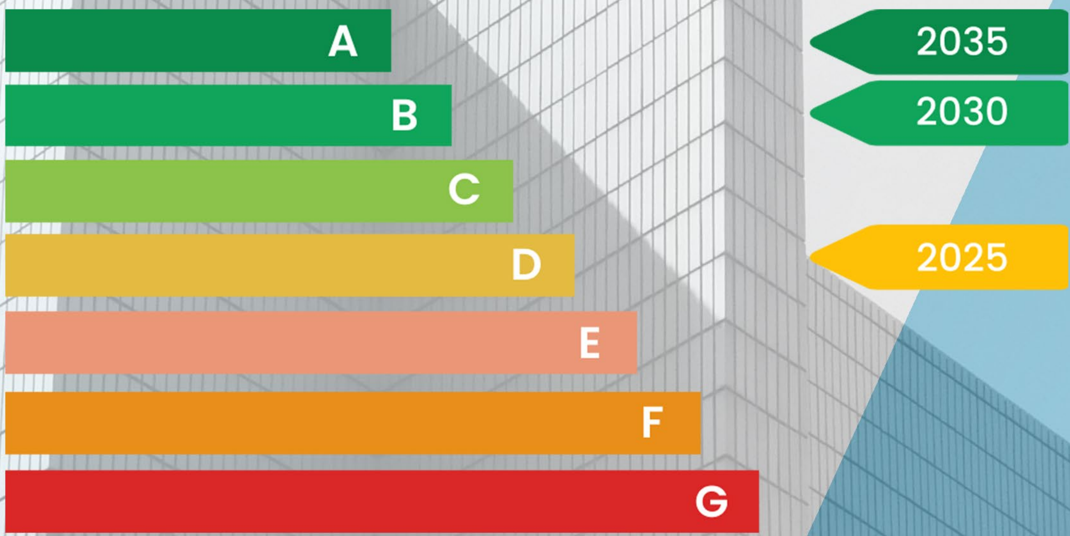
RESEARCH

EMBODIED CARBON BENCHMARKS FOR EUROPEAN BUILDINGS

According to EN 15978:2011 and LEVEL(S) framework



EXECUTIVE SUMMARY

This report provides embodied carbon benchmark data for European buildings. The results are provided for Northern Europe, Western Europe and Eastern Europe, and for five main building types: commercial, educational, industrial, office and residential multifamily.

The purpose of this report is to make high quality, European embodied carbon benchmark data supporting policy creation, publicly and freely available to various regulators and private organisations seeking to establish corporate policies that require pan-European information.

The research is based on a consistent dataset calculated in line with EN 15978:2011 and Level(s) methodologies for life-cycle phases A1-A4, B4-B5 and C1-C4. The dataset used for this research has been carefully screened, and the retained sample which is used in creating these results consists of 3737 actual European buildings for the five building types considered. The retained sample is obtained by screening a total dataset of over 15 000 building LCA projects to retain only projects with consistent minimum scope and plausibility.

The sample is largest for residential buildings and offices, and Northern Europe is the largest single region by number of retained buildings, followed by Western Europe. The prevalence of Northern Europe is partly explained by high demand for low-carbon buildings, and furthermore by a broader rate of use of whole-building assessment scopes in Northern Europe, leading to a higher share of all buildings being retained for the purposes of the study.

All buildings included in the assessment had a complete building in scope for foundations, substructure, superstructure and enclosure. However, only around 40 % of all included buildings had assessed impacts for building services and finishes, and only one quarter of buildings included assessments for external areas. Variance in the scope influences the results and rebasing the sample with a fixed total scope would lead to changes in results.

Based on this sample, which is based on voluntary assessments, the Eastern European buildings have on average the highest embodied carbon per square meter of 580-700 kg CO_2e, followed by Western European buildings where average embodied carbon ranges from 510 to 600 kg CO_2e/m^2, and finally Northern European buildings where average embodied carbon ranges from 310 to 350 kg CO_2e/m^2, depending on the building type.

The differences in average results are partly explained by construction practises and focus of the buildings used in the sample to choose low-embodied carbon products, and partly due to differences in the typical building characteristics in the regions. Northern European region buildings have a significant share of timber construction, and contain many small buildings, whereas most Eastern European region buildings in the sample are large, complex projects.

The report also provides data about the building size and building stock distribution using a mid-sized European city as an example, and discusses cost and value of LCA regulations.

The results and data contained in this report are provided on an as-is basis to support advancement of embodied carbon regulations and policies across Europe. Regulators wishing to discuss the report to advance decarbonisation in their jurisdiction are invited to contact the authors. This report is authored by One Click LCA Ltd (formerly Bionova Ltd).

CONTENTS

1. INTRODUCTION

1.1. PURPOSE OF THIS REPORT

The purpose of this report is to make high quality, European embodied carbon benchmark data supporting policy creation, publicly and freely available to various regulators and private organisations seeking to establish corporate policies that require pan-European information.

This report, and the analysis it contains, are the copyright and sole property of One Click LCA Ltd (formerly Bionova Ltd). The report has not been commissioned nor funded by third parties. While the results have been reviewed carefully, One Click LCA Ltd takes no liability on their fitness for any specific purpose the reader may have.

1.2. OTHER SOURCES OF EUROPEAN EMBODIED CARBON BENCHMARKS

Other European embodied carbon benchmarks are also available; however, these tend to follow the national standard and methodology and are thus not suitable for Europe-wide use.

Such benchmarks include the following:

- RIBA (UK), providing an embodied carbon target for all building types using RICS Whole Life Carbon methodology for the entire life cycle (A-C). The target, annualized for 60 years, in 2020 is < 13,3 kg $CO_2e/m^2/a$ and 2025 target is <10,8 kg $CO_2e/m^2/a$.
- Upcoming regulatory limits for Finland, preliminary values at 10-14 kg CO_2e per m^2 per year from 2025 depending on the building type (whole life-cycle scope, including energy, over 50 years).
- Upcoming regulatory limits for Denmark, initially 12 kg CO_2e/m^2/year from 2023 and decreasing every two years (whole life-cycle scope, including energy, over 50 years).
- Upcoming regulatory limits for France, between 12,8 and 14,8 kg CO_2e/m^2/year and decreasing every three years (whole life-cycle scope, incl. energy, over 50 years).
- LETI (UK) has proposed limits for upfront carbon (A1-A5), starting at 500-600 kg CO_2e/m^2 (not annualized) in 2020 and decreasing to 300-350 kg CO_2e/m^2 by 2030.
- Other limit values including those in Netherlands (MPG), Austria (OI3) and Switzerland (SIA). These are however set using a different LCA indicator.

Of the aforementioned, the Carbon Footprint Limits for Common Building Types for Finnish government has been authored by One Click LCA Ltd.

1.3. UPDATES TO THIS REPORT

Depending on the level of interest and need for the results of this report, One Click LCA Ltd will consider updating and expanding report to cover approximately ten thousand buildings with more detailed breakdowns, potentially with country-specific analyses or other customized analysis. Interested parties are invited to reach out to the authors. To access updates, visit this page www.oneclicklca.com/eu-embodied-carbon-benchmarks/.

