration; BREEAM = BRE Environmental Assessment Method; HQM = BRE Home Quality Mark; Element = e.g. structure, façade, roof, etc.

To date there are few examples of reductions in embodied carbon being tied to financial incentives. In 2016 the London Legacy Development Corporation published a supplementary planning document covering carbon offsets for major schemes within the Legacy Corporation area (LLDC, 2016)[4]. This allowed for demonstrated reductions in embodied carbon to count against the typical offsetting fee – at the time £60/tCO_2e. This fee will increase to £95/tCO_2e under the new draft London Plan, and a number of boroughs have taken an interest in further applying this precedent (e.g. Islington and Merton). If this link were to be commonly established it would provide a sizeable financial incentive to reduce embodied carbon, although there is a risk of applicants gaming the system by assuming carbon intensive baseline designs. This risk has been highlighted by other authorities developing offsetting schemes such as the West of England Combined Authority (Stone et al., 2019).

International Precedents

Numerous cities, regions, and nations throughout the world already have measures in place to address embodied carbon. These have been summarised in a handful of previously commissioned international policy reviews, for instance those produced by Zizzo Strategy (Zizzo et al., 2017). The most recent and comprehensive review, the 2018 Embodied Carbon Review produced by Bionova (Bionova Ltd, 2018), analysed some 216 systems across 26 countries. This included certification systems, regulations, standards and guidelines. Of these, 105 included direct measures for embodied carbon, two thirds of which were certification systems. The authors suggest that the number of systems addressing embodied carbon had more than doubled in the preceding five years. The review classifies these systems by geography and methodological approach, distinguishing five main methods of addressing embodied carbon. These are, in increasing order of efficiency: carbon reporting;

4 A major scheme is defined as developments of over 10 homes or 1,000m²

Table 1: Methods used in embodied carbon systems – adapted from (Bionova Ltd, 2018)

Method	How does it work?	Advantages	Disadvantages	Examples
Carbon reporting	Calculate the construction project's embodied carbon and report it	Reporting carbon is easy Builds knowledge and skills	If reporting is the only requirement, design and impacts may not improve.	EN 15978, BREEAM International
Carbon comparison	Compare design options for carbon; for example, design baseline and proposed designs and show improvements against a self-declared baseline value	The most cost-effective way to influence. Options must be understood prior to acting	Comparison is not necessarily leading to best option being built. This may become a formality in some projects.	LEED v4, Green Star, BREEAM UK
Carbon rating	Evaluation of carbon performance. Variable scale from best to worst on which a project's carbon is rated, but no effective maximum value applied. Fixed scale or clear methodology.	Incremental performance improvements provide additional incentive via better rating.	As also a poor rating is also allowed, the less ambitious projects may not improve at all.	DGNB, BREEAM NL
Carbon cap	Calculate the project's embodied carbon and prove it is not exceeding the CO_2e limit.	All projects must meet the stipulated threshold	Setting the cap to a level where it is effective in carbon reduction and yet cost-efficient is hard.	Énergie Carbone, MPG
Decarbonisation	Reduce carbon to a minimum, then compensate all residual emissions by own energy export or buying offsets.	Direct cost from higher carbon emissions is an incentive to reduce as far as possible	Systems aiming at complete decarbonization need a great deal of political will and suitable incentives to be widely applied	Living Building Challenge, NollCO2

comparison in design; carbon rating; carbon caps; and decarbonisation (see Table 1 for a summary). A range of incentives are also considered, including: rating points; funding conditions; a density bonus; cash impacts; and mandatory requirements. In addition to systems using these approaches the review considers the selection of low carbon products using Environmental Product Declarations (EPD). The review authors also offer a number of best practice principles when designing carbon reduction systems – many of which are intuitive. These are:

1. Target the early phase of the project
2. Set an embodied carbon cap for common building types
3. Apply a fixed method for setting rating or carbon cap values
4. Provide incentives for achieving carbon reductions
5. Set rules and requirements based on official standards
6. Set open compliance requirements and verify outcomes.

In addition to classifying all systems, the review provides a number of detailed case studies.

Amongst the broad range of systems in use globally a few stand out as potential precedents for Scotland to emulate.

The Dutch are generally regarded as world leaders in their regulatory approach to new construction. In 2012, the Netherlands introduced a new version of the Building Act (Bouwbesluit), effective from January 2013, which required all residential and office buildings whose surface exceeds 100m² to account for their embodied impacts in the form of a Lifecycle Assessment (LCA) using a national assessment method, associated database, and approved software tools[5]. The method is based on EN 15804 and EN 15978 with national adaptations, including health impact accounting. The assessment method covers 11 LCA impact categories, including embodied carbon, and converts values to a shadow price which is expressed in Euros (embodied carbon is weighted at €50/tCO_2e). The total impact in monetary terms is divided by the building's gross floor area and assessment period length (75 years for residential, 50 for offices). The regulations were revised with effect from January 2018 to set a mandatory environmental impact cap for buildings at €1/m²/yr. This approach – initially focussing on developing common resources and industry familiarity with assessment procedures through mandatory reporting, followed by the introduction of targets – is already being emulated by the Scandinavian nations and could serve as a template for Scotland.

An alternative, or potentially complementary, approach to the detailed assessment of a building's impacts is the introduction of product embodied carbon limits to encourage low carbon procurement. This is best exemplified by the Buy Clean California Act. The Act requires the Department of General Services (DGS) to establish maximum acceptable emissions limits in terms of global warming potential (GWP, reported in terms of mass of carbon dioxide equivalent, e.g. $kgCO_2e$) for key materials including structural steel (hot-rolled sections, hollow structural sections, and plate), concrete reinforcing steel, flat glass, and mineral wool board insulation[6]. From 1st January 2020, awarding authorities require submission of EPD, and by 1st January 2021 DGS will publish the maximum acceptable GWP for eligible materials. Awarding authorities will then gauge compliance of eligible materials with EPD on all public agency projects from 1st July 2021. By this means the highest carbon materials will be omitted from the market, providing a strong incentive for material producers to decarbonise their supply chains or for designers to specify low carbon materials. This approach could also be emulated by Scotland but may meet resistance, particularly amongst small manufacturers, owing to the cost of EPD production. Many product manufacturers in Scotland and the UK have already invested in the production of EPD; in some cases they have combined to produce industry-average EPD, but such EPD would not be sufficient to demonstrate better than limit level performance. France and Belgium both recently introduced requirements that any construction product manufacturer making an environmental claim must have registered a corresponding EPD within their national databases.

Since publication of the 2018 Embodied Carbon Review, additional proposals have also been brought forward in several jurisdictions.

In June 2018 Sweden's National Board of Housing, Building and Planning (Boverket) introduced a new law governing the climate declaration of buildings, effective from 1st January 2022. This followed the spring 2018 publication of the Swedish construction industry's roadmap for fossil free competitiveness (part of a series, of which an English language summary is available in (Fossil Free Sweden, 2018)). Full details of the regulations will not be published until 2021, with current work ongoing to prepare a climate database, declaration register, and guidance material. The new law will include mandatory reporting requirements for virtually all buildings and limit values for climate impacts expressed in $kgCO_2e/m^2$ BTA[7]. The corresponding documentation for the climate declaration will then be submitted to the responsible authority and stored for 10 years by the building owner. The latest progress in development of the regulations is summarised in Swedish only (Boverket, 2020).

Denmark has been operating a freely available life cycle assessment tool LCAbyg since 2015 and will shortly be publishing a set of voluntary

5 See https://milieudatabase.nl/ for further information

6 Proposals to extend the act to cover cement and concrete mixes are currently under consideration

7 BTA is 'bruttoarea' broadly equivalent to the UK's GFA (Gross Floor Area).

sustainability classes. According to a recent ministerial statement these will serve as a testing ground for monitoring and evaluation before the introduction of mandatory requirements in the building regulations from 2023.

Finland launched a public consultation in 2018 regarding the approach to be taken in whole life carbon footprinting, which will become mandatory for new buildings under construction regulations by 2025. The prospective methodology – still under development – will first be tested on publicly procured building projects on a voluntary basis. Embodied carbon requirements will then be introduced for residential towers before being extended to all building types.

Several Scandinavian cities have also introduced requirements that go beyond national standards, including Copenhagen, Stockholm and Oslo. These include earlier commitments to introduction of life cycle assessment reporting, targets, zero-emission construction sites, and substantial changes in public procurement. Efforts to coordinate actions and harmonise building regulations across the Nordic states are also ongoing through the Nordic Working Group for LCA, climate and buildings launched in 2019[8].

A number of US states, including Washington, Oregon and Minnesota, have followed the example set by California by introducing variants of the Buy Clean Act for consideration by local legislatures. A bill proposing similar requirements for federal agencies was introduced to the United States Congress in 2019 (Klobuchar, 2019). However, there is a very low likelihood that this will be enacted under the present political climate.

A small municipality in Canada, Douro-Dummer, has also taken the novel approach of introducing a financial rebate for housebuilders demonstrating delivery of operational and embodied carbon emissions below set thresholds (Township of Duoro-Dummer, 2020).

Bionova have stated their intention to update the 2018 Embodied Carbon Review to reflect recent changes but, to the authors' knowledge, no timeline is in place for this update. However, in the meantime they are working with Carbon Neutral Cities Alliance and Architecture 2030 to develop a policy framework that identifies and ranks the most effective policies that cities can enact to reduce embodied carbon in construction. The City Policy Framework for Dramatically Reducing Embodied Carbon project is due to publish its findings in May 2020[9].

Other related policies & legislation

Energy Efficient Scotland

Improving the energy efficiency of Scotland's buildings has been a national infrastructure priority since 2015. In May 2018, Scottish Ministers published a Route Map to an Energy Efficient Scotland, setting out a pathway to 2040 (Scottish Government, 2018a). This included a wide range of interventions and targets tailored to different tenures, as well as proposals to strengthen energy performance through the introduction of new policy. Two years into the resultant programme a range of pilot projects and consultations are underway[10]. For instance, a consultation into introducing legally binding standards for home energy efficiency in owner occupied homes from 2024 onwards is concluding at the at the time of writing[11]. The programme is focussed upon operational energy use and the associated carbon emissions and does not explicitly address embodied energy or carbon.

Housing to 2040

In July 2019, the Scottish Government set out a draft vision and principles governing future projects in 'Housing to 2040' (Scottish Government, 2019c). Within this, Principle 9 states that: *"decisions around the quality, location and utilisation of existing stock and new build should be ambitious in enhancing biodiversity, promoting Scotland's energy security, and be consistent with the target for Scotland's emissions to be net zero carbon by 2045."* In particular that *"new build homes are built so that they are net zero carbon (i.e. built to high standards of energy efficiency and use renewable heat or very low carbon heating), taking into account the natural resources consumed by the construction process too.. There is more innovation in environmentally-friendly building and improvement techniques and materials, which are thoroughly tested before being implemented."* The introduction of additional measures to address embodied carbon would be consistent with this principle. A consultation on outline policy options to deliver upon the Housing to 2040 vision closed at the end of February 2020, with a final vision and route map expected to be published in summer 2020[12].

Public Sector Bodies

In December 2019 the Scottish Government concluded a consultation on the role of public sector bodies in tackling climate change[13]. Under the Climate Change (Duties of Public Bodies: Reporting Requirements) (Scotland) Order 2015, Public Sector Bodies (PSB) in Scotland are legally required to report annually on their greenhouse gas emissions and any mitigation measures undertaken. The recent consultation proposed that from 2022 all PSBs would be required to *"state the year by which they will cease to emit any direct greenhouse gases and their targets for reducing indirect emissions"*. As part of current annual reporting PSBs are required to report on procurement. However, the standard questions are very simple, asking how procurement policies and activities have contributed to compliance with climate change duties; respondents are also encouraged to provide supporting information and best practice. A recent review of the current reporting found that: *"the 'procurement' sections currently provide little meaningful data and do not effectively monitor how procurement policies are contributing to emissions reduction"* (Scottish Government, 2019d). The consultation includes proposals to establish a High Ambition Climate Network and a National Forum on Climate Change to encourage greater collaboration and sharing of ideas. Some existing networks already exist with Chief Executives from Scotland's executive agencies connected through the Public Bodies Delivery Group; and other public sector professionals connected through the Scottish Energy Officers Network and the Sustainable Scotland Network.

The public sector in Scotland spends around £4 billion a year on building or civil engineering works and is thus in a strong position to influence the embodied carbon of construction through its procurement. Guidance for Scottish public sector construction procurement is set out in a series of three handbooks[14]. Though the need to consider sustainability issues and take a whole life cycle approach to construction procurement is recognised in the handbooks, there are no explicit requirements around embodied carbon. Guidance in the Project Initiation and Contracts (Scottish Government, 2019e) and Construction Procurement (Scottish Government, 2019f) Handbooks suggests use of the Scottish Futures Trust Whole Life Appraisal Tool which can incorporate consideration of embodied carbon from materials only (Scottish Futures Trust, 2016). [15] A more recent toolkit prepared by the Scottish Futures Trust offers further guidance on setting environmental sustainability performance criteria (Scottish Futures Trust, 2018). The toolkit consists of a guidance note and an environmental performance tracker. The guidance notes embodied carbon as an example of a metric against which the client may wish to set a target and references the RICS PS – the Royal Institution of Chartered Surveyors, Professional Statement – (RICS, 2017) as an appropriate methodology. The uptake of this toolkit and the number of users incorporating embodied carbon as a consideration is unknown. More broadly, the extent to which any consideration or requirements around embodied carbon have already been embedded within individual procurement processes of the numerous PSB has not been assessed as part of this high level report but could be considered as part of future work.

Planning

The Town & Country Planning (Environmental Impact Assessment) Scotland Regulations 2017 implement the Environmental Impact Assessment (EIA) Directive 2011/92/EU, as amended by Directive

8 More information, including publications, can be found at https://www.lifecyclecenter.se/projects/nordic-working-group-for-harmonization-lca-climate-and-buildings/

9 More information at https://www.embodiedcarbonpolicies.com/

10 See https://www.gov.scot/policies/energy-efficiency/energy-efficient-scotland/ for an overview

11 More information at https://consult.gov.scot/housing-and-social-justice/energy-efficient-scotland-owner-occupier-proposals/

12 Consultation details at https://consult.gov.scot/housing-services-policy-unit/housing-to-2040/

13 More information at https://www.gov.scot/publications/role-public-sector-bodies-tackling-climate-change-consultation/

14 Available at https://www.gov.scot/policies/public-sector-procurement/construction-procurement/

15 Available at https://bimportal.scottishfuturestrust.org.uk/page/whole-life-appraisal-tool

2014/52/EU in Scotland. They require an EIA with planning applications for larger developments[16]. The EIA report describes the likely significant effects of the development on the environment, including greenhouse gas emissions, and describes proposed mitigation measures. Following this requirement, embodied carbon assessment is already routinely embedded within infrastructure projects in Scotland but is not required on the overwhelming majority of smaller developments under construction at any given time. Amendments in the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 also require that where the Scottish Ministers publish an infrastructure investment plan, they must also publish an assessment of the extent to which investment in accordance with the plan is expected to contribute to meeting emissions reduction targets.

The broader planning regime in Scotland is undergoing a substantive period of change, following the Planning (Scotland) Act 2019 which received Royal Assent in July. The Scottish Government and other bodies are in the midst of a substantive post bill work programme whereby each section of the Act will be brought into force on a specified date by commencement regulations, which are laid in the Scottish Parliament.[17] The expectation is that most of the Act will be implemented by early 2021. Development of the reforms has already been a major focus of the Scottish Government's Planning and Architecture Division, and of organisations across Scotland with an interest in planning, for the past few years, following an independent review of the planning system which reported in May 2016.

Current Scottish Planning Policy, published in 2014, recognises the need for sustainable development and contains policies designed to promote a low carbon place (Scottish Government, 2014). However, this does not include any explicit references to embodied carbon, instead referring to a range of related indirect measures, for instance to *"promote developments that minimise the unnecessary use of primary materials and promote efficient use of secondary materials"* and *"support the emergence of a diverse range of new technologies and investment opportunities to secure economic value from secondary resources, including reuse, refurbishment, remanufacturing and reprocessing"*.

Work has also begun on preparing the fourth National Planning Framework (NPF4), the long-term spatial strategy for Scotland to 2050, with draft publication expected in September 2020[18]. This is expected to *"provide a spatial planning response to the global climate emergency"* and *"meet targets relating to the reduction of emissions of greenhouse gases"* but as yet, there does not appear to be any focus upon embodied carbon[19].

Voluntary initiatives

In addition to actions driven by policy, there are a wide range of voluntary initiatives that are directly or indirectly addressing embodied carbon. Many of these are UK or international initiatives coordinated by professional institutions, industry coalitions and not for profits.

