Scottish Futures Trust - Embodied Carbon Benchmarks for New Buildings

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1 Introduction

This report documents the development of embodied carbon benchmarks for new buildings and the creation of a high-level embodied carbon benchmark tool, in Excel.

1.1 Background

Carbon footprinting is a topic of rising importance. The carbon footprint of buildings and construction is a significant contributor to national footprints.

Embodied carbon is the carbon footprint of a material or product. It considers the quantity of greenhouse gases (GHGs) that are released throughout the supply chain and is often measured from cradle-to-(factory)gate, or cradle-to-site (of use). Embodied carbon may also be measured with the boundaries of cradle-to-grave, which is the most complete boundary condition. This boundary includes the extraction of materials from the ground, transport, refining, processing, assembly, in-use (of the product) and finally its end of life profile.

Embodied carbon is gaining increasing attention from both industry and government where it is now recognised that embodied carbon emissions make up a large fraction of the emissions from the construction sector. In fact, it is often 20-50% of the whole life (embodied + operational) carbon emissions of a new building. This is already a significant proportion and will only increase as the thermal standards of new buildings improve and as we move towards zero carbon in operation[1].

The opportunity to reduce the embodied carbon of buildings is also significant, but it is an opportunity that is too often overlooked. There are an increasing number of case studies which show how reductions in embodied carbon of construction have also gone alongside large reductions in cost. For example, the HM Treasury Infrastructure Carbon Review, in the context of whole life carbon, which is embodied plus operational carbon, stated that:

> **"Reducing carbon reduces costs"** – HM Treasury Infrastructure Carbon Review, 2013
>
> **"Leading clients and their supply chains have already achieved reductions in capital carbon of up to 39 per cent, and 34 per cent in operational carbon. These reductions in carbon have been achieved in association with average reductions in Capex of 22 per cent"** – HM Treasury Infrastructure Carbon Review, 2013

The above figures are from the infrastructure sector. The HM Treasury Infrastructure Carbon review resulted in the development of a publicly available specification (PAS), for managing carbon emissions in infrastructure, PAS 2080, which was released in May 2016.

Both of those initiatives have taken embodied carbon measurement and reduction forward in the infrastructure sector. It is now time for the building sector to take forward embodied carbon assessment. A key barrier for embodied carbon assessment of new buildings, has been a lack of reliable data on embodied carbon benchmarks for buildings. In comparison to the infrastructure

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[1] Note that the UK Green Building council are currently developing a definition for zero carbon building in the UK (due to be complete at the end of April 2019). https://www.ukgbc.org/wp-content/uploads/2019/02/NZCB-Consultation-Paper.pdf

sector, there are a greater diversity of building types and a more diverse range of materials. It is therefore understandable the challenge around benchmarking new buildings.

Consequently, without reliable embodied carbon benchmarks, setting embodied carbon reduction targets becomes a challenge. This project aims to address these challenges, by providing data on embodied carbon of new buildings and high-level guidance on target setting.

1.2 Project Goal and Scope

Scottish Futures Trust (SFT) were seeking the development of embodied carbon benchmarks for buildings and a new high-level embodied carbon tool, to support with embodied carbon targeting setting within projects. This was to support projects from the briefing stage through to the development process.

The key outputs are a series of embodied carbon benchmarks and a high-level embodied carbon tool, in Excel format.

The embodied carbon benchmarks provide data to the tool, but could also be used as a standalone dataset. They provide a profile of embodied carbon per unit floor area for various building types, such as residential, offices, education, leisure, health and social care centres etc.

The benchmark tool could be used during the early stages of a project. It requires minimal information to complete, such as building type and floor area, to provide an indicative embodied carbon footprint. The profile of results is also used to assist with setting appropriate targets.

In summary, the goal and scope of this project were to:

- Compile embodied carbon case studies from the literature;
- Screen the case studies for method and consistency;
- Analyse the case studies, so that more reliable embodied carbon benchmarks can be formed;
- Produce a high-level embodied carbon benchmark tool for buildings, in Excel format;
- Provide high level advice on reduction; and
- Provide high level embodied carbon target setting guidance.

In order to achieve this goal and scope of study, there are various project outputs:

- This report summarises the embodied carbon benchmarks and excel tool;
- A report summarising good practice approaches to embodied carbon measurement and target setting;
- There is an accompanying Excel file with the embodied carbon benchmarks; and
- The embodied carbon tool, in Excel format.

2 Research & Scoping

Before developing benchmarks to feed into a tool, it was important to define the research and to scope out important areas of the project. The below have been documented in this section:

- Boundaries of embodied carbon assessment;
- Tool coverage of project types;
- Embodied carbon calculation method;
- Data inputs of a tool; and
- Target user audience.

2.1 Boundaries of Assessment

Research was conducted to find the pragmatic boundaries of assessment for initial embodied carbon benchmarks. For example, do the benchmarks assess cradle-to-gate, -site, -construction or -grave? And how do they treat operational carbon?

Starting with the widest boundaries of whole life carbon, which may be thought of in the following ways:

1. Whole life embodied carbon (excludes operational carbon of a building)
2. Whole life building carbon (includes operational carbon of a building)

Whole life embodied carbon includes all activities related to materials. This starts from the cradle, which is extracting materials and energy from the ground, to all transportation activities, refining, manufacturing and assembly operations. The products will then be packaged and delivered to site to be assembled into a building. This is cradle-to-construction embodied carbon. The inclusion of material maintenance, replacement and end-of-life covers whole life embodied carbon. This is shown in the diagram below:

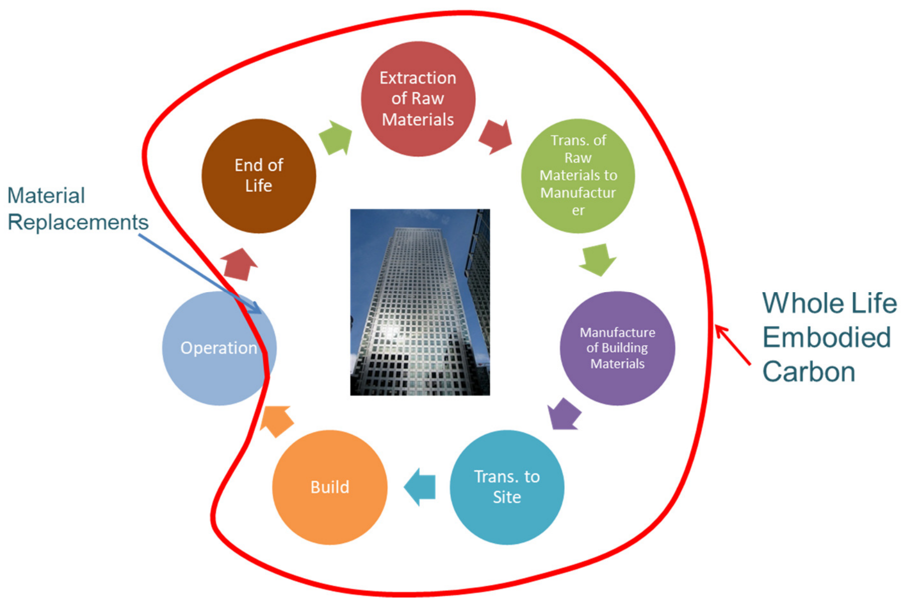

Figure 1 - Whole life embodied carbon

The full whole life carbon of buildings includes operational carbon, which comes from heat and power consumption in operation, and is the most complete assessment of a whole building. True whole life carbon studies are at the time of the project inception were still in a minority and the significant majority of studies focused on the cradle to site or to post construction. The following graph illustrates the increasing time and complexity that is required for a whole life carbon study and compares this against the availability of data and resources.

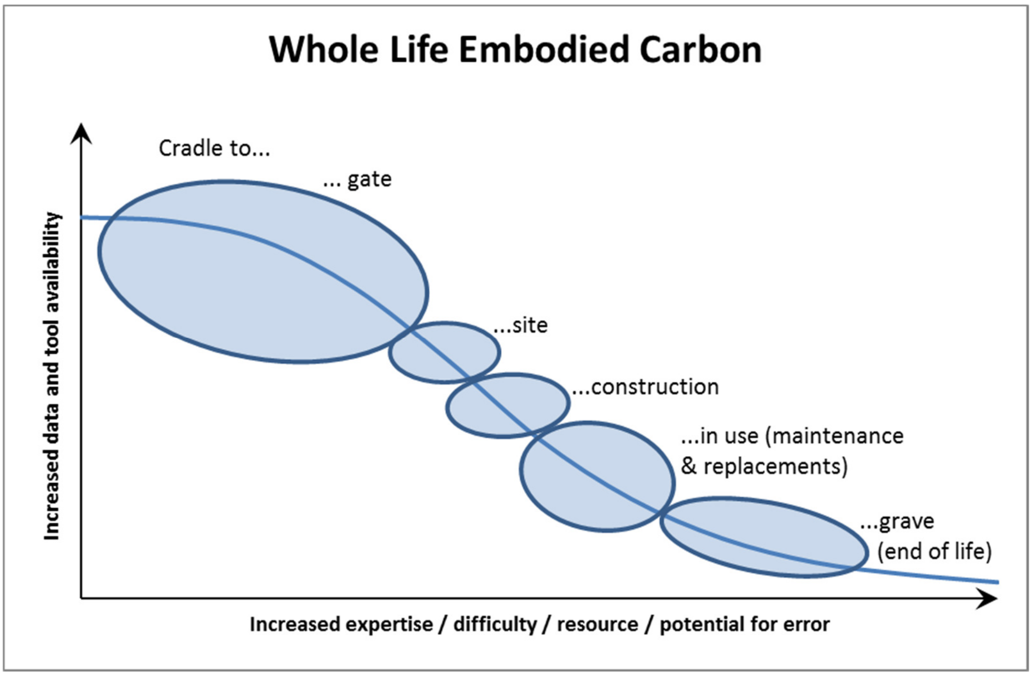

Figure 2 - Whole life embodied carbon, boundaries versus complexity

To summarise the boundaries:

