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Executive Summary

The Green Construction Board’s Low Carbon Concrete Group recently developed an embodied carbon classification scheme for concrete, intended to help users understand the carbon intensity of concrete products currently available in the UK. The scheme provides a common calculation methodology, underpinned by shared definitions and assumptions, helping alleviate the current market confusion over the definition of ‘low’, or ‘lower’ carbon concrete. The scheme is kept up to date by periodic surveys of the carbon content of concrete sold in the UK.

This report describes an extension to this embodied carbon classification scheme, which aims to provide a set of fixed embodied carbon rating bands for concrete (labelled A-G in Figure 1). These can help bodies implement market interventions to stimulate demand for lower carbon concrete, in cases where dynamic rating bands would be hard to use. They can also help communicate industry progress towards net zero.

In summary, this additional work comprises the following items:

- A baseline embodied carbon reference value for each compressive strength class of concrete.
- Static embodied carbon rating bands for concrete products, set at different levels for concretes of different compressive strength classes.
- Additional supporting notes on the use of the scheme.

The outcomes of the work are described in an accompanying brochure titled Embodied Carbon Classification Scheme for Concrete.

“Substantially reducing the carbon footprint of the structures and infrastructure we design and build is crucial in terms of addressing the existential climate crisis and nature loss we are facing globally. Concrete is the most widely used material in the world, responsible for about 8% of CO₂ emissions on its own. We need to establish future-proof approaches towards using it more efficiently, specifying and procuring lower carbon concrete alternatives, while also promoting market transformation policies to accelerate the widest and most rapid decarbonisation of the whole concrete industry. This report builds on existing work in the industry and presents a robust framework for embodied carbon classification of concrete that can aid with the pathway to a net zero industry.”

Dr Fragkoulis Kanavaris, Leading Concrete Materials Expert, Arup

Bruce Adderley, TFI Challenge Director, UKRI

Figure 1: Illustration of the embodied carbon classification scheme for normal weight concrete.
Innovate UK engaged Arup to further develop an embodied carbon (EC) classification scheme for concrete. The scheme was originally developed by the Green Construction Board’s Low Carbon Concrete Group (LCCG), and published in Section 1 of the Low Carbon Concrete Routemap (LCCR), titled ‘Setting the benchmark’[6].

Currently, there is no shared definition of ‘low carbon concrete’ within the concrete industry, making it difficult for buyers, designers, and specifiers to distinguish between different concrete products that might all be marketed as ‘low carbon’. It also makes it hard for companies selling premium-priced concrete, with market-leading low EC, to compete against lower-priced, higher EC alternatives. This deters further development and commercialisation of lower EC concretes.

The intention of this extension to the LCCG scheme outlined in this report is to help standardise communication of the EC of concrete within the industry, by creating a classification scheme for the EC of concrete. This scheme could also be used to support the implementation of market transformation policies to stimulate the market, which give concrete consumers the motivation to procure, and suppliers the confidence to produce, lower EC concrete, as illustrated in Figure 2.

Such policies could include, for example:

- Voluntary or mandatory demand-side measures to promote best-in-class products and create a demand-pull (orange-dotted line in Figure 2b), such as:
  - Measurement and disclosure of concrete EC ratings on projects.
  - Procurement schemes mandating procurement of best-in-class products.
  - Positive labelling and other incentives (e.g., BREEAM credits).
- Research and development (R&D) funding to support the next generation of lower EC concrete technologies (green-dotted line in Figure 2b).
- Mandatory product standards, to remove the worst performing products from the market (red-dotted line in Figure 2b).

The scope of this report excludes the implementation of the findings, or the monitoring, verification or enforcement of any market initiatives that might be based on the proposed scheme.

Figure 2: How market transformation activities change markets. 2a) Typical innovation adoption curve; 2b) Example measures to transform the market. Source: Innovate UK.
2

Existing Schemes for the Embodied Carbon of Concrete

This section outlines the existing schemes that have informed the development of this extension to the EC classification scheme for concrete.

It covers:

– EC classification schemes for concrete in the UK and overseas.
– EC classification schemes for buildings and infrastructure (which typically contain concrete).
– Market transformation initiatives applied elsewhere along the supply chain.
– British and European Standards for specifying concrete and measuring its embodied carbon.

2.1. The Low Carbon Concrete Routemap scheme (UK)

The LCCG published its Low Carbon Concrete Routemap (LCCR) in March 2022. This work supports the concrete industry’s ambition to achieve net zero greenhouse gas (GHG) emissions by 2050. Section 1 of the LCCR outlines the LCCG’s recommendations for establishing an EC classification scheme for concrete, based on letter-grade EC ratings, as shown in Figure 3. The primary features of this scheme are summarised below:

– The ‘A++’ to ‘G’ letter-grade EC ratings have been set based on EC assessments for 624 normal weight concrete mixes, from C8/10 to C80/95, provided by five UK companies².

Around 99% of the data is for concrete strength classes C8/10 to C50/60, so these are the strength classes covered by the EC rating bands.

– The EC rating bands approximately represent percentile ranges. For example, the ‘F’ band contains mixes with EC values in the top 5% of the dataset, while the ‘A++’ band represents EC values below those observed in the LCCG’s dataset.

– The data reflects concrete mix designs produced over a particular period (in the example above, c.2021). The intention of the LCCG was for these EC rating bands to be updated annually, based on the latest industry-reported concrete EC data. This means the rating bands would be dynamic, i.e., the EC values associated with an ‘A’ EC rating would change over time.

– The EC ratings are segmented according to the strength class of the concrete. They do not take account of other characteristics of the concrete, such as the application (e.g., foundations, slabs), production route (e.g., ready-mix, precast), region, or by performance characteristics other than compressive strength (e.g., durability or workability).

– The EC rating bands are accompanied by guidance notes for scheme users.

The LCCG scheme has informed and influenced the proposed scheme outlined in Section 3 of this report. The data behind the LCCG scheme, and similar data collected in future, is intended to be a complementary overlay for the proposed scheme, for reasons outlined herein.

²AMCERETE, Byrne Bros, Price and Myers, Ramboll and WSP.
2.2. Concrete embodied carbon rating schemes in other countries

A report was published by the Mission Possible Partnership (MPP) in June 2022, titled Low-Carbon Concrete and Construction: A Review of Green Public Procurement Programmes. This report outlines initiatives underway in other countries to establish ‘baselines’, or ‘reference values’, for the EC of concrete. These initiatives, listed in Figure 4, have been considered while developing the EC classification scheme described in this report.

The MPP report uses the term ‘reference values’ meaning values that serve as a reference point for the EC of concrete mixes within a certain region, application and/or strength class. According to the Carbon Leadership Forum, which produced material baselines in the US, a baseline is a static reference against which to compare progress towards a goal over time and across projects. This terminology has been adopted for this scheme.

The four EC rating schemes (from Sweden, Germany, USA, and the UK) referenced in Figure 4 used compressive strength as a factor for segmenting the EC reference values for concrete. This is because the functional performance of concrete (i.e., its strength and durability) generally improves as its compressive strength increases, which is typically achieved with a higher cement content. Compressive strength, functional performance, cement content and EC of concrete therefore tend to be positively correlated. However, the authors appreciate that numerous other factors drive the EC of concrete, as will be discussed throughout this report.

The Swedish scheme segmented EC reference values according to compressive strength within each application category (e.g., house interior, house exterior, parking garage). This is because concrete has other performance characteristics (e.g., workability), and thus mix design requirements (e.g., water-to-cement ratio), that are important in some or all application contexts.

However, for the wide adoption of an EC classification scheme it must be simple and understandable. Hence, the approach to segmenting the EC rating bands necessarily involves simplifying assumptions and approaches, and therefore cannot reflect all the variation in the production and use of concrete discussed above.

Some concrete constituents are globally traded, so it is important that there is convergence on a single classification system for the EC of concrete. The classification scheme presented in this report is, in principle, applicable in any market, at any point in time, even if the available products vary. While the scheme is referenced to a nominal baseline, developed for the UK market in 2023, it is not essential that a new baseline be created for each market.

Figure 4: Embodied carbon classification schemes for concrete in other countries, extracted from [1].

2.3. Embodied carbon rating schemes for buildings and infrastructure

EC rating schemes for buildings and infrastructure were also reviewed, and can be split into norm-referenced and criterion-referenced rating schemes:

- Norm-referenced - EC rating bands are set by considering the spread of real-world data. The LCCG scheme (Figure 3) is an example, as it is based on real concrete mix data provided by the industry.