Construction Declares

Construction Declares encompasses a range of voluntary commitments by different professions within the construction industry made in response to the twin crises of climate breakdown and biodiversity loss. Since May 2019 over 900 architecture practices, 150 structural engineering practices, 70 building services engineering, 2000 architectural educators, and nearly 100 civil engineering practices have signed up[20]. The differing declarations include a range of relevant commitments such as to: *"include life cycle costing, whole life carbon modelling and post occupancy evaluation as part of the basic scope of work"*, *"to reduce both embodied and operational resource use"* and to *"accelerate the shift to low embodied carbon materials in all work"*. Efforts are ongoing to implement these measures, supported by shared learning through the initiatives. For instance, Fielden Clegg Bradley Studios hosted an Architects Declare event on Embodied Carbon on the 4th March 2020 to share best practice across the industry. This follows in a long line of similar events, such as those hosted by the Alliance for Sustainable Building Products (ASBP), the London Energy Transformation Initiative (LETI), and the UK Green Building Council (the UKGBC, who hosted an entire Embodied Carbon Week of events back in 2014).

Better Buildings Partnership Climate Change Commitment

Launched in September 2019, the BBP Climate Change Commitment is a collective commitment from 23 property owners with >£300bn of real estate assets and >11,000 properties under management[21]. The commitment includes a range of pledges, including the development of net zero carbon pathways by end of 2020 for new and existing buildings including embodied carbon of development, refurbishment and fit-out works; annual disclosure of progress against pathways; development of guidance for property owners that ensures consistency in definitions and boundaries; and development of climate change resilience strategies by 2022. If implemented these commitments represent a step change in current management of embodied carbon. Most of these signatories already routinely assess and some include the embodied carbon attributable to new developments within their company carbon reduction targets, but few are gathering data on refurbishment and fit-out works. Meeting this commitment will require an extension of existing routine reporting practices to incorporate these elements and the development of pathways that can achieve net zero carbon emissions. It is likely that such pathways will place a high dependence upon the use of carbon offsets. Some of the signatories have already commissioned consultants to begin development of such pathways.

The signatories' current approaches to minimise embodied carbon on projects vary substantially, from setting targets in $kgCO_2e/m^2$ across the whole building at different design stages, to achieving reductions in impacts from 'carbon hotspots' or key materials. Some baselines are determined against an initial project design. Others are against a notional reference building. Some are compared with past projects the client has been involved in. Others are determined from comparison with similar buildings or benchmark data from repositories. In most instances the desired reduction against this baseline is also often determined in an arbitrary manner. Commonly a simple percentage reduction is set based on the client's intuition or past experience. In some cases a specific round value is selected. In other cases, highly specific targets have been instigated through a desire to offset operational emissions or align with a company carbon reduction pathway developed through schemes such as the Science Based Targets Initiative.

RIBA 2030 Climate Challenge

Launched in October 2019, this initiative sets RIBA (Royal Institute of British Architects) Chartered Practices a challenge of achieving reductions in operational energy, potable water use, embodied carbon, and a range of other metrics (RIBA, 2019). The challenge encourages participants to target net zero whole life carbon for new and retrofitted buildings by 2030 by meeting a set of suggested benchmarks, and then offsetting remaining carbon emissions with UK offsite renewable energy projects and/or certified woodland reforestation projects. Practices are encouraged to reduce embodied carbon by at least 50-70% before offsetting the remainder, with targets for 2020, 2025 and 2030 (see Table 2 for those related to embodied carbon). The targets refer to life cycle stages A-C assessed using the RICS PS (RICS, 2017). These targets will also form the basis of RIBA's recommendations to Government for future Building Regulations requirements.

Though a number of practices have committed to the challenge, numerous architects have been critical around a lack of transparency and granularity in the preparation of the targets. For example, the majority of participants at an October 2019 LETI workshop on embodied carbon held shortly after the challenge launch disagreed with the target levels. The extent to which the targets will be adhered to in practice remains to be seen.

16 More specifically those defined in Schedule 1 - http://www.legislation.gov.uk/ssi/2017/102/schedule/1/made and Schedule 2 - http://www.legislation.gov.uk/ssi/2017/102/schedule/2/made

17 See https://www.gov.scot/publications/transforming-planning-practice-post-bill-work-programme/

18 See https://www.transformingplanning.scot/national-planning-framework/ for more details

19 https://blogs.gov.scot/planning-architecture/2019/10/08/national-planning-framework-4-the-essentials/

20 Architects Declare signatories listed at https://www.architectsdeclare.com/ Structural Engineers Declare signatories listed at https://www.structuralengineersdeclare.com/ Buildings Services at https://www.buildingservicesengineersdeclare.com/ and Civil Engineers at https://www.civilengineersdeclare.com/ and architectural educators at https://www.architectureeducationdeclares.com/

21 More information at http://www.betterbuildingspartnership.co.uk/member-climate-change-commitment

Table 2: RIBA 2030 Climate Challenge target metrics for embodied carbon

Building type	Benchmarks and targets ($kgCO_2e/m^2$)			
	Current benchmark	2020	2025	2030
Domestic	1000	<600	<450	<300
Non-domestic	1100	<800	<650	<500

Science Based Targets

Increasingly, corporate actors are disclosing information on their carbon emissions and voluntarily committing to different forms of climate action including commitments on renewable energy, energy efficiency, carbon pricing, protection of land, and investment in green bonds. For instance, in 2018, 6937 companies were disclosing climate change information through CDP, compared with just 220 in 2003 (CDP, 2019). The Science Based Targets initiative (SBTi)[22] is a joint initiative first launched by WWF, WRI, UN Global Compact and CDP in 2014. The SBTi encourages corporations to set carbon reduction targets aligned with pathways that have a high probability of restricting global warming to below 2°C above pre-industrial levels. These corporate 'science-based targets' (SBT) are developed using a common set of resources and target setting methodologies, then independently assessed and approved by a technical advisory group. When initially launched the SBTi had a limited range of generic criteria, resources and methodologies, which have been significantly expanded upon over subsequent years, incorporating additional detail such as sector-specific guidance and further target criteria. Most recently, following the IPCC Special Report on global warming of 1.5°C (IPCC, 2018), the SBTi announced a number of substantial changes to the target validation criteria and associated technical resources (SBTi, 2019a). The additional resources (SBTi, 2019b) included an updated version of the Science Based Target Setting Manual (v4.0), Validation Criteria and Recommendations (v4.0), Target Validation Protocol (v1.0), and a new Target Setting Tool (v1.1). Changes to the initiative included a requirement that from October 2019, targets must be compatible with a 'well below 2°C' pathway. As well as requiring greater ambition for new entrants to the initiative, this change entails increased ambition from current participants as they periodically review existing targets, with 'well below 2°C' alignment becoming mandatory by 2025. At the time of writing, 827 companies had committed to setting targets through the initiative, including more than 90 involved in real estate and construction and associated supply chains. Of these around 30 are based in the UK. A number of other UK construction firms have also publicly stated they intend to set SBT in the coming years.

The SBTi has recently been developing more detailed guidance for the buildings sector in order to better address topics such as embodied carbon, with a view to incorporating more stringent targets. Amongst the companies that have set targets to date, the approach to setting targets for embodied carbon has varied substantially. This is consistent with the initiative's evolving approach to Scope 3 targets (which embodied carbon from construction typically falls under). For SBT approval a Scope 3 screening must be conducted, and where a company's Scope 3 emissions are 40% or more of total Scope 1, 2, and 3 emissions, a Scope 3 target is required. This Scope 3 target may take the form of an emission reduction target or supplier engagement target, or both. Some companies have opted for a combined Scope 1, 2 and 3 target – others have addressed these separately. Recognising more limited control and influence, Scope 3 targets need not be 'science-based' and the associated criteria for SBT validation have changed over time. Current criteria (v4) require a target that covers at least two thirds of total Scope 3 emissions and demonstrates an appropriate 'level of ambition', delivering absolute reductions consistent with the level of decarbonisation required to keep global temperature increase below 2°C compared to pre-industrial temperatures: a 7%/yr reduction in emissions per unit of value added or 2%/yr reductions in a physical intensity metric (SBTi, 2019c). Prior criteria (v2) simply required companies to demonstrate how they were *"addressing the main sources of GHG emissions within their value chain in line with current best practice"*. Consequently the range of commitments made under the initiative span a wide range of ambition, despite all being notionally consistent with the climate science.

It should be noted that numerous companies have also set carbon reduction targets, including for embodied carbon, independent of any larger scheme such as SBTi. See for instance those compiled on the UKGBC's Climate Commitment Platform (UKGBC, 2019) or in Giesekam et al. (2018) and UKGBC (2017a).

Networks and working groups

A number of formal and informal networks and working groups have been established to address the topics of embodied and whole life carbon. These include the Alliance for Sustainable Building Products (ASBP) Whole Life Carbon Working Group[23]; the international Embodied Carbon Network (ECN)[24], and the UK Whole Life Carbon Network. The ASBP working group is a small set of experienced UK practitioners in embodied and whole life carbon assessment. The ECN is a much larger network, hosted by the Carbon Leadership Forum at the University of Washington. It consists of nearly 700 professionals around the globe, though a majority of these are located in North America. The ECN has several focus groups, organises a series of webinars, and utilises Basecamp to host ongoing discussions and to act as a repository for reference documents. The UK's Whole Life Carbon Network is a smaller Google group of around 70 people. In addition, various ongoing industry led initiatives are addressing some aspect of embodied carbon. For example, one of the Net Zero Infrastructure Coalition working groups is currently preparing an assessment of the embodied carbon associated with the UK's future infrastructure requirements[25].

22 See https://sciencebasedtargets.org/ for more information

23 See https://asbp.org.uk/ for more information or contact group leader Jane Anderson

24 See http://www.carbonleadershipforum.org/embodied-carbon-network/ for more information or to join the network

25 See https://www.mottmac.com/download/file?id=37333&isPreview=True for information on the coalition

Metrics

3

Tracking progress in reducing embodied carbon

This chapter summarises different metrics that ZWS may wish to consider using to monitor progress in reducing embodied carbon across the Scottish construction industry at large. There are a limited set of options at present and ZWS may wish to consider developing additional metrics.

Tracking progress in reducing embodied carbon requires metrics at different levels. For individual construction projects the 2017 RICS Professional Statement (RICS, 2017) stipulates different units of measurement for different project types (e.g. $kgCO_2e/m^2$ net internal area for most building classes or $kgCO_2e/km$ for linear infrastructure assets such as roads and railways) and a modular reporting framework that facilitates comparison between similar projects. This can facilitate monitoring of emissions throughout a construction project or comparison across a company's portfolio. However, in the absence of any mandatory or consistent reporting of embodied carbon to a common repository, it is not possible to reliably infer national trends in embodied carbon from the disparate project data that has been compiled on an ad hoc basis to date. For organisations, such as ZWS, that are interested in national trends, metrics that capture the impacts of the sector in aggregate are essential. However, at present there are no direct metrics capturing the total embodied carbon attributable to annual construction activities in Scotland.

Territorial emissions accounts for the country, known as the Scottish Greenhouse Gas Inventory, are typically reported both as a full inventory and as a series of nine aggregated sectors (The Scottish Government, 2019). Embodied carbon from construction spans a number of these sectors including 'Business and Industrial Process', 'Transport', and 'Waste Management'. Within the detailed inventory it is possible to distinguish numerous sources of emissions that would typically be considered embodied carbon (e.g. combustion from cement production); however, many inventory entries cover production of a material with a range of applications beyond construction. Similarly, though a large proportion of emissions from freight and waste management are due to the handling of construction products, there is no means of distinguishing this share within the inventory. Thus, it is not possible to simply extract a metric from the existing emissions inventory. Further to this, any metric based upon territorial emissions alone is arguably inappropriate for a sector with a high dependence upon imported products. A high proportion of emissions intensive products (such as steel and aluminium) are imported and the associated production emissions contribute to climate change irrespective of the location in which they are emitted. The emissions associated with the production of these building products can be considered within the influence of the UK industry, as specifiers can choose between many producers and other practitioners can reduce material use through design choices and on-site practices. Therefore, it is more appropriate to adopt a metric based upon the full consumption based supply chain emissions irrespective of country of origin. This is the boundary that was adopted for the UK by the Green Construction Board (GCB) when selecting an embodied carbon metric for the 2013 Low Carbon Routemap for the Built Environment (GCB, 2013). An overview of other preceding UK sector estimates can be found in Giesekam et al. (2014). The GCB settled upon a consumption based metric derived from a UK MRIO model, with results disaggregated by material and construction type using additional bottom up data and models such as UK BIEC (Giesekam et al., 2016). The boundary and methodological approach is described in the last formal Routemap update (Steele et al., 2015) with additional data published as part of the UKGBC State of Sustainability in the UK Built Environment project (UKGBC, 2017b).

In the absence of an existing Scottish metric, there are three alternative approaches to tracking progress in reducing embodied carbon. These are: the compilation of a bottom-up estimate of embodied carbon using product consumption volumes and LCA data; the use of a top-down estimate derived from multi-region input-output models; or the use of proxy metrics that indirectly indicate progress. The following sections outline these alternatives, recommend current best available metrics, and highlight opportunities for future development of metrics.

Bottom-up estimates

Compiling a bottom-up sector estimate is exceptionally time consuming and difficult to replicate, as demonstrated by past attempts to compile a similar indicator for the UK. For instance, in 2014, Doran painstakingly combined PRODCOM data for 185 construction categories with BRE's proprietary collection of product LCA data to produce a UK estimate (Doran, 2014). This required compilation of a large volume of primary data and numerous assumptions in order to map between available datasets. Such an approach is also fundamentally limited to the production impacts of construction products and excludes other components of embodied carbon, such as emissions from transport and construction activities on-site. Filling these gaps would require a highly impractical amount of additional primary data gathering, such as assessing emissions from a representative sample of construction sites each year. Thus, a metric based upon a bottom up approach is both resource intensive to produce and limited in scope[26].

Top-down estimates

By contrast, top-down estimates derived from multi-region input-output (MRIO) models are comprehensive in scope and simple to replicate. Such models underpin estimates of Scotland's greenhouse gas emissions on a consumption basis, which are published regularly by the Scottish Government as Scotland's Carbon Footprint (Scottish Government, 2019b). This dataset has been published periodically since 2013, with the latest release covering the period 1998-2016. Within such a release it is possible to distinguish consumption-based emissions attributable to final demand from the construction sector in Scotland. This estimate is based upon aggregated final demand for 'Construction of Buildings', 'Civil Engineering' and 'Specialised Construction Activities' (respectively SIC 41, 42 and 43 in the 2 digit Standard Industrial Classification 2007 as implemented in Scotland (The Scottish Government, 2008)). However, this final demand is applied to sectoral emission intensities that are representative of the UK construction sector, owing to an absence of sufficient data to construct a uniquely Scottish MRIO model (as documented in Giesekam et al. (2019)). Therefore, changes in this metric over time reflect a combination of changes in Scottish construction output and UK sectoral emissions intensity. Given the broadly comparable construction techniques and supply chains, it is unlikely that there is a large difference in the sectoral emissions intensity between Scotland and the UK; however, in the absence of a Scottish estimate this assumption is difficult to affirm. It may be that differences, such as the higher market share of timber frame construction in Scotland, would result in differing sectoral emissions intensities. In spite of this substantial limitation, this remains the best currently available high level metric for assessing progress in reducing embodied carbon across Scotland's construction sector. Recent trends in the metric and its components are shown in Figure 4 overleaf.

It can be seen from Figure 4 that total embodied carbon emissions attributable to the Scottish construction sector have been of the order of 4-5 $MtCO_2e/yr$ over the past two decades. The emissions intensity of the UK sector's output has declined throughout this period, though the rate of decline has been lower in recent years. Whilst the average year on year reduction in emissions intensity was 4.5% for the years up until the global financial crisis in 2007, this has fallen to 2.8% in the period since. Indeed, emissions intensity in 2015 were almost the same as in 2010, the bulk of the reduction since the recession has been driven by a 12% drop in 2016 which coincided with a drastic reduction in the use of coal as a power source in the UK and changes in the composition of key imports. This large year on year reduction is unlikely to be emulated again in the years since 2016, with early indications suggesting a slower rate of reduction as the likely trend. Meanwhile, apart from the recession years following the global financial crisis, output from the sector has been on a generally increasing trajectory throughout the analysis period. This combination of increasing output and declining emissions intensity has resulted in broadly stable total sectoral emissions throughout the period since 1998, with minor peaks and troughs corresponding to temporary increases and decreases in output prior to and after the global financial crisis.

In addition to the use of UK intensity data described above, it should be noted that such a metric is also subject to the usual limitations of any consumption-based metric derived from MRIO models, including the implicit dependence upon financial transactions as proxies for exchanges of materials, energy and emissions (see Giesekam et al. (2019) for a summary).