Cradle-to-gate: The boundaries of cradle-to-gate covers all activities up to products leaving the factory gate. The availability of data, tools and guidance within these boundaries is generally good. These boundaries are also the least complex and are an ideal starting point for individuals new to this subject area. In EN 15978, Sustainability assessment of construction works for buildings, which is an EU wide standard, these boundaries are known as Modules A1-3.

Cradle-to-site: The next lifecycle stage of site would include delivery of goods to site. This is a lifecycle stage that earlier embodied carbon studies neglected. However, delivery of goods to site is not too troublesome to include in an assessment. In EN 15978 these boundaries are known as Modules A1-4.

Cradle-to-construction: These boundaries also include the construction site energy and waste (embodied carbon of producing waste materials). There are more studies being released that quantify the on-site energy consumption. There is also data on construction waste and resources such as the WRAP net waste toolkit or BRE Smart Waste data. The site has less data, guidance and tools availability than cradle to gate, it also requires a bit more time and expertise. Although it’s still too troublesome to complete a study that's includes these stages. In EN 15978 these boundaries are known as Modules A1-5.

Cradle-to-in-use (maintenance & replacements): The maintenance stage includes material repairs, general maintenance and would include replacements throughout the lifetime of a building. Studies that include maintenance to this extent are at present rare. It requires more expertise and there is a lack of guidance, tool and data for this stage. There is also a greater chance for variability in results given the influence of assumptions required. It raises questions such as what is the lifetime of a product and how does this compare with the lifetime of a building. This stage is more complicated and time intensive to complete. In the future software could help with this lifecycle stage. In EN 15978 the boundaries of the use phase are captured in module B.

Cradle-to-grave (end-of-life): The end-of-life stage is the most complicated to include in an embodied carbon assessment. There is considerable uncertainty at this point in the assessment because of the long building lifetimes. End-of-life is excluded from the majority of historical studies to date but there are an increasing number of newer studies that include the end-of-life stage. This is the stage that requires the highest level of expertise and has the least data, tools and guidance. It also has the most assumptions associated, due to the uncertainty of what will actually happen at the end of lifetime of a new building, e.g. this might be in 60 years' time. In EN 15978 the boundaries of end-of-life is Module C. There is a further Module D, which is benefits and burdens in future life cycles.

Summary of Boundaries

Considering the above the following boundaries of cradle-to-construction was recommended as a pragmatic place to start and used for SFT benchmarks and the Excel tool.

Cradle-to-construction boundaries generally covers the largest share of whole life embodied carbon. At present there is also a greater amount of case study data, guidance and tools to cover these boundaries. As a result, it would be troublesome for most people new to this subject to do a study beyond these boundaries. There is a learning curve that will need to be started and the boundaries of cradle-to-construction would offer an appropriate entry point.

The benchmarks and tool could be upgraded in the future to include cradle-to-grave results. It is therefore a pragmatic place to create embodied carbon benchmarks.

2.2 Tool Coverage of Project Types

For this project the below building categories were used in the benchmarks and tool:

- Offices;
- Community;
- Educational (all) – with breakdowns available for:
    - Nurseries
    - Primary and secondary schools
    - Universities
- Leisure;
- Health and social care centres;

- Residential (all) – with breakdowns available for:
    - Apartment
    - Detached house
    - Generic house
    - Multi-family house
    - Semi-detached house
    - Terraced house
- Industrial;
- Mixed-use;
- Retail; and
- Other.

These categories were developed based upon progress from the initial literature review of embodied carbon case studies. Examples of data sources for embodied carbon case studies are journal papers, published case studies and the embodied carbon database from WRAP and UK-GBC[2], which has since been overtaken to be managed by the RICS. It was one of the largest sources of case studies.

2.3 Method of Calculation

There are various ways in which embodied carbon calculations can be performed. This is heavily defined by the calculation method, which will define influential things such as treatment of biogenic carbon storage, method for recycling of metals, allocation between co-products.

Historically, embodied carbon studies have not been using consistent methods. This was likely to be to the lack of a prescriptive method on embodied carbon calculation. However, there is now and embodied impact assessment method for Europe. The standard EN 15978:2011 is on the sustainability assessment of construction works and cover over 20 different environmental and resource use categories. Embodied carbon (global warming potential in the standard) is one of the impacts covered. EN 15978 has improved the comparability of studies.

It is therefore proposed that a detailed calculation tool (phase 2) should use EN 15978 as the ideal calculation method. It is difficult for a high-level benchmark tool to only rely on EN 15978 case studies, because it would limit the sample size of case studies too much at present. However, EN 15978 data will be considered as the most desirable data to extract from the literature.

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[2] **WRAP, 2016.** Embodied carbon database of buildings. Accessible at http://ecdb.wrap.org.uk/, last accessed: 8th December, 2016.

2.4 Data Required by a Benchmark Tool

This section looks to address the question of, what data input fields will be required in the tool.

For a high-level embodied carbon benchmarking tool, data inputs are:

- Building type – select from drop down list, e.g. residential, offices…etc
- Gross internal floor area – in m^2, a tool could easily be created to accept square feet (ft^2)
- Operational carbon – this will be an optional field
- Lifetime of building – this will be an optional field

The first two data inputs provide a simple and quick data entry, but contains the two key parameters to show the user the appropriate embodied carbon results for their building type and size. The operational carbon and lifetime of the building are options that may be useful to some users.

2.4.1 Target Audience

It is anticipated that the main target audience of the benchmarks and tool will be procuring authorities to inform brief and measure performance. Such requirements will filter down the supply chain, for example project design team, architects, engineers, quantity surveyors, contractors and specifiers. The accompanying report on good practice approaches to measuring embodied carbon and target setting, outlines wider tool that would be of interest to these audiences.

3 Phase 1 - Development of Embodied Carbon Benchmarks and a High-Level Tool

3.1 Introduction

A high-level embodied carbon benchmark tool has been created to provide operational and embodied carbon data for construction projects. It is intended that this tool will be used at the business case stage to inform authorities as to the indicative carbon footprint for a project.

The user of the tool simply enters the following data before clicking on the selected project type, "Calculate Carbon Footprint for 2050" button.

- Building type - e.g. residential, offices, education etc;
- Floor area – gross internal floor area in m^2; and
- First year of operation (i.e. year when tenant/owner/occupier moves in – optional, the default is current year + one).

For personalisation, a project name can also be entered, if desired. There is also the option to add specific operational carbon data (e.g. from SAP or SBEM assessments) and to define the period of assessment (up to 80 years from construction). This feature might be useful if the user is interested in knowing the total carbon over the entire lifetime of the building or the split between embodied and operational at the end of a concession period, for example. In addition, there is the option to add specific GHG emission factors for electricity and heat used during operation for any year of operation. This feature might be useful to estimate effect of grid electricity decarbonisation or the installation of a biomass boiler (for example) at year X.

Results are presented in tonnes of carbon dioxide equivalents (tCO_2e) for embodied and operational aspects of the project over the lifetime of the building until 2050. This is an important date as the UK government have committed to carbon reductions of 80% by 2050 (based on 1990 levels) in the Climate Change Act. Alternatively, if the user has defined their own period of assessment, results will be presented up until the last year of this period (up to 80 years from construction).

Results are calculated using the median value of benchmark data (in tCO_2e per m^2) collected from the literature for each project and the floor area entered by the user. The potential range of carbon footprints for the project is also provided using 10^{th} and 90^{th} percentile values of the benchmark data per project type.

3.2 Approach to Developing Benchmarks

The general approach used to gather and select embodied carbon case studies is summarised below:

- Suitable case studies were collected from the literature;
- These case studies were 'mined' for benchmark data;
- An Excel based data extraction template was used to compile the embodied carbon and log details of the building type, methodology used etc.;
- Boundaries of all case studies were made consistent so all are cradle-to-construction;

- Statistical analyses were performed on all data to establish the median, range, upper/lower quartiles and various percentiles per building details;
- Case studies were then screened to remove unsuitable data and ensure methodologies used were as consistent as possible, starting with those on the extremities of the range;
- Statistical analyses were then repeated on the 'short-list' of case study data to obtain the median and 10th and 90th percentile values per building type; and
- Finally, median and 10th and 90th percentile values were used to create the benchmarks, which feed into the tool. This is used along with user-entered floor area data to calculate embodied carbon footprints in the tool.