- Criterion-referenced - EC rating bands are relative to a set criterion. The IStructE SCORS rating system shown in Figure 5 is an example. The criterion referenced is 0 kgCO₂e/m² GIA, from which ratings are set at +50 kgCO₂e/m² GIA intervals. Norm-referenced schemes necessarily evolve over time, so that accurate, contemporary comparisons can be made. Practically, this means a reporting database and associated reporting and data governance system must be established to keep the rating scheme up to date.

It is important that any bias in data collected is minimised by ensuring that not only low carbon mixes, or only batches of a certain size, are reported. Norm-referenced EC ratings also change over time, and so to avoid confusion, an allocated EC rating would need to be linked to the version of the rating scheme. For example, EC rating ‘B-2024’, would need to be differentiated from ‘B-2028’.

Criterion-referenced schemes are static and so don’t require regular updates to stay relevant. This makes them suitable for implementing market interventions, or inclusion in technical standards, both of which require unchanging values. Complementary overlays can be developed over the static rating scheme, allowing comparisons between concrete mixes based on factors such as the production route, application, or region in which the concrete was produced. For example, time-relevant Science Based Targets have been overlaid on the SCORS scheme.

Figure 5: SCORS embodied carbon classification scheme for building structures, extracted from [2]. The scheme is an example of a criterion-referenced classification scheme.
2.5. Relevant technical standards and their limitations

The classification scheme outlined in this report refers to several technical standards (shown in Table 1) governing concrete specification and carbon assessment for concrete and concrete products. It is intended that the proposed scheme be aligned with, and based upon, these industry-recognised standards.

However, this project has identified limitations within these standards that could inhibit implementation of the scheme as intended. In particular:

- BS EN 16757 does not provide guidance on the inclusion of carbon capture and storage (CCS) at cement plants in environmental product declarations (EPDs) for concrete. Further details are provided in Section 4.5.
- BS EN 206, BS 8500-1, and BS 8500-2 do not provide guidance on specification of all concrete products, some of which have a lower EC than conventional concrete. Further details are provided in Section 5.3.
- There is currently no industry-accepted guidance on how to manage resource availability issues related to the use of fossil-based binders to reduce the EC of concrete. Further details are provided in Section 5.4.

Table 1: Relevant standards and guidelines referred to in this report

<table>
<thead>
<tr>
<th>Subject</th>
<th>Relevant standards and guidance referred to in this report</th>
<th>Notation used herein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete specification</td>
<td>BS EN 206:2013+A2:2021 – Concrete – Specification, performance, production, and conformity</td>
<td>BS EN 206</td>
</tr>
</tbody>
</table>

Notes:

1. Others include technologically established binders such as FA and silica fume, and emerging technologies such as magnesium-based binders.
2. Market transformation policies for cement, and comprehensive emissions trading schemes are not precluded or endorsed by this report. Market transformation policies proposed in this report could target products at various points along the supply chain.
3. Market transformation policies for buildings and infrastructure are envisioned to operate alongside those for concrete.

This interrelationship is out of scope for this report. The International Energy Agency (2022) report titled *Achieving Net Zero Heavy Industry Sector in G7 Members* proposes establishing product standards for cement, being the binder and primary source of ‘hard-to-abate’ emissions in concrete. However, the report does not preclude the parallel development and implementation of product standards for concrete. Further work is needed to understand how this might interact with the market for asbestos-containing materials.

Decarbonisation can also be driven via carbon pricing mechanisms, such as the UK emissions trading scheme (UK ETS), which can be complemented with carbon border adjustment mechanisms (CBAMs) to prevent ‘emissions leakage’ from UK to overseas production.
The embodied carbon classification scheme was developed following two interactive, multidisciplinary stakeholder workshops, and desktop-based research and analysis. Further details are provided in Appendix A. This section provides an overview of the scheme that was developed. It is aligned with (but expands upon) the content of the accompanying brochure. Section 4 explains and justifies the scheme’s features.

3.1 What is the purpose of the scheme?

The purpose of this EC classification scheme for concrete is to function as a tool to standardise communication of the EC of concrete within the industry. The scheme is applicable to all normal weight concrete mixes, regardless of how they are produced or used.

In EPDs, the EC of concrete is typically reported in kgCO₂e/m³ or kgCO₂e/kg of concrete. However, colour-coded, letter-grade (A-G) EC ratings will enable comparison of the EC of concrete products using terms that are familiar to technical and non-technical stakeholders, including designers, concrete suppliers, asset owners, and policymakers.

Ultimately, the scheme can underpin market transformation policies which motivate the production and procurement of lower EC concrete, as explained in Section 1, and enable designers, contractors, specifiers and technology developers to contribute to a rapid decarbonisation of concrete.

3.2 What are the key features of the scheme?

The scheme is shown illustratively in Figure 7 and the accompanying user notes are in Table 2. The scheme’s key features include:

– The baseline - These are EC reference values reflecting the differences in EC associated with different strength classes. The baseline values are informed by real-world data and reflect what is happening on UK construction sites. They serve as a static reference point, against which comparisons can be made over time and between projects. The values are different for different strength classes because the EC of concrete tends to increase as its compressive strength increases. The intention is that the different EC reference values should present a similar technological challenge for each strength class.

– EC rating bands - The choice of A-G letter-grade rating bands is borrowed from comparable rating schemes for home appliances that are familiar to the public. Boundaries between the EC rating bands are fixed ratios (80%, 60%, 40%, 20% and 0%) of the baseline. The position of the EC rating bands will remain the same, allowing for comparability across all time periods, concrete applications, regions, and concrete production routes.

– User notes - These define terms such as ‘EC rating’ and outline how the EC of concrete should be calculated by suppliers. They should be read and understood in full before using the EC rating scheme.

Table 2: User notes

<table>
<thead>
<tr>
<th>User notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>– EPDs used to report producer declared EC ratings for concrete shall be in accordance with BS EN 15804:2012+A2:2019 and BS EN 16757:2022.</td>
</tr>
<tr>
<td>– Intentional carbon sequestration during manufacture can be included in the producer declared EC rating. Natural carbonation (reaction of atmospheric carbon dioxide and calcium hydroxide) cannot be included.</td>
</tr>
<tr>
<td>– Carbon capture and storage (CCS) can be included in the producer declared EC rating only if the captured carbon is permanently sequestered. Carbon offsetting, and carbon capture with temporary storage or use, cannot be included.</td>
</tr>
<tr>
<td>– The calculation is specific to concrete and therefore excludes reinforcement and finishes.</td>
</tr>
<tr>
<td>– For calculating producer declared EC ratings, the carbon intensity of the concrete or constituents shall be from product-specific EPDs. Mix constituent quantities shall be from the supplier’s mix design or batching records.</td>
</tr>
</tbody>
</table>

Definitions

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodied carbon (EC)</td>
<td></td>
</tr>
<tr>
<td>Cradle-to-gate embodied carbon, including life cycle analysis (LCA) modules A1-A3 defined in BS EN 15804:2012+A2:2019. EC is measured in kilograms of carbon dioxide equivalent (kgCO₂e) per cubic metre (m³) of concrete.</td>
<td></td>
</tr>
<tr>
<td>Baseline (EC100)</td>
<td></td>
</tr>
<tr>
<td>Reference EC values for different strength classes. Baseline = E/G boundary.</td>
<td></td>
</tr>
<tr>
<td>ECXX</td>
<td></td>
</tr>
<tr>
<td>An EC of XX% of the baseline (EC100). E.g., EC80 means an EC 80% of the baseline.</td>
<td></td>
</tr>
<tr>
<td>EC rating</td>
<td></td>
</tr>
<tr>
<td>A-G classification for the EC of a concrete.</td>
<td></td>
</tr>
<tr>
<td>Producer declared EC rating</td>
<td></td>
</tr>
<tr>
<td>EC rating for a concrete product based on certified, product-specific Environmental Product Declarations (EPDs) and actual concrete constituent quantities.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7: Embodied carbon baseline and rating bands for normal weight concrete.
### 3.3. Who should use the scheme and how?

The classification scheme will serve different functions depending on the user. Table 3 outlines the main uses, sorted by user, envisioned for the scheme.

Crucially, when used by concrete suppliers, designers, and asset owners as a design tool, the intention is that the EC classification scheme is not used in isolation, but as part of a whole life-cycle carbon assessment exercise for the asset constructed of concrete. This is because the EC of concrete is just one part of the whole life-cycle GHG emissions of buildings and infrastructure.