Proxy metrics

Actors in the construction industry routinely gather data comprising a range of metrics across projects and portfolios. See BRE (2017) for an overview of current KPIs and their status in Scotland. Amongst those commonly gathered at present a number have some relevance to embodied carbon. For example, those listed in Table 3 overleaf are routinely gathered through platforms such as BRE's SmartWaste. Tracking the evolution of some metrics, such as emissions from transport of construction products, could provide a useful - albeit very incomplete - picture of progress in reducing embodied carbon across a sample of projects. Such proxy metrics are subject to two further limitations: the relatively small sample size (e.g. BRE's SmartWaste contains only a few hundred projects in Scotland from more than ten years of data gathering), and the inability to determine if the projects gathering this data are representative of the industry at large (it may be that projects gathering such data represent a subset of projects with more ambitious environmental targets).

Project estimates

A small number of companies do routinely gather embodied carbon data for project benchmarking but this data is largely used for internal purposes and not submitted to common repositories. Examples of public reporting of this information can be seen in annual sustainability reports by the likes of Derwent London and Landsec. A full review of all major Scottish companies for evidence of such data gathering or reporting is beyond the scope of this study but it is likely that only a very small minority of the industry are engaged in benchmarking. To address this gap, WRAP and UKGBC established a common public repository in 2014 – the Embodied Carbon Database – initially populated with 205 projects (WRAP and UKGBC, 2014). However, despite having hundreds of registered users, the database received few project submissions in the following years. The database subsequently transferred to ownership by the RICS, and received a prolonged visual overhaul along with some minor improvements in functionality. The relaunched RICS Building Carbon Database (RICS, 2019) had 878 users at the time of writing, but still only contained 249 projects. It remains difficult to see public reporting to such a database increasing in the absence of any requirement or incentive to do so. Consequently, there is no single amalgamated source of project data that could serve as a metric for measuring progress.

Conclusions

In the absence of better options, the primary metric for ZWS to assess progress in reducing embodied carbon in Scotland should be the combined carbon footprint of SIC sectors 41, 42 and 43 in the annual release of Scotland's Carbon Footprint. A medium term priority for ZWS should be to support development of additional metrics. This could, for example, take the form of providing a small financial incentive for companies to annually report projects to a common benchmarking database (such as the RICS Building Carbon Database) to allow for monitoring of a sample set of projects in Scotland. ZWS could further encourage publicly funded projects to routinely include such reporting. This should facilitate project level benchmarking in addition to providing a second metric of sector progress.

26 Note that when bottom-up and top-down approaches were compared for materials extraction, manufacturing and production for the UK construction sector, the difference in totals was <13% (Giesekam, 2016), implying that the two approaches yield broadly similar results despite substantially different resource requirements.

Figure 4: Total embodied carbon emissions and primary drivers. Total embodied carbon emissions are represented by the carbon footprint for SIC 41-43 construction sectors in Scotland's Carbon Footprint 2019 release (The Scottish Government, 2019a). Adjacent panels represent the sectors' total final use of products and the UK sector emissions intensity (ibid).

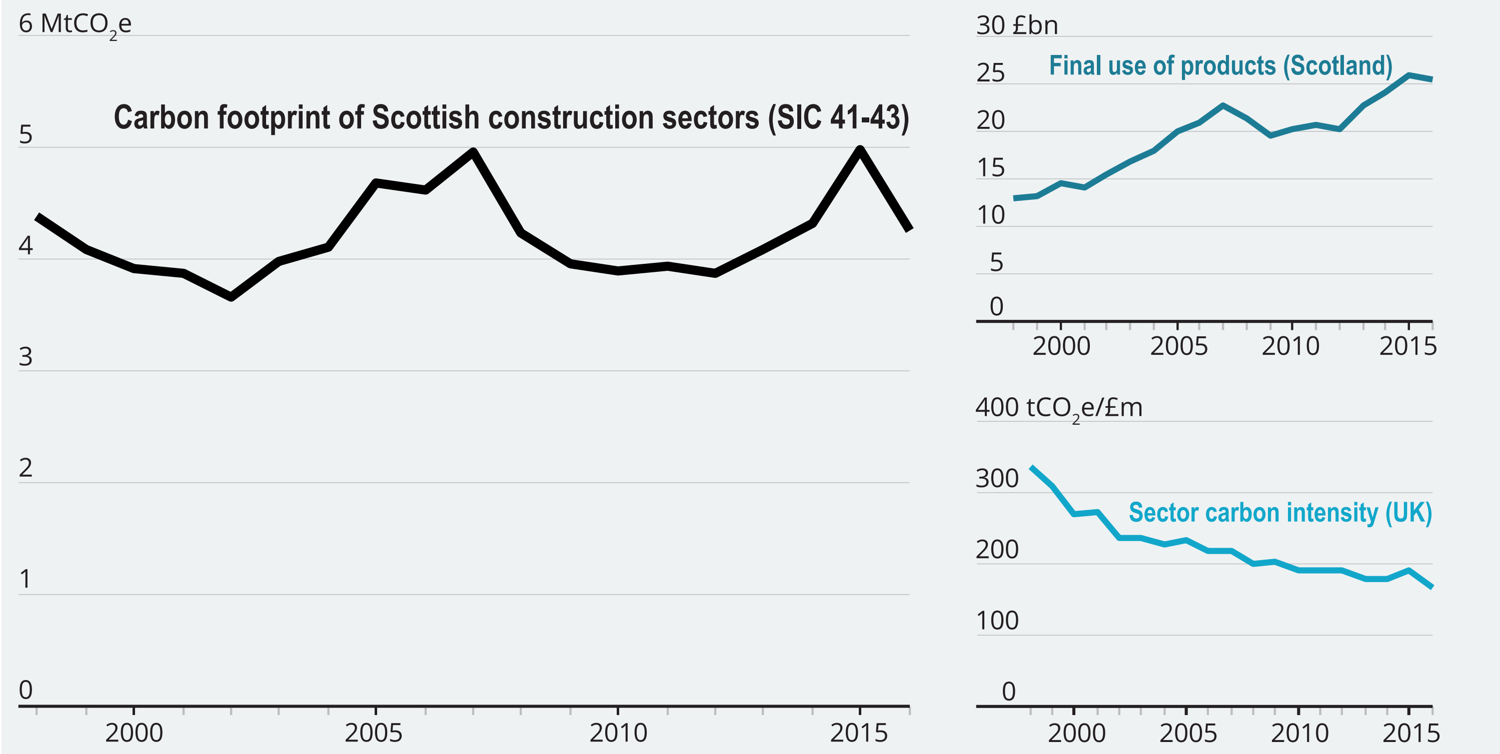


Table 3 – Potential proxy metrics already currently gathered – adapted from (BRE, 2017)

Category	KPI	Ease of data collection	Availability of data for benchmarking	Current usage in UK
Waste arisings	Tonnes/£100K m^3/£100K Tonnes/100m^2 floor area m^3/100m^2 floor area	High	If reporting is the only requirement, design and impacts may not improve.	Widely used
Waste diverted from landfill	% total waste arisings diverted from landfill (reuse, recycle, energy recovery)	High	Comparison is not necessarily leading to best option being built. This may become a formality in some projects.	Widely used
Reuse/recycling of waste	% total waste arisings reused % total waste arisings recycled % total waste arisings sent for energy recovery	High	As also a poor rating is also allowed, the less ambitious projects may not improve at all.	Some usage
Energy use on site related to project value	Tonnes CO_2e/£100K project value	Medium	Setting the cap to a level where it is effective in carbon reduction and yet cost-efficient is hard.	Some usage
Water use on site related to project value	Total m^3 water used/£100K project value	Medium	Systems aiming at complete decarbonization need a great deal of political will and suitable incentives to be widely applied	Some usage
Energy from transport of construction products	Tonnes CO_2e/£100K project value Total fuel consumption Total kgCO_2e emissions	Medium	Medium Limited Limited	Some usage
Distance travelled in delivery of construction products	Total distance travelled (km)	Medium	Limited	Some usage
Vehicle movements	Number of road vehicle movements to site per £100K project value	High	High	Widely used

Tools & datasets

4

Estimating the embodied carbon of construction projects

In an effort to facilitate project-specific estimation of embodied carbon emissions, a wealth of methods and tools have recently came to light. This chapter is an attempt to provide an overview of the most recent developments in software tools and datasets for carbon estimation specifically used by (and available to) construction practitioners in the UK.

Before screening and evaluating existing tools and methods for assessment of embodied (and/or whole-life carbon) greenhouse gas (GHG) emissions in construction it is useful to briefly clarify the greater methodological context and historical background.

First attempts at assessing environmental consequences (either positive or negative) of a certain human activity or action started taking shape in the second half of the twentieth century. Such scientific interest in measuring impacts of human activities on the environment (and humans themselves) was mostly driven by the increasingly visible and unplanned 'side-effects' of the industrial revolution. The changing climate we are experiencing today is perhaps the most important unintended consequence attributable to a global model of industrialisation that is heavily reliant on fossil fuel energy.

All the scientific work built up over time from disparate fields aimed at developing methodologies for environmental impact assessment has eventually culminated into a unified framework termed Life Cycle Assessment. LCA is the most refined and scientifically proven methodology currently available for assessing environmental impacts associated with the entire life cycle of a product (e.g. a building material) a process (e.g. construction) or a service (e.g. housing or office space). The International Organisation for Standardisation codifies LCA into four separate phases (ISO-14040, 2006) as shown in Figure 5.

In the first phase (goal and scope definition) the purpose of the assessment is defined (i.e. what the exercise is aiming to assess) and decisions are declared on the modelling details of the product, process or system being studied and how the study will be conducted (A. Bjørn et al., 2017).

Defining aim and scope and methodological details (e.g. boundaries of the system being assessed) is a critical aspect of any LCA application regardless of the subject or scale of investigation. The outputs of a LCA are obviously sensitive to the model and assumptions adopted to simulate the system around the process, product or service under investigation. Given the epistemic uncertainty in the model (due to limited data and knowledge on how the system actually works), detailing aim, scope and methodology is good practice in order to minimise the risk of misinterpretation and/or misuse of LCA results. Interpretation of results is, in fact, an integral task of LCA as shown in Figure 5.

In order to enable impacts estimation, a required phase in any LCA is the creation of a Life Cycle Inventory (LCI).

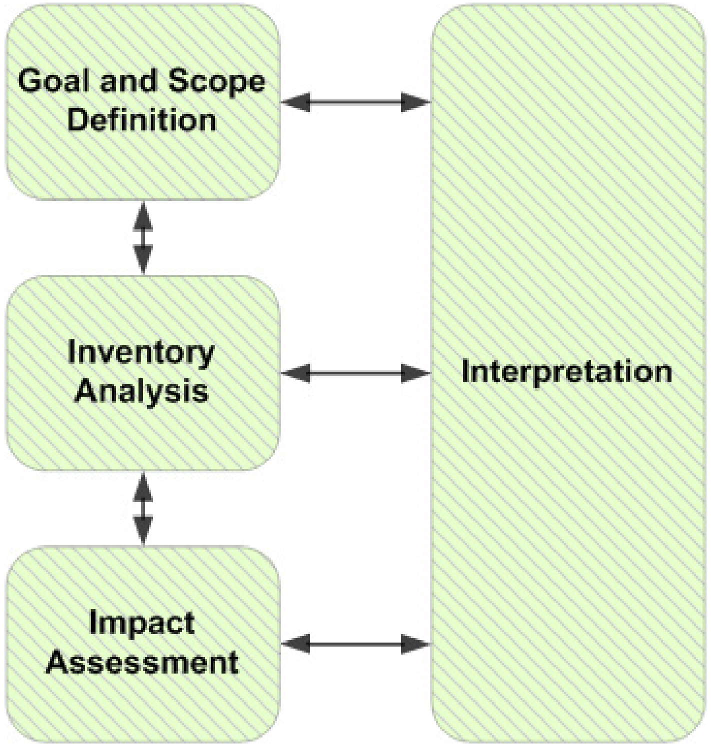
Life cycle inventory

Life Cycle Inventory (LCI) analysis is the LCA phase at which an inventory of the flows of resources and externalities, involved with the product being assessed, is defined and modelled. Such flows include materials and energy inputs and releases to air, land and water. In order to compile the inventory, three main approaches exists: process-based analysis, Input-Output analysis (IO)—originally developed as an economic method which looks at sectoral transactions between several sectors of an economy—and hybrid analysis (a combination of the previous two). The differences between these are described in Chapter 6.

Carbon coefficient databases

Developing a life cycle inventory is a time and resource consuming activity, which requires expert knowledge of the system under assessment along with a wealth of primary data to enable accurate modelling. As an example, estimating the global warming potential (GWP) embodied in a building structure (e.g. a reinforced concrete frame) would require knowledge of the overall materials quantities (cement, aggregates, steel rebar, etc.), energy quantities and mixes, and emissions (CO_2e) which are expected to occur during all of the production stages: from extraction of raw materials all the way down to construction site.

Figure 5: the four general phases of a life-cycle assessment, as described in ISO 14040.



In order to facilitate such data collection, a series of databases have been developed over time. Such databases usually provide embodied carbon coefficients (ECC) and/or coefficients of energy per category of construction material. Estimates are usually expressed in kgCO_2e per unit of material volume or mass, so that practitioners can readily work out total quantities of embodied CO_2e by simply multiplying the ECC of a certain material with the corresponding overall quantity as specified in the bill of quantities of the construction project being assessed.

ICE

A database of ECCs widely used by industry practitioners is the Inventory of Carbon and Energy (ICE) (C. Jones, 2019) which contains data for over 200 construction materials, categorised into around 30 main material categories such as bricks, glass, timber, etc. Data points in the ICE are limited to the up-front share of embodied GHG emissions, i.e. it has a cradle-to-gate focus, thus excluding emissions linked to building construction, operation (e.g. due to maintenance works) and end-of-life activities (e.g. demolition, deconstruction). Despite its widespread use from both industry and academia, and its use of EPD data (see below) the ICE lacks a full detailed description of the adopted methodology behind derivation of its coefficients, with the background data not open to inspection. Clearly, a lack of knowledge about the underpinning methodology prevents any interpretation of the data; hence, it does not allow the analyst to assess potential sources of error deriving from discrepancies between methodological assumptions underpinning the ICE data and the specific context of the construction project the analyst is assessing.

EPiC
A group of researchers at the University of Melbourne has recently released a new database of 250+ material entries of embodied carbon, water and energy coefficients named EPiC, which stands for Environmental Performance in Construction (R. Crawford et al., 2020). EPiC is accompanied by a thorough description of the methodology used in deriving such coefficients. Specifically, a Path Exchange hybrid analysis (M. Lenzen and R. Crawford, 2009) has been adopted to account for all the indirect inflows and outflows occurring upstream at the various levels of the supply chain, which eventually feed into the construction sector.

EPD
Material databases such as the ICE and EPiC clearly facilitate the time and resource-intensive task of compiling a fully-fledged LCI for every single construction project, however aggregating all sources of construction materials under a single label clearly exacerbates estimation errors. This kind of error can be mitigated by providing additional subcategories for each construction material. This permits, for instance, differentiation between two concrete mixes, one manufactured with 15% fly ash replacement for cement and another using 30% fly ash replacement, therefore having two separate entries in the database for the 'concrete' category. Such a reductionist approach effectively shifts the burden of work from the analyst who uses the database to the analyst who compiles it.

There are, however, some important parameters influencing the embodied impacts of materials that cannot be captured by simply adding new and more specific entries to the database. Age of the database compilation and geographical relevance are two of them. For instance, the energy mix (e.g. the share of renewable and fossil fuel energy) assumed for a certain production phase can be expected to change over time, therefore making database obsolescence likely to increase over time.

An alternative source of information regarding embodied GHG in construction products is the Environmental Product Declaration (EPD). EPD are documents attached to a product providing information on the environmental performances of that product, usually including other impact categories in addition to GWP. The embodied carbon per functional unit of product in an EPD is calculated through LCA. The relevant standard for compiling EPD is the ISO 14025, where they are referred to as type III environmental declarations. It should be noted however that methodological assumptions behind EPD are largely unavailable to the final user (for instance, the building designer) which makes it virtually impossible to allow for a fully consistent and informed comparison of alternative products.

A further critique of the reliability of information contained in EPD arises when impacts beyond the cradle-to-gate stage (stages A1-A3) are also being provided as shown in Figure 6 and as in BS EN 15978:2011. While assessing impacts occurring during the A1-A3 stages can rely upon a collection of historic data of the industrial processes behind the material or product (process-based and hybrid LCA), assessing impacts beyond A1-A3, such as the end-of-life stage (C1-C4), requires assumptions to be made on events which will occur in the future. This adds further uncertainty around the reliability of these estimates. In theory, such uncertainty can be handled by rooting the model assumptions on statistical observation of similar past events, therefore deriving likelihood estimates for a certain material or product to be processed in a certain way at the end of its life cycle (e.g. likelihood of being landfilled vs recycled). However, in contrast to the manufacturing stage, such data are not readily available from the product's manufacturer, whose involvement usually terminates at the factory gate or at the installation stage, therefore making such data more difficult (if not impossible) to collect. The absence in EPD of confidence intervals for impacts quantification (Figure 6 is an example of this) is a symptom of the difficulty in evaluating the uncertainty of the model assumptions, especially for impacts beyond the cradle-to-gate stages.