This is also shown in Figure 3 and is expanded upon in the following sub-sections.

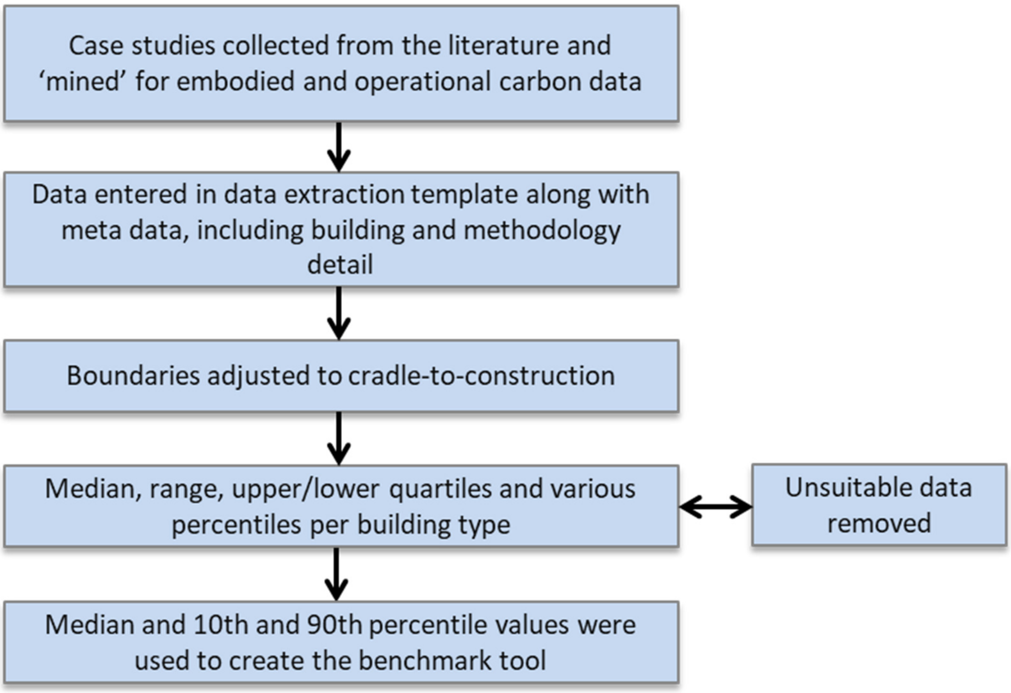

Figure 3 – General approach to the benchmark tool development

3.2.1 Compiling Benchmark Data – Case Studies

An extensive literature search was carried out of Circular Ecology's in-house literature, academic databases, industry databases and wider internet searches to gather suitable scientific papers and industry and government reports. Each study was then subjected to an initial screening process to ensure the correct information was detailed (e.g. floor area, embodied carbon) and the study was from a good source.

Those case studies that were suitable were 'mined' for benchmark data and meta-data (e.g. building details and methodology used), which were entered into an Excel based data extraction template (Figure 4).

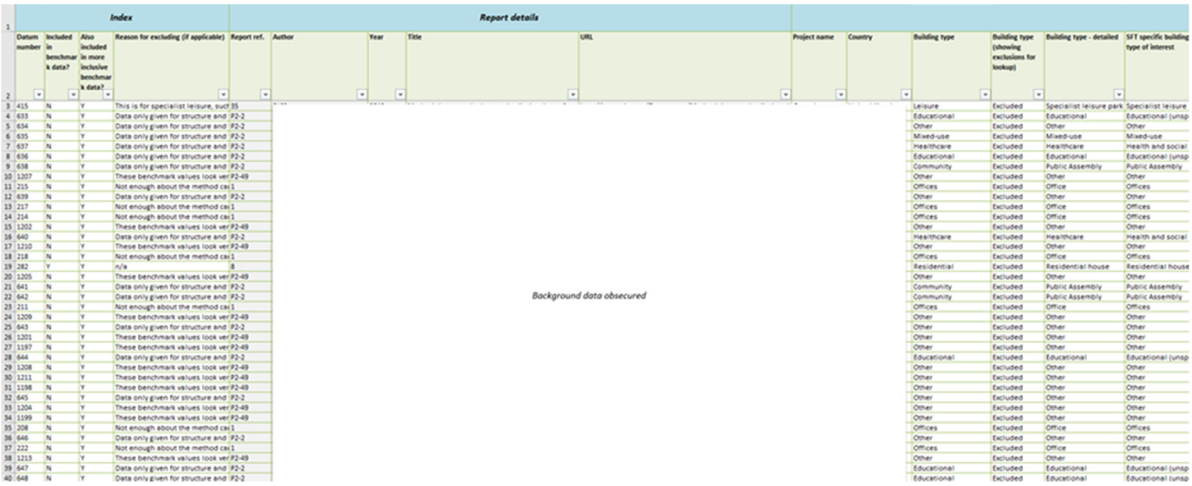

Figure 4 – Screenshot from extraction template

These data comprised:

- Report details: report reference, author, year, title, URL;
- Building details: project name, country, building type, detailed building type, residential category (if applicable), frame main material, building envelope main material, gross internal area;
- Methodology details: boundaries of assessment, type of review, method used, inclusion of carbon storage, all greenhouse gases or just CO_2;
- Carbon footprints per building and per m^2 in tCO_2e; and
- Any other notes.

A total of 1213 data points for embodied carbon were collected, each datapoint representing one building. The second largest source of data, and the largest UK data source, came from the WRAP and UK-GBC embodied carbon database, which has since been taken over to be now managed by RICS. Of the 248 projects in the WRAP data, around 150 case studies were left, after the screening process, which was applied to determine method and boundary consistency.

There were also notable data resources from RIBA, RICS and BRE. The largest source of data was from the University of Washington, 2017[3], which contains over 1190 data points (573 for new building with cradle-to-construction, or cradle-to-construction plus demolition boundaries), collected from around the world. However, the authors of that study acknowledge that details on what each case study includes and the method are quite sparse in places. That made integration of the data into the SFT embodied carbon benchmarks challenging.

The boundary of assessment for these studies varied, with some cradle-to-gate, cradle-to-site and cradle-to-construction (plus demolition). For the purposes of the benchmark calculator, the most useful boundary is cradle-to-construction. Therefore, all suitable case study boundaries were adjusted to this boundary using generic data from HM Government on the contribution to whole life embodied carbon that transportation of materials to site, site energy and waste and demolition typically make up.

[3] https://digital.lib.washington.edu/researchworks/handle/1773/38017

An iterative process of statistical analyses was performed on all data to establish the median, range, upper/lower quartiles and various percentiles per building details. Outliers of the ranges in each case were investigated and screened.

3.2.2 Screening Case Studies

The range of data from the initial 1,213 data points for embodied carbon was large (~ 0.1 – 5 tCO_2e per m^2). This range was largely due to the historical differences in method, data and tools for embodied carbon assessment. For example, some studies consider the carbon contained in timber products as being stored at the end-of-life stage and apply a credit equal to the amount of atmospheric CO_2 removed whilst the tree was growing, leading to negative carbon footprints. It is therefore difficult to fairly compare studies that have included biogenic carbon storage with those that have excluded it.

However, a level of variation would also be expected as normal (e.g. CAPEX build costs vary considerably) and these "real" differences in embodied carbon are important to capture in the benchmark tool. Therefore, a screening exercise was undertaken to attempt harmonise the data as much as possible by ensuring data used was calculated using similar methodologies and by removing any poor-quality data, following Figure 5.