1.4. QUERIES REGARDING THIS REPORT

Regulators or other organisations wishing to make use of the report for development of policy and regulations and wishing to discuss the report in further detail are welcomed to reach out to the authors via www.oneclicklca.com.

2. SOURCE DATA FOR THE BENCHMARKS

2.1. SOURCE OF THE UNDERLYING DATA USED FOR THE REPORT

The source data used for this analysis is sourced from the Carbon Heroes Benchmark Program. The Carbon Heroes Benchmark Program is a consistent benchmarking methodology applied to building whole-life carbon and building life-cycle assessments calculated on the One Click LCA platform.

In essence, the benchmark program performs a set of anonymized shadow calculations using a consistent methodology for every actual building project calculated on the One Click LCA platform. It furthermore calculates a range of plausibility and completeness metrics to evaluate quality of results. The shadow calculation aligns with Level(s) and EN 15978:2011.

2.2. PRIMARY DATA SAMPLE AND CLEANING THE SAMPLE

The primary dataset consists of over 15 000 commercial building LCA calculations. This excludes all calculations performed by educational and trial users and calculations for other types of assets (such as infrastructure or construction products).

The Carbon Heroes Benchmark Program contains a subset of manually verified building LCA data. As not all data could be manually verified, a set of mechanically verified building LCA datasets is also used. The dataset has been cleaned to only contain data from Europe, and to only contain data of sufficient quality for the purposes of this benchmark as explained below.

2.3. QUALITY REVIEW FOR THE DATA

For every project, unless a calculation could be identified as the final result, the highest impact calculation has been retained for the purpose of this analysis. As the projects using One Click LCA for carbon or LCA assessment are greener than typical projects, the highest impact calculation in most cases would be the counterfactual baseline – that is, a normal project where no specific green measures are applied.

The following criteria were applied to exclude potentially poor-quality data from the dataset:

- Calculations for refurbishments or partial buildings only (only whole buildings retained)
- Any calculations without data for all of the following elements were excluded: substructure, superstructure and enclosure of building.
- Any calculations that did not contain plausible data for substructure and superstructure were excluded. A plausibility threshold was established by minimum mass and GWP of materials for substructure and superstructure.
- Implausibly high or low results were excluded automatically, based on global warming potential results for the entire project.
- Projects with too few individual materials (with a threshold set at 10 different materials) to represent an entire building at least for structure and enclosure scope were excluded.
- Any datasets that could be reasonably considered as not representing actual projects (e.g., test or training projects)
- Calculations that cannot be denominated for an internal floor area

2.4. REGIONS PROVIDED IN THE DATASET

Only calculations from the countries listed below were retained for analysis. The data was grouped into the following three regions. The rationale for regional grouping follows high level construction practises and allows some of the variance within Europe to be demonstrated.

Eastern Europe	Northern Europe	Western Europe
Croatia Cyprus Czech Republic Estonia Greece Hungary Latvia Lithuania Poland Romania Slovak Republic Slovenia	Denmark Finland Norway Sweden	Austria Belgium France Germany Ireland Italy Luxembourg Netherlands Portugal Spain United Kingdom

2.5. GROUPING OF BUILDING TYPES IN THE DATASET

The buildings were grouped into the following five types:

Building type	Specific types
Commercial	Hospitals and healthcare centres Hotels and similar buildings Retail buildings
Educational	Day care centres for children Educational buildings Schools (primary education)
Industrial	Industrial production buildings Transport buildings Warehouses
Office	Office buildings
Residential	Apartment buildings Attached or row houses

The benchmark excludes all buildings from following types, in total around 786 buildings: cultural buildings, data centres, leisure buildings, historic or protected monuments, other buildings, prisons, one-dwelling buildings, social welfare buildings, and sports halls.

The exclusion of single-family homes, the largest excluded group in the sample, was assumed to not be an initial focus of potential policy or regulatory efforts.

2.6. BIASES IN THE UNDERLYING SAMPLE

The underlying sample has the following biases compared to the entire building stock in Europe:

- It is based on self-selection by building projects pursuing environmental objectives. This characteristic is counterbalanced by methodology of choice of using the highest calculation in each project as outlined previously.
- It is based on customer selected data, some of which are generic and others based on manufacturer-specific datasets from Environmental Product Declarations.
- It is based on a self-selected geographical sampling. It overrepresents countries where sustainable building is highly represented.
- It contains a significant proportion of large construction projects (commercial projects). The average area of retained projects in the sample is 11 600 m2.
- It is much more heavily geared towards commercial construction than residential.

The biases are a natural consequence of whole-life carbon and building life-cycle assessment being voluntary activities.

In the view of the authors, the above biases do not limit the value of the results, as the sample is significant enough to provide a good level of representation.

3. SCOPE OF THE ANALYSIS IN THE REPORT

3.1. ALL RESULTS USE A CONSISTENT ASSESSMENT METHOD

All assessments in the sample use a consistent, EN 15978-compliant method and a consistent set of standard parameters. These are ensured by running a shadow calculation.

Results are fully consistent also in terms of biogenic carbon storage accounting, which has no impact on the results over a life-time including also deconstruction and disposal of buildings.

3.2. FUNCTIONAL UNIT

Every assessment included in the sample is denominated for internal floor area, where the standard definition is based on IPMS/RICS. The exact internal floor area measure however varies between the countries of assessment.

3.3. ASSESSMENT PERIOD AND MATERIAL SERVICE LIFE

The fixed assessment period is 60 years. Material service lives follow One Click LCA standard scenarios, where the end user has not adapted them to their case.

3.4. SYSTEM BOUNDARY

The standard scope considered in the assessment is shown in the below visual.

Product stage			Assembly stage		Use stage							End of life stage				Beyond the system boundaries		
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D	D	D
X	x	x	x	MND	MND			x	x	MND	MND	x	x	x	x	MND		
Raw materials	Transport	Manufacturing	Transport	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction /demolition	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling

Modules not declared = MND.

3.5. ASSESSMENT BACKGROUND DATA FOR LCAS

All assessments are performed using the One Click LCA database, which comprises a range of European and global datasets. All of the underlying data complies with EN 15804.

The vast majority of the underlying LCA data does not apply any “top-up factors” or “conservative values” such as used in government generic databases e.g., Swedish Boverket data, but is used as is. Such figures are however not cleaned out from the results for these purposes, and it is certain that some of the calculations use topped up values.

Details of the data quality can be read in this article www.oneclicklca.com/how-we-work-with-data-at-one-click-lca/.