In addition to providing information to the client, EPD also allow the product's manufacturer to use it for promotional purposes, thereby providing a further incentive to produce EPD. In fact, the amount of construction products with an attached EPD is constantly growing, to a point where building designers are now able to make comparative (albeit uncertain) assessments among several products (in some categories) fulfilling the same construction function.

Assessment tools specific for building construction

Given the continuously growing interest (and requirement) by construction practitioners to be able to measure the environmental impacts of their buildings, a wealth of computer tools have been developed in the last few years. An overview of the most widely adopted software currently available follows.

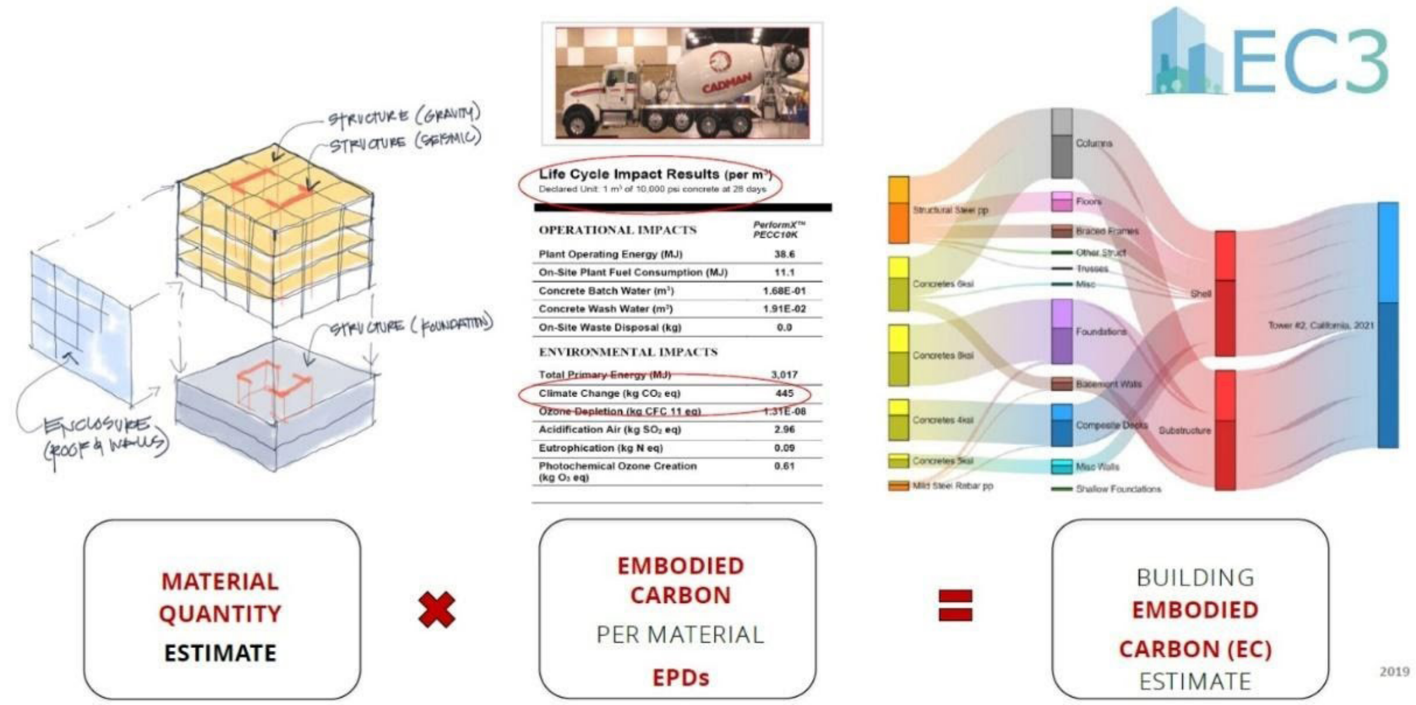
Although the capabilities and functioning of each piece of software differ from one another, there is an underpinning common logic across software products: estimates for a certain impact category (e.g. GWP) are obtained by combining project-specific information (e.g. material quantities, geographic location, etc.) with information on the environmental impact of the materials or products. The first set of information (mostly relevant for stages beyond A1-A3) is obtained from inputs specifically provided by the user, with each piece of software allowing for different degrees of input specification. The second set of information, that is, environmental impacts linked to materials, products or systems (mostly relevant for A1-A3), are mainly retrieved from existing libraries or databases of materials and products such as the ICE, and/or from EPD.

EC3
Embodied Carbon in Construction Calculator (EC3) is an assessment tool containing a continuously updated database of EPD (CLF, 2019). The infographic shown in Figure 7 gives a glimpse of how the tool works. The underlying logic is similar to that underpinning the use of carbon coefficient databases (e.g. ICE, EPiC), where overall embodied

Figure 6: Example of EPD for a Cross Laminated Timber panel. Source (Environdec, 2020)

ENVIRONMENTAL IMPACT CATEGORY	UNIT	MANUFACTURING STAGE			INSTALLATION STAGE		USE STAGE							END OF LIFE STAGE				LIFE CYCLE TOTAL	D
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4		
Global warming potential (GWP)	Kg CO_2 eq.	-716,18	27,45	3,20	47,82	7,39	0,0	0,0	0,0	0,0	0,0	0,0	0,0	4,99	2,38	859,38	0,0	236,42	-56,52
Acidification potential (AP)	Kg SO_2 eq.	9,2E-01	6,6E-02	2,1E-02	1,1E-01	5,0E-02	0,0	0,0	0,0	0,0	0,0	0,0	0,0	3,8E-02	5,7E-03	0,0	0,0	1,22	-3,77E-01
Eutrophication potential (EP)	Kg PO_4^{3-} eq.	2,1E-01	1,4E-02	4,7E-03	2,4E-02	1,3E-02	0,0	0,0	0,0	0,0	0,0	0,0	0,0	8,7E-03	1,2E-03	0,0	0,0	2,78E-01	-9,55E-02
Formation potential of tropospheric ozone (POCP)	Kg C_2H_4 eq.	1,4E-01	4,2E-03	6,5E-04	7,4E-03	2,2E-03	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0E-03	3,7E-04	0,0	0,0	1,58E-01	-3,60E-02
Abiotic depletion potential – Elements	Kg Sb eq.	4,0E-04	8,5E-05	1,2E-06	1,5E-04	3,4E-04	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,5E-06	7,3E-06	0,0	0,0	9,78E-04	-1,55E-04
Abiotic depletion potential – Fossil resources	MJ, net calorific value	1.900,62	440,19	60,12	766,78	116,97	0,0	0,0	0,0	0,0	0,0	0,0	0,0	76,80	38,11	0,0	0,0	3.399,58	-840,35
Ozone layer depletion	Kg CFC-11 eq	1,9E-05	5,2E-06	4,3E-07	9,0E-06	1,2E-06	0,0	0,0	0,0	0,0	0,0	0,0	0,0	9,1E-07	4,5E-07	0,0	0,0	3,57E-05	-6,22E-06
Water pollution[1]	m^3 eq.	195,60	29,07	2,55	50,63	9,51	0,0	0,0	0,0	0,0	0,0	0,0	0,0	4,24	2,52	0,0	0,0	294,12	-87,62
Air pollution[1]	m^3 eq.	35.448,32	2.705,98	341,80	4.713,78	1.320,18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	609,70	234,25	0,0	0,0	45.374,02	-26.828,81

Figure 7: infographic showing the functioning of EC3. Source: (CLF, 2020)



carbon quantities are obtained by multiplying each material quantity within a building project with the corresponding CC retrieved from the corresponding EPD. An advantage of using EC3 is that it can generate a Sankey diagram of embodied carbon broken down per building element (Figure 7), therefore enabling the designer to visualise how embodied carbon is distributed within the building system and to take appropriate design steps to further its reduction.

One of the tool's key features is the possibility of inputting material quantities both manually (e.g. via Excel spreadsheet) or by linking with a Building Information Modelling (BIM) software. This latter option enables design changes applied in the BIM model to be automatically assessed in terms of embodied carbon.

AECB PHribbon
PHribbon is an Excel-based add-on tool developed as an extension of Passivhaus Planning Package (PHPP), which in turn is a software specifically developed for passive house design (AECB, 2017). Similarly to EC3, the tool leverages on a database of carbon coefficients based on the ICE database to work out overall carbon quantities as a function of construction material types and quantities. Unlike the EC3 the tool's methodology can account for the whole building life cycle (A-C including stage D), including a break-down of carbon estimates for each life cycle stage (AECB, 2017).

Tally
Tally is a plug-in application for Autodesk Revit (a BIM software) that can perform environmental assessments by automatically retrieving information on construction materials from the BIM model, and by combining them with environmental coefficients from EPD, it generates graphical outputs (see Figure 8 overleaf) summarising the embodied/whole-life environmental impacts for a series of categories other than GWP.

One Click LCA
One Click LCA is a software for Life Cycle Assessment which is available both as a plug-in application for Autodesk Revit as well as standalone product (Bionova, 2019). In the first case a bill of quantities is automatically retrieved from the BIM model, thereby enabling the user to assess how changes in the building model affect environmental performances.

When used in the standalone version, the user is guided through a series of predefined questions concerning the selection of material/product types, which are then assigned to the predefined categories of building construction sub-systems (e.g. vertical structure; façade, internal walls and non-bearing structure). Once a material has been selected, the user can then specify additional attributes for that material (e.g. thickness; transportation distance; service life). Such information enables the production of a bill of quantities, which combined with EPD information (embedded in the software) for the selected material, allows quantification of several environmental impacts (including GWP) broken down for each life cycle stage. The tool also permits accounting of energy use (both embodied and operational) if relevant information on the type of energy vector and energy use are provided (type of fuel, HVAC system, etc.).

The standalone version of the tool is particularly suitable for early stages of the building design since it does not require a fully defined bill of quantities (either user-inputted or retrieved for a BIM model) but it works it out based on the predefined set of categories defined by the various construction sub-systems.

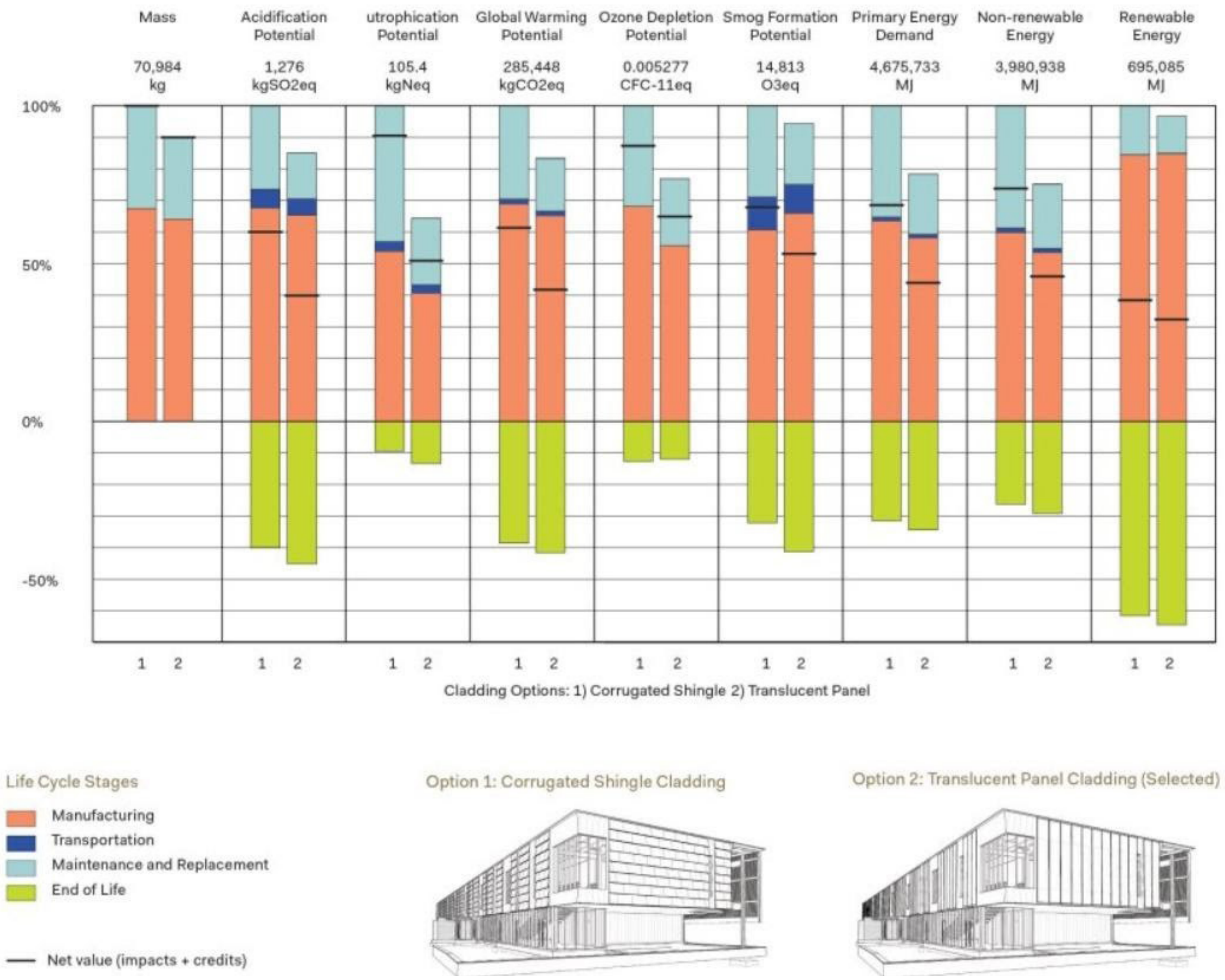
Carbon Planning Tool
Carbon Planning Tool is developed by the UK Environment Agency for infrastructure works. According to the product's brochure (Environment Agency, 2016) the tool consists of two components: a Carbon Modelling Tool designed for use during the project appraisal phase; and a Carbon Calculator to allow for a more detailed assessment.

Carbon Emissions Calculator
Carbon Emission Calculator is a carbon accounting tool used by Highways England to keep track of data on carbon emissions from their supply chain construction and maintenance contractors (Highways England, 2019). The accounting tool is an Excel file organised into ten categories, primarily based upon the Specification for Highways Works. Suppliers are required to insert the material and energy data quantities using the appropriate unit and then select the corresponding carbon coefficient from those available from the inventory. If the exact option for the carbon coefficient is not available within the tool, the user is allowed to pick the closest item from the list. The user is also allowed to input their own carbon factor, provided the methodology used to derive it is also stated (there is a clear inconsistency issue behind the tool).

Rail Carbon Tool
Rail Carbon Tool is a web based tool specifically developed for railway construction in UK (RSSB, 2015). It allows the user to organise the inventory of materials and processes using a data-tree structure which makes it easier to navigate. The tool relies on a library of carbon coefficients (termed carbon factors) which are based on the ICE database.

Carbon Portal
Carbon Portal is a carbon calculator tool developed in-house by Mott Macdonald (Mott MacDonald, 2016). As with other tools, it can be used to assess both embodied and operational carbon footprints of building and infrastructure projects. The tool can be linked to BIM models for a streamlined automated information retrieval.

Figure 8: an example of Tally output showing a comparison of the environmental impacts of two design options: corrugated cladding and translucent cladding. Source: (ArchitectMagazine, 2016)



Carbon Critical Knowledgebase
Similarly to Carbon Portal, Atkins have also developed their own in-house tool called Carbon Critical Knowledgebase. According to the product information sheet (Atkins, 2019) the tool is a web-based database of 'verified' carbon coefficients,combined with a pre-defined library of components (materials, products and processes).

ECCOLAB
ECCOLAB is a web-based tool developed by the architectural firm Architype. According to the product website (RAPIERE, 2020) the tool allows whole-life assessment of carbon emissions, energy and cost. The tool can be integrated as a plug-in for most widely used BIM and CAD software such as Revit and SketchUp. Software capabilities include the possibility to explore alternative design options for a specified budget. The tool also allows automatic generation of BREEAM/LEED certification reports. The library of carbon coefficients is based on EPD. An infographic of the workflow for the carbon assessment module is shown in Figure 9.