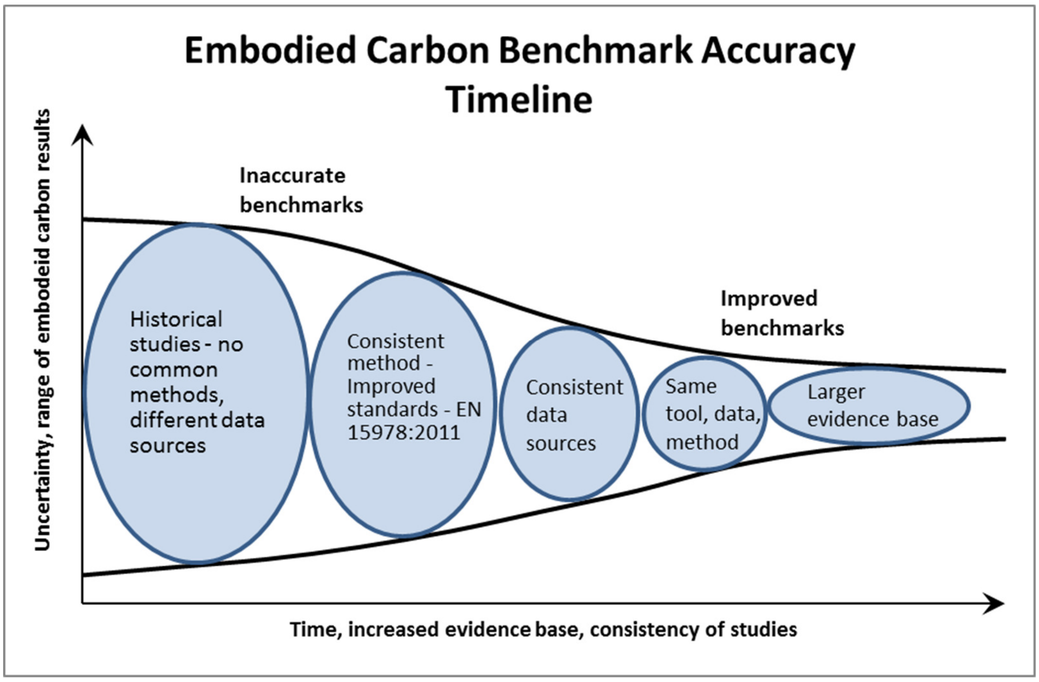

Figure 5 – embodied carbon accuracy benchmark timeline

This screening process was iterative, with a focus on the outliers initially but was expanded to all data collected. After a number of iterations, the large initial embodied carbon range was reduced to a point where the majority of differences between values were thought to be more "real" (i.e. a result of differences in the choice of site, building materials and onsite practices) rather than due to mainly methodological differences. That said, ensuring that all remaining studies are exactly the same method is not fully possible, due to too many studies not reporting method in full.

Following the screening process, hundreds of embodied carbon data points were removed, leaving a total of 532. Reasons for excluding these data point can be summarised as follows:

- Mistakes in calculations in source data;
- Out of date data, poor quality data or unreasonable assumptions used to calculate data;
- No floor area or embodied carbon per m^2 provided;
- Lack of transparency in the method;
- Replacement of materials in the use-phase, which not breakdown to allow boundaries to be made consistent with cradle-to-construction; and
- Biogenic carbon storage was included in results (we needed excluded carbon storage for consistency).

Statistical analyses were then repeated on this 'short-list' of case study data to obtain the median and 10^{th} and 90^{th} percentile values per building type, which were used to create the embodied carbon benchmarks and feed into the tool.

4 Embodied Carbon Benchmarks – A Selection of Results

4.1 Introduction

An overview of the embodied carbon benchmark results at the time of writing this report is shown in this section. However, there is an accompanying excel file, which has the most up to data benchmarks and should be considered as the primary embodied carbon benchmark resource.

4.2 Embodied Carbon Benchmarks for New Buildings

An example of the embodied carbon benchmark results, from the statistical analyses of embodied carbon case study data, are provided below. This representation shows the minimum, lower quartile, median, upper quartile and the maximum datapoints as a box and whisker plot.

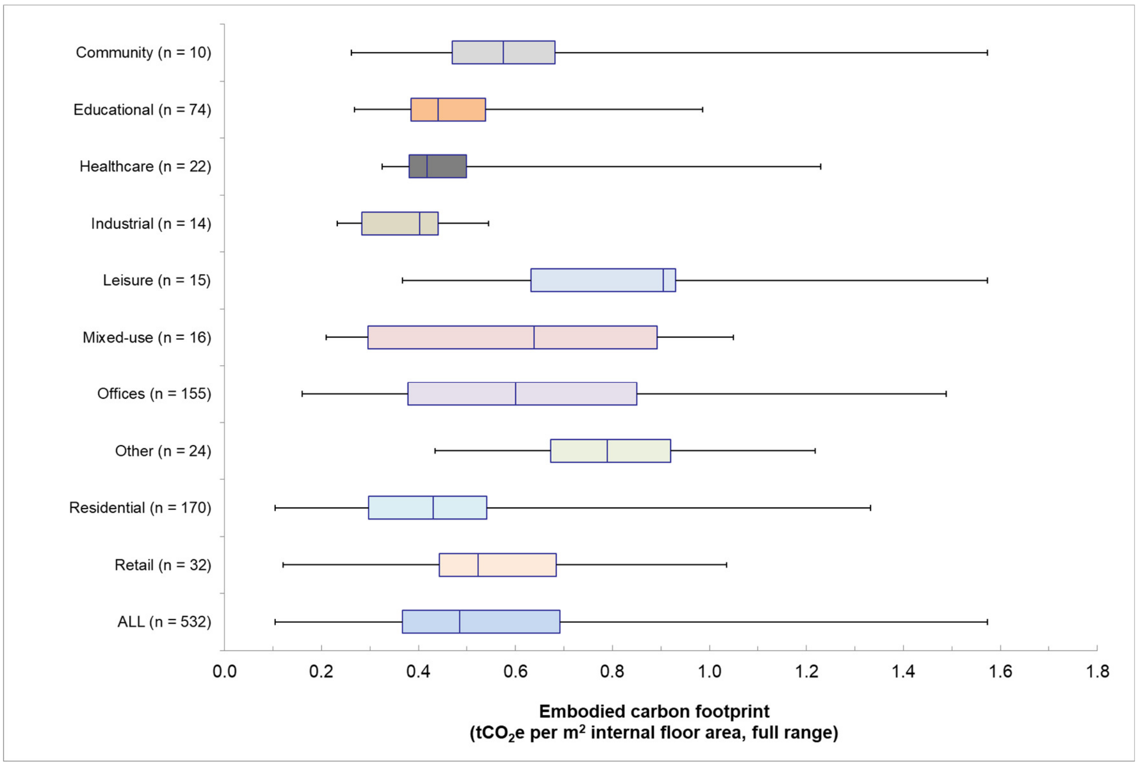

Figure 6 – the full range of embodied carbon benchmark data following the complete screening exercise.

These results show the full range of data, after the screening exercise was completed. The full range of data before the screening of studies, was 0-5.0 tCO_2e per m^2 on the x-axis. The scale on Figure 6 shows that this was reduced immensely from the screening process.

After analysing the data, it was considered that the results for the 10-90th percentiles produced a sensible range. This is shown in Figure 7. The 10-90th percentile results were considered as ideal, because as much as the screening process has attempted to remove difference in method and boundaries, there should still be expected to be some studies that differ. The 10-90th percentile results, remove the lowest 10% of embodied carbon results and the highest 10% of embodied carbon results. This leaves 80% of the studies remaining and helps to bring the data range down nicely, as shown in Figure 7.

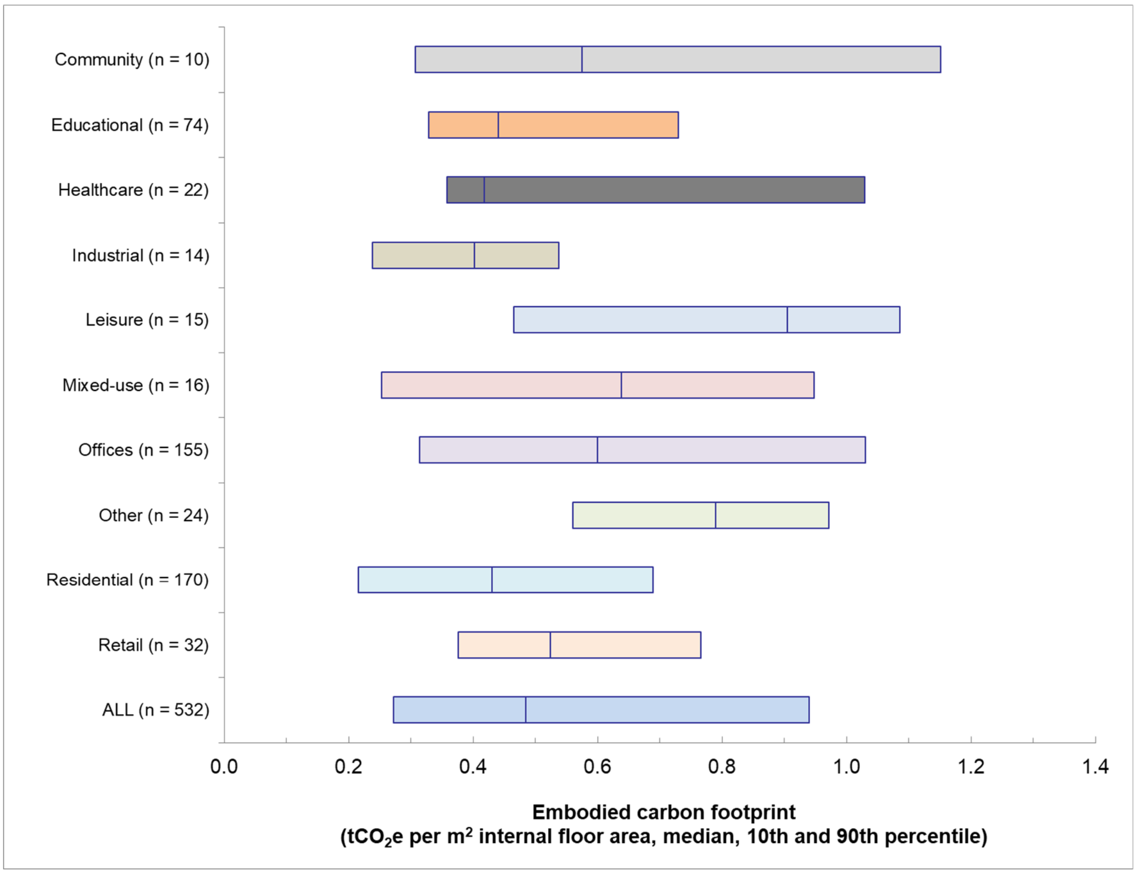

Figure 7 – the median and 10th and 90th percentiles of embodied carbon benchmark data following the complete screening exercise.