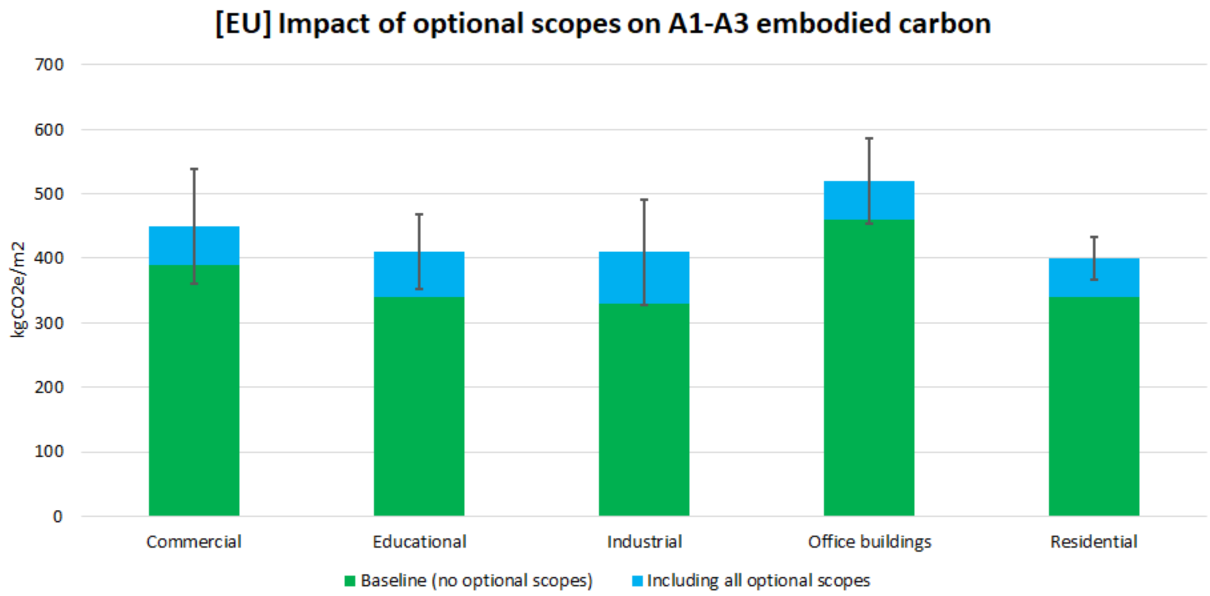
3.6. SCOPE OF BUILDINGS COVERED IN THE RETAINED SAMPLE

Within the buildings in the retained sample, all buildings report foundations, structures and enclosure. However, there are variances in scope for reporting building services, finishes and external areas. These scopes are not yet covered in reporting requirements by all common LCA requirements or regulations, and hence are omitted at times. Building services are considered complex and time consuming to report. Hence, in many regulatory contexts, such as the French and Finnish systems that require building services to be reported, these reporting scopes can be covered by opting for default values for services.

The completeness of reporting for these scopes by building types is summarized below.

Building element	Foundation / substructure	Super-structure	Enclosure	Interior finishes	Building services	External areas
Commercial	100 %	100 %	100 %	33 %	30 %	35 %
Educational	100 %	100 %	100 %	35 %	35 %	23 %
Industrial	100 %	100 %	100 %	27 %	32 %	44 %
Office	100 %	100 %	100 %	55 %	30 %	21 %
Residential	100 %	100 %	100 %	42 %	57 %	19 %
Total	**100 %**	**100 %**	**100 %**	**42 %**	**40 %**	**25 %**

The impact of including all these scopes in the dataset is visualized below. The comparison is made by calculating the average embodied carbon of A1-A3 life-cycle phases for all assessments excluding all optional scopes, and the same for buildings including all optional scopes. The impact of omitting or including the above scopes in all assessments is visualized below.



The reader is reminded that the life-cycle impact of finishes and building services in a regulatory context fundamentally depends on the retained regulatory scenarios and service lives to be applied to such building elements: replacement frequency and the inclusion of top-up factors can make a significant difference.

3.7. SIZE OF THE FINAL SAMPLE BY REGION

The remaining buildings were grouped into the following five types:

Building type	Eastern Europe	Northern Europe	Western Europe	Total
Commercial	28	130	275	**433**
Educational	10	445	150	**605**
Industrial	35	91	290	**416**
Office	157	340	554	**1051**
Residential	85	794	353	**1232**
Total	**315**	**1800**	**1622**	**3737**

3.8. KEY DIFFERENCES BETWEEN DIFFERENT EUROPEAN REGIONS

The purpose of this report is not to explain the differences of construction practises; however the following key differences are highlighted as they make it possible to understand essential practises.

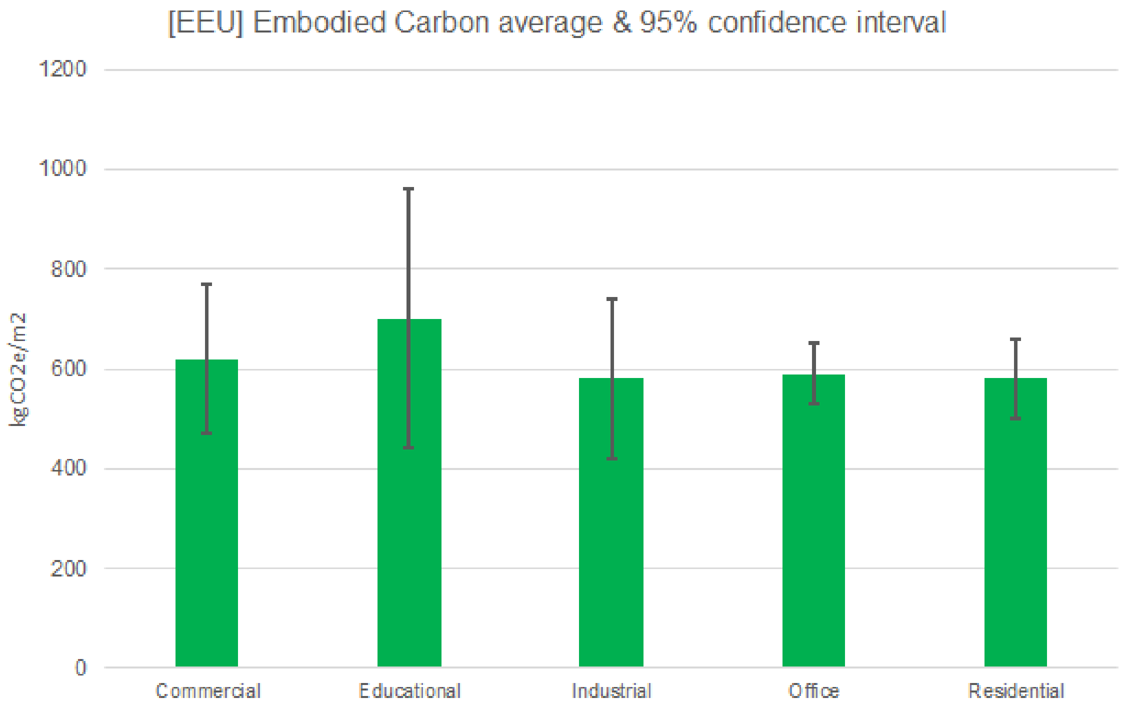
Considering the sample is also based on voluntary assessment, the representativeness of the sample is also elaborated in the table below.