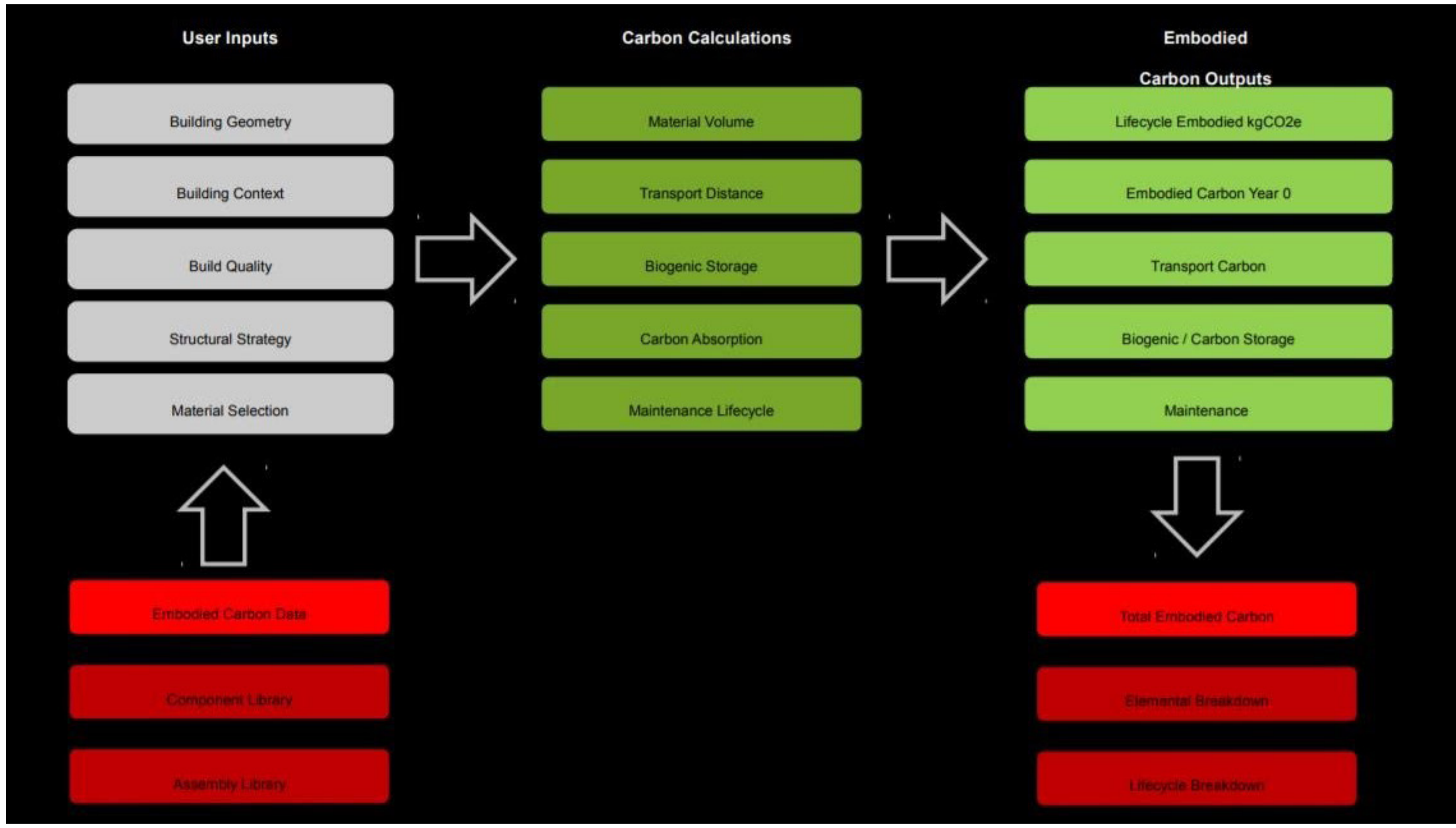
E-Tool
E-Tool is a web-based LCA tool specifically developed for assessment of building projects (E-Tool, 2011). The tool allows assessment of multiple impact categories other than GWP and it can be integrated to Autodesk Revit via a dedicated plug-in. Alternatively, the user can select options for building components or materials from a predefined list of templates, therefore being able to quickly assess and compare how a certain option effects the overall building footprint. Carbon coefficients are based on EPD. E-tool also has a function for automated reporting based on the building and LCA model without the need for editing in MS Word or other text formatting software.

Carbon Infrastructure Transformation Tool
The Carbon Infrastructure Transformation Tool (CITT) is an output of a research collaboration between the Centre for Business and Climate Change at the University of Edinburgh and industry partner Costain Group plc. According to the project's executive report (CITT, 2020), the main focus of the tool is on civil infrastructure projects rather than buildings. The tool enables automatic matching of material and products' information contained in the bill of quantities with emission factors (carbon coefficients), on a cradle-to-gate basis. Research also focused on assessing the risk of "burden shift", that is, reducing impacts in one part of an infrastructure project's life cycle (e.g. embodied emissions) but increasing impacts elsewhere (e.g. the use phase). A dedicated webpage (CITT, 2019) does not currently allow for a download of the tool.

Hawkins-Brown Revit tool
The tool is the end-result of a research collaboration between the design firm Hawkins-Brown and UCL Institute for Environmental Design and Engineering and it can be freely downloaded from the firm's website (Hawkins-Brown, 2016). The main characteristic of the tool is its integration with the BIM software Autodesk Revit which allows assessment at whole building level and real-time appraisal. Impact coefficients are automatically retrieved from EPD.

General LCA tools
The abovementioned software tools are specifically developed for use in the context of the building and construction industry; however, there also exist 'general-purpose' software, such as Open LCA (Michael Srocka et al., 2005) and Simapro (SimaPro, 1995). These examples are not tailored for use within a specific sector, rather their aim is to provide

Figure 9: Workflow of the ECCOLAB tool for whole life carbon assessment. Source: (Rapiere, 2019)



a general platform for the analyst to create her/his own LCI model do describe materials and energy flows. As such they allow more flexibility in the way processes and flows can be modelled, whereas industry-specific tools are usually programmed around a pre-defined framework. For the building and construction sector for instance, the framework is usually the one described in EN 15978 according to which the whole life cycle of a building or infrastructure is modelled as a series in time of pre-defined life cycle stages. Clearly, the presence of a pre-defined frameworks eases the user from the delicate task of specifying a range of assumptions and conditions about the assessment model, its boundaries and functional unit, therefore it greatly lowers the level of competence required for impact assessment. The downside is of course the user's inability to explicitly modify or change the assessment model embedded in the software.

Design guidance

Guidance and certifications

In addition to software tools specifically developed for embodied (and whole life) carbon assessment in construction and the built environment in general, the rising interest on the subject has also led to the development and update of design guidance and sustainability schemes which now include specific guidance on achieving design solutions embedding low carbon. The following is an overview of the most authoritative guides and schemes that are mostly relevant to the UK landscape.

RICS

The Royal Institute of Chartered Surveyors (RICS) issued a professional statement in 2017 for its members providing a standard framework on how to conduct whole life carbon assessment for the built environment (RICS, 2017) in line with the EN 15978 requirements. The framework differentiates between two assessment approaches: Dynamic and Static. In the first case, a whole life carbon assessment for the project is carried out at an early design stage so that it provides a baseline to compare the results of later assessments, so as to monitor the carbon progress of the project. In the static case, a collection and analysis of whole life carbon is carried out at the 'as built' stage. Two main 'aims' are highlighted in the professional statement, Scope section: to provide a consistent assessment procedure and to enable integration of life carbon assessment into the design process.

As mentioned, the framework adopts the modular approach of EN 15978 to break down whole life into separate consecutive stages. Yet, carbon estimates (and/or methodologies to derive them) are only provided for some of the life cycle stages. For the cradle-to-gate stages (A1-A3) no information is provided whereas for construction and installation (A4) an estimate of 1400 $kgCO_2e$ per £100k of project value is given as a guidance. Similarly, recovery rates for some metals commonly used in construction are also provided, which is relevant for carbon emissions estimates at the end of life stage. The guide also provides indicative values for lifespans of buildings components, which are relevant piece of information when assessing for emissions linked to the in-use stages, such as replacement emissions (B4). The guide also provides information on how to account for biogenic carbon, i.e. carbon sequestered into wood and wood-based construction products. The assessor is allowed to account for the benefit of sequestered carbon only if stage C (end-of-life) is included in the assessment and the timber used in the product originates from sustainable (certified) sources.

BREEAM

The Building Research Establishment Environmental Assessment Method (BREEAM) is a voluntary scheme first introduced in 1990 by the UK Building Research Establishment as a certifying scheme for newly constructed office buildings. The scheme has expanded over time and it can now be applied to several types of building construction as well as refurbishment projects. The assessment is undertaken by an independent (BRE-certified) assessor in two stages: a design stage assessment, resulting in an interim certificate being issued; and a post-construction assessment, resulting in a final certificate being issued and rating awarded. The overall rating is based on a qualitative 5-point scale, ranging from 'Pass' to 'Outstanding' based on a range of indicators across several categories (Ongreening, 2017):

- Energy: building operational energy and CO_2 emissions
- Management: management policy, commissioning, site management and procurement
- Health and Wellbeing: indoor and external issues (noise, light, air, quality, etc.)
- Materials: environmental impacts of building materials
- Transport: transport-related CO_2 and location-related factors
- Water: building consumption and efficiency
- Waste: construction and operational waste management
- Pollution: water and air pollution
- Land Use & Ecology: site and building footprint and ecological value and conservation.

Given the incompatibility of metrics among categories, the scheme relies on a credit points system, with more points being assigned to higher performance achieved in each category. For instance, to score an 'Outstanding' rating, the sum of credits scored in each category must be at least 85% of the total available credits.

As it can be seen in the list above, embodied CO_2 emissions are not explicitly accounted for in a dedicated category. Rather, they are included in the environmental impacts (i.e. Materials) category for which they can account for up to half of the available credits in that category (BREEAM, 2019). The assessment criteria by which credits are awarded takes into account a series of aspects. One of these for instance is how environmental impacts of the building projects (estimated via LCA) compare against the BREEAM LCA benchmark. Another criterion is the number of alternative design options being appraised using LCA. The scheme also defines methodological restrictions with regard to the life cycle assessment task, which must be undertaken either using the BREEAM Simplified Building LCA Tool; tools compliant with the IMPACT database (BRE, 2018); or any other building LCA tool recognised by BREEAM such as One Click LCA or E-Tool. A complete list of recognised tools can be found on the BREEAM website (BREEAM, 2020).

LETI

The London Energy Transformation Initiative (LETI) is a voluntary group of built environment professionals which aims to drive building design solutions to achieve a net-zero carbon future for the UK built environment. Among the various activities and projects, a design guide has recently been released (LETI, 2020) with the overarching aim to increase carbon literacy among professionals and to provide a reference building design guide to enable practical implementation in order to meet the 1.5°C limit set by the Paris Agreement. To achieve this the guide first explains the basic differences in definitions between whole-life, embodied, and operational carbon. Then, it provides a series of guidance for different building archetypes (e.g. small/large-scale housing, offices, etc.) which are required to be considered during design. Such design measures are classified into the two categories of operational energy measures and embodied carbon measures. The first set of metrics refers, for instance, to design specification limits for U-values of the building fabric, air tightness and power efficiency performance limits. With regard to embodied carbon, a single requirement is specified to limit embodied carbon below a prescribed value: the limit being in the range of 500-600$kgCO_2e/m^2$, depending on the building archetype. No information can be found in the guide on the methodology adopted to derive such embodied carbon limits. Also, no specific tool or methodology is mentioned in the document with regard to how embodied carbon should be estimated. The only advice is to read the guide *"in conjunction with the latest guidance and technical toolkits available, including (but not limited to) those from the UKGBC, RICS, CIBSE, and the RIBA."* (LETI, 2020).

A further document, issues by LETI as a supplement to the Climate Emergency Design Guide, is the Embodied Carbon Primer (LETI, 2019). The primer provides additional details about key concepts, terms and methods for assessing whole-life carbon in the built environment alongside further design guidance and mitigation strategies. Concepts such as design for adaptability and disassembly, material substitution and re-use, are thoroughly discussed and supported by an excursus of case studies of real design projects.

The Alliance for Sustainable Building Products

ASBP's briefing papers on EPD aim to improve understanding of sustainability in the context of construction products, and to highlight their utility to product designers, client groups, regulators, and local authorities (ASBP, 2019 & ASBP, 2020). They also briefly outline how the EPD system functions through governing standards, EPD programme operators, and independent verification for instance. In 2019 there were 6000 downloadable EPD to EN 15804 across the different programmes, with France, Germany and the USA in front, and a relatively small but growing number from the UK.

Construction Products Association

The CPA guide to understanding the embodied impacts of construction products (CPA, 2012) aims to improve understanding of the topic across the industry. The guide includes a section on embodied carbon, although overall it covers the full suite of environmental impacts addressed by LCA – not just carbon. An accessible introduction to LCA and its use in construction is included, before introducing EPD and Product Category Rules, and the various schemes around Europe. Although some of the material is showing its age (e.g. references and tools) this still provides a worthwhile introduction to anybody then prepared to look beyond it for the detailed and up-to-date information they need.

WRAP

The resource management 'catalyst' WRAP indirectly addresses embodied carbon in much, if not all, of its work. Although construction is not one of its three stated priority sectors (food & drink, clothing & textiles, and plastics), it has published a nine-page information sheet on cutting embodied carbon in construction projects (WRAP, 2014). Rather than covering the theory and calculation of embodied carbon, this is about showing what good practice looks like. The document outlines the practical steps that can be taken (compact building form, design for less waste on site, design for reuse and deconstruction, material selection, etc.), and gives examples of their use and possible savings in embodied carbon for different categories of project.

UKGBC

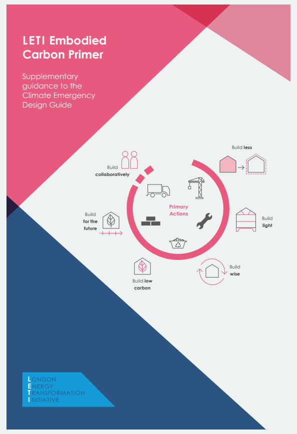
In 2017, the UK Green Building Council (UKGBC) set up a specialist working group to draw up a guidance report on how to effectively prepare briefs for commissioning embodied carbon estimates. The resulting guide has been specifically tailored for users who *"may be at an early stage of embodied carbon knowledge"* (UKGBC, 2017). Given the guide's remit, it does not provide any technical standard or methodology for embodied carbon assessment. Rather it defines a framework to enable clients (e.g. real estate investors, developers, and local authorities) building their own approach for embodied carbon assessment at an organisational level.

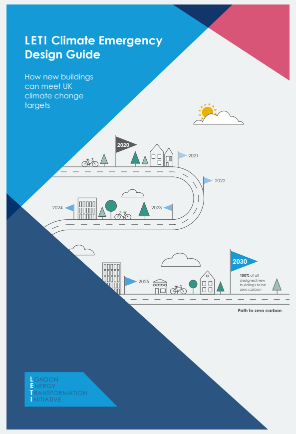
The UKGBC also issued an earlier guide (UKGBC, 2015) aimed at clients and practitioners, to increase awareness on the subject. The guide explains, for instance, the basic difference between operational and embodied carbon in buildings; it provides an overview of the assessment methodologies and practical design steps to identify and mitigate carbon hotspots (e.g. structural system); and it also provides a list of design case studies exemplifying how embodied carbon mitigation can be achieved via efficient design.

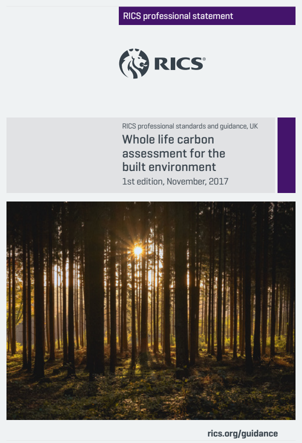
RIBA

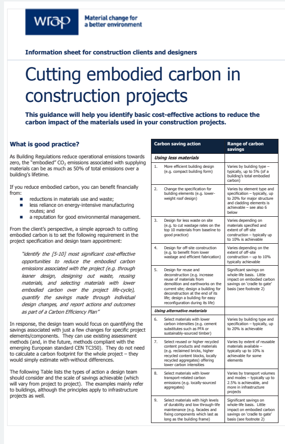
The Royal Institute of British Architects (RIBA) has also launched its own design guidance (RIBA, 2018). The document is tailored around the concept of whole-life carbon, with strong emphasis on the assessment methodology developed by RICS which underpins the whole document. The guide is, in practice, an introductory brief explaining (and encouraging) architects to adopt the RICS statement methodology for whole-life carbon assessment described at the beginning of this chapter. The guide also provides a timeframe for undertaking assessment tasks at specific intervals (and levels of details) according to the RIBA plan-of-work stages congruently with the life-cycle stage modules of BS EN 15978.

