THE EMBODIED CARBON REVIEW

EMBODIED CARBON REDUCTION IN 100+ REGULATIONS & RATING SYSTEMS GLOBALLY

The Embodied Carbon Review is updated at
www.embodiedcarbonreview.com

#embodiedcarbonreview

References: The Embodied Carbon Review, 2018, One Click LCA Ltd, www.embodiedcarbonreview.com

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IN SUPPORT OF THE EMBODIED CARBON REVIEW

"The recent IPCC report removes all doubt: to achieve the aims of the Paris Agreement, the building and construction sector must decarbonise by 2050. With nations all over the globe tackling operational emissions from buildings, we must now address our total emissions impact. One Click LCA Ltd's report is an incredibly valuable addition to the debate on embodied carbon, and we thank the Finnish Ministry of Environment, the Finnish Transport Agency, Saint-Gobain and Stora Enso for their leadership in helping to share this knowledge with the world. It demonstrates that efforts to address embodied carbon are truly global, and our collective challenge now is to make the good work in this space more visible to political and industry leaders so they are guided in how they can take action. We look forward to working with our global networks to make this happen."

James Drinkwater, Director Europe, World Green Building Council

"The decarbonization of the built environment until 2050 is a must to achieve the 2°C target of the Paris agreement. Both operational and embodied carbon will have to be addressed. This study is a very useful contribution to highlight the current developments on embodied carbon, both in voluntary labeling schemes and public policies and to support the way forward on this matter."

Pascal Eveillard, Deputy Vice President Sustainable Development, Saint-Gobain

"Embodied carbon is becoming the dominant source of carbon impacts from buildings. This study identified 156 systems of certifications and regulations addressing environmental sustainability in the construction sector globally, out of which 105 include direct measures for embodied carbon. The study provides an excellent mapping on the systems available in different geographic regions as well as their assessment methodologies. Bearing in mind #embodiedcarbonreview's definition of embodied carbon, it further demonstrates the importance of acting on the sustainable development goals in a holistic way, notably accelerating the shift towards sustainable consumption and production patterns (SDG 12)."

Pekka Huovila, One Planet Network, Sustainable Buildings and Construction Programme Coordinator

"CEN/TC 350 develops European Standards for performance-based assessment of sustainability of construction works. As this exceptional report demonstrates, the impact category indicator Global Warming Potential, including both operational carbon and embodied carbon over the life-cycle of a building, is clearly one of the most understandable and important metrics of the sustainability in the construction sector."

Ari Ilomäki, Chairman, CEN/TC 350 Sustainability of Construction Works

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WHAT IS EMBODIED CARBON?

In the context of this report, embodied carbon means the total impact of all the greenhouse gases emitted by the construction and materials of our built environment. It includes the impacts of sourcing raw materials, manufacturing, transport, and wastage in the process. Further, during their life cycle, the same products also cause carbon impacts when they are maintained, repaired, or disposed of.

Embodied carbon has no established standardized definition. Depending on the context, it may or may not include life-cycle impacts of materials, and may include or exclude the construction process. It is also referred to as the 'capital carbon' in the UK, as opposed to 'operational carbon'. In Greenhouse Gas Protocol terms, embodied carbon is a supply chain emission for the tenants, investors, developers and builders, or part of so-called Scope 3 emissions.

In this report, we focus on the construction sector, and, therefore, construction products and materials. Construction and related material flows are responsible for 40% of all demand for raw materials, making this focus essential. These material flows are visualized below. **[1]**

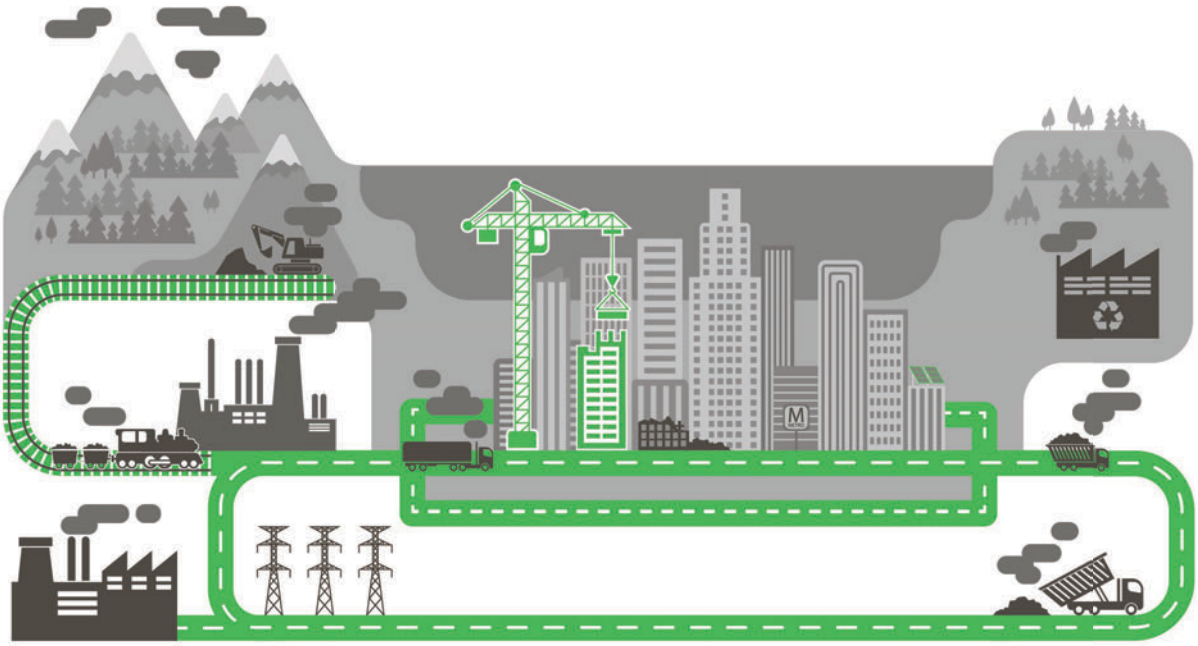

Illustration: *embodied carbon emissions arise from the life-cycle material flows of buildings*

GLOSSARY

The following terms are used in this report:

Carbon-dioxide equivalent (or **CO2e**), which refers to global warming that is caused by all greenhouse gases released by activity. In addition of the carbon dioxide (CO2), it includes the impact of other gases.