Results show that whilst there are differences in median embodied carbon benchmark values between building type, there is considerable overlap between the ranges, when the 10 – 90th percentile range is used and this should be kept in mind when comparing building types with the benchmarking tool.

4.3 Analysis

4.3.1 Educational Buildings

For educational buildings, the data was sub-categorised further:

- Educational (all) – with breakdowns available for:
    - Nurseries
    - Primary and secondary schools
    - Universities

The results for these categories are shown in Figure 8, below.

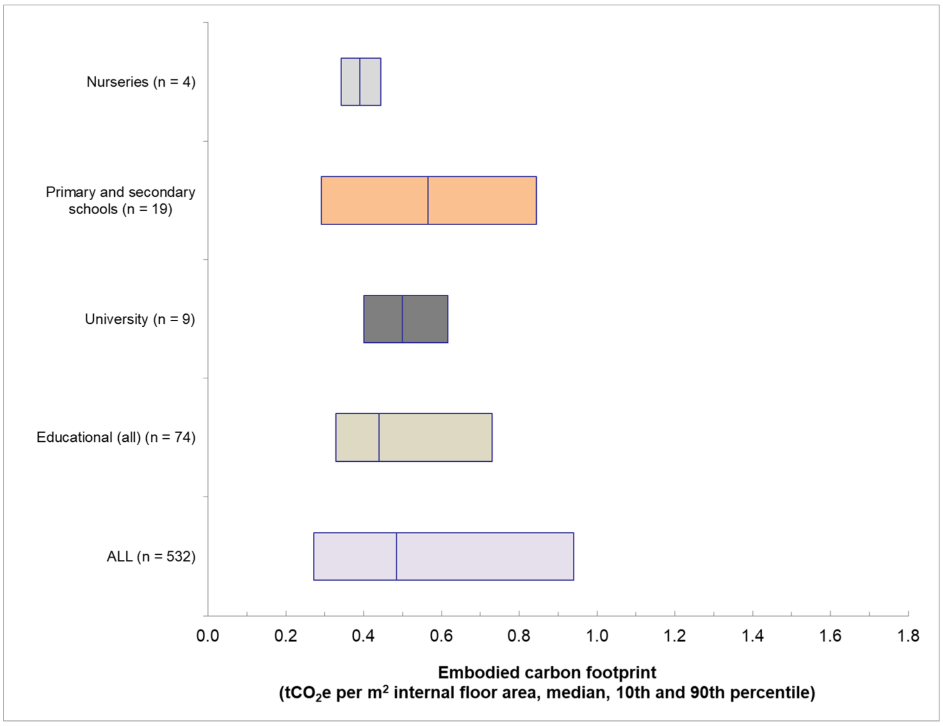

Figure 8 - embodied carbon benchmarks for educational buildings

The aspiration was to produce separate data for primary school sand secondary schools. However, the initial results showed a difference in results that could not be justified with the relatively small sample size of data. As a result, a combined primary and secondary school category was presented.

4.3.2 Residential Buildings

In the case of residential buildings, it is possible to separate results further. Figure 9 shows the 10 – 90th percentile range for different residential buildings.

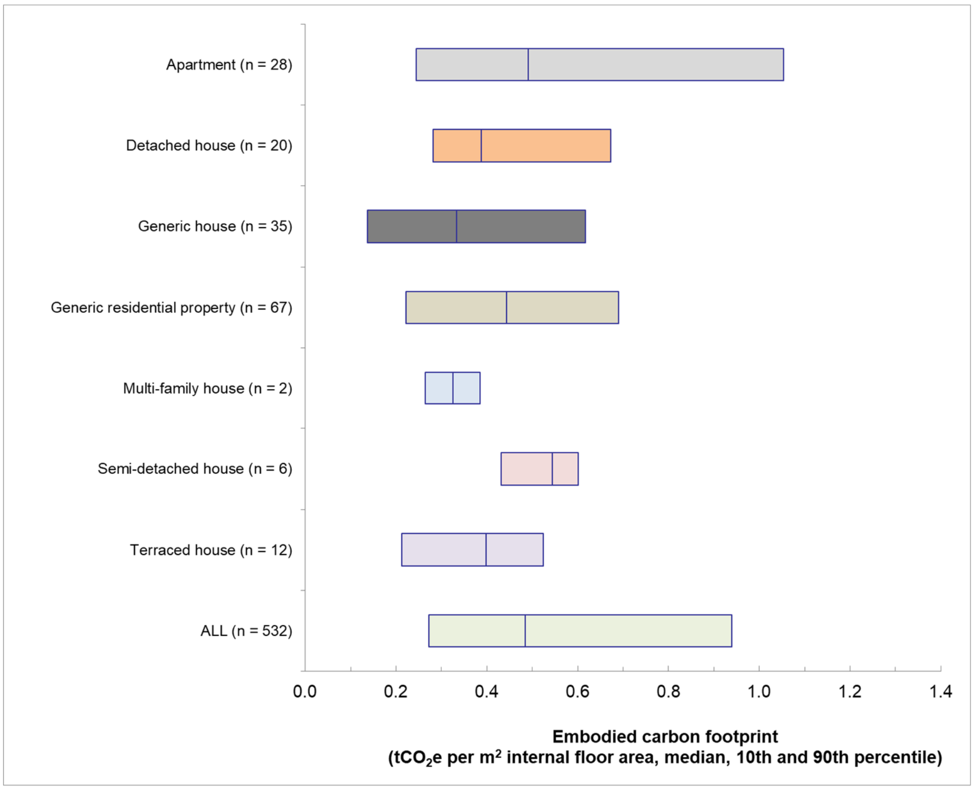

Figure 9 – the median and 10th and 90th percentiles of embodied carbon benchmark data following the complete screening exercise for residential building only.

4.3.3 Building Frame

Figure 10 shows the 10 – 90th percentile range for all buildings, broken down by frame type (i.e. timber, concrete or steel).

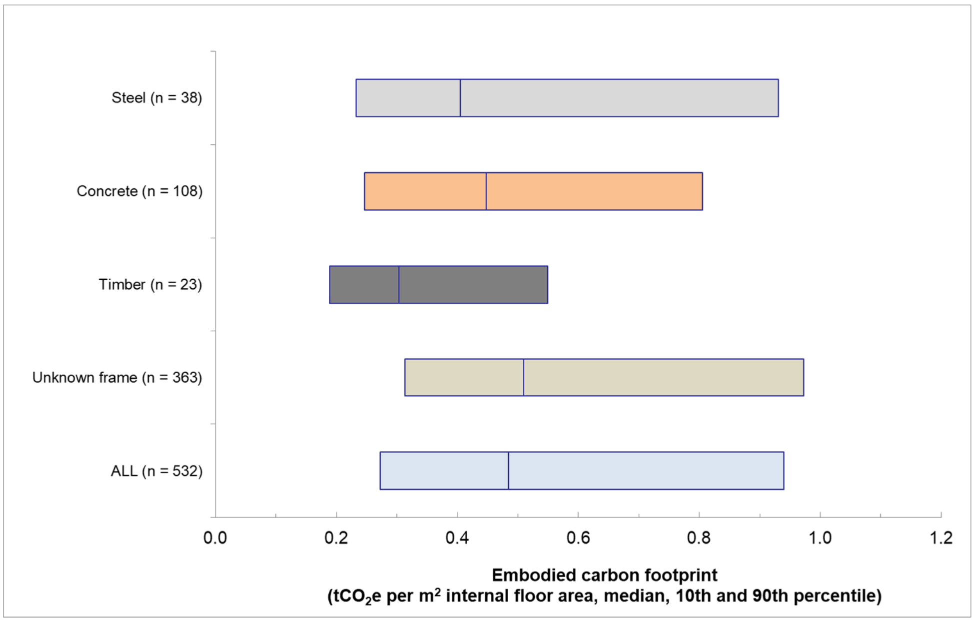

Figure 10 – the median and 10th and 90th percentiles of embodied carbon benchmark data following the complete screening exercise, per frame type.

Again, there is considerable overlap between the ranges but median values follow the order (from lowest to highest) timber, concrete and steel. Timber is generally a low embodied carbon material. These results do not consider carbon storage benefits of sustainable timber. Including the carbon storage benefit would reduce the embodied carbon impact of the timber frame further, within these boundaries of cradle to gate.