Region	Eastern Europe	Northern Europe	Western Europe
Construction practises	Limited share of timber Carbon intensive materials Limited secondary materials Limited BIM adoption rate	Significant share of timber High adoption of BIM (efficient materials use) Low-carbon concrete Significant use of precast	High adoption of BIM (efficient materials use) Choice of materials based on embodied carbon applied
Sample representativeness	Sample represents predominantly large buildings pursuing commercial certifications.	Sample represents all types and sizes of buildings, including residential and public sector buildings. Lots of small buildings included.	Sample represents all types and sizes of buildings, including residential and public sector buildings.

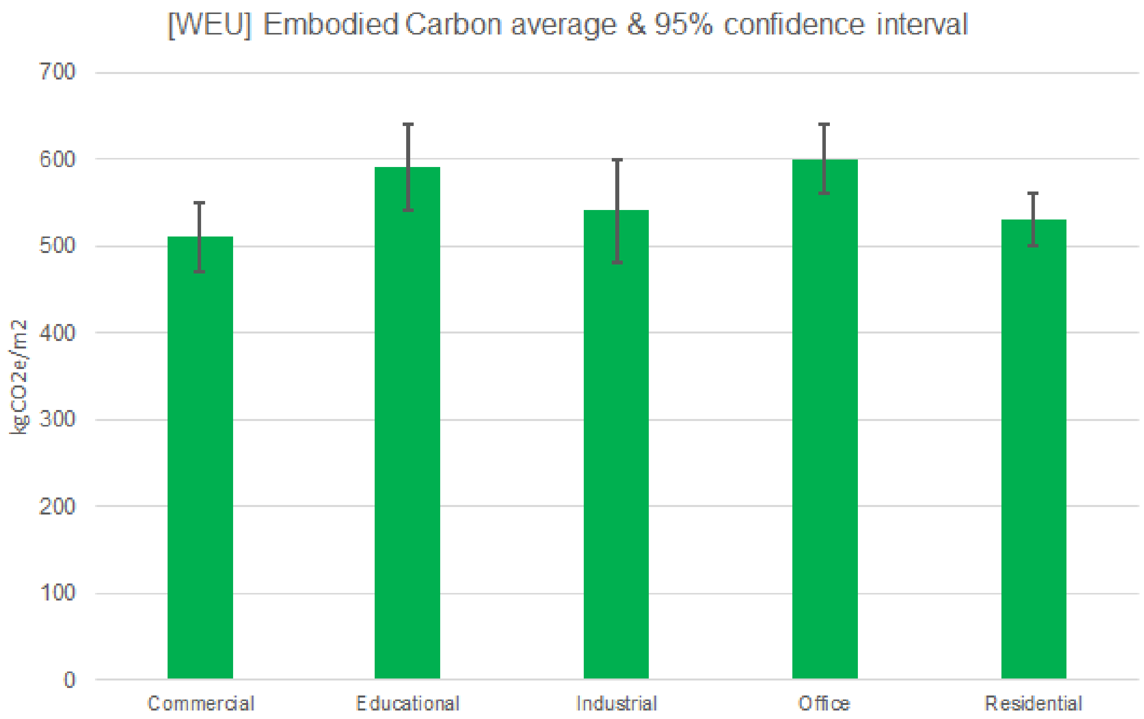
An additional difference between Northern Europe and Western Europe relates to the use of LCA data. In many Western European markets, government-issued generic LCA data is used with topped up emission factors. This practise has not been applied in the Northern European markets for the data in this sample, as relevant government-issued generic databases were only introduced by Swedish and Finnish governments in March 2021.