Embodied carbon is explained in the preceding chapter.

Environmental Product Declaration (or **EPD**) is a third-party verified report of Life Cycle Assessment (LCA) results, relating here to a construction product or material. It uses ISO standards, and often also EN standards. It documents the actual environmental performance of a product.

Life Cycle Assessment (or **LCA**) is a method of assessing the environmental impacts associated with all the stages of a product's or building's life, from raw material extraction through to its processing, manufacture, distribution, use, repair, maintenance, and disposal or recycling. For buildings, this is also referred to as Whole-Building Life Cycle Assessment.

Life Cycle Costing (or **LCC**) is a method of assessing the life-time costs arising of the development, construction, operation and decommissioning and disposal of a building or a constructed asset, including both capital and operating costs. This is also referred to as Life Cycle Cost Assessment (LCCA). LCC can be used either separately, or in connection with LCA.

System as used in this report is a shorthand that means a regulation, voluntary certification, standard, or guideline applied to construction works that includes at least one aspect of environmental impacts.

FOREWORD

This research aims to help policymakers and other organizations to address embodied carbon. Embodied carbon remains relatively little understood, and best practices and effective measures are relatively unknown and not widely shared outside the national context. This paper was written to provide a global perspective on the status quo and outline the way forward.

Our initial intention was to publish this as a one-off study. One year ago, we'd identified 85 green building systems to review. However, when conducting the research, we soon found that embodied carbon is considered in far more green building regulations and certification systems than previously thought – the final number of systems we analyzed was 216.

At this point, we decided to seek funding to complete the work with the coverage and scope it merits. We are extremely grateful for the sponsors who have made this possible.

As the field is moving so fast, this information will be far more valuable if maintained up to date. We are going to keep the results updated at **www.embodiedcarbonreview.com**, and welcome any notifications for updates or corrections.

This research is entirely based on verification of the original documents. Where necessary, clarifications were requested from the actual authors or operators of the relevant systems. This was done to ensure every system, in every language, is evaluated in a uniform manner.

We are grateful to the partners who have worked with us to distribute the findings of this study, and to the organizations who have reviewed the content. Any errors or omissions are the authors'.

This study has been authored by experts from One Click LCA Ltd. We are better known through our software product brand, One Click LCA.

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1 EXECUTIVE SUMMARY

In this report embodied carbon is the total of all greenhouse gas emissions that result from the manufacture and supply of construction products and materials, as well as the construction process itself. Embodied carbon reductions contribute to climate goals in the short term. This review covers how global regulations and certifications systems address embodied carbon and the best practices of decarbonization.

The global urban population is set to grow by 2.75 billion by 2060. The required new buildings will create over 100 gigatons of embodied carbon – more than three years' global fuel combustion carbon emissions. If carbon intensity is not drastically cut, global construction activity carbon until 2060 may exceed 230 gigatons.

EMBODIED CARBON FROM NEW BUILDINGS EXCEEDS 100 GIGATONS

Embodied carbon resulting from buildings constructed from today until 2050 is as high as the carbon from their cumulative operating energy demand until 2050, before energy grid decarbonization is considered. As energy grids decarbonize and buildings become more energy efficient, the importance of embodied carbon only grows. If the energy grids decarbonize, the embodied carbon of the new buildings may be higher overall than operating carbon, as shown in **chapter 2**.

Embodied carbon needs to be included in building codes, possibly aligned with energy codes, and supported by voluntary incentive systems for further improvement. City-level tools, including zoning regulations and planning rules, are other essential tools to influence how buildings are planned, designed and delivered.

This review covers environmental sustainability certifications and regulations applied to construction works that are used at least regionally. The study identified 216 systems, of which 156 met the criteria. Of these, 105 include direct measures for embodied carbon. Two thirds of these are certification systems, and the rest are regulations, standards and guidelines.

We identified local systems in 26 countries. Embodied carbon is used in all systems in Germany, Finland, France, the Netherlands, Belgium, Norway, Sweden, and Switzerland, and it features in local systems on all continents, except Africa. The number of systems addressing embodied carbon has more than doubled in the last 5 years. The research methodology and the scope are explained in **chapter 3**.

This research identified five main methods of addressing embodied carbon. These are, in increasing order of efficiency, carbon reporting, comparison in design, carbon rating, carbon caps, and decarbonization. Applying these measures is estimated to lead to embodied carbon reductions from a few percentage points to up to one half of a project's impacts. Different ways to set targets and incentives for carbon performance were identified. These methods are discussed in **chapter 4**.

All but one of the 20 international and pan-European standards and rating systems target embodied carbon. Northern Europe has 24 such systems, some of them very sophisticated, and the most per capita for anywhere in the world. Continental Europe has 38 regulations and certifications in use, including the first regulatory programs targeting embodied carbon. North and South America combined have 23 relevant systems, with embodied carbon being present in approximately half of them. In Asia-Pacific, which has 23 green building systems, and the Middle East and Africa, which have 8, embodied carbon is more an exception than the rule. The detailed status of embodied carbon application by region for buildings is given in **chapter 5**.

Infrastructure was considered separately. This study identified 20 infrastructure-relevant systems, of which 70% apply embodied carbon reduction or LCA methods. Most of the infrastructure-targeting tools are voluntary certifications. Embodied carbon reduction in infrastructure systems is detailed in **chapter 6**.

Chapter 7 provides a visual comparison of the regional differences between carbon reduction and cap/rating methods, incentives and the use of product EPDs. On average, Continental European systems use the greatest number of best practices in the report. Internationally-used systems, as well as Northern European systems, also do generally well.

Chapter 8 explains best practices for designing embodied carbon targeting policies. To have a high impact, the early phase of the project must be targeted. Setting an embodied carbon cap for common building types is recommended, as is providing incentives for carbon reductions. This study recommends setting rules and requirements based on standards, and having an open and verification-based process.

Chapter 9 highlights successful cases of embodied carbon reduction methodology. When looking at national development, examples from the Netherlands and Austria are highlighted. With regard to building certification, examples from BREEAM UK New Construction 2018, the French pilot regulation Énergie Positive & Réduction Carbone, and Norwegian FutureBuilt were selected. In relation to infrastructure, High Speed Two from the UK and Trafikverket from Sweden are highlighted.