<table>
<thead>
<tr>
<th>Function</th>
<th>Policy makers</th>
<th>Concrete suppliers, manufacturers and contractors</th>
<th>Designers and specifiers</th>
<th>Asset owners</th>
<th>LCCG</th>
</tr>
</thead>
<tbody>
<tr>
<td>To support the development of market transformation policies.</td>
<td>✅</td>
<td>✅</td>
<td>✅</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To enable communication and comparison of the EC of concrete mixes considered in design.</td>
<td>✅</td>
<td>✅</td>
<td>✅</td>
<td></td>
<td></td>
</tr>
<tr>
<td>To enable communication of industry performance regarding concrete EC.</td>
<td>✅</td>
<td>✅</td>
<td>✅</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Functions of the embodied carbon classification scheme by user.

In particular:
- Designers should be given sufficient time to optimise the design to reduce material use.
- Users should consider the impact of LCA stage A4 transport emissions when specifying lower EC concretes that are not available locally.
- Fly ash (FA) and ground-granulated blast furnace slag (GGBS) are commonly used to reduce the EC of concrete. However, as these are by-products of fossil fuel intensive industrial processes, alternative solutions should be sought for longer term reductions in concrete EC.

The complementary presentation is shown illustratively as box-and-whisker plots atop the static rating bands in Figure 8. Plots can be segmented according to factors such as the concrete application, year produced, location, production route, and any other factors of interest to the industry and policymakers. These different plots will have bespoke uses for different users of the scheme and can provide insights into what is driving the EC of concrete, so that its EC can be reduced at the element, project, or national level. The data overlaid the fixed rating bands will help answer the question of ‘what concretes are commercially available?’ and can show the industry’s progress towards net zero.

### 3.4. The way concrete is produced and used varies. How is this accounted for?

Concrete serves many different functional purposes and is produced in many ways. The proposed classification system is intended to be static and does not provide different EC rating bands for different applications (e.g., piles, slabs), production routes (e.g., ready-mix, precast), or geographic regions. This allows for comparability of EC ratings across time and between projects. However, scheme users should account for variations in the production and use of concrete when using the scheme as a design tool, for communicating industry performance, and for developing market transformation policies.

To enable communication of industry performance, it is intended that concrete EC data, such as that collected by the Mineral Products Association (MPA) on behalf of the LCCG, be plotted alongside, or overlaying the fixed EC rating bands.
4 Design of the LCCG Scheme Extension

4.1. Standards, data sources and LCA scope for embodied carbon calculation

This section identifies the standards, acceptable data sources and LCA scope for calculating the EC ratings for concrete mixes to be used in the proposed scheme.

Feedback from stakeholders is that the scheme must use established industry guidance for calculating embodied carbon. BS EN 15804 and EN 16757 outline the product category rules for generating EPDs for ‘construction products’ and ‘concrete and concrete elements’, respectively. EC ratings used with the proposed scheme therefore must be based on EPDs generated in accordance with these standards.

To maintain the integrity of the classification scheme, and to ensure EC ratings are comparable, EC values used within the scheme must be calculated using accurate, product-specific data. Therefore, a new term has been created for the classification scheme: producer declared EC rating. Producer declared EC rating means an EC rating for a concrete product based on certified, product-specific EPDs and actual concrete (or concrete constituent) quantities. Section 1.2 of the LCCR lists a hierarchy of data sources for calculating embodied carbon. Table 4 reproduces these data sources and identifies which ones are regarded as sufficiently accurate and product-specific to be used for generating producer declared EC ratings.

This term distinguishes producer declared EC ratings from more ‘indicative’ ratings, which could be based on generic rather than product-specific data, such as industry average EPDs, or less accurate information, such as concrete element design information. Indicative EC ratings may, however, be useful for comparing potential mix designs at early design stages, when the supplier’s mix design has not yet been produced. However, designers, concrete suppliers, and asset owners should be wary of the limitations of using generic or inaccurate data to generate indicative EC ratings.

The EC rating should be based on a ‘cradle-to-gate’ LCA, including LCA modules A1-A3, in accordance with BS EN 15804. This is because these are the life-cycle stages controlled by the concrete supplier. They are product specific, rather than project (e.g., building) specific. This approach is consistent with that proposed by the LCCG. Despite its limited scope, an A1-A3 LCA is expected to capture the majority (i.e., more than 80%) of the GHG emissions associated with concrete over its life cycle. Furthermore, the EC ratings need only consider the global warming potential (GWP) of the concrete. It would be impractical, and beyond the original intent of the classification scheme, to include other impact categories (e.g., ozone depletion) in the classification scheme. The LCA is specific to concrete, and therefore excludes reinforcement and concrete finishes for all concrete types including precast and ready-mix.

The EC rating should be calculated using accurate, product-specific data. Inaccurate or generic data should not be used.

<table>
<thead>
<tr>
<th>Description</th>
<th>Producer declared EC ratings</th>
<th>Indicative EC ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concrete quantity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier’s EPD for the concrete, delivered to site.</td>
<td>Design information1.</td>
<td>Design information1.</td>
</tr>
<tr>
<td>Supplier’s mix design.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mix constituent quantities</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batching records for material delivered to site.</td>
<td>Design information1.</td>
<td>Design information1.</td>
</tr>
<tr>
<td>Supplier’s mix design.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Carbon intensity of concrete constituents</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPDs for the constituent materials.</td>
<td>Average industry values for the carbon coefficients of constituent materials from industry databases5.</td>
<td>Generic industry EPDs for concrete of the specified strength class5.</td>
</tr>
<tr>
<td>Supplier’s EPD for the concrete, assessed against as-batched constituent quantities once available.</td>
<td>Generic average values for cast concrete from industry databases5.</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Acceptable data sources for assessment of concrete embodied carbon producer declared and indicative ratings.

Notes:
1. Data sources acceptable for use in generating producer declared EC ratings can also be used to generate indicative EC ratings.
2. Not necessarily required for calculating concrete EC.
3. Insufficiently accurate for producer declared EC ratings.
4. Insufficiently product-specific (i.e., too generic) for producer declared EC ratings.
4.2. Shared declared and functional units
The LCA functional and declared unit definitions are important because they are linked to how the EC ratings are segmented. The declared unit describes a quantity of a product, whereas the functional unit relates the quantity to the performance it delivers in its end-use application (e.g., strength class, intended use, type and dimension of the product). The choice of functional unit is important because it helps enable like-for-like comparison between different products that can be used for doing the same thing.

Section 6.3 of BS EN 16757, and Sections 6.1-6.3 of BS EN 15804 outline requirements for the functional/declared units for concrete product LCAs. However, these standards allow flexibility in the definition of the functional unit for concrete. To achieve consistency in how the EC of concrete is reported in the EC classification scheme, shared/common properties of the concrete LCA functional and declared units must be established.

4.2.1. Shared declared unit
The shared declared unit for this scheme is: one cubic metre (m$^3$) of hardened concrete.
This was selected because it is the volume of concrete and its strength that allows it to bear load, not its mass or area. This is consistent with the recommendation of the LCCG.

4.2.2. Shared functional unit
The shared functional unit proposed for this scheme is: one cubic metre (m$^3$) of hardened concrete of a specified strength class.

It is accepted that performance characteristics of the wet concrete (e.g., workability), and the resulting mix design requirements (e.g., the water-to-cement ratio) can be important drivers of the concrete’s EC, as illustrated in Figure 9. However, hardened concrete is considered the functional unit on the basis that wet concrete properties are important during production of the functional unit, not during its functional life, as only the hardened concrete can carry load. Nevertheless, it is acceptable for the EC of concrete be calculated using mix constituent quantities measured at the time of batching (when ready-mix concrete is wet) for practical reasons and given the wet and hardened constituent quantities per cubic metre of hardened concrete are practically the same. Compressive strength class is included in the shared functional unit because compressive strength is:

- A property of the hardened concrete.
- Applicable in almost all concrete applications.
- Closely tied to the concrete’s EC.
- Readily quantifiable, available, and understandable.

It is accepted, however, that hardened concrete serves different functional purposes, and therefore has different performance characteristics, depending on factors such as the application and environment, also illustrated in Figure 9. Other performance characteristics were analysed to see whether they should be included in the shared functional unit, such as density, chemical durability, workability, and setting time. All were excluded for one or more the reasons given in Table 5. Adopting compressive strength as the only performance characteristic of the shared functional unit is therefore a simplification, meaning it does not allow for perfect comparison of like-with-like. However, this approach avoids segmenting EC ratings based on multiple performance characteristics, making the scheme simpler to understand, maintain and adopt.

For this scheme, the time at which the specified compressive strength must be achieved is deliberately excluded from the shared functional unit. 28-day strength is typically adopted in design, but 56-day strengths and later are also possible. Designers can therefore specify compressive strength at ages later than 28 days, as one way to reduce the concrete’s EC. BS EN 206 and BS 8500-1 define compressive strength class, including procedures to accommodate the adoption of later stage design compressive strengths.