3.9. EMBODIED CARBON – AVERAGES AND 95 % CONFIDENCE INTERVAL

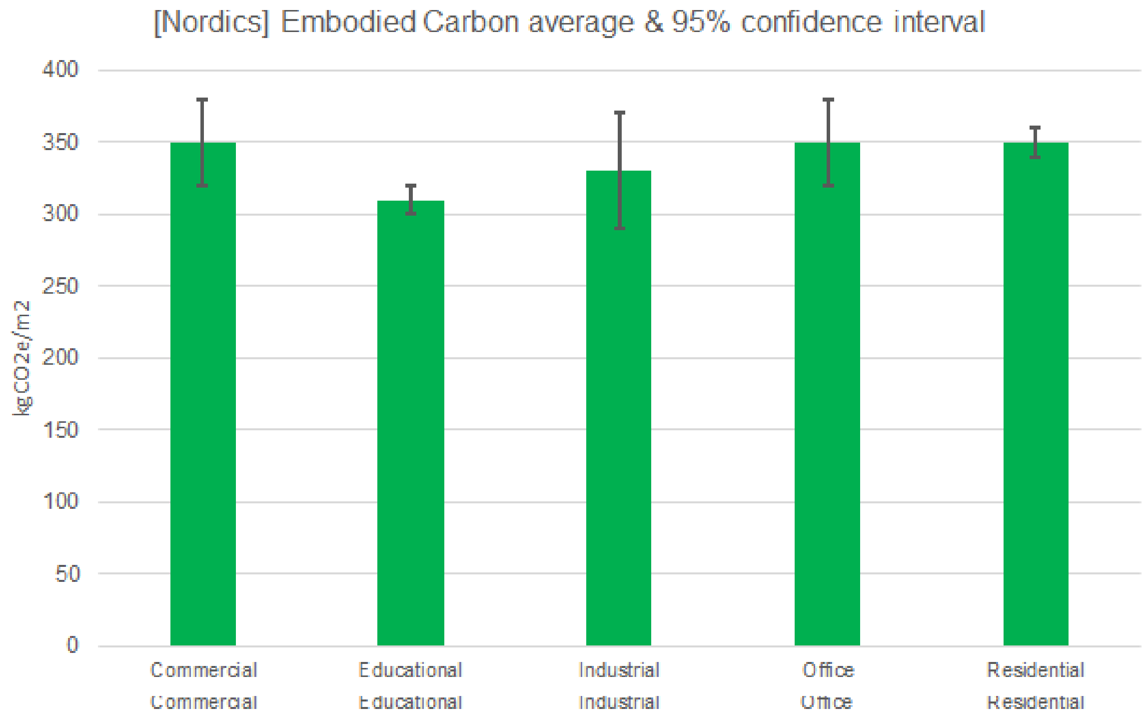
Eastern Europe



Western Europe

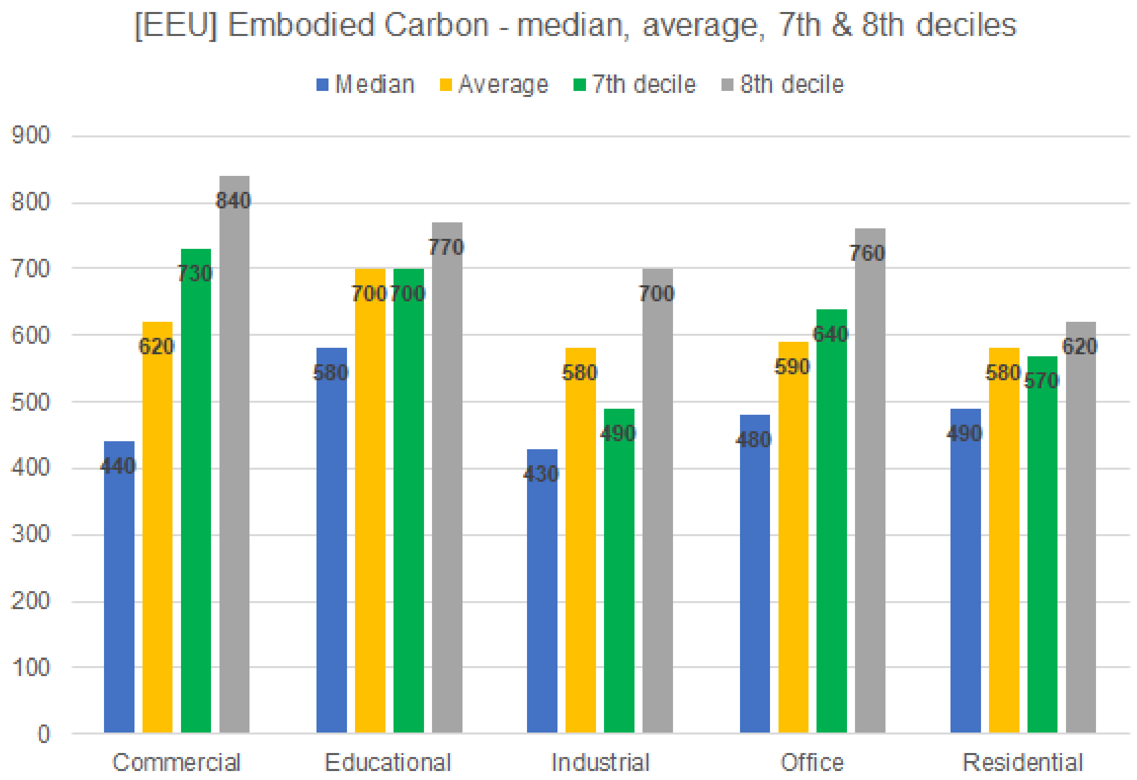


Northern Europe

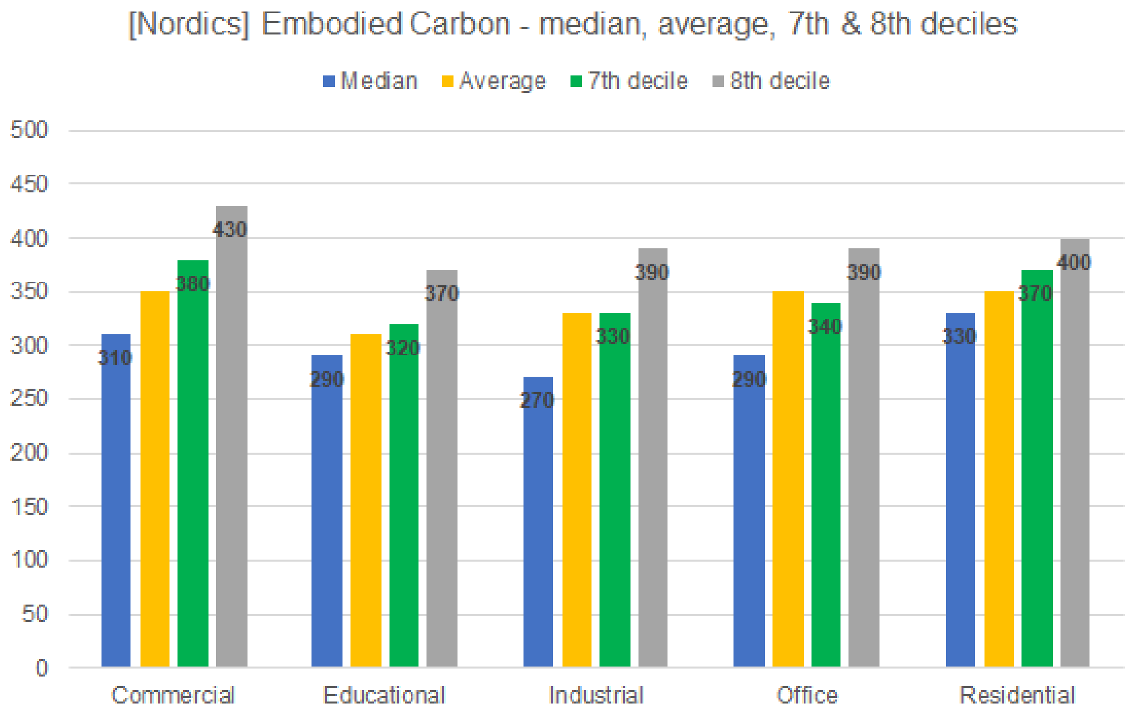


3.10. EMBODIED CARBON – MEDIAN, AVERAGE, 7TH AND 8TH DECILES

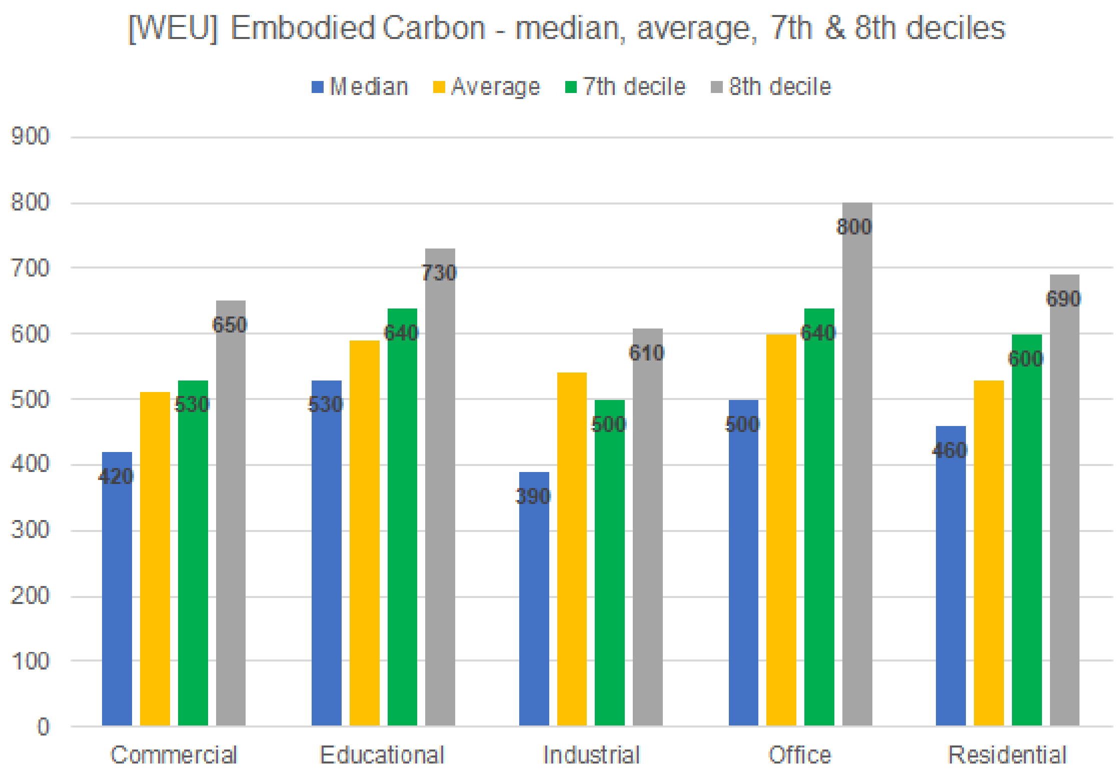
Eastern Europe



Northern Europe

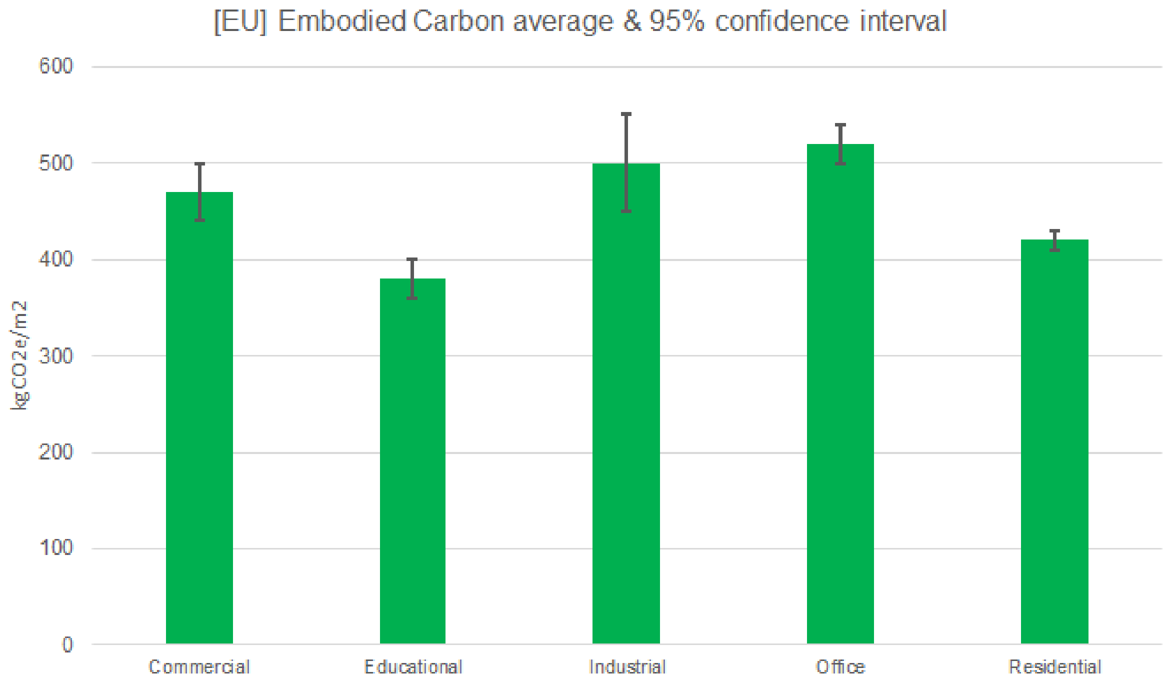


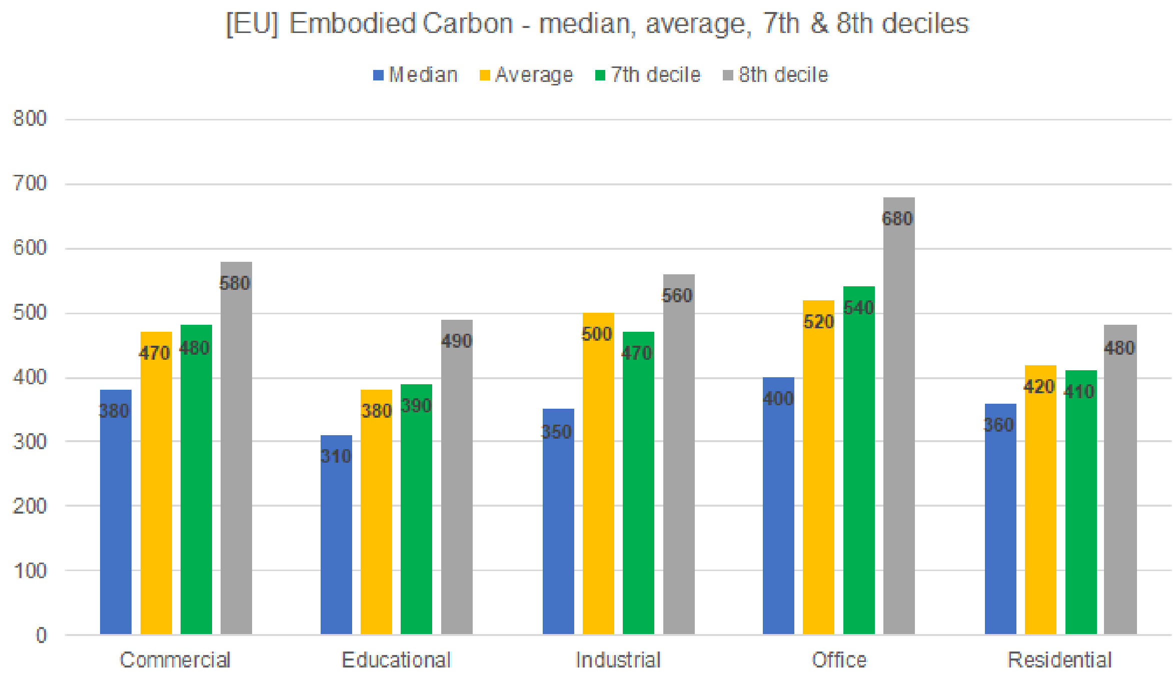
Western Europe



3.11. ENTIRE EUROPE LEVEL VISUAL ANALYSIS

The same statistical results scaled to the whole Europe level are heavily influenced by the lower than usual figures from Northern Europe, which represents nearly half of the sample. Therefore, for initiatives aimed at pan-European coverage, these figures should be considered with caution.





4. BUILDING SIZES AND BUILDING STOCK

4.1. MINIMUM BUILDING SIZE LIMITS APPLIED ON LCA REGULATIONS

Some jurisdictions have opted to introduce a minimum building size limit for buildings to be subjected to LCA regulations.

The current regulatory area-based waivers in Europe are as follows:

- Denmark: 100 m2 and above required to calculate from 2023, limits for above 1000 m2 buildings until 2025, from which point all buildings would apply limit values
- Finland: no political decision on size limit made, considerations of a 100 m2 limit floated
- France: no minimum building size, only extensions exempt from regulations (<17 m2)
- Netherlands: 100 m2 and above required to calculate from 2018, limits for all sizes
- Sweden: 100 m2 and above required to calculate from 2022, limits from 2027

4.2. BUILDING STOCK TOTAL AREA DISTRIBUTION BASED ON BUILDING SIZE

This analysis was prepared to inform decisions about potential minimum building size considerations in future regulations. For this analysis, the entire building stock of a mid-sized European city was analysed. The city has a population of 200 000.