Chapter 10 concludes with an outlook on embodied carbon reduction policies. Embodied carbon is going to be increasingly regulated, either separately or in connection with energy regulations. Where no national code exists, cities have an essential role to play. Embodied carbon can be addressed by city-level regulations and incentive programs. Certification systems will also help address embodied carbon. The complexity of embodied carbon accounting is reduced by innovative and automated tools, as well as education and experience from working with it in practice.

2 EMBODIED CARBON IS ESSENTIAL TO ACHIEVE CLIMATE GOALS

2.1 GROWTH IN CITIES DRIVES A SURGE OF EMBODIED CARBON

Growth of urban populations is estimated to double the global building stock by 2060. In that time, the world population is expected to increase by 2.67 billion, and the urban population by 2.75 billion. The present global building floor area is 223 billion m2. This is set to more than double, growing by 230 billion m2 by 2060. Almost all of this growth is projected to happen in cities. [2]

The rapid growth of urban populations drives demand for more construction materials for new buildings, extensions, renovations, and infrastructure. This creates significant and immediate carbon emissions before a project's completion, as opposed to carbon from energy use, which accrues over time and may yet be reduced with grid decarbonization.

NEW BUILDINGS CAUSE >100 GIGATONS OF CARBON, ALL OTHER CONSTRUCTION DOUBLES THAT

The resulting carbon impact is enormous. Calculating the new construction impacts at 450kg CO2e/m2, the global floor area growth will cause over 100 gigatons of carbon by 2060. This is over three times the world's total CO2 emissions from fuel combustion. This figure, if anything, is conservative, considering that national building materials manufacturing carbon emissions for China alone were 2,4 gigatons in 2015. This figure does not take into consideration carbon from civil engineering and the repair of existing buildings. [3]

Emissions from all construction activities are far larger. Recent research calculated the global construction sector carbon impact to be 5.7 gigatons, which also includes renovation and infrastructure. Continuing emissions at this pace will create 100 gigatons of emissions in the next 18 years. However, as global pace of construction is accelerating to meet the demand, unless carbon intensity is reduced, the construction sector's accumulated carbon impacts will exceed 230 gigatons by 2060. [4]

To stay within the IPCC's 1.5 degrees scenario, significant embodied carbon reductions are necessary. The graph below highlights the timing of embodied carbon and operating carbon.

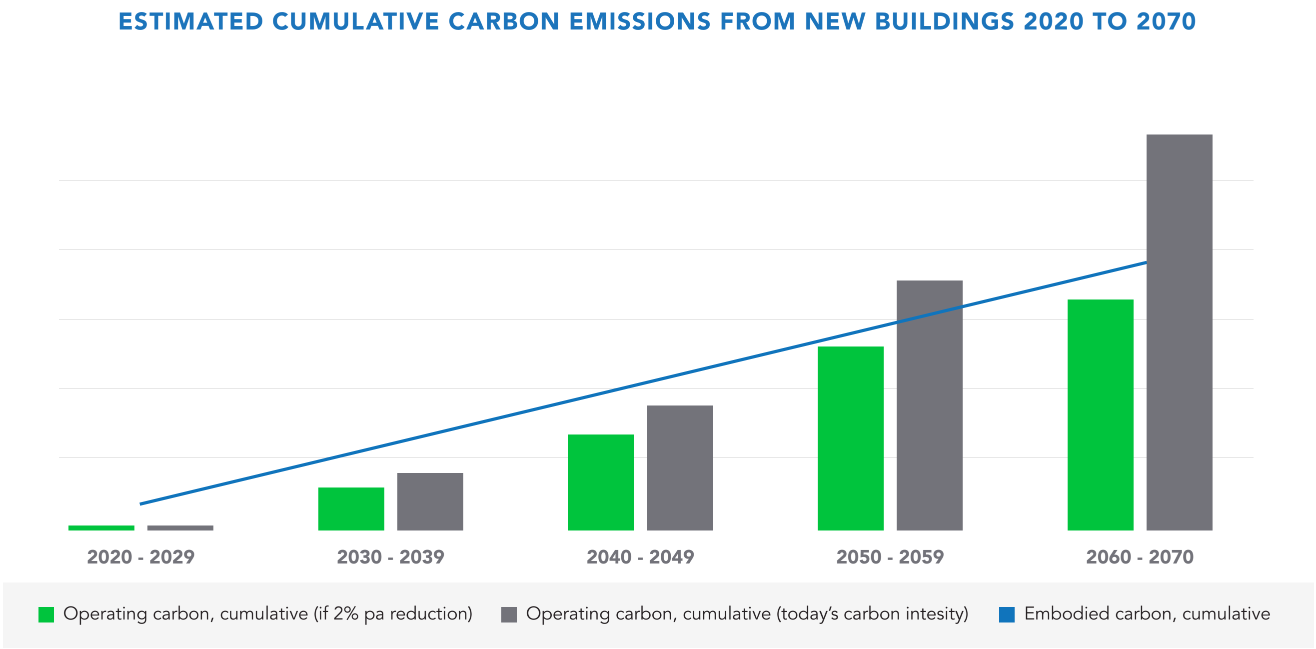


***Illustration**: embodied and operating carbon for new buildings 2020-2070*

The illustration assumes a steady rate of new construction from 2020 to 2070, and initially-released embodied carbon accounting for one fifth of a building's life-cycle emissions. With these assumptions, embodied carbon and the operating carbon of new buildings have the same overall impact until 2050, after which operating carbon becomes more important. However, if an annual 2% decarbonization rate is assumed for operating energy, the embodied emissions will dominate life-cycle impacts for the whole of this period.

2.2 EMBODIED CARBON'S IMPORTANCE CONTINUES TO GROW

The carbon footprint of energy use will be influenced by policy decisions that have already been taken and those that will be taken in the future, and by the lowering cost of renewable energy solutions. Embodied carbon impacts are incurred before occupancy of a building, and are thus irreversible.

