

Carbon Heroes Benchmark Program – whole building embodied carbon profiling

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Abstract. Reducing the embodied carbon of the building stock requires a better understanding of the life cycle impacts of the materials used in those buildings. However, the characteristics of the building stock vary significantly by geography and building type. The “Carbon heroes benchmark program” is a cooperative initiative for carbon profiling by building type across different countries. The program's aim is to create uniform, full life-cycle of materials benchmarks for common building types. The benchmark program is on track to achieve 1000 fully completed and verified buildings by end of 2019, and contains data breakdowns for over 100 different material types and essential structural parts of a building. All data used in the program is rigorously anonymized and statistically small sets of data are also not used to protect data anonymity. The program implements the EN 15978/ISO 21930 standards as the basis of measurement, and includes life-cycle stages A1-A3, A4, B4-B5, and C1-C4. This presentation will share the preliminary findings of this project. 659 verified buildings (February 2019 cut-off), with substantial datasets for many European countries for some of the most common building types. The benchmark is generated using One Click LCA.

1. Introduction

Embodied carbon in the built environment is not well understood, and designers and project teams lack reference points to analyze their project performance. When a subject is at the same time new, and it does not have a clearly established reference point, it's easy to get lost and the issue of embodied carbon remains unaddressed.

Among the findings of the Embodied Carbon Review [1], five (5) methodologies were identified that help deal with embodied carbon in the building sector. These methodologies are carbon reporting, carbon comparison (in design), carbon rating, carbon caps, and decarbonization. With the exception of the first method, all share the need to develop a benchmark or baseline to measure or compare against to drive carbon reductions. Thus, carbon benchmarks can become instrumental for policy-making as they serve to set actionable targets.

The present study shares the preliminary results of the Carbon Heroes Benchmark program developed with anonymized building data. The article will describe the design of the data collection procedure, the assumptions in the organization of data, and the challenges found to this date in the program.

2. Developing embodied carbon benchmarks for buildings

The role of embodied carbon benchmarks for buildings is recognized as an important instrument for policy makers to help reduce the impacts of the building stock. However, a single benchmark cannot be applied across the all buildings as the normalization of embodied carbon per unit area ignores the impact

of building type on its carbon footprint [2]. Moreover, previous attempts at establishing carbon benchmarks, several challenges have been identified in their creation. Some of these challenges include the use of different life cycle inventory (LCI) databases, variability in the reported LCA methodologies used and variability in the material scopes of existing studies, inconsistent meta data to properly classify the data, and the reduced sample size to make significant statements [3,4]. Another study for multi-unit residential buildings done in Canada also highlighted the limitations of sample size and the impact of regionalization in the development of the benchmarks [5].

In order to address these issues, the Carbon Heroes Benchmark program is capable of leveraging the use of a single LCA software platform, One Click LCA, to guarantee consistency in the input of data and the calculation of its impacts.

2.1. Pre-requisites for the quality of embodied carbon benchmarks for buildings

As previous experiences have shown, ensuring consistency of embodied carbon benchmarks is all but easy. Carbon Heroes Benchmark Program is designed to ensure high quality control and robustness of the results. These include:

2.1.1. Consistent building information meta data. Each project includes information on building type (refer to Table 1), LCA scope reported according to EN-15978 standard, and gross internal floor area.

2.1.2. Relevant material classification. The materials included are classified by types and sub-types. For example, metals as a type is sub-divided into reinforcement steel, structural steel, aluminium, copper, etc.

2.1.3. Automated material feedback. An internal algorithm checks the quantities of materials per building element and the ratio between material sub-types to guarantee that the quantities reported are plausible and/or fall within expected ranges. This information is provided to the users so they may review the data introduced and make necessary corrections. For example, ratio of concrete mix to steel reinforcement.

2.1.4. Anonymized data. All identifiable information is removed before generating the dataset for statistical analysis. This is to ensure privacy and avoid bias in the analysis. Only the country location of the building is reported for the development of national and regional benchmarks.

2.1.5. Expert verification and removal of incomplete datapoints. An LCA expert reviews the scope of materials and results. Some potential sources of errors include incomplete scope for calculation, unusual quantities by building area, or suspected values. If errors or incomplete data cannot be resolved, the building is withdrawn from the sample.

2.2. Scope of benchmark program

The aim of this program is to create uniform, life-cycle embodied carbon benchmarks for common building types. The benchmark program is on track to achieve 1000 anonymized, verified buildings by end of 2019, and contains data breakdowns for over 100 different material subtypes and essential structural parts of a building. The benchmarks are generated and updated approximately every six months.