For guidance on calculating carbon sequestration for timber, see the EU wide standard EN 16449:2014[4].

4.3.4 Correlation of Year versus Embodied Carbon

For all data collected, benchmark embodied carbon values were plotted against the year of study to assess the correlation between the two. It was hypothesised that values would be seen to decrease over time, due to the increased awareness of embodied carbon in the construction sector in the last 20 years. However, a weak correlation was observed between year of study and embodied carbon results. However, what was observed to some degree, was a smaller embodied carbon range for

[4] Wood and wood-based products — Calculation of the biogenic carbon content of wood and conversion to carbon dioxide. British Standards Institute, 2014.

more modern studies. This suggests that more modern embodied carbon studies are using less difference in embodied carbon calculation method.

4.3.5 Benefit of the Screening Process

As part of this project, data for over 1,200 embodied carbon case studies were collected. This was reduced to 532 case studies through a screening process, which left those with a more consistent method and boundaries. The 532 remaining case studies were used as the basis for embodied carbon benchmarks. However, analysis was also completed with 1,107 case studies (those with clear errors were excluded completely).

The screening process has brought more consistency to the benchmarks. For some building types it was more beneficial than for others. The comparison is show in Figure 11 and Figure 12.

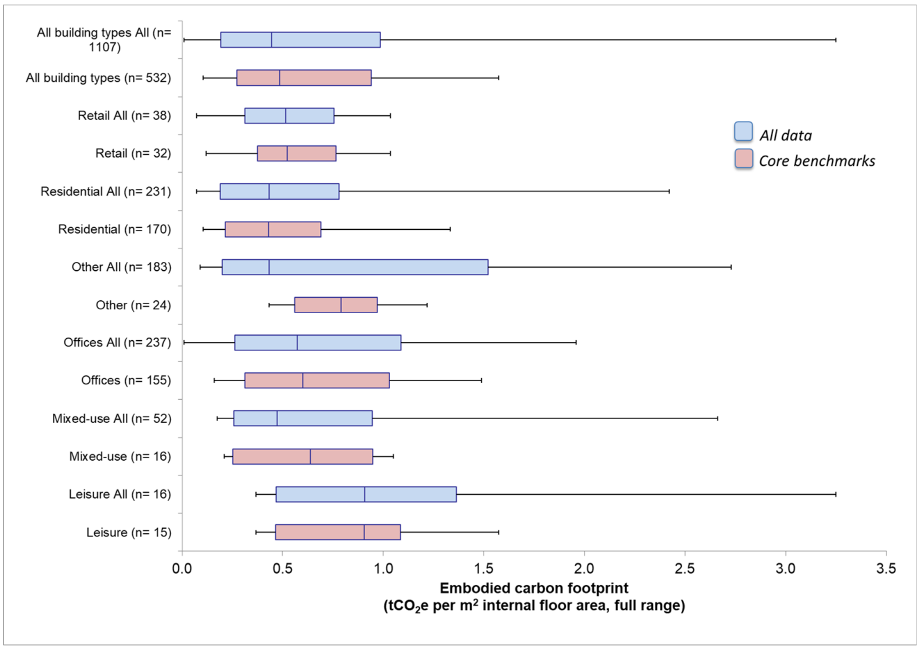

Figure 11 - Embodied carbon results for all data and for the screened dataset (called core benchmarks)

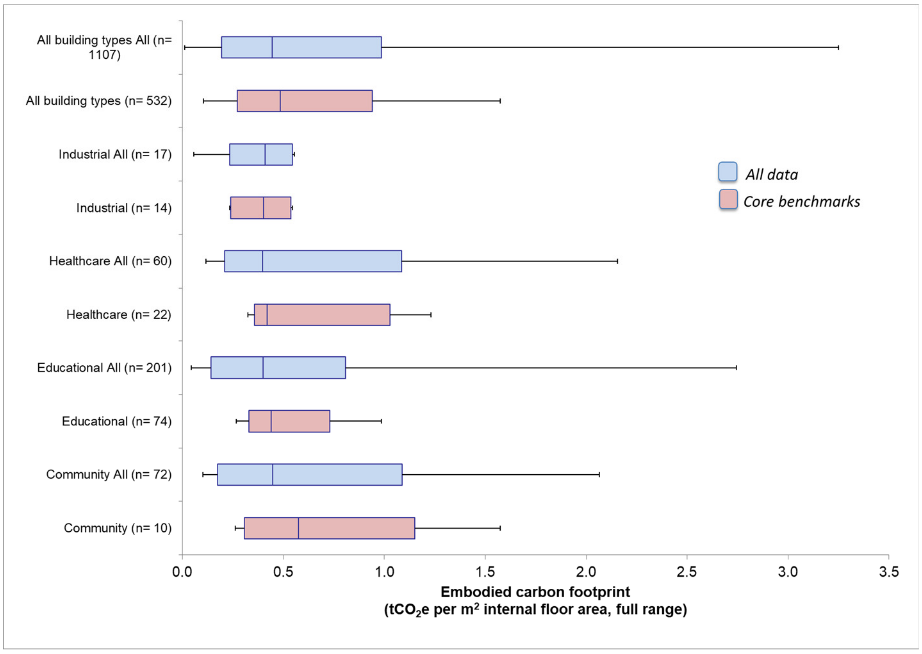

Figure 12- Continued, embodied carbon results for all data and for the screened dataset (called core benchmarks)

The comparison shows that for many building types the range of embodied carbon data is smaller for the core embodied carbon benchmarks. This is particularly notable in the minimum and maximum values. The 10^{th} and 90^{th} percentile is a notably smaller range for leisure, educational, healthcare, and for the all buildings category. This reduction in range is one of the benefits of the screening. The core benchmarks have a more consistent boundary and method.

4.3.6 Profile of Embodied Carbon Case Studies

During the analysis of the embodied carbon benchmarks, a profile of embodied carbon results was observed. This is shown in Figure 13.

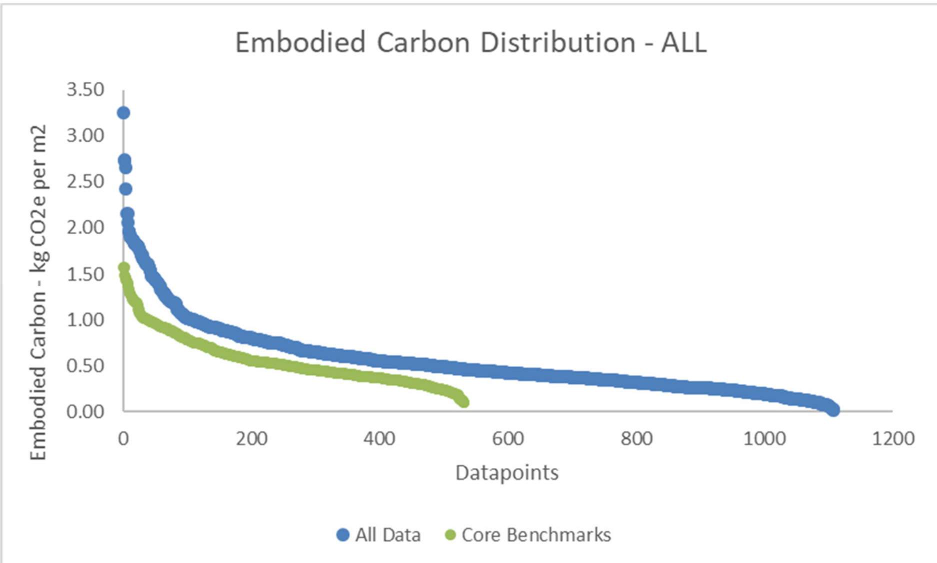

Figure 13 - Embodied carbon profile of results

The results for many sub-building categories displayed a similar curve to these results. The chart shows all of the data collected, as well as the core benchmarks. The core benchmarks have a smaller data range, showing well how the screening process has been beneficial.

However, an interesting observation is on the common curvature, or profile, of embodied carbon results. Even after the screening exercise, the shape of the profile is similar. This was also observed for other building types, for example, Figure 14 for educational and Figure 15 for office buildings.