EMBODIED CARBON IS IRREVERSIBLE, AS IT IS RELEASED BEFORE THE USE OF THE ASSET

Embodied carbon is becoming the dominant source of carbon impacts from buildings as energy supply decarbonizes. The following accentuates this growth:

1. Buildings become more and more energy-efficient
2. Building energy supply increasingly uses locally produced energy or low carbon sources
3. Energy grids are decarbonizing, while manufacturing processes and transport run on fossil fuels
4. Buildings embed more systems, whose manufacture and replacement causes emissions

The actual tipping point at which embodied carbon takes over operational energy depends largely on the carbon intensity of the energy system of the location. Countries and locations with a high proportion of renewable energy, like Norway, have already reached the point where embodied emissions exceed operational energy emissions for most buildings over 50 years, even when no decarbonization is assumed. The typical proportion of embodied carbon in countries with mixed energy supply is from one quarter to one third of life-cycle impacts over 50 years, before any grid decarbonization is assumed. [5]

Embodied carbon importance grows constantly

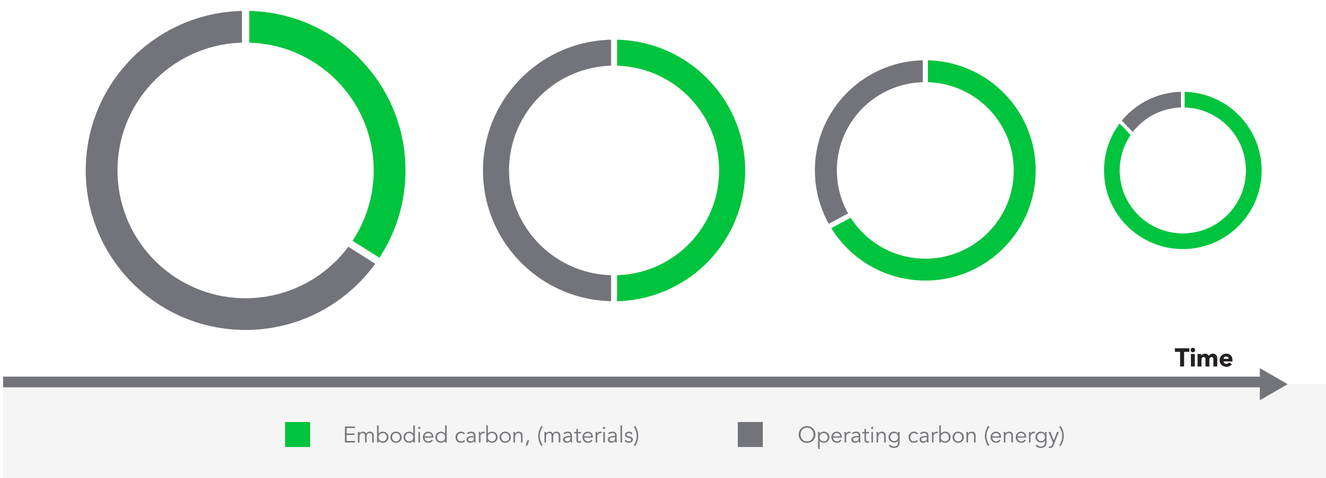


Illustration: *importance of embodied carbon grows as operational energy decarbonizes*

In locations with coal- or oil-dependent energy systems, the embodied emissions represent a lesser part of the whole. However, product manufacturers in those locations may be at a disadvantage when exporting. Emission levels for energy-intensive products can vary greatly between countries. As export clients consider their project emissions, suppliers with starkly higher materials emissions may find their products being a less attractive choice.

2.3 EMBODIED CARBON IN CONSTRUCTION NEEDS REGULATION

Embodied carbon needs to be included in building codes, and supported by voluntary incentive systems for further improvement. Regulations, zoning, and planning rules are essential tools to reduce embodied carbon, as they strongly influence how buildings are planned, designed, and delivered.

Embodied carbon, as global warming in general, is a textbook case of the tragedy of commons. As the party causing the emissions suffers from their own emissions only to very limited extent, the economic feedback loop is insufficient to drive sufficient improvement. This is why embodied carbon needs a regulatory response – which can be supported by a range of voluntary measures and programs.

REGULATIONS, ZONING AND PLANNING RULES ARE ESSENTIAL TO REDUCE EMBODIED CARBON

Improving just carbon intensity of materials, while essential, is not sufficient. The necessary improvements also require rethinking materials efficiency and materials use in building design. The focus of the regulation needs to be the process of designing and delivering buildings. Manufacturing emissions regulations, while useful, are not enabling this kind of change.

While this report does not provide a model for regulating embodied carbon, it highlights several examples of success cases and provides a detailed breakdown of best practices.

3 THE GLOBAL STATUS QUO OF EMBODIED CARBON REDUCTION

3.1 THE SCOPE OF THE REVIEW

The number of certifications and regulations (from here, systems) addressing embodied carbon in construction sector has been growing very rapidly. Most of these have been developed as separate initiatives by the organization in charge of the system. This means that best practices are not shared nor adopted – something this study aims to change.

Overall the study identified 216 systems, of which 156 were qualified for inclusion using the below criteria. Of these systems, 105 included direct measures for embodied carbon. This research is entirely based on verification of the original documents. Where necessary, clarifications were asked from the actual authors or operators of the relevant systems.

OF THE 156 ANALYZED SYSTEMS, 105 ADDRESS EMBODIED CARBON DIRECTLY

The following principles were applied to include systems within the scope of this review:

1. The field of the system must be green building and construction. We have only considered systems that contribute to environmentally more sustainable buildings.
2. The system must have as its object buildings, infrastructure or civil engineering works. This means that all product, district, city, site and organization-level systems were excluded. This led to the exclusion of several dozens of systems. However, we included regulatory systems that regulate products only when used in buildings.
3. The scope of the system must be either multi-criteria (holistic), or single criteria, with the criteria being embodied carbon, life-cycle carbon or life-cycle assessment. This means that all single criteria systems focusing e.g. on energy or health are excluded.
4. The system must be formally defined, public and supported by a host organization. This means that a single publication, unless broadly adopted, would not make the cut. Official EN and ISO standards

pass this criterion due to their nature.

5. The system must be a system, not a software or a template. All such are excluded.

These exclusion criteria led to the removal of 60 systems from the initial scope of review:

1. The system must be active. It has to be currently in use, or about to roll out soon. This criterion led to the exclusion of circa 20 outdated green building rating tools.
2. The system must be public and used generally by the market. It has to be used at least regionally, as opposed to being used in one city or organization. This led to the exclusion of schemes and requirements that individual cities or investors impose.
3. An exception to the previous point has been made for national government agency requirements (e.g. by infrastructure agencies and property arms of governments). This is meaningful, as many governments operate a monopoly on infrastructure, and in the case of buildings, the government properties are used to lead the market.