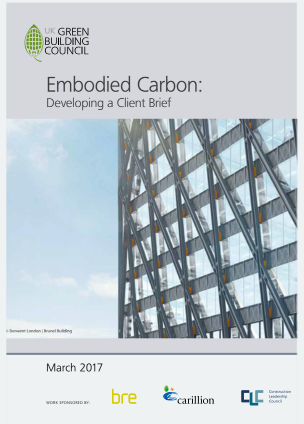
Useful introductory guidance documents

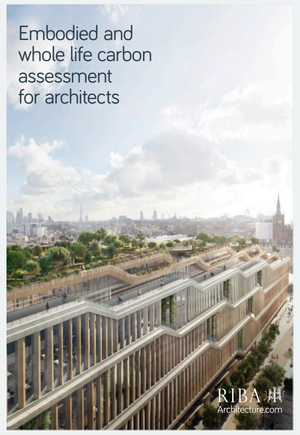


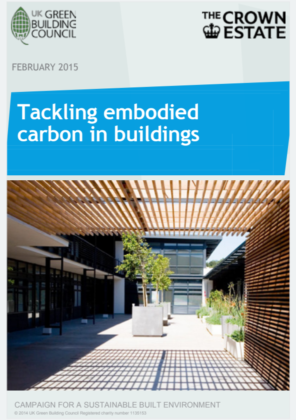


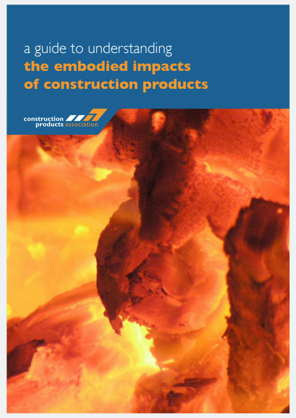












Current gaps

6

Gaps in knowledge, data and methods

The existing knowledge around embodied carbon developed over the past four decades (Costanza, 1980), and more recently translated to buildings and the construction sector. The somewhat scattered development of the knowledge on the subject has inevitably influenced the practical uptake of the topic. As a result, existing knowledge around embodied carbon is currently fragmented and different communities of practice (e.g. structural engineers vs. construction manager) are likely to address the issues very differently. Giesekam and Pomponi (2017) offer an overview of gaps and guidance around EC. This section highlights the main gaps in key areas..

Gaps in knowledge

Embodied carbon is seemingly simple, but in fact, there is a lot complexity hidden behind a single number. An embodied carbon coefficient for a building material represents – as a minimum[27] – a proxy for all the greenhouse gas (GHG) emissions that occurred in relation to energy use throughout the supply chain that led to the existence of that material (including winning raw materials, transportation, manufacturing, packaging, handling, storage, etc.), plus GHG emissions linked to chemical reactions that might have also happened during production (as is the case for cement, for instance). For simplicity and practicality, rather than mapping the supply chain behind a product or material at each assessment, there is an assumption of homogeneity believing that the supply chain remains identical and therefore coefficients coming from (at best) one data collection exercise get used across time and space. The complexity behind embodied carbon coefficients is particularly poorly understood by construction professionals (De Wolf et al., 2017). For instance, the embodied carbon (EC) of a building structure s, can be estimated in a simplified way through eq. 1

$$EC_s = \sum_{i=1}^{n} m_i \cdot ecc_i$$

where the overall mass m of each material i is multiplied by the embodied carbon coefficient (ecc) of that specific material i. Structural engineers would obsessively focus on the accuracy and reduction potential of the mi term of the equation without however paying much attention to the ecci term, for which they will happily accept an off-the-shelf, inaccurate, and non-peer reviewed value.

Gap 1: There lacks detailed knowledge and understanding of the complexity behind embodied carbon coefficients

The importance of the variability of ECCs, and the potential consequences on the accuracy of assessments and future performance gaps have been brought to light by Pomponi and Moncaster (2018). Table 4 captures this variation for a few construction materials based on numbers used in published embodied carbon assessments.

Gap 2: There lacks guidance on how to handle the variability of ECCs for their correct use in embodied and whole life carbon assessments

The great variability of ECCs contributes to a significant uncertainty of embodied carbon estimates used in the assessments. This is another significant gap which has only recently started to receive significant attention. Due to the continued variability of supply chains, and the great variation in ECCs, it should be clear that any assessment is only an estimate of the actual embodied carbon of a building or building product. Thus, it is imperative to be able to say something on the accuracy of such an estimate in comparison to the actual value. This is possible through the combined use of two main techniques: uncertainty and sensitivity analysis. Uncertainty analysis assesses the uncertainty in model outputs that derives from uncertainty in inputs. Sensitivity analysis assesses the contributions of the inputs to the total uncertainty in analysis outcomes. Mendoza Beltran et al. (2018) have demonstrated the implications of omitting an uncertainty analysis in EC assessments, and Pomponi et al. (2017) have developed a facilitated method to conduct uncertainty analysis of buildings. Gantner et al. (2018) developed probabilistic approaches to the measurement of EC and Richardson et al. (2018) assessed the uncertainty of comparative EC assessments at the design stage. These are all novel approaches that are contributing to the growing awareness of the role uncertainty plays in EC assessments.

Uncertainty plays a role in at least two stages in the assessments. First, different sources are used with boundaries and assumptions that are not often declared, thus preventing a transparent comparison of the results which in turn further increase the uncertainty around numbers. Second, such sources are used to produce assessments which result in unique, very definite numbers with no information whatsoever on their uncertainty and probability distribution, as explained by Pomponi and Moncaster (2016).

27 In academic circles there is wide agreement that embodied carbon also includes process and activities downstream from the manufacturing gate, such as transportation to construction site, installation, maintenance and repair and end-of-life disposal and waste processing. These activities are formalised in full in the BS EN 15978:2011 and refer to production and construction, use, and end-of-life stages (A, B and C respectively). Additional loads and benefits beyond the life cycle can and should be captured through an additional life cycle module (module D), whose use in practice remains however both limited and controversial as, depending on the interpretations behind its use, it is possible to greatly favour or severely penalise certain materials.

Table 4 - Minima and maxima ECCs and sample calculations for 1 metric tonne of each material (reproduced from Pomponi and Moncaster, 2018)

ECCs [$kgCO_{2e}/kg_{MAT}$]	Cement	Concrete	Masonry (LB)	Steel	Steel (recycled)	Timber
Minima	0.196	0.033	0.074	1.340	0.160	0.200
Maxima	1.050	0.295	0.550	3.809	1.670	0.720
Ratio M/m	536%	894%	743%	284%	1044%	360%
EC [$kgCO_{2e}/1\ t_{MAT}$]	Cement	Concrete	Masonry (LB)	Steel	Steel (recycled)	Timber
Minima	195.88	33.00	74.00	1340.00	160.00	200.00
Maxima	1050.00	295.00	550.00	3808.76	1670.00	720.00
Difference [$kgCO_{2e}$]	854.12	262	476	2468.76	1510	520

Gap 3: There is an urgent need to increase awareness, knowledge base, and understanding of the role uncertainty plays in the accuracy and reliability of EC assessments.

Linked to the previous issue of uncertainty, but worthy of a separate discussion, is the time element linked to life cycle stages and life spans of buildings. Arguably, no other 'products' last for so long as buildings, and there is also a lack of awareness, at the design stage, on the number of owners and stakeholders that will ultimately determine a building's fate. For this reason, despite existing methodologies (e.g. RICS 2017) suggesting lifespans for whole buildings and their constituting elements, these should not be used to normalise EC results from assessments. This is particularly the case when the vast majority of the whole-life EC is incurred in the initial stages of a building's life (e.g. years 1-3), and therefore spreading it over the 60/100 years of assumed useful life dilutes impacts and weakens the importance of immediate and imperative EC reduction.

The lack of sufficient education of a national EC community of practice is evidenced by the newly published guidance on embodied carbon by LETI (London Energy Transformation Initiative, 2020). The RICS (2017) Professional Statement was developed as a necessary clarificatory guidance to help a wider uptake of the BS and EN standards developed by the TC350. It seems now clear that the work done for the RICS PS has been insufficient for, or insufficiently communicated to, the wider community in the UK, since LETI represents a voluntary collective to clarify and shed light on how to conduct EC assessments and work towards the net-zero carbon targets.

Gap 4: There is a lack of formalised knowledge offering and knowledge base throughout the UK for reliable and replicable execution of EC assessments in practice.

Gaps in methodologies

Embodied carbon assessments of buildings are methodologically similar to the more well-known and standardised life cycle assessment (LCA) focused on the quantification of environmental impacts (including GHG emissions) throughout the life cycle of a product. While existing LCA standards only consider and accept one methodology, there is widespread agreement in academia that, in fact, there are at least three options in choosing how to conduct an LCA (Pomponi and Lenzen, 2018).

Process-based analysis

Process based analysis consists in the quantification of the inputs and outputs linked to a specific system boundary drawn around the product/process under examination. It consists of highly disaggregated data which refer to products and processes strongly linked to the object of assessment. Data should also be location specific and characterised by good technological correlation. Whilst process-based analysis offers highly-accurate and highly-specific data in relation to what is being assessed, it inevitably neglects most of the impacts occurring upstream in the supply chain. As an example, a process-based analysis of a manufacturing plant producing steel structural sections would have a very good overview of what happens within the plant but would struggle to capture data and impacts upstream (e.g. suppliers of the plant, suppliers of their suppliers, mining of iron ore etc.). This results in process-based analysis being characterised by high truncation errors and Lenzen (2000) has demonstrated these can be in the order of 40-70% of omitted impacts.

Input-output analysis

Input-output (IO) matrices are an economic tool for which Wassily Leontief was awarded the Nobel Prize in Economics in 1973. They map the whole of intersectoral transactions that occur in a national economy and as such they offer a complete perspective of supply chains. Over the years the field has evolved significantly in two main directions. Firstly, IO tables have gone beyond national borders and multi-regional IO (MRIO) datasets have been compiled. Secondly, in the so-called satellite accounts, data on environmental repercussion of economic activities and industrial sectors allowed the creation of environmentally extended MRIO (EEMRIO), as originally envisaged by Leontief (1970) himself. An IO approach offers theoretically perfect full system coverage since mathematically it can trace upstream impacts in the supply chain until they become infinitesimal. However, this greater accuracy is achieved at the expense of granularity, and so IO-based analyses suffer from the so-called aggregation error, whereby different sectors of an economy (e.g. rice vs. wheat cultivation, which have very different water requirements) are aggregated into a larger sector (e.g. agriculture) and therefore individual differences are lost and impacts averaged.

Hybrid analysis

Unsurprisingly, there have been attempts since the late '90s to combine the best of both worlds and create hybrid approaches for the environmental impact assessment of buildings and construction. This has been pioneered by Treloar (1997) in Australia, and Australia remains to date a pioneer in hybrid LCA (Stephan et al., 2018; Teh et al., 2018, 2017). Hybrid LCA requires manual interpolation of data, which is still a labour intensive task, but there have been rapid and promising steps forwards to overcome limitation in its application to building and construction (Stephan et al. 2019). Lastly, the latest and most accurate dataset developed for environmental impacts assessment of building and construction (Environmental Performance in Construction, EPiC) adopts hybrid LCA to produce ECCs (Crawford et al., 2019).

Gap 5: There is a lack of agreement on the most appropriate methodology for EC assessment of buildings and construction. National governments could support the creation of national committees and task forces to develop the most appropriate approach for a country and a realistic roadmap leading to reliable assessments in the near future.

Additional methodological issues

There is also a lack of consensus on a clear global methodology to be used for EC assessments (despite the RICS PS aiming to fill precisely this gap for the UK, and possibly beyond). As a resul,t the Sub-Task 1 of the Annex 72 of the International Energy Agency (IEA) is working on the development of a global, harmonised methodology[28]. So far, comparisons of national methodologies have highlighted utterly different results, demonstrating that (1) there is still scope for significant improvements and (2) it is hard to foresee a standardised, global approach in the near future (Frischknecht et al., 2019). De Wolf et al. (2017), concluded that national governments should support both methodological development and national inventories and datasets to overcome these issues.

Evidence supporting the need of agreed methodologies and methods in the UK comes from Moncaster et al. (2018) who identified, and quantified, the three major areas of methodological variation in an EC assessment of a building: temporal differences in the stages considered; spatial differences in the material boundaries; and physical disparities in the data coefficients. They demonstrate that that varying the methodological choices can change the results by an alarming factor of 10 or even more. Similarly, Pomponi et al. (2018) compared fifteen real projects for which EC assessments were producing by leading UK consultants starting from identical information contained in the bill of quantities. In spite of this, variations in EC results were worryingly different, with discrepancies up to 40-60%.

28 http://annex72.iea-ebc.org/subtasks

Gaps in data

An EC assessment is only good as the data behind it. This is often heard in practice as well as in academia as there is sufficient awareness that poor data fed into any model, no matter how good it is, will most probably produce poor results. An example is the Inventory of Carbon Energy (ICE) produced for the UK over a decade ago (Hammond and Jones, 2008). Circular Ecology (the current owner/curator of the ICE) report over 25,000 users of the ICE, and it is very clear that a large number of its users are from outside the UK despite the UK ICE being tuned to the UK context.

The ICE also embeds many of the issues often seen with EC assessments of buildings and construction, in that it can be difficult to judge the applicability of the data to the context in which it is used, and to make comparisons with results coming from other assessments. A lack of concerted, centralised intervention to produce national and reliable datasets and mandate their use in EC assessment in buildings and construction has led to the proliferation of hundreds of case studies of individual buildings based on ICE data as well as the creation of tens of in-house EC calculation tools which rely on EC data for calculation. The likely output is different organisations producing EC values based on different levels of accuracy and expertise coming from their in-house or chosen tools, but all reliant on data relevant for different contexts (Pomponi and Moncaster, 2016).

There have been attempts in the UK to create national inventories, linked to the EC of buildings, such as the old (althouth now revamped through the RICS) voluntary WRAP database[29]. The WRAP database allows for the voluntary submission of EC data linked to building projects but it lacks the necessary data infrastructure that would allow for full transparency and replicability. In its current form, it's ability to change the status quo is limited, and may simply tell us that the EC of buildings is characterised by huge variability, a fact known for some time (De Wolf et al., 2017).

The lack of data – in the UK and globally – also leads to the lack of benchmarks, despite some attempts to define them (Simonen et al., 2017). The new LETI sister documents also offer benchmarks for four different building types, but it is evident that they are based more on professional expertise and rules of thumb than a proper benchmark development process. The lack of data and benchmarks at regional and national levels therefore inhibits real development of EC assessments in practice since keen professionals would (1) struggle to find date to underpin their EC assessment and (2) not know whether their EC results are good or bad in comparison to similar buildings.

Gap 6: There is scarcity of data at national and regional level in the UK to support smooth, reliable and streamlined EC assessments of buildings and construction. Whilst a number of plausible initiatives exist, it is unlikely that these can make up for concerted action and a centralised approach supported by national government and devolved administrations.

29 See http://ecdb.wrap.org.uk/Default.aspx and https://wlcarbon.rics.org/Default.aspx

Mitigation options

7

How can we reduce embodied carbon?

Once embodied carbon has been measured, a number of mitigation measures can be implemented to reduce it. These can range from strategies linked to material efficiency (using less of the same material), material substitution (using a low-carbon material instead of a carbon intensive one where possible), optimising building design, choosing low carbon procurement routes, favouring local materials where appropriate which incur fewer emissions due to transport. The following summarises the high-level evidence around these options and highlights the need for a concerted and collaborative effort because no single approach can yield the necessary reduction.

The mitigation of EC is best achieved as early as possible in a project's life cycle, as clearly shown years ago by the Green Construction Board (Figure 10).

This approach offers an intuitive and simple to use visual element to support macro strategies aimed at EC reduction and it has been adopted in the recent LETI guidance.