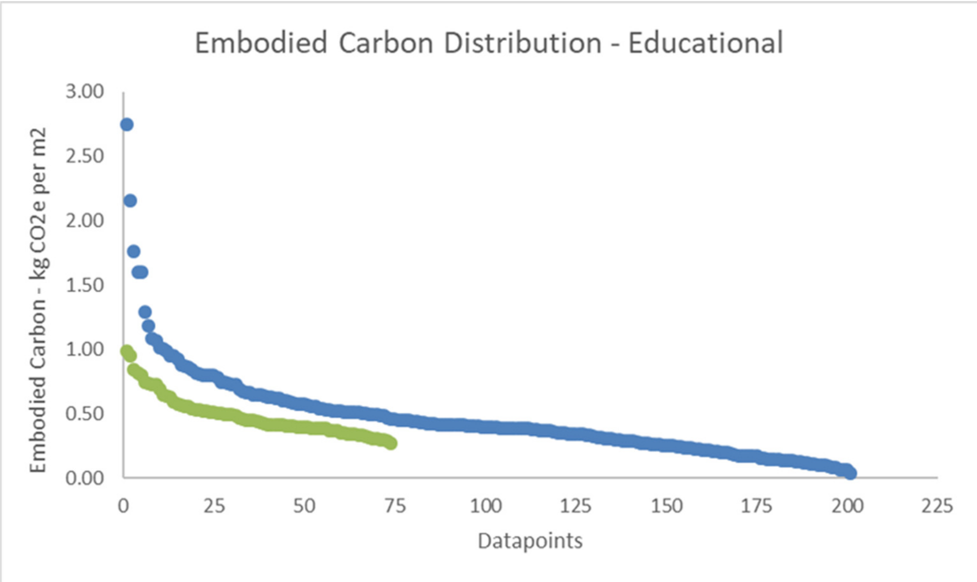

Figure 14 - Embodied carbon profile for educational buildings

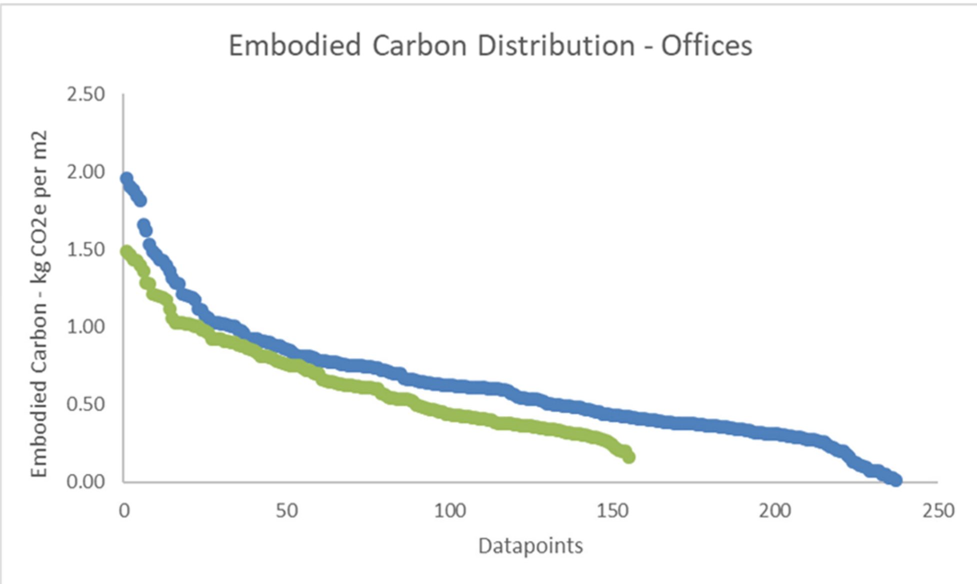

Figure 15 - Embodied carbon profile for office buildings

4.4 Embodied Carbon Benchmark Summary

Table 1 below details all embodied carbon benchmark data used in the embodied carbon tool.

Table 1 – Benchmark embodied carbon data used in the SFT embodied carbon tool

Project type	**Number of data points**	**Embodied carbon footprint (tCO_2e per m^2 internal floor area)**				
		Min	**10th percentile**	**Median**	**90th percentile**	**Max**
Community	10	0.26	0.31	0.58	1.15	1.57
Educational	74	0.27	0.33	0.44	0.73	0.99
Healthcare	22	0.32	0.36	0.42	1.03	1.23
Industrial	14	0.23	0.24	0.40	0.54	0.55
Leisure	15	0.37	0.47	0.91	1.09	1.57
Mixed-use	16	0.21	0.25	0.64	0.95	1.05
Offices	155	0.16	0.31	0.60	1.03	1.49
Other	24	0.43	0.56	0.79	0.97	1.22
Residential	170	0.10	0.22	0.43	0.69	1.33
Retail	32	0.12	0.38	0.52	0.77	1.04
All	**532**	**0.10**	**0.27**	**0.48**	**0.94**	**1.57**

For the most up to date data, please check the accompanying excel file, referenced at the start of this report.

5 Operational Carbon Data

The same general approach as that used to gather and select embodied carbon data for the embodied carbon tool was also used for operational carbon and is summarised below:

- Suitable case studies were collected from the literature;
- These case studies were 'mined' for benchmark data;
- An Excel based data extraction template was used to compile the operational carbon and log details of the building type, methodology used etc.;
- Statistical analyses were performed on all data to establish the median, range, upper/lower quartiles and various percentiles per building details;
- Case studies were then screened to remove unsuitable data and ensure methodologies used were as consistent as possible, starting with those on the extremities of the range;
- Statistical analyses were then repeated on the 'short-list' of case study data to obtain the median and 10^{th} and 90^{th} percentile values per building type, which were used to create the SFT embodied carbon tool; and
- Typical benchmark data collected from the Scottish Energy Officers' 2018[5] study carried out by SFT were used in preference to median values of other data collected for many building categories (see reference in Table 2).

In addition to the meta-data collected for embodied carbon, the assumed building lifetime was also collected for operational carbon data. This exercise resulted in a total of 139 data points for operational carbon from 19 case studies, each representing one building. The largest source of data came from CIBSE TM46, with substantial contributions from Carbon Buzz and BRE.

[5] Typical Building Energy Benchmarks from Scottish Energy Officers' Benchmarking Study of 2016-17 Data, 2018.

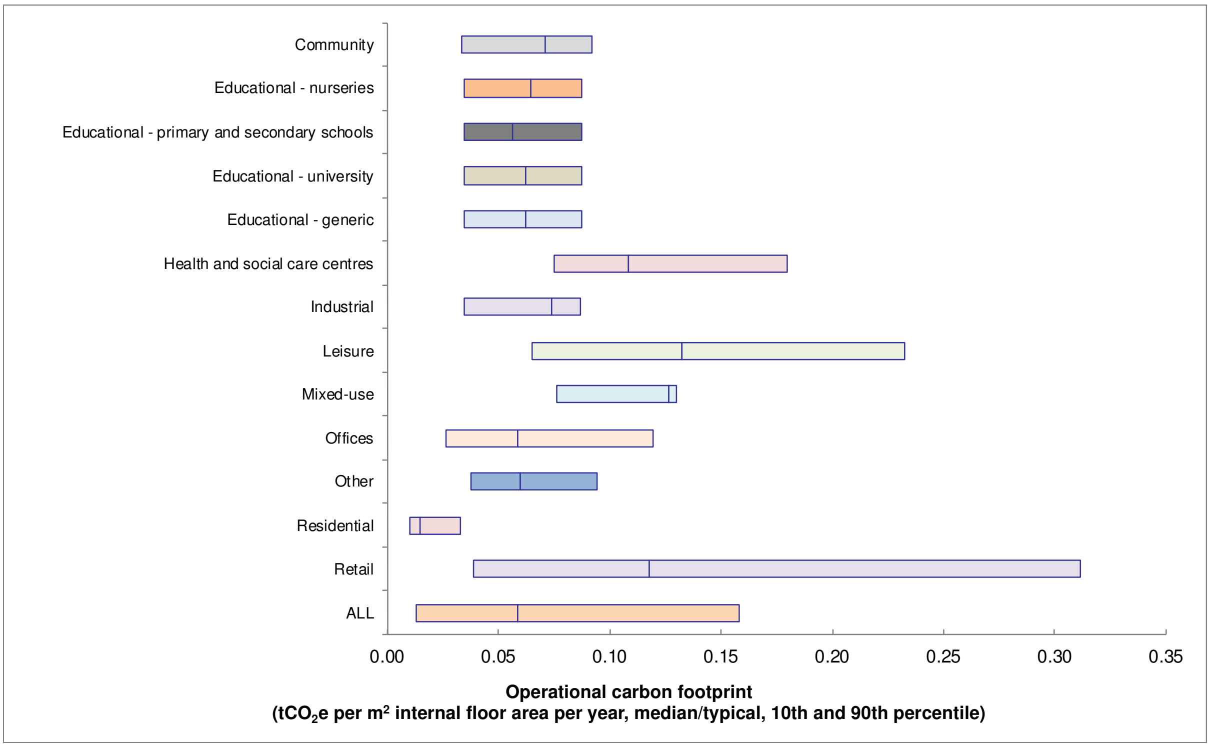

Figure 16 – the median/typical and 10th and 90th percentiles of operational carbon benchmark data following the complete screening exercise.

Following a similar data screening exercise as that described above for embodied carbon, 9 data points were excluded, leaving a total of 130. The 10 – 90th percentile range of operational carbon data for all buildings is shown in Figure 16 and Table 2 details all operational carbon benchmark data used in the embodied carbon tool.