This program is operated in cooperation with Green Building Council Ireland, Green Building Council Italia, Green Building Council Hungary, Dutch Green Building Council, Romanian Green Building Council and Norwegian government real estate organization Statsbygg. Also, Chile Green Building Council has joined the program, but no verified datapoints from Chile are available. The synthesized results of the program are made available to the participating partners and software users.

The benchmark is developed by building type through a standardized life cycle model. Results are regionalized and communicated in a clear way to the non-expert public.

2.2.1. *Building typologies.* Currently, the program is collecting data for 18 building types. These typologies are listed in Table 1.

Table 1. Building typologies in Carbon Heroes Benchmark program

Building group	Building Type
Residential	Apartment buildings
	Attached or row houses
	One-dwelling buildings
	Social welfare buildings
Educational / Institutional	Cultural buildings
	Day care centres for children
	Educational buildings
	Historic or protected monuments
	Hospitals and healthcare centers
	Schools (primary education)
	Sports halls
Commercial	Hotels and similar buildings
	Industrial production buildings
	Office buildings
	Retail and wholesale buildings
	Transport buildings
	Warehouses
	Other buildings

2.2.2. *Standardised life cycle model.* The scope of the analysis follows the EN-15978 / ISO-21930 standard as the basis of measurement. The system boundary and essential methodology of the benchmark calculations is standardized. All calculations included in the program are uniform and cover life-cycle stages A1-A3, A4, B4-B5, and C1-C4; it excludes the module D. In other words, this covers the impacts from material production, the replacement and/or refurbishment due to the end of the material service life, and the end of life stage. Figure 1 includes the information modules described in the EN-15978 standard.

Participants in the program pursue specific requirements in green building certifications such as BREEAM [6] and LEED [7], that require a whole building life cycle assessment to measure the environmental impacts of the materials used to build and operate the building. As a requirement of these certifications, the period of study is 60 years. Also, the certifications require the report of embodied carbon as Global Warming Potential (GWP) 100 years in Kg CO₂-eq. Other environmental categories differ between the certifications. As a consequence, this benchmark was developed with GWP as a common denominator and easy to understand indicator associated with climate change.

Moreover, the benefits of biogenic carbon are not included in the benchmark. This is a result of the uncertainty associated with the disposal method or end of life scenario. For example, the incineration of vegetated products releases the stored carbon back to the atmosphere and results in a zero sum for the purposes of the analysis. Consequently, the assumed carbon storage benefits reported in module A1 are added back in module C. Nevertheless, biogenic carbon is calculated and reported as a separate indicator in One Click LCA.

Product Stage			Construction Process Stage		Use Stage							End-of-Life Stage				Benefits and loads beyond the system boundary		
Raw material supply	Transport	Manufacturing	Transport to building site	Installation into building	Use/application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction/demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D

Figure 1. Life cycle stages according to EN-15978

2.2.3. *Regionalized samples.* The sample is classified by countries at the moment with the aim at grouping buildings with similar construction techniques. Table 2 shows the breakdown of countries for the sample of European projects. Additional data is available for North America, Middle East, and Asia.

Table 2. Countries by region, Europe

Region	Countries
Northern Europe	Denmark, Finland, Iceland, Norway, Sweden
Eastern Europe	Croatia, Czech Rep., Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Serbia, Slovak Rep., Slovenia, Ukraine
Southern Europe	Italy, Portugal, Spain
Western Europe	Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland
British Isles	Ireland, United Kingdom

2.2.4. *Facilitate the consistent input of building data.* The collection of building information for the development of these benchmarks are the result of material quantity inputs made by users of One Click LCA. To assist the users in the correct input of information, the software includes two tools: Model Checker and LCA Checker. The Model Checker reviews the quality of the geometric information found in the Building Information Models (BIM) during the import process into One Click LCA. And, LCA Checker reviews that the material quantities are plausible using a set of proprietary algorithms and automated verifications.

2.2.5. *Sample size.* Currently, there are 659 buildings included in the program. The aim of the Carbon Heroes Benchmark Program is to reach 1000 buildings by the end of 2019, at which point the analysis is repeated. The results included in section 3 show the preliminary findings of this study for a limited number of building types: multi-family apartment, office, and warehouse/industrial. Also, this analysis will include only buildings in Eastern Europe Another review/update is expected at the end of 2019 and it will determine which building types will be reported based on their statistical significance.

2.3. Communicating results

Results are reported in two graphical forms that are easy to read. First, in a Boxplot with whiskers showing the median and range, including outliers. And, second as a performance metric as shown in Figure 2. The performance metric includes the range of results at two standard deviations of the mean for the building type. The range is divided into 7 (seven) bands equally distributed. The mean of the

results falls within band “D” and the lower and upper extremes of the range are in bands “A” and “G” respectively.