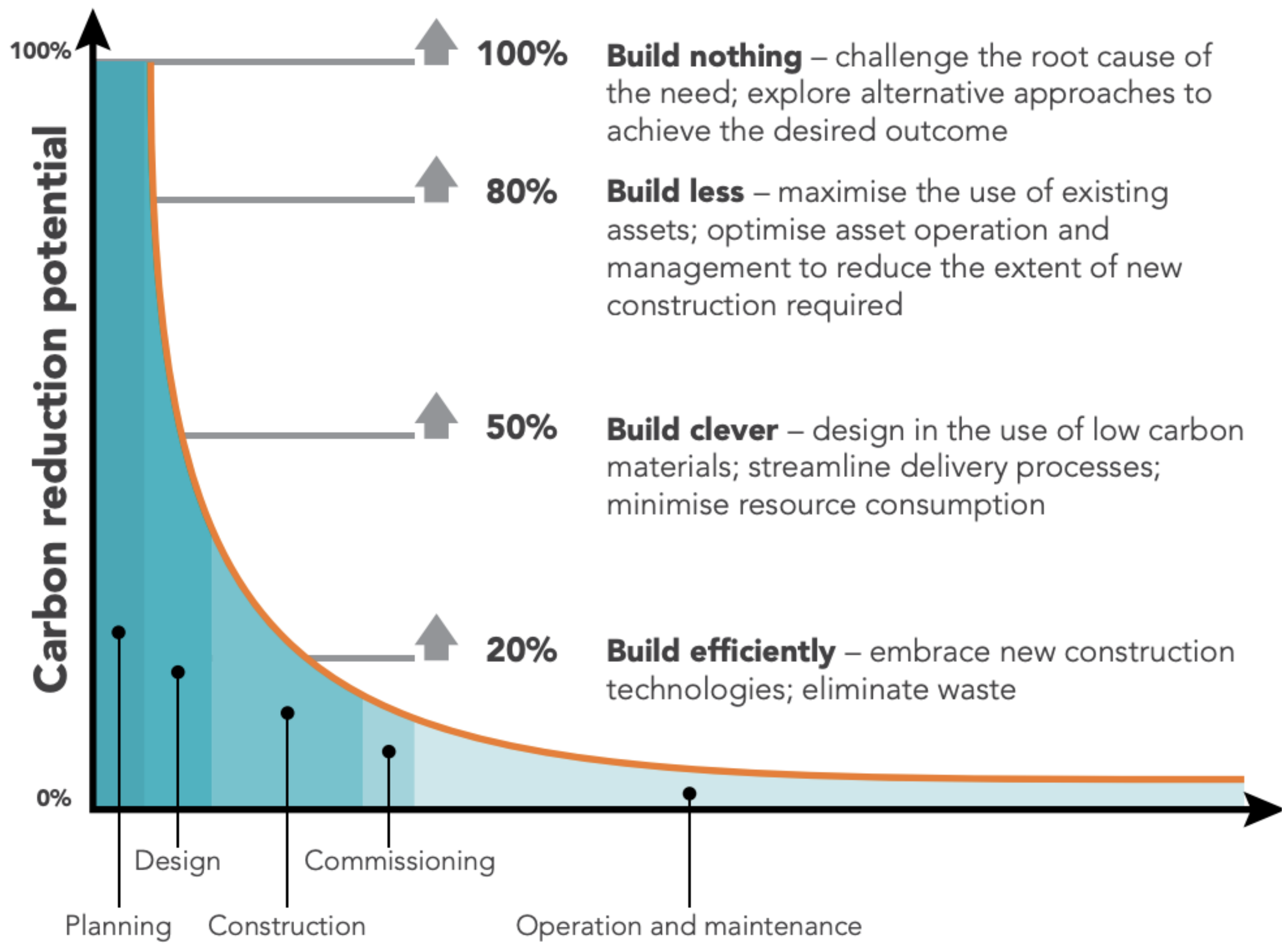
On a different level, Pomponi and Moncaster (2016) offer a thorough understanding of the different mitigation options and cluster them in categories linked to different stakeholders and to different stages in a project's life cycle, as discussed below.

The use of materials with low embodied energy and carbon is the most common solution, and this strategy often relies on greater use of natural (bio-based) materials such as timber, bamboo, or hemp-lime composites.

EC reductions achieved in real projects and reported in the literature can be as high as 30-50%. It is unclear whether such a reduction refers to a poorly designed building with carbon intensive material vs. an optimally designed building with low-carbon material (an unfair comparison) or to an optimally designed building with carbon intensive material vs. an optimally designed building with low-carbon material (a fair comparison).

Other important strategies for EC reduction are to improve the design process, targeting EC as standard, making appropriate choices at the design stage and good design techniques (such as design for deconstruction). Reported reductions in the literature appear to be in the range of 20-40%, supporting more recent findings from D'Amico and Pomponi (2019) who investigated the EC reduction potential by optimising building forms. Reduction, re-use, and recovery of carbon-intensive construction materials follows as an EC mitigation strategy with 7-20%

Figure 10 - EC reduction potential at different stages of a building project



fewer emissions reported. Refurbishment of existing buildings is also offered as a mitigation strategy over new construction, with a reduction potential again around 20%. These values are generally derived from fairly detailed analysis of case studies. Therefore, if they are as accurate as they can reasonably be for the building under examination, there remains a (significant) degree of uncertainty on whether they can be applicable to other buildings in different contexts.

Additional mitigation strategies, which are characterised by widespread agreement in the literature (both academic and grey) are: the inclusion of waste, by-product, and used materials into building materials; an increased use of local materials vs. those coming from global supply chains; more efficient construction process and techniques (such as prefabrication and off-site manufacturing); the extension of buildings' lives; and better tools, methodologies, and policies. While there is agreement on the usefulness and beneficial effect of such measures there lacks evidence on their alleged potential in terms of EC reduction.

The latter set of mitigation measures perhaps deserves further explanation. A tool is in fact unlikely to mitigate EC per se, and so is a methodology. However, the opinion here is that (better) tools and methodologies would allow a better understanding of EC, the identification of carbon hotspots, and a smooth integration of EC into the existing workflow of a building project and design (e.g. via BIM). These opportunities are the ones which, in turn, would enable EC mitigation.

Overall, no single mitigation strategy can or will be effective towards driving the EC reduction needed to meet current and future carbon targets, and progress is required on multiple fronts. It is also clear that collaboration across stakeholders is crucial, since no mitigation strategy is in effect an isolated silo. Designers, material manufacturers, researchers and policymakers all need to convene to discuss and agree effective solutions. For instance, the development and use of materials with low EC is intertwined with better design, which in turn is seen as the key element to reduce, re-use and recover EC-intensive construction materials. New tools, methods and methodologies are also needed to facilitate the transition to a low-carbon built environment, as are policies at both government and construction sector levels. The latter, however, require support from society at large if a substantial change is to be achieved.

These options are also in line with the latest guidance from the World Green Building Council (WGBC) in its dedicated report 'Bringing Embodied Carbon Upfront' (WGBC, 2019). The WGBC adopt the staged approach of building nothing, building less, build clever and build efficiently which first appeared in the 2013 Infrastructure Carbon Review by HM Treasury and transform it into four key principles to pave a way forward.

Much as we would reason in a waste hierarchy, the first principle is *prevention*, which implies considering embodied carbon emissions from the outset, questioning the use of materials at all, or investigating alternative approaches to achieve the desired function (e.g. strengthening and investing in home-working policies and procedures instead of building new office space). Increased utilisation rates of existing assets, that is deep renovation and reuse of existing floor area, also fall into this category.

The effectiveness and EC mitigation potential of most strategies comes from case studies and there is a lack of evidence over how different strategies should be prioritised and when (both in terms of project types and stage within a project's life cycle).

The second principle is *reduce and optimise*, which reinforces the academic evidence presented in this section. The WGBC suggest minimising/optimising the quantity of new materials at the design stage through low carbon design guidance and the opportunities offered by modern computational tools; prioritising low-carbon materials with supporting evidence coming from EPD; and choosing low-carbon construction methods that are characterised by maximal efficiency and minimum-to-zero on-site waste.

The third principle is captured under the *plan for the future* umbrella. This resonates with other approaches described in this section, such as design for flexibility or disassembly, and its ethos is about considering as much as reasonably possible future use scenarios and end of life in order to maximise the potential to maintain, repair and renovate while offering sufficient flexibility for future adaptation. This principle includes approaches at whole-building level (e.g. entire reuse of a building in the future) down to material level (e.g. bolted rather than welded connections to ensure materials can be deconstructed and reused in full).

The last principle is also the last resort in embodied carbon mitigation: *offset*. The WGBC acknowledge this should be used to offset residual embodied carbon emissions through verified schemes once all the other principles have been exploited to the full. The WGBC guidance on mitigation is necessarily high level since each building is unique, thus requiring targeted strategies to maximise the reduction potential. This is the reason why a collaborative, multi-stakeholder approach is needed: a material scientist, an architect, and a committed local authority can achieve much more by working collaboratively than they would do independently.

A widely-agreed approach to embed EC reduction in design thinking is to consistently consider the different lifespans of building elements (or layers). This is far from new, being first proposed by Brand (1994), but has resurfaced frequently in the last few years both as an underpinning to EC mitigation as well as to promoting circular economy strategies in the built environment (ARUP, 2016; Pomponi and Moncaster, 2017).

Industry views

8

Scottish stakeholder consultation

Background research for this project included informal consultations with a selection of individuals who know or represent aspects of the construction industry in Scotland. This section summarises commonly expressed views from those conversations.

The research work for this project included informal telephone consultations with a selection of individuals who know or represent aspects of the construction industry in Scotland. The purpose of this was to get an overview of opinions and experiences to inform the other sections of this report as they were being researched. As such, the format of the interviews was fluid, following the interests of the stakeholder – not a statistical data-gathering exercise.

The discussion guidelines were that the following topics would all be covered where applicable to the stakeholder.

- The stakeholder's interest and involvement with embodied carbon to date
- Client and customer demand for embodied carbon measurement and targeting
- Reasons for internal engagement with embodied carbon when customer demand is lacking
- Project experience and case studies
- How have other participants in the value chain participated in embodied carbon related activities?
- Costs of undertaking embodied carbon assessments, or of gearing up to deliver them, and other potential barriers
- Additional skills and training required to add value in relation to embodied carbon
- Tools, data and guidance – awareness and experience – strengths and weaknesses
- Knowledge of the science behind embodied carbon and confidence in the results. Trade-offs between embodied and whole-life carbon
- Awareness of, and views on, support and funding packages
- The need for benchmarks, planning requirements, and regulation
- Views on how ZWS can support the stakeholder's offering with respect to embodied carbon, and the development of embodied carbon literacy generally across the sector.

Stakeholders fell into one or more of the following categories

- Tier 1 contractors
- Architects
- Consultants
- Academics
- Energy services
- Planners
- Membership bodies
- Sector support programmes.

The following commentary should be read as a synthesis of the views of the stakeholders consulted.

Drivers for assessment

The near-universal view of the stakeholders is that final demand for embodied carbon (EC) assessment – specifically in the form of low-EC buildings – is mainly absent. This is not something that clients are asking for, with some exceptions. Clients are generally more interested in operational carbon – as this ultimately becomes their problem, whereas embodied carbon is understood as more of a question for the industry.

On the other hand, voluntary certification programmes such as BREEAM and CEEQUAL are requirements for many clients to demonstrate the sustainability of their construction projects and programmes. Those seeking high scores in these schemes will want – at the very least – an assessment of GHG emissions, and preferably a full LCA. Some clients also set stretch targets independently of such schemes: examples given included one that aimed to reduce whole-life carbon by 50% after the outline design stage, and another that set a target for the use of recyclate (a proxy for EC). Some consultants routinely provide a sustainability overview on all significant projects, potentially including LCA, which means there is a good opportunity to corral the various project actors towards a common goal that embraces carbon reduction. Other consultancies are moving in this direction.

Putting the lack of demand for low-EC to one side, however, it is clear that some of the stated client priorities are actually complementary to low-EC design and construction, and can be good proxies for it. Examples would include recycled materials; retrofit programmes; local procurement; natural biogenic materials; breathability and indoor air quality; adaptability and maintainability; and 'low carbon' generally. This applies at any scale of procurement, from commissions for individual homes, to public sector frameworks, with different types of client likely to stress different priorities. Clients are, by and large, understood to be environmentally conscious, but only a small (albeit growing) minority are prepared to push for some of the 'deeper green' strategies that might also require deeper pockets.

Whilst clients rarely, if ever, require anything specific on EC, many actors in the value chain – architects and contractors for instance – expect to see more focus on the subject, driven by some combination of client demand, planning requirements, or regulation. As such, they see great benefit in leading on the agenda or – at the very least – being ahead of the curve as part of a responsible future-proofing approach to business planning.

Whilst there is a feeling that main contractors are reluctant to pursue low EC as an end in itself, respondents understand the lack of incentives for those contractors to do so. And it turns out that representatives of the contractors themselves do have a high level of interest, understanding, and – in fact – data on embodied carbon; all that is missing is the demand to follow through on reducing it.

In public sector procurement, clients are increasingly (although by no means uniformly) well-informed about embodied and whole-life carbon and about their sustainability objectives more generally. As such, it may become increasingly difficult for tenders to respond to questions on the subject without making specific commitments to measure and target EC and whole-life carbon. Contractors must then make the judgement about what the client is willing to pay for in this area, both in terms of the process and in terms of material selection, for instance.

Barriers to action

Knowledge, interest and experience of working with EC is fragmented across the whole value chain, meaning that an unusual level of commitment is required by one powerful actor (such as the client) to deliver real change through a project.

The innate conservatism of the industry, and contractors in particular was noted by some, albeit with recognition that there are some very good reasons underpinning this. Contractors want to use tried-and-tested products and processes that they are familiar with, and very strong justifications are needed to deviate from these, including robust evidence for the safety and performance of products and systems. Therefore considerable effort is needed to bring them on board, giving them certainty over cost, material quality, constructability, etc. As a result, more collaboration is needed throughout the industry to build confidence.

Another barrier is the complexity (whether real or perceived) of following the different frameworks, methodologies and data sources that are in use. It is still seen as very difficult to gather all of the information on suppliers and products in time to affect decision-making. Embodied carbon can present a very steep learning curve for architects for instance, and it is a lot to ask for them to follow the RICS method routinely and in detail – especially smaller practices – and so streamlined tools and associated training would be helpful. This could help with strategic decisions at the earliest design stages, embedding low EC at the start, and steering away from costly mistakes.

There is a shortage of skills on how to measure and categorise emissions and then how to translate this into design options: it is one thing to measure EC, but progress requires a good understanding of the pros and cons of the various options for reducing it. Skills gaps also permeate the supply chain, and there are still challenges with basic carbon literacy that need to be addressed if tier 2 and 3 contractors are to contribute proactively to EC and whole-life carbon reduction (as opposed to simply following a prescriptive scope of works).

It is well-known that there is a lot of confusion about embodied carbon generally, and even the experts do not always appear to be performing in harmony. There is a need for the industry to coalesce around a single standard and a protocol for EC using digital models in order to foster collaboration. One respondent suggested there exists *"an element of paralysis from the industry about coalescing around an effective method and standards"*.

Different assessors may well use different methodologies and different data to reach different conclusions. To different people, the EC of a building is cradle-to-gate (i.e. lifecycle impacts of the various completed products, up to the factory gate), cradle-to-site, cradle-to-practical completion (construction site impacts included, although one contractor estimated that 98% of impacts on this metric come upstream of the construction site), or cradle-to-grave (the full lifecycle carbon emissions other than emissions associated with heating and powering the building). Furthermore, it is conceptually challenging to predict, understand and explain the impact on EC of: using recycled materials; assumptions around different end-of-life options in a cradle-to-grave assessment; the benefits of temporary carbon storage in biogenic materials; and sequestration of carbon by concrete during its operating life. Furthermore, EC should always be considered in the context of whole-life carbon (Jackson and Brander, 2019), as trade-offs between EC and operating carbon are routine (for instance more insulation means more EC, which means less operational carbon, and so there must be an optimum quantity of insulation that will minimise whole-life carbon).

Reuse of end-of-life construction materials is a potential route to low EC buildings, but this can be difficult to achieve. The Resource Efficient Scotland Construction Material Exchange is potentially a step in the right direction, but there is a feeling that it will require a concerted push to make it work, including a lot of persuasion to get organisations to populate it with data, and supporting infrastructure to help with the sorting, categorisation, and storage of materials[30].

No section on barriers would be complete without mention of cost. One contractor considered that it was some distance from paying extra for low-carbon materials, and progress without regulation would continue to be difficult: more stick is needed, as *"the carrot isn't working"*, although at the same time they suggested they had sometimes paid extra to meet their operational carbon targets.

Guidance & tools

Various documents were cited, including UKGBC and RICS documents on EC, and the London Energy Transformation Initiative (LETI) embodied carbon primer.

The most frequently cited tools that were being used by the stakeholders for tracking EC are:

- BRE SmartWaste, which might not at first appear to be directly connected to EC, but as it keeps track of material types and quantities on live projects, it can be linked through to the ICE database and estimate the EC in materials – whether those materials are used productively or wasted. Use of this by contractors will, over time, enable the creation of useful EC datasets, and benchmarks for different building categories.
- One-click LCA, which is one of the allowable tools for those aiming to get maximum scores in the relevant part of the BREEAM assessment.

Others mentioned included ETool (also applicable as an LCA tool for BREEAM), and – in the architecture community – HBERT and the AECB Passivhaus tool, which are all discussed in chapter 4 of this report.

Benchmarks, planning & regulation

As would be expected, nobody disagreed with the need for more benchmarks and associated case studies: at the moment, even when a reasonably accurate figure for embodied carbon is calculated, can we say whether it is good or not, and would such a statement have any meaning outwith the context of whole-life carbon? At least one contractor has its own dataset to draw on, and – for instance – One Click LCA users have access to benchmarks in the form of anonymised data from projects assessed on that platform. However, for the most part, reliable embodied carbon benchmarks are not freely available.