Figure 9: Production and application factors driving the embodied carbon of concrete. Only compressive strength, a performance characteristic of the hardened concrete (i.e., in its end-use application) is included in the shared functional unit.

<table>
<thead>
<tr>
<th>Performance characteristic(s)</th>
<th>Reason for excluding the performance characteristic from the shared functional unit definition and EC rating segmentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workability/consistence, setting time.</td>
<td>The performance characteristic is of the wet concrete, rather than the hardened concrete.</td>
</tr>
<tr>
<td>Impact resistance, UV stability, abrasion resistance, thermal properties.</td>
<td>The performance characteristic is not applicable to most applications of concrete.</td>
</tr>
<tr>
<td>Creep and shrinkage.</td>
<td>The performance characteristic is not closely related to the EC of the concrete.</td>
</tr>
<tr>
<td>Sulfate resistance, carbonation resistance.</td>
<td>The performance characteristic is not readily quantifiable, available, and/or understandable to non-technical stakeholders.</td>
</tr>
<tr>
<td>Flexural strength, tensile splitting strength, modulus of elasticity.</td>
<td>The performance characteristic is primarily explained by the compressive strength of the concrete, meaning segmentation by both factors would add little value.</td>
</tr>
</tbody>
</table>

Table 5: Reasons for excluding other performance characteristics from the shared functional unit.
4.3. Embodied carbon rating segmentation

Segmentation means to break down concrete into sub-groups. One way of doing this is illustrated in Figure 10. EC rating bands can then be different for each sub-group, or segment, of concrete. For example, concrete could be segmented according to its strength class and production route, meaning a ‘B’ EC rating for C32/40 precast concrete could be different to a ‘B’ for C32/40 ready-mix concrete.

For this scheme, strength class is the only factor used to set different values for the EC rating bands. However, as discussed previously, many other factors drive the EC of concrete. This section explains:

- Why other factors have not been used to segment concrete when setting the EC rating bands.
- How differences in concrete production and use should be accounted for by scheme users.
- The range of strength classes covered by the scheme.

4.3.1. Why other factors are not used to segment the embodied carbon rating bands

Consideration was given to whether EC rating bands should be segmented depending on factors such as the application, production route, location, or mix design requirements. However, these factors have not been used to segment the EC rating bands for the following reasons:

- Alignment with the shared functional unit – The scheme segments the EC ratings based on the performance delivered by the concrete in the end-use application, i.e., based on its functional unit. Since the shared functional unit is segmented based on strength class only, the rating bands are also segmented based on strength class only. To avoid having multiple EC rating bands for the same shared functional unit.

- Comparability of EC ratings – This approach allows for comparability across different regions, concrete applications, and production routes, helping identify those that are most carbon intensive. The IStructE SCORS rating system was designed based on a similar philosophy of comparability (in the case of SCORS, comparability across different building structure types).

- Technology agnosticism – Suggestions were made to have different EC rating bands for different cement types and/or production routes. However, it is intended that this scheme remains technology agnostic, in the sense that it does not set different EC rating bands for different technologies used to produce the same shared functional unit of concrete.

- Assigning concrete to different segments could create distortions – If EC ratings were segmented by other factors, there must be clear definitions to classify concrete products within these segments. For example, BS 8500-1 and BS EN 206 provide clear definitions allowing concrete to be classified according to its strength class. However, if EC rating bands were segmented by, for example, production route, definitions would need to be developed for distinguishing between these different production routes, such that concrete products could be consistently assigned to them. Different EC ratings by production route could then lead to distortions. For example, if a ‘B’ EC rating could be achieved with a higher mix EC by adopting precast concrete, compared to ready-mix concrete, this may encourage greater adoption of precast, rather than ready-mix concrete.

4.3.2. How differences in concrete production and use should be accounted for by scheme users

Despite the choice of a single performance characteristic for segmenting the EC rating bands, it is recognised that differences exist in the performance characteristics of hardened concrete, and that many other production and use factors drive the EC of concrete. Table 6 outlines how this variation should be addressed, depending on how the scheme is used. It is beyond the scope of this work to propose the nature of any market transformation policies based on the scheme. However, it is recommended that the above-mentioned variation in concrete production and use be accounted for in future policy development activities.

Figure 10: How concrete can be segmented according to factors such as strength class, production route and/or application. Different embodied carbon rating bands could be developed for each segment.
4.3.3. Strength classes covered by the scheme

In the first instance, the scheme should only cover normal weight concrete, which is the most used type of concrete. The scheme does not cover lightweight concrete, which has strength classes LC8/9 up to LC80/88, or heavyweight concrete. However, these may be added in the future.

The EC rating bands cover all normal weight strength classes included in BS 8500-1 and BS EN 206. The LCCG scheme covered normal weight strength classes from C8/10 up to C50/60, largely due to a lack of data gathered for higher strength classes. Over 98% of the 624 mix designs collected by the LCCG were for concrete mixes in the range C8/10 to C50/60. Higher strength classes evidently represent a minority share of the UK market, meaning there is less benefit to including them within the scheme. However, if the scheme were used as the basis for establishing EC limits for concrete, a scheme covering strength grades C8/10 to C50/60 could encourage designers to adopt concretes outside this strength range to avoid imposed EC limits. Due to the limited concrete EC data available, the EC rating bands come with a greater degree of uncertainty at these higher strength grades. Further details are provided in Appendix B.

Publicly available information on the strength capability of commercially available concrete technologies was analysed. No data was identified to suggest these technologies deliver concretes with strengths outside the range of C8/10 to C100/115. Therefore, it is not recommended to extend the range, based on commercially available concrete technologies.

The scheme’s scope regarding other segmentation factors is given in Table 7. The scheme covers all applications for concrete, all production routes, and while it is based on data from c.2020, it applies to all time periods. The baseline is derived using UK-specific data because it was developed in the UK. However, the baseline simply represents a series of reference EC values. Therefore, it has the potential to provide a common standard against which the EC of concrete is measured globally.

<table>
<thead>
<tr>
<th>Segmentation factor</th>
<th>Explanation and examples of how the factor affects concrete EC</th>
<th>Scheme scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength class</td>
<td>Compressive strength class, e.g., C32/40, gives the compressive strength, in MPa, of the concrete. In general, more cement is needed to produce stronger concrete, resulting in higher EC.</td>
<td>C8/10 to C100/115. Normal weight concrete only.</td>
</tr>
<tr>
<td>Performance characteristics other than compressive strength</td>
<td>Performance characteristics are properties of the concrete material (e.g., setting time) that may be important for the design, depending on its application and environment. E.g., additional Portland cement clinker is often added to concrete to achieve faster setting times, when this is required by the programme.</td>
<td>All included but not part of shared functional unit.</td>
</tr>
<tr>
<td>Application</td>
<td>Application means the element in which the concrete will be used, and this affects its position, dimensions, and loading. Different applications place different demands on the performance characteristics of both the wet and the hardened concrete. E.g., piles and raft foundations require more flowable concrete, so that the concrete can be placed into deep holes. This increases the required water-to-cement ratio, cement content, and therefore mix EC for achieving a desired strength class.</td>
<td>All applications.</td>
</tr>
<tr>
<td>Production route</td>
<td>Production route means how the concrete element is produced, usually cast in-situ (ready-mix) or precast. Different production routes place different demands on the wet concrete performance characteristics such as workability and setting time. E.g., precast concrete typically requires higher early strength and thus higher cement content, than ready-mix concrete of the same application and strength class.</td>
<td>All production routes.</td>
</tr>
<tr>
<td>Location</td>
<td>Location refers to where the concrete is produced. Different locations have different access to raw materials (cement, aggregate, etc.) with different EC. E.g., London-based projects have greater access to lower EC supplementary cementitious materials (SCMs) like GGBS, and therefore can more easily reduce the EC of concrete mixes used, compared with projects elsewhere in the UK.</td>
<td>All locations but informed by UK-specific data.</td>
</tr>
<tr>
<td>Time / date produced</td>
<td>Time refers to when the concrete is produced. The EC varies over time for reasons such as the decarbonisation of the concrete industry. E.g., concrete produced in 1990 had a higher EC, on average, than concrete produced in 2020 because the industry has reduced its carbon intensity during that time.</td>
<td>All time periods.</td>
</tr>
</tbody>
</table>

Table 7: Segmentation factors for the classification scheme, and the scheme’s scope.
4.4. Embodied carbon rating bands

This section outlines the considerations regarding the position of each EC rating band, which include:

- A ‘G’ EC rating band for concrete with an EC above the baseline.
- Intermediate EC rating bands ‘B’ through ‘F’, for ranges between fixed ratios (i.e., 80%, 60%, 40%, 20% and 0%) of the baseline.
- An ‘A’ EC rating band, for concrete with an EC of less than or equal to zero.