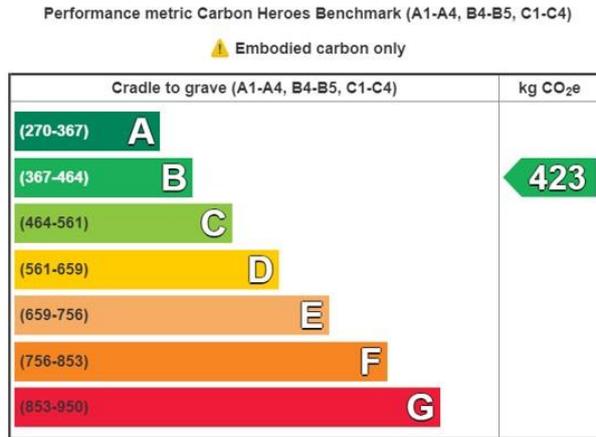


Figure 2. Performance metric Carbon Heroes Benchmark, example

3. Results & Discussion

For this article, three building types for Eastern Europe are presented here as an example of our data analysis process. In Table A1, the descriptive statistics for the sample of office buildings is included. The high values of Kurtosis and Skewness show the possibility that this dataset is not normally distributed. The histogram for the same dataset presented in Figure 3, seems to corroborate this assumption. The data shows positive skewness and a long tail to the left.

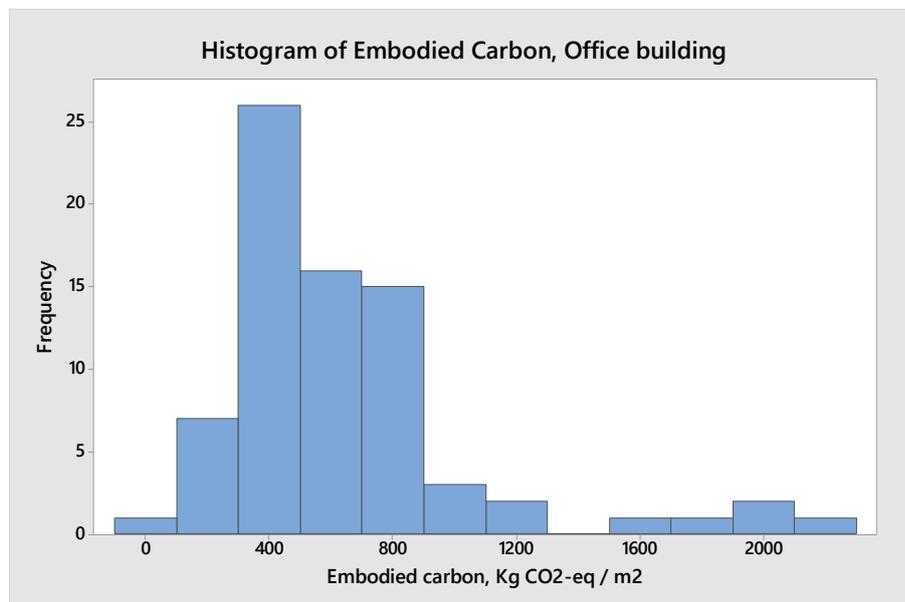


Figure 3. Histogram of office building, Eastern Europe

As a consequence, a 1-sample sign non-parametric test was applied to check if the median is a better test of central tendency for this dataset. The results of the test are included in Table 4, with similar test results for two other building types: “apartment buildings” and “warehouse/industrial facilities”.

Overall, the median shows to be on target in its central tendency, and the resulting range (lower and upper values) captures with 95% confidence the values of the dataset.

Table 4. Median embodied carbon results per building type

Building type	Median embodied carbon, Kg-CO2-eq/m2	Confidence Interval, 95%
Apartment buildings	444	285, 886
Office	531	410, 591
Industrial & warehouses	609	357, 1115

Alternatively, additional building information can shed insights into the skewness of the distribution. This will be tested as the sample grows. Meanwhile, using the histogram of the office building subset, the outliers to the left were extracted from the sample, and a set of descriptive statistics were calculated. With a reduced sample (n=70), the mean and median were closer to each other, and the results are more normally distributed ($M=538$; $SD=238$) and range (63,1013) $p=0.05$. Figure 4 shows boxplot of the sample. Table A2 shows the descriptive statistics of this sub-sample.