Every family of systems (e.g. LEED) with similar rules in regards this matter were calculated as a single system. Where systems had varying national versions, they counted as separate. The scoping has also led to the exclusion of regulatory emission cap- and-trade systems that have legal power and also apply to some construction product manufacturing sectors.

3.2 EMBODIED CARBON REDUCTION SYSTEMS BY GEOGRAPHY

Local embodied carbon reduction systems were identified in 26 countries. Furthermore, 19 international and European systems are available for adoption in all jurisdictions and cases where national systems are not appropriate. The number of systems addressing embodied carbon has more than doubled in last 5 years.

NUMBER OF SYSTEMS ADDRESSING EMBODIED CARBON HAS DOUBLED IN THE LAST 5 YEARS

It is worth noting that, of the systems that do not address embodied carbon directly, almost all address it via practices such as recycled material use, waste reduction and material efficiency measures. Considering the importance of embodied carbon, the number of systems to reduce embodied carbon is expected to continue growing rapidly.

The visualisation below shows the number of different embodied carbon reduction systems used by country. Some of the systems are complementary tools, and others competing certifications or, in the case of federal countries, state/province-level regulations. In addition to the countries shown in the visual below, at least one system addressing embodied carbon was identified in following countries: Bulgaria, Brazil, Chile, Czech Republic, Denmark, Hong Kong, Korea, New Zealand, Romania, Taiwan and Turkey.

NUMBERS OF SYSTEMS ADDRESSING EMBODIED CARBON BY GEOGRAPHY

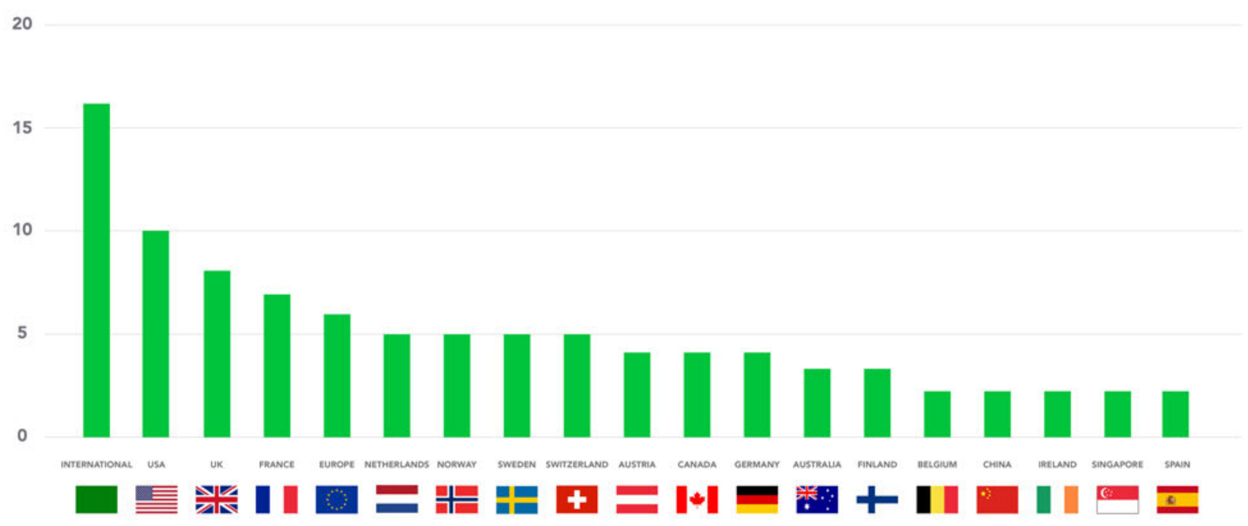


***Illustration**: leading countries have several embodied carbon systems in place*

3.3 PREVALENCE OF EMBODIED CARBON IN SYSTEMS BY REGION

Embodied carbon is used in all identified systems in Germany, Finland, France, Netherlands, Belgium, Norway, Sweden and Switzerland, as well as in a number of countries with only one system. Embodied carbon features in local systems in all regions in the world, except Africa.

We divided the world into sub-regions to study the regional prevalence of embodied carbon reduction. We found that embodied carbon is used in over four fifths of all of the studied systems in Benelux, Nordic countries, German-speaking Europe and France. The lowest rates of adoption for embodied carbon are in the Middle East, South America, and Asia. The below map shows the rate of embodied carbon adoption by region. Europe was split into Northern Europe (comprising of Nordic countries, UK, and Ireland) and Continental Europe.

Please note that due to accounting of both multi-criteria and embodied carbon only systems (see **3.1**), percentages are higher than if only looking at multi-criteria systems. If only multi-criteria systems are considered, embodied carbon is directly addressed in 58% of them. Further 8% of systems address it with a simplified approach or an indefinite approach.

PREVALENCE OF EMODIED CARBON IN GREEN CONSTRUCTION SYSTEMS

Scope: multi-criteria building & infrastructure certifications & carbon only regulations