The approach is that EC rating bands between the baseline and zero EC will have ranges equal to 20% of the baseline EC value. This is based on the philosophy that, for a given strength class, the difference in absolute carbon emissions between an ‘A’ and a ‘B’ should be the same as between a ‘B’ and a ‘C’, and so forth. This is consistent with similar rating schemes such as SCORS but differs from the LCCG scheme, in which the spacings between EC rating bands are non-uniform within a strength class. However, it is acknowledged that it may become more costly to achieve similar absolute reductions in EC as the EC decreases.

The derivation of the baseline, including the methodology followed, and data sources used, is outlined in Appendix B. The baseline values are reference values reflecting the differences in EC associated with different strength classes. The baseline’s position was informed by a combination of:

- Real concrete mix (‘project’) EC data, provided by the LCCG.
- Industry carbon intensity suites.
- Concrete EC ‘reference values’ from other countries.
- Mix design data derived using machine learning algorithms trained on real concrete mix data, from peer-reviewed academic research.
- Practical considerations, based on how the scheme is expected to be used and understood by the industry.

The following approaches are recommended for the scheme, regarding inclusion of concrete carbonation, carbon capture, utilisation, and storage (CCUS), and offsetting.

4.5. Carbonation, CCUS and offsetting

4.5.1. Carbonation

This scheme deals with cradle-to-gate LCAs, covering concrete production only (LCA modules A1-A3). Most natural carbonation of concrete occurs after construction has been completed, thus falling within LCA modules B-D, and is therefore excluded from the scheme. However, some concrete manufacturers carry out intentional sequestration of CO\(_2\) within concrete during manufacture. This will be included in product EPDs for concrete and is therefore included in the scheme. It is not appropriate for the scheme to account for carbonation occurring beyond LCA modules A1-A3 because the extent of carbonation is contingent upon several factors (e.g., the extent of concrete crushing at its end-of-life) outside the control of the concrete supplier.

4.5.2. Carbon capture, utilisation, and storage

Stakeholders generally agreed that CCS with permanent storage should be included in concrete EC ratings. However, carbon capture and utilisation (CCU) should not be included because it usually results in CO\(_2\) being released back into the atmosphere shortly after it is captured.

4.5.3. Carbon offsetting

There was consensus amongst stakeholders that any form of carbon offsetting should be excluded from the scheme. This is consistent with the stipulations of BS EN 15804 Section 5.4.3.
5

Scheme Limitations and Proposed Mitigation

This section outlines the scheme’s limitations and proposes ways these can be mitigated. The scheme itself, including the EC rating bands, user notes and brochure, include measures to mitigate identified possible limitations specific to the scheme. Wider limitations that are not specific to, or caused by, the scheme may require action by others (e.g., policymakers) to address.

5.1. Items excluded by the embodied carbon calculation

The scheme excludes some LCA stages, environmental impact categories, and concrete types.

This scheme considers GWP in LCA stages A1-A3 (product stage), and therefore excludes the following LCA modules:

- A4 – Transport of concrete or precast concrete element to the construction site.
- A5 – Installation in the building or civil engineering work (including construction site wastage).
- B – In-use phase (including natural carbonation).
- C – End-of-life (including natural carbonation).
- D – Benefits and loads beyond the system boundary.

Although all life cycle stages should be considered by designers, only modules A1-A3 are in scope of this proposed scheme. Module A4 emissions are usually less than 10% of total A1-A5 emissions for concrete but could be higher if there are fewer batching plants for a particular concrete product. Therefore, text is included in the brochure specifically instructing designers to consider module A4 emissions, which can be influenced by designers and contractors. The brochure also instructs users to consider concrete EC as part of a whole life-cycle carbon assessment (WLCA) exercise for the asset constructed of concrete, thus covering all other life-cycle stages.

Scheme users should not confuse EC ratings with environmental impact categories, other than GWP, are excluded from the scheme, as are social and economic sustainability indicators. For example, an ‘A’ EC rating for concrete means the concrete has an EC less than or equal to zero. It does not communicate whether that concrete is produced from sustainably sourced materials, or whether workers were fairly treated along the concrete supply chain. Other rating schemes for concrete and construction products include more holistic considerations and should be used alongside the EC classification scheme.

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5.2. Mitigations for possible unintended consequences of the scheme

Any scheme that focuses on transforming a single aspect of a larger system risks creating unintended consequences, through encouraging counter-productive behaviours. All scheme users must be aware of such possible distortions.

Use of the scheme in isolation – A singular focus on lowering the A1-A3 embodied carbon of concrete is not the most effective way to reduce whole life-cycle emissions for building and infrastructure assets constructed of concrete. To mitigate this, the brochure states that the scheme should not be used in isolation, but part of a whole life-cycle carbon assessment exercise, therefore considering all LCA modules and building/infrastructure elements.

Overemphasis on concrete carbon intensity at expense of concrete volume – The scheme does not account for the total amount of concrete used or whether it is used efficiently. This could mean larger quantities of concrete, with a lower EC rating, are adopted in favour of lower quantities of concrete with a higher EC rating, which may not reduce emissions overall. Therefore, alongside the note to use the scheme as part of a WLCA exercise, the brochure also instructs users allow sufficient time to optimise the design to reduce material use.

Slope of EC rating bands – As illustrated in Figure 11, the slope of the EC rating bands could encourage users to adopt higher or lower strength concrete, depending on how easily better EC ratings can be achieved by changing the strength class. Flatter bands, in general, would encourage users to adopt lower strength concrete, while steeper bands would encourage users to adopt higher strength concrete. The approach adopted in setting the EC rating bands was that it is better for the bands to be too flat (favouring lower, but still sufficient strength concrete), than too steep.

Clustering of product EC values at the upper end of EC rating bands – As illustrated in Figure 11, EC values for concrete products may cluster towards the upper end of the EC range within each EC rating band, if there is limited perceived additional benefit (e.g., in terms of product marketing) of having a lower EC concrete within the same rating band. The ‘ECXX’ terminology could help counteract this, by providing a higher degree of granularity to distinguish between concretes within the same EC rating band.
5.3. Potential for disadvantaging some types of concrete

Lightweight and heavyweight concrete are excluded from the scheme but may be added in the future. However, lightweight concrete will require separate EC rating bands because the strength classes are different and mix proportions can be substantially different compared to normal weight concrete. Further consideration is required to decide whether heavyweight concrete, which has the same strength classes as normal weight concrete, can use the same EC rating bands as normal weight concrete.

The scheme is technology agnostic, and therefore gives the same EC rating to different products delivering the same shared functional unit, regardless of how it was produced. It therefore does not differentiate EC ratings based on technology factors such as the production route or the binder type (e.g., Portland cement clinker versus GGBS). This approach may lead to perceived unfairness, in instances where one market segment (e.g., precast concrete) is more carbon intensive than another. It is intended that the scheme highlight these differences, by applying consistent EC rating bands, regardless of application, production route, or region. However, scheme users should account for these differences in concrete production and use when using the scheme, as explained in Section 4.3.2. This should help alleviate any perceived unfairness.

Some products, while not disadvantaged by the scheme itself, could remain at a disadvantage within the scheme if industry standards and guidance are not updated to accommodate them. This includes:

- Concretes with CCS applied along their supply chain – As discussed in Section 4.5, the user notes signal to industry the intention that CCS with permanent storage be included in, and thus rewarded by, the scheme. However, industry guidance should be developed on the inclusion of CCS at cement plants in EPDs for concrete and concrete constituents.

- Concrete products not covered by BS EN 206 and BS 8500-1 – The intention of the EC classification scheme is to help shift the market towards lower EC concrete. However, concrete technologies that are not covered by these standards may face difficulties in gaining market share. This may be mitigated if technology developers conduct comprehensive testing of their products for potential future integration into standards. The LCCG aims to help address this through its workstream 3 ‘BSI Flex Standard’, which will provide guidance for specifying lower EC concretes. However, additional work may be required.

5.4. Possible unintended wider impacts of transforming the concrete market

Implementation of the EC classification scheme, and wider efforts towards a lower emissions cement and concrete industry, will help the UK reach its climate change mitigation commitments. However, unintended negative impacts may emerge, three of which are highlighted below.