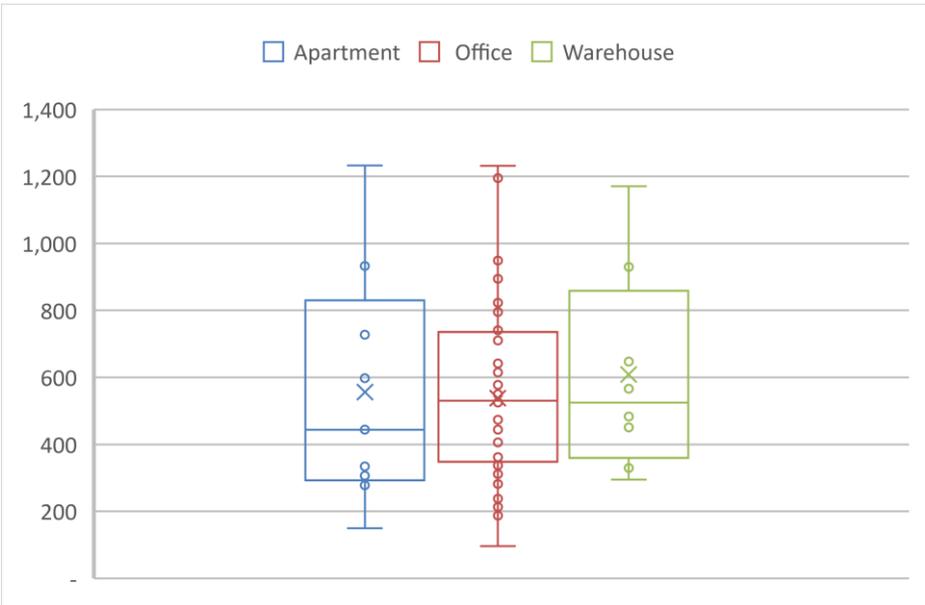


Figure 4. Boxplot of mean/median embodied carbon, Eastern Europe

In addition, global warming potential (GWP) is reported by information module as a percentage of overall embodied carbon (Kg CO₂-e) in Figure 5. It is not surprising that the largest share of GWP takes place during the construction phase. However, a study we conducted about modelling the impact of retrofit on accumulated impacts has shown that the impacts of module B4-B5 might be underrepresented [8]. At the moment, the results in B4-B5 represent changes in materials due to the technical service life of materials and do not consider changes in building renovations or retrofit scenarios. This can lead to a review of the scope of the analysis for module B.

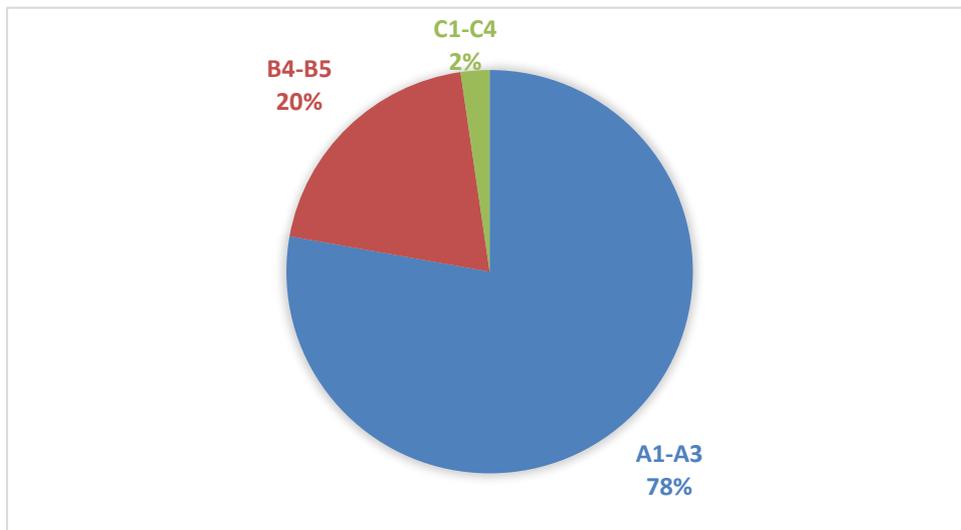


Figure 5. Distribution of %GWP, office buildings, Eastern Europe

Closing remarks

Finally, it is expected that as the sample grows the dataset will tend towards a normal distribution. This will facilitate its use in the performance metric shown in Figure 2. However, it is also possible that underlying effects are responsible for the spread in the dataset. This will be subject of future analysis and could lead to explain what other factors are correlated with the embodied carbon in buildings, and help improve its representation in the Carbon Heroes Benchmark.

References

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Appendix

Mean	630
Standard Error	48
Median	550
Mode	#N/A
Standard Deviation	417
Sample Variance	173,702
Kurtosis	4
Skewness	2
Range	2,010
Minimum	97
Maximum	2,107
Sum	47,214
Count	75
Confidence Level (95.0%)	96

Mean	538
Standard Error	28
Median	531
Mode	#N/A
Standard Deviation	237
Sample Variance	56,402
Kurtosis	0
Skewness	1
Range	1,136
Minimum	97
Maximum	1,232
Sum	37,641
Count	70
Confidence Level (95.0%)	57