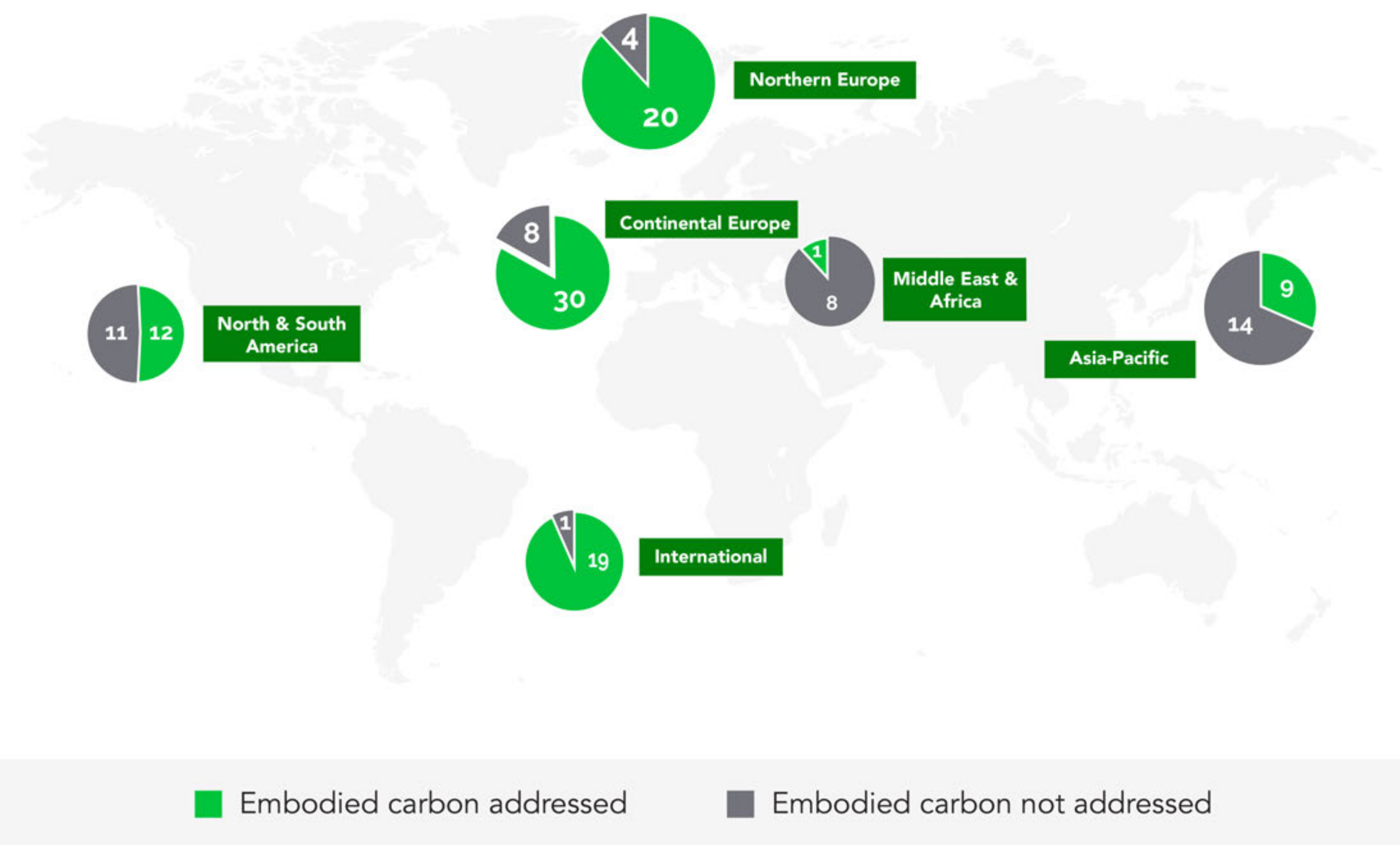


***Illustration**: embodied carbon inclusion ratio in green building systems globally*

3.4 REGULATIONS, CERTIFICATIONS, STANDARDS, AND GUIDELINES

Embodied carbon reduction systems identified in this study consist of:

- Voluntary certifications (108), representing 69% of the total,
- Regulations (22), representing 14% of the total
- Standards (19), representing 12% of the total, and
- Guidelines (7), representing 4% of the total.

Where a national government agency imposes mandatory requirements for contracts, while those do not have a formal regulatory status, those have been classified as regulations here. Such requirements tend to behave as regulations, as especially for national infrastructure, the government is often a monopoly buyer.

The graphic below shows this distribution by region.

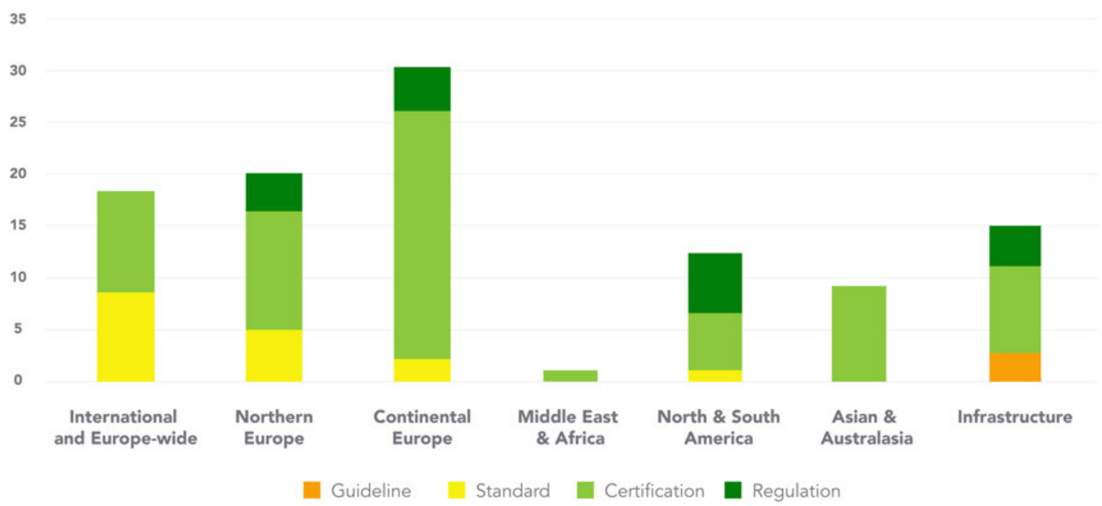


***Illustration**: types of systems addressing embodied carbon by region globally*

The mix of different systems is largely explained by the scoping of the survey. The study has mostly not considered guidelines. The retained guidelines each have specific properties, e.g. their issuer or role in the practical application, which make them behave partially like certifications or regulations.

The share of systems addressing buildings is 87%, whereas infrastructure/civil engineering works represent the balance. There are also three systems included whose object are construction products used in buildings.