Unsustainable use of fossil-based binders – It is outside the scope of this report to propose detailed guidance for addressing this issue. However, it is recommended that guidance developed by working groups such as ConcreteZero WP3 (supported by the IStructE) be integrated into the scheme’s user notes once available. The problem is that fossil-based binders (such as GGBS and FA) are globally limited resources, and by-products of carbon-intensive industrial processes (basic oxygen steelmaking and coal burning, respectively). There are also challenges in allocating emissions generated by these processes to their economically valuable by-products, i.e., GGBS and FA. Stakeholders raised concerns that the scheme’s implementation will lead to greater Portland cement clinker replacement with fossil-based binders in concrete, but that this may not necessarily reduce global GHG emissions.

Durability issues with untested concrete technologies – Stakeholders cited examples of durability and performance issues with concrete products that had been adopted before being properly performance-tested. This should be mitigated through more comprehensive testing and integration of concrete products into building codes and standards once adequate material performance is consistently demonstrated.

Green premium for lower EC concretes – There is likely to be a green premium associated with procuring lower EC concrete. For example, if CCS is adopted at cement plants, this will mean greater energy requirements to produce the concrete, because of the need to capture, transport and securely store captured CO₂. This green premium will then have flow-on impacts throughout the supply chain, impacting concrete suppliers, designers, builders, and consumers. The scheme may also be less readily embraced by consumers (e.g., property developers) in the same way that similar schemes, such as those for appliances, have been. This is because, energy efficient appliances, while initially more expensive in general, can save consumers energy and money. Lower EC concrete may come with a similar green premium, but without necessarily saving asset owners money through better performance. Hence, stronger regulatory incentives (e.g., mandatory rather than voluntary product standards) may be needed to drive industry-wide uptake of the scheme. This message, advocating for mandatory rather than voluntary product standards, is echoed in a 2022 report by Frontier Economics, titled How Product Standards Can Grow the Market for Low Carbon Industrial Products.
Summary and Recommendations

6.1. Summary
This report presents the development of the methodology for creating an EC classification scheme for normal weight concrete. The scheme builds upon prior work conducted by the LCCG, with the intention to improve the classification scheme. Contrary to the LCCG scheme, the Arup scheme is characterised by static EC rating bands, that do not change over time. Due to this fundamental difference, the two schemes are not conflicting, but complementary. The LCCG scheme should be used to collect and publish dynamic industry performance data, atop the static EC rating bands developed by Arup, as part of a single, combined system.

The aspects of the scheme already developed by the LCCG enable:
- Concrete producers to compare the EC of their concretes to those produced by their competitors.
- Concrete designers and specifiers to understand the lowest EC concretes available commercially.
- All scheme users to track progress made by the industry towards net zero.

This extension to the scheme also provides:
- A simple way to specify and recognise lower EC concretes, which could be used for procurement standards or market transformation interventions. The scheme also enables designers, contractors, construction project owners and manufacturers to make informed decisions when specifying, procuring and using concrete.
- A common reference that could, in principle, be used in any market, for any normal weight concrete.

6.2. Recommendations
Recommendations are given below for each of the three main groups who will take this scheme forward, through implementation, and as the basis of market transformation policies.

For the LCCG Taskforce, supported by Innovate UK, who will oversee further development of the scheme:
- Adopt the features of the proposed EC classification scheme for concrete outlined in Section 3.
- Develop the rating scheme into a Publicly Available Specification (PAS).
- Integrate guidance (yet to be developed) into future revisions of scheme’s user notes for the use of fossil-based binders, and inclusion of CCS at cement plants in EPDs for cement and concrete.

For the LCCG, who are responsible for implementing the scheme:
- Continue to collect industry data and develop systematised product databases for concrete EC.
- Publish industry EC data as box-and-whisker plots atop the fixed EC rating bands, by segment.
- Consider adding the proposed LCCG-Arup combined scheme in future versions of the LCCR.

For policymakers creating market transformation policies based on the scheme:
- Understand the limitations of the scheme highlighted in section 5 and take steps to mitigate them.
- Coordinate market transformation policies developed for the cement and concrete sector with policies related to the EC of buildings and infrastructure. Product (concrete) baselines should sit alongside project (whole asset) baselines.
A.1. Project Stages

This project progressed in the following four stages, involving stakeholder workshops, and desktop-based research and analysis.

Stage 1
In-scope concrete strength classes and applications were determined. This was based on a review of the LCCR, and a review of the compressive strength capacities and applications of commercially available concrete technologies.

Stage 2
Features of the EC classification scheme were developed, based on stakeholder inputs from workshop 1, and further desktop-based research and analyses.

Stage 3
Concrete EC rating bands were established, based on stakeholder inputs from workshop 2, and using data on the EC of concrete mixes.

Stage 4
The brochure and report were produced, based on the outputs of project stages 1-3.

A.2. Stakeholder workshops

Two two-hour stakeholder workshops were held during the project, on the 11th of January 2023 and the 2nd of March 2023. Between 15 and 20 stakeholders and facilitators attended each workshop, which were held online using MS Teams. Stakeholders were present from industry organisations (including the LCCG, MPA, IStructE and ConcreteZero), public sector (including BEIS and Innovate UK), concrete suppliers, contractors, designers, and academia.

During the workshop, participants engaged in structured discussions around features of the proposed EC classification scheme (see Table 8). Following the workshop, response forms were circulated to the attendees to collect further written responses and raise any further points.

The purpose of the workshops was to understand stakeholder perspectives and to highlight important issues that may have otherwise been missed. Given the limited duration of the workshops, it was not possible to discuss all aspects of the proposed scheme. Only the most important aspects were covered. Nor was it the purpose of the workshops to establish consensus on issues discussed. Rather, differing perspectives were encouraged, and valued by the facilitators.
A.3. Other analyses

Most of the inputs for the project came from stakeholder workshops and desktop research. However, the project also involved two other supporting analyses:

– Concrete technology review – The analysis was undertaken at stage 1 to understand whether commercially available concrete technologies have compressive strength capabilities or applications falling outside the range of conventional concrete, and therefore whether the scheme’s coverage of concrete strengths and applications should be extended to account for this. It involved listing currently available concrete technologies and cataloguing supplier-provided information on their compressive strengths and applications. The analysis was undertaken because the scheme’s EC rating bands are static but must remain relevant if new, and less-widely-used technologies gain greater market share in the future. However, the scheme remains technology agnostic, in the sense that EC rating bands are not differentiated depending on the technology (e.g., binder type, production route) used to produce a shared functional unit of concrete.

– High-level impact analysis – The research-based analysis was undertaken at stage 2 to qualitatively understand the potential consequences of transforming the market towards lower EC concrete on whole building life cycle carbon emissions, asset performance, the economy, and the environment (excluding carbon impacts). This supplemented discussions with stakeholders on the same topic at workshop 1. Understanding these potential wider unintended impacts can support policymakers to develop holistic policies that address issues identified. Key findings of this analysis are outlined in Section 5.4.

Table 8: Questions posed to stakeholders at workshops 1 and 2.

<table>
<thead>
<tr>
<th>Workshop</th>
<th>Questions posed to stakeholders</th>
<th>EC classification scheme feature(s)</th>
<th>Report Section(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (11th January 2023)</td>
<td>Should re-carbonation of concrete be accounted for in the life-cycle assessments (LCAs) for concrete mixes? If so, how can it be accounted for in a way that is representative of real life?</td>
<td>User notes.</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Should carbon offsetting and carbon capture, utilisation, and storage (CCUS) be included in the LCA for concrete? If so, under which life cycle stage(s) should these processes be included?</td>
<td>User notes.</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>What opportunities are there for gaming the system of emissions intensity benchmarks/limits for concrete? How might these be mitigated?</td>
<td>Brochure.</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>What are the potential consequences of specifying low carbon concrete on whole building life cycle carbon emissions; asset performance; the economy; the environment (excluding carbon impacts)?</td>
<td>Brochure.</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>To what extent might regional availability of materials and consequent additional transport (stage A4) emissions impact the net carbon impact of using low carbon concretes in different locations? Based on this, should the scheme account for A4 transport emissions? If so, how?</td>
<td>User notes, brochure.</td>
<td>4.1 and 5.1</td>
</tr>
<tr>
<td></td>
<td>How will data for the embodied carbon of the concrete (i.e., concrete quantity, mix constituent quantity, and carbon intensity of concrete constituents) be obtained?</td>
<td>User notes.</td>
<td>4.1</td>
</tr>
<tr>
<td></td>
<td>How can the total mass of concrete embodied carbon, and not just the carbon intensity of concrete, be accounted for to prevent perverse decision making?</td>
<td>Brochure.</td>
<td>5.2</td>
</tr>
<tr>
<td>2 (2nd March 2023)</td>
<td>What should define the ‘baseline’ embodied carbon curve for concrete? What data source(s) should be used for the carbon factors? What method(s) should be used to determine the mix constituent quantities?</td>
<td>Baseline (EC100).</td>
<td>4.4 and Appendix B</td>
</tr>
<tr>
<td></td>
<td>What should define the ‘best’ embodied carbon rating? I.e., should it be above, below or aligned with the x-axis?</td>
<td>EC rating bands.</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>What should be the highest, lowest, and intermediate embodied carbon ratings (e.g., A-G)? And how should they be positioned relative to each other (e.g., equidistant)?</td>
<td>EC rating bands.</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>How should the embodied carbon ratings (or corresponding embodied carbon limits) for concrete be segmented? Are case-specific graphs needed?</td>
<td>EC rating segmentation.</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Notes:
1. Stakeholders suggested the question be reworded to focus on potential distortions, rather than gaming opportunities.
2. These three questions were not discussed during workshop 1 but were included in the list of questions circulated after the workshop.
Appendix B: Baseline (EC100) Derivation

This appendix outlines how the baseline (EC100) has been derived using different types and sources of concrete EC data and considering practical requirements for how the scheme is expected to be used.