The building stock for these purposes was cleaned of buildings that typically would not be subject to ordinary building thermal or carbon regulations, such as garages, sheds, greenhouses and other similar buildings. The regulated building stock (excluding single family homes) consists of a total 28 598 buildings, representing 30,2 million m2. Single-family homes comprise a further 48 264 buildings, representing 15,2 million m2.

Other buildings except single family homes above 100 m2

Building size range, m2	100 – 500 m2	501 – 1000	1001 – 2000	2001 – 5000	5001+ m2
Count of buildings	15 518	5 388	3 050	1 950	1 137
Share of buildings	54 %	19 %	11 %	7 %	4 %
Building stock, million m2	4,1 M	3,8 M	4,2 M	2,6 M	15,5 M
Share of building stock	12 %	11 %	12 %	18 %	46 %

Single family homes below and above 100 m2

Building size range, m2	< 100 m2	100+ m2
Count of buildings	2 291	45 973
Share of single-family homes	5 %	95 %
Building stock, million m2	0,14 M	15,1 M
Share of single-family homes m2	1 %	99 %

5. COST AND VALUE LCA REGULATIONS

5.1. COST OF EMBODIED CARBON REGULATIONS FOR PROJECTS

Most regulations come with regulatory burdens and embodied carbon is no exception.

Project embodied carbon assessment cost has decreased by a factor of ten over the last decade in Europe. This has been made possible by the introduction of automation, enhanced tools, more data, and most importantly, by demand for such assessments which allows cost optimisation curve to progress.

For clarity, it is stated that the cost of requiring full building life-cycle assessment with multiple impact categories or focusing on just embodied carbon of materials does not have any significant impact on either the time or the cost of the assessment.

The following types of embodied carbon assessments are used in the market today. The indicative levels of effort shown here are not based on any quantified research but represent the understanding of the authors from supporting a large volume of projects across Europe. The levels of effort vary greatly based on complexity of the building and applied LCA requirements, as well as the volume of LCA adoption. A higher volume of adoption leads to the experience curve bringing down the costs of delivering the service. The figures given here refer to a person with experience, a person who needs to yet learn the process would require significantly more time, and reporting requirements would also add to the time needs.

Assessment type	Assessment description	Indicative level of effort
Accounting only (internally automated)	Typically, heavily automated and fully standardized process with very low manual effort. Data obtained from automated inhouse sources that are used for core processes.	One hour of work
Accounting only (market-based)	Typically, highly (but not fully) automated analysis, often performed by a designer who is delivering other services for the project, such as energy performance calculations or design services. Requires some data collection and reporting.	Circa 1,5 days of work.
Optimization (market-based)	Typically, partially automated analysis, covering the scope of services above, but enhanced with optioneering.	Circa 3 days of work.

The efforts and costs vary significantly based on how frequently results are updated, what data is available for the purpose of the assessment (quality of BIM model, for instance), complexity of the project and, of course, on the experience, training, available tools and labour costs of the relevant organisation.

It is further important to understand that the cost trend for building embodied carbon assessment is on a continued downward trend as toolchains and digitalisation automate the processes further across different user groups and value chains. The authors expect to publish further research on the costs of LCA in the course of 2021.

5.2. EMBODIED CARBON REDUCTION ACHIEVED BY REGULATIONS

Where regulatory embodied carbon thresholds are introduced, embodied carbon reductions are commensurate with the reduction level set by the threshold.

The authors are not aware of statistical evidence demonstrating direct and quantified causal link between embodied carbon reduction and the introduction of only LCA reporting requirements. However, the following mechanisms that allow reductions to be achieved are clearly understood:

- mandatory disclosure allows demand-side organisations to set their own requirements for performance without facing limitations on the project team's ability to calculate or use the metrics
- the same organisation performing LCAs over time leads to lower average emissions per project as they learn how to reduce carbon while saving cost or at cost parity (as evidenced in many countries where the new building stock is gravitating towards an optimal energy performance class)
- previous project-based embodied carbon optimisation shows that achieving single digit carbon reduction saves up to about 5-8 % of costs depending on the project
- previous project-based embodied carbon optimisation shows that in most European countries, projects can reduce carbon by up to 15-20 % through simple optimization requiring only a little effort.

5.3. COST OF BUILDING LCA TOOLS AND ONE CLICK LCA PLANETARY

All successful regulatory building LCA tools used in scale in Europe are paid for, or have a paid version and a limited free version. While other tools exist for specific countries, the authors highlight one – which is developed by their company – which is free to use for all European countries and, critically, has both local generic data for all European countries and local EPD data for most European countries. One Click LCA Planetary is already used in all European countries as of today.

One Click LCA Planetary has the following capabilities:

- It is free to use and accessible by a browser interface.
- It allows users to calculate embodied carbon of a project and compare different options
- It covers the life-cycle phases A1-A3 and is being updated to also cover A4 and A5 to enable accounting for the entire upfront carbon emissions of a construction project.
- It is available in English, Spanish, French, German, Italian, Dutch Swedish, Norwegian and Finnish.
- It includes localized generic LCA data for cement, ready-mix concrete, precast concrete, steel, aluminium, gypsum, bricks, insulation, glass and wood.
- It includes local EPDs for all materials in the above categories in most countries.
- The software includes selected construction assemblies.

It generates an easy-to-read PDF report to make the results easier to read and understand For more information about the One Click LCA Planetary readers are invited to visit www.oneclicklca.com/planetary/.

ANNEX: ABOUT THE AUTHORS

One Click LCA Ltd (formerly Bionova Ltd) is the developer of the world leading building LCA & EPD software, One Click LCA. In addition to its software business, we deliver selective professional services in the field of construction sustainability, with a focus on training, verification, policy and analysis.