4 OVERVIEW OF EMBODIED CARBON REDUCTION METHODS

4.1 FIVE MAIN METHODOLOGIES USED TO ADDRESS EMBODIED CARBON

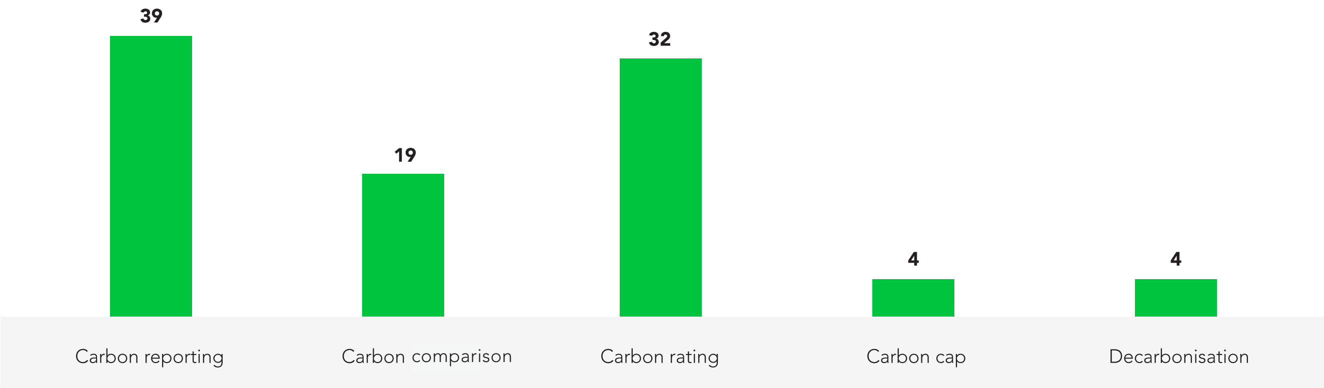
This research identified five methodologies to address embodied carbon. These are in increasing order of efficiency: carbon reporting, comparison in design, carbon rating, carbon caps, and decarbonization. Other measures have an indirect impact on embodied carbon.

The following table outlines the carbon reduction methods from most basic to most advanced, as evaluated based on their ability to reduce carbon emissions. The ranking of categories should be considered indicative, as within each approach the implementation determines much of its efficiency.

A too permissive carbon cap will not challenge projects to improve in a meaningful manner. However, here it is considered a more effective measure than carbon rating, as it is mandatory to meet.

METHOD	HOW DOES IT WORK?	EXAMPLES
1. Carbon reporting	Calculate the construction project's embodied carbon and report it	EN 15978, BREEAM Int'l
2. Carbon comparison	Compare design options for carbon; for example, design baseline and proposed designs and show improvements against a self-declared baseline value	LEED v4, Green Star, BREEAM UK
3. Carbon rating	Evaluation of carbon performance. Variable scale from best to worst on which a project's carbon is rated, but no effective maximum value applied. Fixed scale or clear methodology	DGNB, BREEAM NL
4. Carbon cap	Calculate the project's embodied carbon and prove it is not exceeding the CO_2e limit	Énergie Carbone, MPG
5. Decarbonization	Reduce carbon to a minimum, then compensate all residual emissions by own energy export or buying offsets	Living Building Challenge, NollCO2

Carbon reduction methods by volume of application for building-targeting systems



4.2 DIRECT (LCA-BASED) AND INDIRECT CARBON REDUCTION METHODS

Life-cycle carbon footprint or LCA is a science-based methodology to quantify carbon emissions over a construction works life-cycle. The methodology includes materials manufacturing, transport, site wastage and installation, maintenance, use and repair, replacements during the life-cycle, as well as end of life processing.

Carbon impacts can be reduced by both direct and indirect means. Direct carbon emissions reduction relies on life-cycle carbon footprint or LCA. Indirect emissions reduction includes specifying renewable or recycled products, or choosing products with EPDs, for example. These also include material saving and waste reduction strategies. Some of these measures are very specific and target e.g. the cement content of concrete.

The indirect methods generally are beneficial, but do also carry a risk of increasing emissions, for example, when the recycled or renewable material is not having comparable durability over the lifetime of the asset being constructed, or by having higher transportation impacts, or requiring additional material use.

As a rule of thumb, material efficiency and waste reduction strategies have no life-cycle drawbacks as long as the durability of the structure does not suffer. However, specification of recycled or renewable materials does not necessarily result into carbon reductions, and can sometimes increase the emissions. Prescriptive measures limit solutions and don't consider life-cycle, and thus bias the approaches and limit efficiency.

LCA, when correctly applied, avoids sub-optimization, it is the gold standard for environmental performance measurement for constructed assets. This review recommends the indirect carbon reduction methods as supporting tools to complement LCA, for example to choose high performing products (see **6.5.**)

Applying the LCA methodology also provides a solid basis for combining this with Life Cycle Costing (LCC). LCC provides a full picture of the long term of owning and operating a building, including the maintenance and replacement processes required for the building itself, as well as the operational energy and water use costs, and carbon impact via LCA.

4.3 ESTIMATED EFFECTIVENESS OF CARBON REDUCTION METHODS

Different carbon reduction methods vary in their capability to reduce the embodied carbon of construction projects. For example, a reporting requirement does not actually require any improvement – even if some projects can make use of the information received and adjust design or procurement decisions. The table below shows the authors' estimate range of effectiveness of the different methods. For clarity, decarbonization does not yet reduce embodied carbon to zero but applies offsetting or exported energy for balance.

The estimated effectiveness is based on author estimates, which are formed on basis of the embodied carbon performance projects pursuing one of the targeted methodologies have achieved. The typical reduction range (green) is the reduction that most applications of these methodologies would likely achieve, whereas the higher reductions (grey) are possible with rigorous implementation and sufficient incentives.

Several systems also combine methods. For example, both DGNB 2018 and BREEAM UK 2018 combine carbon rating and carbon design methods. Combined methods are common.

The reduction potential ranges for carbon reporting, design, and rating start from no reduction. Typical projects applying the methodology can be expected to achieve relatively limited embodied carbon reductions. Projects that utilize the methodology to the full potential are naturally able to achieve more substantial improvements. However, the carbon cap and decarbonization approaches are in all cases more effective. The actual impact of a carbon cap system depends on how ambitious a cap is set – as discussed below.