B.1. Mathematical description of the baseline function

The baseline is a linear function, describing concrete carbon intensity (kgCO₂e/m³) as a function of concrete cube strength (MPa). From this baseline function, the EC rating bands (A-G) were derived. The linear function for the baseline can be described mathematically as per Equation 1, where \( x \) refers to the concrete cube strength (MPa) and \( y \) refers to the baseline EC reference values (kgCO₂e/m³).

\[
y = \begin{cases} 
5x + 200, & 10 \leq x \leq 60 \\
2.5x + 350, & 60 < x \leq 115 
\end{cases}
\]

Equation 1: Mathematical description of the baseline function.

B.2. Approaches to setting the baseline using available data types

Table 9 describes two possible approaches to establish the baseline, using two types of concrete EC data: project data, and theoretically derived data. Stakeholders maintained that the EC classification scheme would be more acceptable to industry if informed by project data from real concrete mixes produced and used on UK construction sites (Approach A in Table 9). However, a combined approach was taken for this project, considering both theoretically derived and project data, for two reasons:

1. There is a lack of available project data for strength classes higher than C50/60. Theoretically derived data can help fill this gap, so that the baseline encompasses all strength classes in BS EN 206 and BS 8500-1, for reasons given in Section 4.3.3.
2. The two approaches have advantages and disadvantages, as outlined in Table 9. A combined approach, which considers all available data types, is meant to alleviate these disadvantages.

The collection of primary data from concrete suppliers was outside the scope of this project. Therefore, all data used was provided by others.

Table 9: Possible approaches to establish the baseline, including underlying concrete embodied carbon data types.

<table>
<thead>
<tr>
<th>Data type</th>
<th>Approach 'A'</th>
<th>Approach 'B'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project data: Concrete mix designs, typically developed by concrete suppliers, and implemented on construction projects.</td>
<td>Theoretically derived data: Concrete mix designs theoretically derived to achieve concrete strengths, but not implemented on construction projects. The extent to which these mix designs are informed by practical design considerations varies and depends on the theoretical method adopted.</td>
<td></td>
</tr>
</tbody>
</table>

| Example datasets | Low Carbon Concrete Group concrete EC project data. | Concrete mix designs generated using the BRE concrete mix design method. This approach may be deemed inappropriate as it does not account for inclusion of admixtures, such as plasticizers and other high-range water reducing admixtures, which are commonly used in modern concrete production. Concrete EC data from a study employing digital methods for the embodied carbon of concrete: Embodied carbon analysis and benchmarking emissions of high and ultra-high strength concrete using machine learning algorithms [3]. |

| Approach explanation | Form the baseline using regression to a parameter (e.g., the median or 95th percentile) of the project data. | Form the baseline using a suite of theoretical mix designs, informed by an explicit set of practical design considerations (e.g., UK concrete specification standards and common industry mix design practices). |

| Advantages | Stronger perception that reference baseline is based on real-world practice. | Relatively easy to generate and compare mix design quantities with international standards. Avoids unknown bias within project datasets. Assumptions made to generate mix designs can be explicit. |

| Disadvantages | Uncertainty in data completeness and approaches taken to produce the data. | Purely theoretically derived data may not accurately reflect real-world practice or may be perceived as such. |

Notes:
1. EC values for all concrete mix designs can be calculated using EPD data for regionally relevant concrete constituents.
B.3. Practical requirements for the position of the baseline

In addition to the choice of underlying concrete EC data, several practical requirements have informed the mathematical description of the baseline. These requirements are based on how the scheme is expected to be understood and used by the industry.

Function type – The selection of the baseline’s expected to be understood and used by the industry.

**Requirements** are based on how the scheme is expected to be understood and used by the industry. These requirements are based on how the scheme is expected to be understood and used by the industry. The baseline is described well by linear functions. Linear functions also have the practical advantage that they can be easily described mathematically, meaning the scheme will be simpler to implement and adopt. Linear functions are described by their slope and y-intercept. These parameters are the focus of the following two sections.

Slope – The philosophy adopted is that the slope of the EC rating bands should reflect the incremental EC required to increase the concrete’s cube strength, but that in the face of uncertainty, it is better for the rating bands to be too flat (favouring lower, but still sufficient strength concrete), than too steep. This is because the slope of the baseline could encourage users to adopt higher or lower strength concrete, depending on how easily better EC ratings can be achieved by changing the strength class of the concrete. Flatter bands, in general, would encourage users to adopt lower strength concrete, while steeper bands would encourage users to adopt higher strength concrete, as explained in Section 5.2.

Y-intercept – The baseline’s y-intercept has been set with the intention that the baseline sits above a large majority (i.e., approximately 95-100%) of concrete mixes produced in the UK in c.2023. The y-intercept, and thus the EC reference values, must not be too low, otherwise this would place too many mixes in the ‘G’ EC rating band, which could discourage uptake of the scheme. The y-intercept must also not be too high, otherwise EC rating bands become too wide, losing their ability to differentiate between the EC of concrete products. However, without a complete dataset containing the EC of all concrete mixes produced in the UK, it is impossible to ascertain the extent to which the baseline sits above the EC of UK concrete mixes. This residual uncertainty is the subject of the following section.

B.4. Data sources and uncertainty

There is uncertainty in the underlying data used to establish the baseline, and therefore uncertainty in the selection of the baseline’s slope and y-intercept. This section outlines the data sources used to establish the baseline, and the uncertainty associated with these data sources, for the two segments of the baseline covering C8/10 to C50/60 and C55/67 to C100/115.

Access to more, and better-quality concrete EC data would help to reduce the level of uncertainty associated with the baseline’s position. However, as mentioned previously, it was beyond the scope of this project to collect additional primary data.

B.4.1. Concrete strength classes C8/10 through C50/60

A slope of 5.0 kgCO₂e/m³-MPa (cube strength), and a y-intercept of 200 kgCO₂e/Mpa have been selected for the baseline covering strength classes C8/10 to C50/60.

Data sources that have informed the baseline’s position are shown in Table 10. Some data sources were considered less reliable.

The most relevant dataset informing the baseline’s y-intercept is the LCCG dataset, which provides information about the spread of EC values with each strength class. All but four of the 624 datapoints (>99%) in the LCCG dataset lie below the proposed baseline.

Uncertainty remains on the most appropriate values of the baseline’s slope and y-intercept. The authors are confident that the selected y-intercept places the baseline above the EC of a large majority of UK concrete mixes in c.2023, based on the LCCG data and MPA UK 2021 industry means. However, since the LCCG data only includes mixes from five suppliers, it cannot be assumed to represent the whole UK market.

**Illustrative carbon intensity suite for mixes containing a higher proportion of SCMs: Flatter slope.**

**Illustrative carbon intensity suite for CEM I based mixes: steeper slope.**

Figure 14: How CEM I based carbon intensity suites better inform the baseline’s position.
B.4.2. Concrete strength classes C55/67 through C100/115

For strength classes C55/67 to C100/115, a slope of 2.5 kgCO₂e/m³/MPa (cube strength) has been adopted. However, there is less real concrete mix data available to establish the baseline, and therefore a higher level of uncertainty exists regarding its appropriate slope.

As shown in Table 10, industry carbon intensity data suites rarely extend beyond C50/60, and the latest LCCG data has only about 1% of the datapoints above C50/60. Therefore, the function used for concrete strength classes C8/10 to C50/60 cannot be used for higher strength grades.