Low carbon construction software

Low carbon construction policy

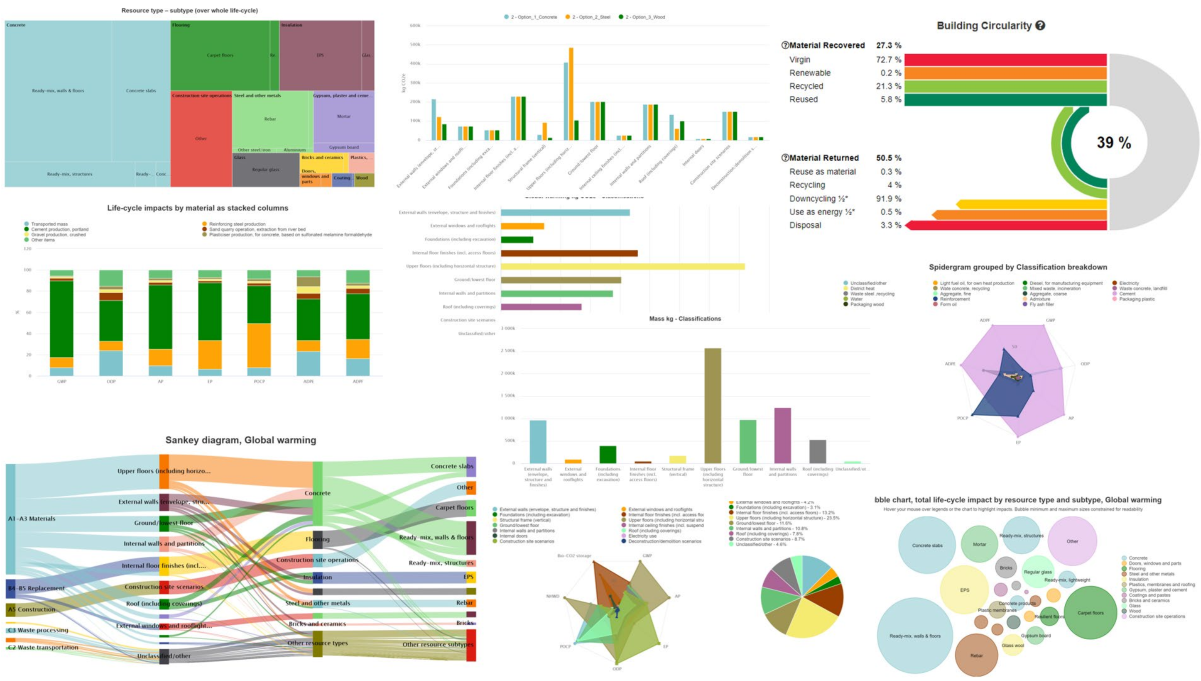
WE ARE ONE CLICK LCA

KEY FIGURES

100+ COUNTRIES
50 INHOUSE STAFF
15 BIM INTEGRATIONS
40+ CERTIFICATIONS
100 000+ DATASETS

Our clients

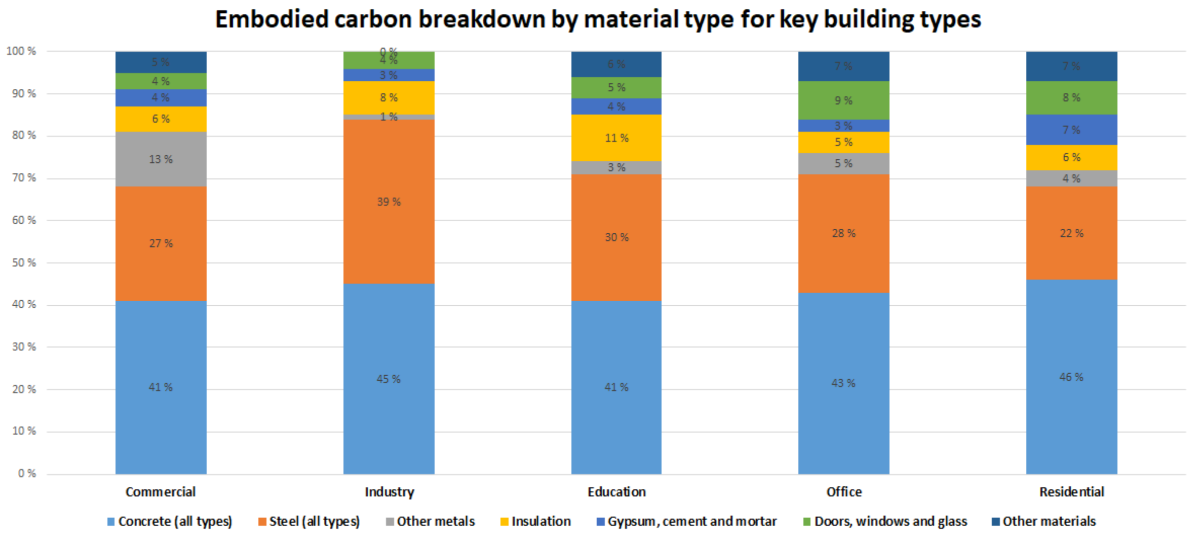
Regulators or other organisations wishing to make use of the report for development of policy and regulations wishing to discuss the report or analysis contained in further detail are welcomed to reach out via www.oneclicklca.com.



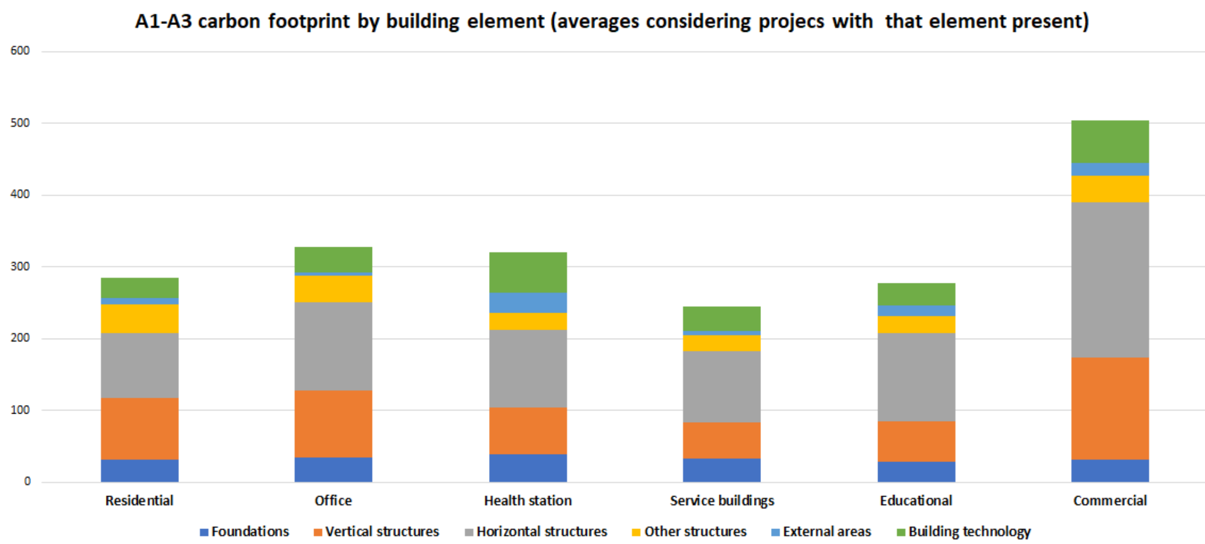
ANNEX: EMBODIED CARBON DISTRIBUTIONS

Embodied carbon distribution by key material category

The four most important construction material categories for embodied carbon are cement, steel, aluminium and plastics. Of the remaining material categories, insulation, doors, windows and glass products, and gypsum, cement and mortar categories also stand out in importance. While wood stands out as a category of materials for wood-framed buildings, it does not stand out at European scale in the benchmarks. Fuels used in earth-moving and other construction equipment and transporting materials also have significant impacts as well as building services.
A sample of one thousand European buildings from the Carbon Heroes Benchmark Program was extracted to demonstrate typical distribution of embodied carbon and is shown below[1].



Embodied carbon distribution by building element
The contribution of different building elements as part of the A1-A3 embodied carbon in a sample of approximately 500 Finnish buildings was analysed and is visualized below [2].



[1] World Business Council for Sustainable Development: Decarbonizing Construction - Guidance for Investors and Developers to Reduce Embodied Carbon (2021, pending publishing)
[2] Ministry of Environment, Finland: Carbon Footprint Limits for Common Building Types (2021)