Despite the lack of existing benchmarks, there was a perhaps surprising level of support for planning and regulatory interventions to increase focus on embodied carbon. Whilst this does have the potential to increase costs, cost was not seen as an insurmountable problem as long as the same applies to everybody[31]. Many respondents actually made it clear that they would actually welcome being pushed into action, as they want to do this but are held back by commercial imperatives. A cap on emissions would put high-emission products and convoluted supply chains under closer scrutiny, and shift priorities onwards from lowest cost and clients' sometimes arbitrary aesthetic requirements. That said, a finance director from a volume house builder would not necessarily share the views of its sustainability managers.

One suggestion is that a declaration of material content might be made at warrant stage. A standardised, approved carbon index for materials would enable a uniform approach to calculating an embodied carbon metric for any new development. This keeps questions about data quality and relevance to a high level, rather than applicant level, and would allow a project to earn an EC label to sit alongside its alongside its Energy Performance Certificate and sustainability label.

Some notes of caution or realism were sounded, however. For instance, how are overstretched planning departments and the Scottish Building Standards Division meant to approach enforcement? Building Control are unlikely to visit sites and audit the selection and provenance of materials for instance; and at the planning stage, developments are typically a long way short of having the detail needed for a reasonably accurate EC calculation. Although planning does have some power to influence built standards regarding low carbon developments, there would be some caution about applying prescriptive planning policies to the EC arena: the feeling in planning circles is that this approach has previously taken planners into realms that they were not well equipped to handle, and are better dealt with through regulation. Planning's power to deliver on low-carbon objectives is more in its influence on place-making and the interface with transport and lifestyle than in its direct influence on building qualities. Therefore it is important to consider carefully how much can be achieved by such methods. A reasonable worst case might be that whilst a firm cap on EC might be unenforceable in practice, a requirement to measure and report EC does actually encourage a good proportion of actors to engage with the topic, ultimately leading to identification and uptake of opportunities for EC reduction.

One other area for planning to influence low-carbon developments is through the heritage and conservation agenda: retaining existing buildings can be an enabler both for place making and for low EC.

Potential ZWS support

The items mentioned in this section summarise the key themes that arose in discussion. Some are covered by ZWS and its strategic partnerships already, but are included here for completeness.

A dearth of case studies and supporting data has been pointed out, and there may be potential for ZWS to intervene, leveraging its long-standing relationship with the industry and trade bodies, and helping with the production of good case studies and – particularly – benchmarks. ZWS might need to support pilot projects to test or model new products, systems, and digital approaches (e.g. using Building Information Modelling to engage with EC proactively throughout the supply chain).

ZWS long-term involvement in knowledge sharing, awareness raising and training was widely noted and supported. With more and more organisations bringing carbon to the fore in their corporate planning, the timing is surely good for ZWS to continue and step up its involvement with strategic partners in training and continuing professional development (CPD) for instance. There was some suggestion that this could be more targeted, with every such engagement having a specific purpose to move participants incrementally towards specific goals. It would be a challenge to translate this sentiment into specific actions beyond being more strategic in the planning of industry engagement.

Several stakeholders discussed the opportunity for ZWS to run a targeted support programme for businesses using independent expertise. One had benefited in the past from such support relating to site waste management, although not all were aware of previous work in this space. Clearly there is an opportunity to expand the scope of the new SME support programme being delivered by ZWS partners to cover embodied and whole-life carbon, as this would be complementary to the existing themes covering digital technology, circular design, sustainable procurement, and material efficiency.

The transition from EU funding to another funding model potentially provides an opportunity to reach beyond SMEs with support and engagement programmes. Alternatively, working even more closely with organisations that have access to other sources of funding might be considered. As one stakeholder put it, raising the capabilities of the supply chain can only achieve so much if tier one contractors are not on board, and engaging through an experienced construction site manager would potentially move things on.

ZWS could support architects by identifying and supporting them through a process of accessible, quick and streamlined assessment of embodied and whole-life carbon at proposal stage, supported by benchmarks.

As many respondents suggested that they were limited in how far they can push the EC agenda without themselves being pushed or forced by planning or regulatory instruments, there is a strong case for ZWS to be actively involved in this space. This could be in concert with others when appropriate, such as the Royal Incorporation of Architects in Scotland (RIAS); responding to the call for ideas in the NPF4 consultation (deadline imminent); and engaging with planners and the Scottish Building Standards Division to determine the scope for maximising impact with a light touch approach.

Several stakeholders made points to the effect that "the lowest EC building is one that already exists", drawing attention to the need to raise the profile of retrofit as a preferred option. No specific guidance for ZWS was offered, but there are likely to be potential planning and regulatory routes to explore, in addition to the long-standing, well-understood but never-acted-on problem of the VAT regime creating perverse incentives to build new rather than retrofit.

ZWS can help the sector by supporting and promoting innovation and product development from entrepreneurs and manufacturers with an interest in low carbon materials and products. There are links here to the Construction Scotland Innovation Centre (CSIC) and ZWS's own circular economy work. As much of the sustainability-focused innovation coming through CSIC is centred around new construction materials and products, there is potential to develop a distinct Scottish approach or branding associated with low-EC construction. As part of this, a programme aimed at getting more EPD for products manufactured in Scotland would be an important enabler – especially those products that are expected to have a good emissions profile (e.g. those based on natural materials, recyclate, or with local supply chains).

In its efforts to put the spotlight on EC, ZWS should take care to avoid burden shifting. EC should be viewed in the context of whole-life carbon especially, but also in relation to ZWS priorities on circular economy (and vice versa).

In order to increase the reuse of construction materials through the Construction Material Exchange – for instance – some combination of supporting infrastructure, publicity and incentives may be required. A review – in consultation with the industry – on the opportunities for reuse and the investments required (e.g. in local or central material repositories) would be a reasonable starting point if that has not already been covered.

General consensus

Stakeholders generally indicate a willingness – even enthusiasm – to drive down embodied carbon, but also say how difficult this will be without firm demand from clients, which in turn needs to be driven by regulatory pressure. There is, therefore, significant support for development of policy and regulation. In general, there is also a desire for more and improved guidance, tools and training, benchmarks, data, and case studies.

30 The quantities of construction material listed on enviromate (www.enviromate.co.uk) are enough to suggest significant potential (albeit with a significant proportion of DIY rather than commercial interest), and real progress from earlier iterations of the idea, such as the waste exchange briefly tried in the early days of the National Industrial Symbiosis Programme.

31 It was not explicitly stated, but the emphasis on the need for a level playing field it might suggest a preference for regulation rather than planning interventions at the local level.

Roadmap

9

Suggested actions and timeline for ZWS

In response to the gaps previously identified by stakeholders and within the literature here we set out a range of priorities and possible interventions for ZWS to encourage greater assessment and mitigation of embodied carbon. These are classified under two headings 'Creating drivers' and 'Enabling action' and summarised in Figure 11.

Creating drivers

The primary reason for the minimal uptake of embodied carbon assessments to date – identified by both the stakeholders and the broader literature – is the lack of any substantive drivers. On projects where embodied carbon assessment is undertaken at present this is largely the result of client requirements which stem from voluntary targets. Though there is strong evidence of increasing client attention to embodied carbon, in the long term, regulation must be the primary driver of embodied carbon assessment and mitigation.

ZWS should **work with partners to formulate a policy position** that is appropriate for Scotland's unique context. The wide array of international precedents highlighted in Chapter 2, and the existing work to develop plausible UK policy options, should provide sufficient inspiration. Given the evolving nature of many of these policies, ZWS may wish to begin by engaging with regulators in the Netherlands and Scandinavia and groups such as the Nordic Working Group for LCA, climate and buildings; and the authors of the Embodied Carbon Review and the upcoming City Policy Framework for Dramatically Reducing Embodied Carbon, to acquire a deeper understanding of international best practice. Broadly speaking the choice is between addressing embodied carbon at a national or local scale: through planning or standards; at a whole building, elemental or product level; and through mechanisms which impact design, procurement or construction. Of course these are not binary choices, and some combination of measures may be preferable, provided the policy interfaces are carefully designed. Each approach offers different challenges. For example, interventions focussed upon planning necessitate early stage embodied carbon assessments that may not yet have sufficient detail to yield an accurate estimate. Consequently schemes that are approved based upon this estimate may subsequently incur significantly greater carbon emissions once the design is further developed and products specified. On the other hand, approaches that depend upon standards require enforcement. Given the limited number of precedents, the applications of regulatory limits in practice have yet to be tested. For instance, would a compliance officer ever come to site and penalise a developer for using a higher carbon product than was specified in the compliance calculation? Many such details need to be considered as part of a more detailed policy design and proposal. ZWS could play a role in developing a response to these issues and may wish to start by contacting the GLA for the latest update on the development of their policy. Other parties that ZWS may wish to engage in formulating a policy position include: professional institutions currently engaged with the topic (e.g. RIBA and RICS); leaders of prominent voluntary initiatives (such as Architects Declare; Architects Climate Action Network; and the others highlighted in Chapter 2); and academics with related expertise. These would be in addition to ZWS' usual stakeholders from across the industry.

Once a policy position has been agreed, ZWS should **advocate for policy reform**. This may take a number of forms depending upon the preferred policy position. If the preferred approach is through Building Standards it will be necessary to consider the steps to encourage introduction to either the 2024 or 2027 iteration. Similarly, if the preferred option is through planning, then a swift response will be needed if recommendations are to be incorporated into NPF4, with the current call for ideas closing on 31st March and public consultation scheduled for September 2020.

In addition, ZWS may wish to **review existing knowledge and consideration of embodied carbon within planning departments and documents across Scotland's major local authorities**. This could involve a desk based review of documentation and a consultation exercise with representatives from each authority. This could provide a more detailed assessment of the current state of knowledge within local authorities and identify opportunities for a tailored response, such as a targeted guidance package.

As significant construction clients, ZWS should also **engage public sector bodies on the topic**, reviewing the extent of any existing requirements and offering advice on opportunities to strengthen these. This review could also be informed by additional work gathering best practice examples of project briefs and procurement requirements from leading construction clients, updating recommended practice in (UKGBC, 2017).

Enabling action

In tandem with longer term work to establish substantive drivers, ZWS can take a series of near term actions to support willing actors in taking greater action.

One of the greatest challenges to undertaking embodied carbon assessments at present is simply the large amount of time and expertise required to navigate the disparate array of guidance, datasets and tools that are already available. ZWS could **support the creation of a simple central online resource** to house key guidance documents and link to ongoing initiatives.

Some stakeholders, particularly those from SMEs, expressed a desire for **supporting consultancy**, similar to that provided under existing ZWS programmes on related topics. This could be procured separately or incorporated into existing programmes. This may take a number of forms and should be tailored to each organisation's needs and current expertise. This could range from targeted support for an organisation's first embodied or whole carbon assessment on a current project – for instance, providing the organisation with support in establishing a process, tool selection and troubleshooting – through to support for benchmarking and target setting within organisations that already routinely gather data in some form.

It is also important that ZWS **assess the consistency of existing programmes** with the whole life carbon terminology and agenda by, for example, reviewing existing support programmes focussed on resource efficiency and the circular economy.

ZWS may also wish to consider providing **targeted support for SMEs in the development of EPD**, particularly in the gathering of industry average data for small suppliers.

ZWS can take a series of simple actions to **upskill the internal team**. This could include disseminating this report and other key guidance packages, such as the RICS PS; hosting an internal training day; and joining established networks of practitioners, such as the Embodied Carbon Network and the UK Whole Life Carbon Network.

ZWS should **support the creation of CPD content** on embodied carbon. We advise that this is undertaken in partnership with other groups and institutions, such as the RICS and UKGBC. ZWS should also seek to fill gaps identified for certain stakeholders for whom such training is not already on offer through professional institutions (such as RIBA and ICE). For example, the creation of training materials or a guidance package tailored for local authorities, could give greater confidence to local authorities that are considering setting local requirements. This could include: information on UK and international policy precedents; example policy wording; information on costs to developers of adherence; practical examples of how compliance would be demonstrated; and the offer of technical support to upskill their compliance teams. ZWS should also engage with guidance providers to ensure ZWS have an opportunity to feed in to future packages and revisions (e.g. the 2nd edition of the RICS PS).

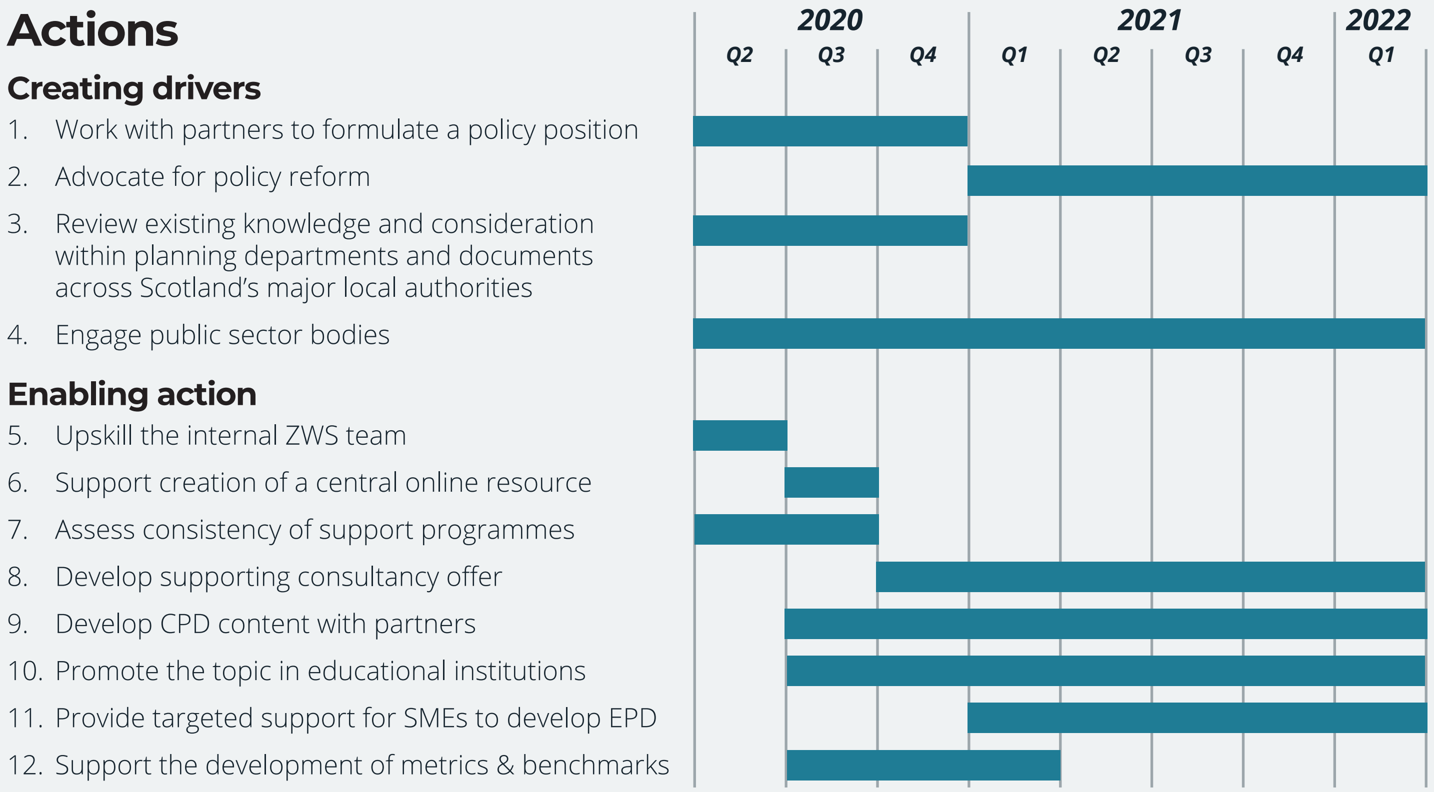
ZWS should work to **promote the topic amongst Scotland's educational institutions**. This review did not consider the detail of current curricula, however, the authors have noted wide variations in the extent to which this topic is addressed within undergraduate, postgraduate and professional training. A number of stakeholders identified challenges in recruiting sufficiently skilled individuals to support this agenda.

ZWS should **support the development of Scotland specific data and benchmarks**. As highlighted in Chapter 3, at present there are no good quality high level metrics for tracking progress in reducing embodied carbon. The development of a suitable set of metrics could thus be the foundation of another priority research project. Such a project could also be supported by efforts to gather existing bottom up data from key providers, e.g. BRE SmartWaste project for Scottish sites; or estimates of embodied carbon associated with BCIS returns from the RICS. This data could also support the generation of benchmarks for use in design and procurement.

Other considerations

We do not propose any actions focussed upon creation of additional tools for carbon assessment. We believe that the existing range is sufficient and that commercial software developers will continue to expand their offer in response to growing demand, including simplified or streamlined processes. We would strongly advise against funding or dedicating time to developing further alternatives. However, it may be useful to provide resources which help those new to embodied carbon assessment to select the most appropriate tool. ZWS may also wish to directly facilitate comparison and selection, for example, through a webinar or training day demonstrating a selection of the available tools.

Figure 11 - Suggested roadmap



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