A separate function has been developed so that the baseline covers all concrete strength classes in BS 8500-1 and BS EN 206. To achieve this, data was accessed from a peer-reviewed journal article titled Embodied carbon analysis and benchmarking emissions of high and ultra-high strength concrete using machine learning algorithms [3]. The data contained in this article, reproduced in Figure 15, informs the baseline’s slope at these higher strength grades.

While this dataset contains theoretically derived data, the machine learning algorithms used to produce these mix designs were trained using real mix designs, or ‘project data’, and thus are informed by real-world design considerations. In the absence of project data for higher strength concrete, it is believed that this approach delivers the best possible estimate of EC of higher strength concrete mixes.

However, this data uses carbon factors from an Australian database, and therefore is not UK-specific. It also includes SCM-containing mixes, rather than purely CEM I based mixes. Taking this into account and given the lack of project (real) data at these strength grades, the baseline’s slope has been set at 2.5, flatter than the slope of approximately 2.8 calculated from the article’s data. This is based on the philosophy described earlier, that in the face of uncertainty, it is better for the baseline to be too flat, rather than too steep.
### Data sources informing the baseline’s position from C8/10 to C50/60

<table>
<thead>
<tr>
<th>Data source</th>
<th>Description</th>
<th>Location</th>
<th>Underlying mixes</th>
<th>CEM I</th>
<th>Strength range</th>
<th>Slope(^{1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Carbon Concrete Group (LCCG)</td>
<td>Project data: Whole dataset</td>
<td>UK</td>
<td>624</td>
<td>Mixed(^{2})</td>
<td></td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>Project data: CEM I-based mixes only</td>
<td>UK</td>
<td>54(^{1})</td>
<td>CEM I</td>
<td>C8/10- C50/60</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Regressed curve based on project data: ‘G’ EC rating band</td>
<td>UK</td>
<td>624</td>
<td>CEM I</td>
<td></td>
<td>5.2(^{1})</td>
</tr>
<tr>
<td>Mineral Products Association (MPA)</td>
<td>UK industry 2021 means based on project data</td>
<td>UK</td>
<td>Unknown</td>
<td>Mixed(^{2})</td>
<td>C8/10-C50/60</td>
<td>3.9</td>
</tr>
<tr>
<td>Inventory of carbon and Energy (ICE) version 3 database</td>
<td>Theoretically derived carbon intensity suite: Ready-mix concrete CEM I</td>
<td>UK</td>
<td>Unknown</td>
<td>CEM I</td>
<td>C8/10-C40/50</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>Theoretically derived carbon intensity suite: Ready-mix concrete</td>
<td>UK</td>
<td>Unknown</td>
<td>Mixed(^{2})</td>
<td>C8/10-C40/50</td>
<td>4.8</td>
</tr>
<tr>
<td>OneClick LCA</td>
<td>Theoretically derived carbon intensity suite: Ready-mix CEM I</td>
<td>UK</td>
<td>Unknown</td>
<td>CEM I</td>
<td>C25/30-C55/67</td>
<td>4.8 - 5.2(^{1})</td>
</tr>
<tr>
<td>Concrete Sustainability Council (CSC)</td>
<td>Theoretically derived carbon intensity suite</td>
<td>Germany(^{3})</td>
<td>Unknown</td>
<td>Mixed(^{2})</td>
<td>C20/25-C50/60</td>
<td>3.2</td>
</tr>
<tr>
<td>Swedish Concrete Association</td>
<td>Reference values: ‘house interior’</td>
<td>Sweden(^{3})</td>
<td>Unknown</td>
<td>Mixed(^{2})</td>
<td>C16/20-C50/60</td>
<td>4.0</td>
</tr>
<tr>
<td>Carbon Leadership Forum (CLF); National Ready-mix Concrete Association (NRMCA)</td>
<td>Reference values: Baseline (high)</td>
<td>US(^{4})</td>
<td>Unknown</td>
<td>Mixed(^{2})</td>
<td>0-17.2MPa to &gt;55.1MPa</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>Reference values: Typical (median)</td>
<td>US(^{4})</td>
<td>Unknown</td>
<td>Mixed(^{2})</td>
<td>0-17.2MPa to &gt;55.1MPa</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>Reference values: Achievable (low)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.8</td>
</tr>
</tbody>
</table>

### Data sources informing the baseline’s position from C55/67 to C100/115

<table>
<thead>
<tr>
<th>Data source</th>
<th>Description</th>
<th>Location</th>
<th>Underlying mixes</th>
<th>CEM I</th>
<th>Strength range</th>
<th>Slope(^{1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodied carbon analysis and benchmarking emissions of high and ultra-high strength concrete using machine learning algorithms</td>
<td>Data-driven theoretical mix designs: high and ultra-high strength concrete</td>
<td>Australia(^{5})</td>
<td>&gt;400</td>
<td>Mixed(^{2})</td>
<td>50MPa-130MPa</td>
<td>2.83</td>
</tr>
</tbody>
</table>

### Table 10: Data sources informing the position of the baseline.

Notes:
1. Approximate slope of line of best fit, in kgCO\(_2\)/m\(^3\)/MPa (cube strength).
2. Only 6 mixes in strength grades above C50/60.
3. Curved function, slope varies.
4. Slope varies slightly across the carbon intensity suite.
5. Aspect of data making it less suitable for informing the baseline’s position.

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**Figure 16:** Most relevant data sources informing the baseline’s position.
Glossary of Terms and Abbreviations

Terms in red are new terms established for this EC classification scheme.

**Baseline (EC100)**
Reference EC values for different concrete strength classes. Baseline = F/G boundary.

**BEIS**
The Department for Business, Energy, and Industrial Strategy. As of February 2023, BEIS split into three government departments, namely: The Department for Science, Innovation and Technology (DSIT); The Department for Energy Security and Net Zero (DESNZ); and The Department for Business and Trade (DHT).

**CCS**
Carbon capture and storage. The term CCS describes processes whereby CO₂ is captured (e.g., at a cement production plant) and stored, to prevent it being released into the atmosphere, typically to mitigate climate change.

**CCU**
Carbon capture and utilisation. Processes whereby CO₂ is captured and used in intermediate products (such as synthetic fuels), before being released into the atmosphere.

**CDT**
Concrete Decarbonisation Taskforce. The CDT, convened by the ICE, will oversee the delivery of the LCCR.

**CEM I**
A cement mix containing at least 95% Portland cement clinker.

**Producer declared EC rating**
EC rating for a concrete product based on certified, product-specific EPDs and actual concrete constituent quantities.

**CO₂**
Carbon dioxide. CO₂ is the primary GHG released during cement and concrete production.

**ConcreteZero**
ConcreteZero is a global initiative that brings together organisations to create a global market for net zero concrete. This initiative is led by Climate Group in partnership with World Green Business Council.

**Declared unit**
BS EN 15804 defines declared unit as a ‘quantity of a construction product for use as a reference unit in an EPD based on LCA, for the expression of environmental information needed in information modules.’

**DESNZ**
Department for Energy Security and Net Zero. DESNZ may implement market transformation policies based on this EC classification scheme for concrete.

**ICE**
Institution of Civil Engineers.

**Impact category**
An impact category groups different emissions into one effect on the environment. Examples include change of climate, ozone depletion, and eutrophication. The impact category most relevant to this report is GWP.

**Innovate UK**
Innovate UK is the UK’s national innovation agency, supporting business-led innovation in all sectors, technologies, and UK regions. Innovate UK is part of UKRI.

**IStрукT**
Institution of Structural Engineers.

**LCA**
Life cycle assessment. An LCA is a systematic, standardised approach to quantifying the potential environmental impacts of a product (e.g., concrete) or process that occur from raw material extraction to end-of-life.

**LCCG**
The Green Construction Board’s Low Carbon Concrete Group. The LCCG, formed in 2020, includes professionals from the concrete and cement industry, academia, engineers, and asset owners.

**LCCR**
Low Carbon Concrete Route map, produced by the LCCG. The EC classification scheme in this report is based on a similar scheme outlined in the LCCR, Section 1.

**MPa**
Megapascals, an SI unit of pressure equal to 10⁶ pascals. This is the typical unit for describing the compressive strength of concrete.

**MPP**
Mission Possible Partnerships.

**Normal weight concrete**
Concrete with oven dry density between 2000 and 2600 kg/m³, according to BS EN 206. Typically, most concrete produced (both structural and non-structural) is normal weight. Others include lightweight concrete (oven dry density 800-2000 kg/m³) and heavyweight concrete (oven dry density greater than 2600kg/m³).

**PAS**
Publicly Available Specification.
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