Table 2 – Benchmark operational carbon data used in the SFT embodied carbon tool

Project type	Operational carbon footprint, per year (tCO_2e per m^2 internal floor area per year)					Source
	Min	10th percentile	Median	90th percentile	Max	
Community	0.02	0.03	0.07	0.09	0.18	M = SEO 2018, 10th and 90th = core data
Educational - nurseries	0.03	0.03	0.06	0.09	0.10	M = SEO 2018, 10th and 90th = core data
Educational - primary and secondary schools	0.03	0.03	0.06	0.09	0.10	M = SEO 2018, 10th and 90th = core data
Educational - university	0.03	0.03	0.06	0.09	0.10	Core data
Educational - generic	0.03	0.03	0.06	0.09	0.10	Core data
Health and social care centres	0.06	0.08	0.11	0.18	0.19	M = SEO 2018, 10th and 90th = core data
Industrial	0.03	0.03	0.07	0.09	0.09	M = SEO 2018, 10th and 90th = core data
Leisure	0.02	0.07	0.13	0.23	0.39	M = SEO 2018, 10th and 90th = core data
Mixed-use	0.06	0.08	0.13	0.13	0.13	Core data
Offices	0.02	0.03	0.06	0.12	0.23	M = SEO 2018, 10th and 90th = core data
Other	0.03	0.04	0.06	0.09	0.10	Core data
Residential	0.00	0.01	0.01	0.03	0.08	Core data
Retail	0.02	0.04	0.12	0.31	0.69	Core data

The results showed that the range of operational carbon benchmark values is quite large. It is likely that the range of data predominately reflects “real” differences in operational carbon due to differences in energy requirements and thermal properties of materials used, for example. However, it is acknowledged that there are limitations in these operational energy data, including:

- The use of data for new and existing buildings, whereas data for only new builds might be more appropriate;

- The inclusion of "small power" (e.g. consumption of laptops, TVs, appliances) for some studies;
- The decarbonisation of grid electricity over time was not carried out due to difficulties in separating electricity from fuel combustion in source data;
- The tendency for published studies to showcase "exemplar" buildings with low operational energy and carbon (particularly for residential buildings); and
- Operational energy consumption for residential buildings appears low, this may be due to mainly low energy properties in the case studies compiled. The operational carbon data for operational buildings would likely benefit from more case study data.

It is therefore suggested that future updates to data should perhaps use SBEM and SAP assessment results, which are for new buildings, exclude small power and align with the boundaries of operational carbon recommended in the EN 15978 standard.

To overcome these limitations, the embodied carbon benchmark tool has been created to accept a user entered operational carbon value.

5.1.1 Embodied Versus Operational Carbon

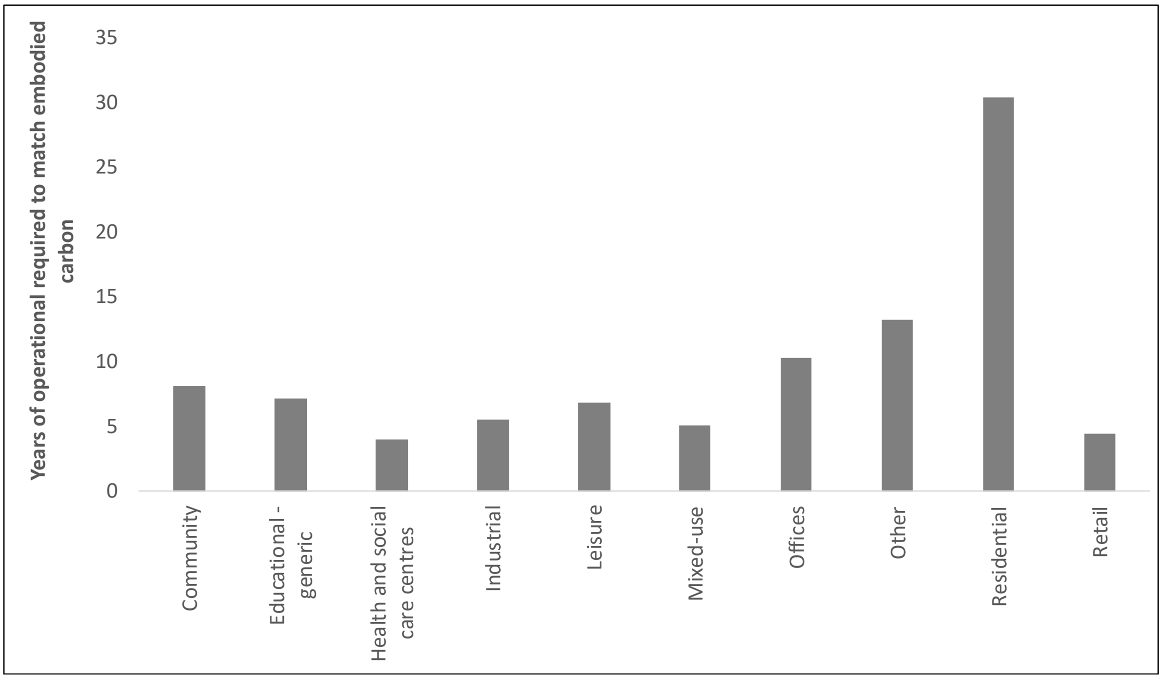

Figure 17 – the number of years of operation required to match operation carbon, per building type

Figure 17 above provides estimates of the number of years of building operation required to match embodied carbon, based on median benchmark values. Depending on building type it can type between ~2.5 to 31 years of operational for operational carbon to equal that of embodied carbon. Therefore, embodied carbon can still represent a substantial proportional of total carbon emissions even after the building has been operating of a long period of time. This data doesn't consider decarbonisation of grid electricity over time.

The limitation documented in the previous section, on the residential data should be noted when looking at Figure 17 for residential buildings. A further limitation of this comparison, is that the embodied carbon values are only related to the fabric of the buildings. Whereas, the operational carbon includes all energy consumption. For example, the embodied carbon of appliances, IT and other equipment is not included. However, the operational carbon includes their energy consumption.

As an example, Figure 18 shows the embodied and operational carbon of a 1,000 m^2 office building over time until 2050, where the tenant occupies the building in 2020. As can be seen from the figure, it takes until 2030 (10 years of operation) until operational carbon overtakes embodied carbon in terms of the proportion of total carbon it represents. At 2050, embodied carbon still represents 25% of total carbon for the building.

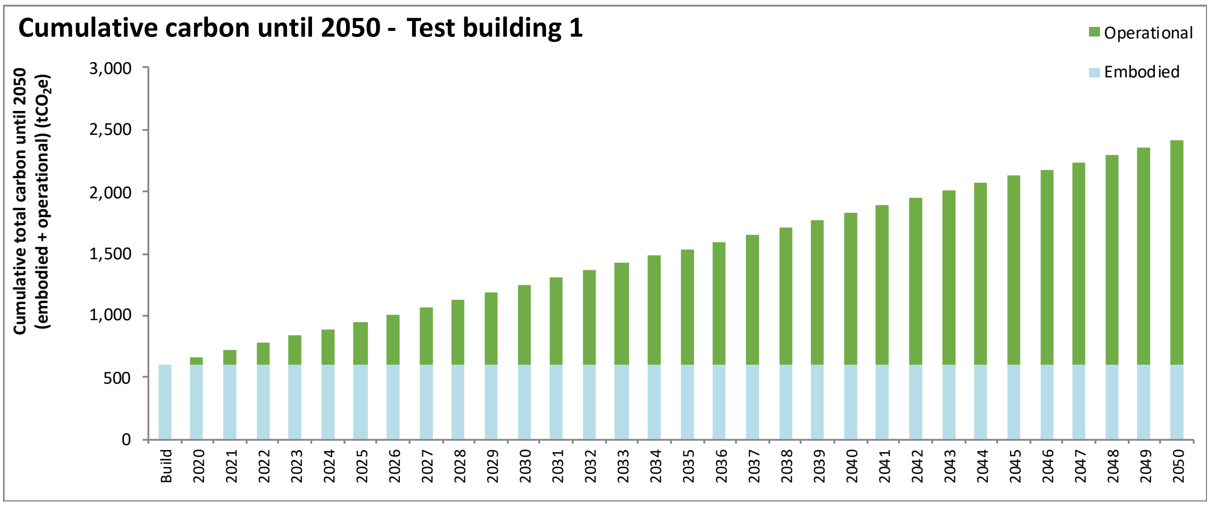

Figure 18 – embodied and operational carbon of an example office of 1,000 m^2 over time until 2050

6 Summary

A high-level embodied carbon benchmark tool has been created to provide operational and embodied carbon data for construction projects. The user is only required to input data of project/building type, floor area and first year of operation to generate embodied and operation carbon footprints for their building.

The high-level embodied carbon benchmark tool allows users to set embodied carbon assessment targets. The tool has been created through the process of compiling embodied carbon case studies from the literature. The initial range of embodied carbon results was determined to be unworkably high. The tool considers over 1,200 data points from the literature, with a focus on over 530 as the core benchmarks. These were selected after a screening process to ensure robust and good quality data, using comparable methodologies were included.

The screening process reduced the range of data immensely. The removal of the 0-10th percentile and 90-10th percentiles reduced the range further. The 10-90th percentile results were therefore used as the evidence base to form embodied carbon benchmarks, which are used in the first version of the benchmarking tool. Embodied carbon is best considered as an iterative field and therefore these benchmarks could be developed over time and with a larger evidence base.