Embodied carbon reduction methods from least to most effective with estimated reduction potential

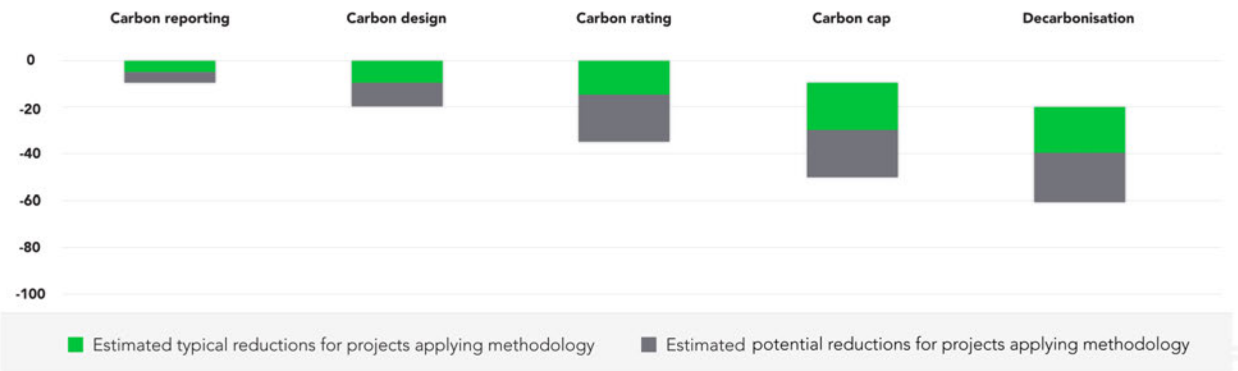


***Illustration**: estimated embodied carbon reduction potential with different methods*

4.4 PROS AND CONS OF THE DIFFERENT CARBON REDUCTION METHODS

Each of the carbon reduction methods has its advantages and disadvantages. The main advantages and disadvantages of the considered methods are outlined in the below table.

Method	Advantages	Disadvantages
1. Carbon reporting	Reporting carbon is easy Builds knowledge and skills.	If reporting is the only requirement, design and impacts may not improve.
2. Carbon comparison	The most cost-effective way to influence. Options must be understood prior to acting.	Comparison is not necessarily leading to best option being built. This may become a formality in some projects.
3. Carbon rating	Incremental performance improvements provide additional incentive via better rating.	As also a poor rating is also allowed, the less ambitious projects may not improve at all.
4. Carbon cap	All projects must meet the stipulated threshold.	Setting the cap to a level where it is effective in carbon reduction and yet cost-efficient is hard.
5. Decarbonize	Direct cost from higher carbon emissions is an incentive to reduce as far as possible.	Systems aiming at complete decarbonization need a great deal of political will and suitable incentives to be widely applied.

4.5 SETTING EMBODIED CARBON CAP OR RATING THRESHOLDS

For systems applying a carbon cap or a rating, the threshold values are essential. A carbon cap that is too vaguely defined is not enforceable. A fixed value is extremely clear. However, it may not allow for location specific criteria, such as earth quake resistance or type of soil.

The threshold values themselves are set in different ways, and all identified systems apply one of the following methods.

METHOD	DESCRIPTION	WHERE THIS IS USED
1. Self-declared	This is not considered a threshold method. End users declare their own baseline performance. This provides flexibility for use, but makes applying it as an effective cap impossible. Because of this, these systems are classified as 'Carbon comparison' systems.	LEED v4, all other infrastructure tools
2. Methodology	Threshold values are generated using a well-defined baseline calculation method. This ensures different users have clear guidance on how to create the performance thresholds for their specific project. This allows accounting for project specificities, and results to verifiable threshold values.	FutureBuilt, HS2 (infrastructure)
3. Fixed scale	Threshold value, or scale, is fixed for the building type and results mechanically from given parameters without judgement being applied. In the French E+C- system the mandatory parking requirement allows adjustment of the threshold values to allow for parking structure, for example. This method is not well suited to infrastructure projects.	BREEAM NL, DGNB and Énergie Carbone

The visualization below shows the popularity of these methods in the systems reviewed.

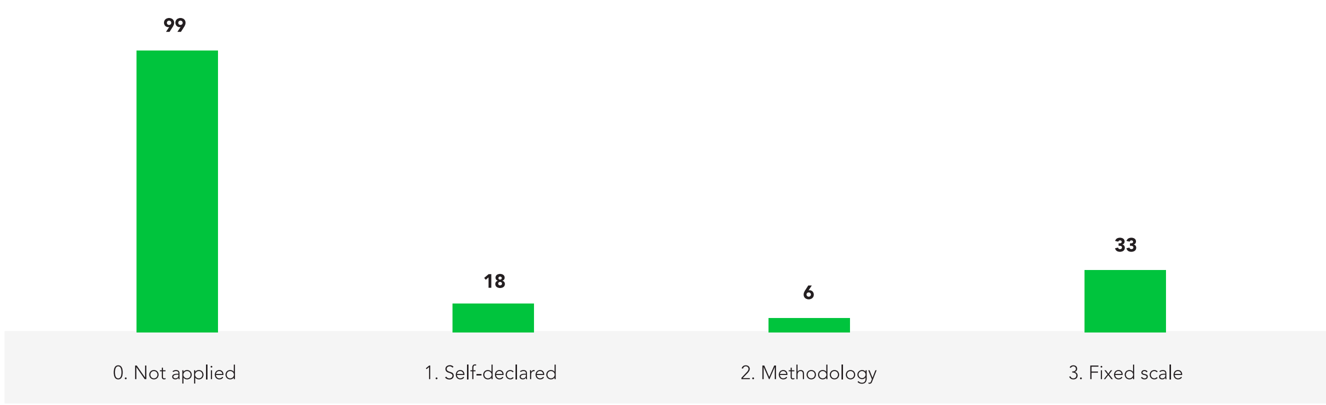


***Illustration**: popularity of different carbon rating strategies*

In the category of self-declared baselines, the most commonly applied reduction requirement is a 10% reduction against a self-declared baseline. This requirement is found for example in LEED v4, Green Star, and Miljöbyggnad 3 systems.

The main applications of the threshold value methodology are in the Norwegian methodologies for carbon reduction, including FutureBuilt and government building requirements. These follow a specified methodology for generating threshold values. Another application is the UK's High Speed Two infrastructure program, where baseline values were calculated by the client, and are rebased to reflect design changes as needed.

An example of the fixed scale is the DGNB system, where the highest scores are achieved by reducing impacts by 45% from the reference value. In the BREEAM NL system the highest scores are achieved by 60% reduction from the reference values. In Énergie Carbone the mandatory performance level is set as a fixed value that must be met.

4.6 INCENTIVES FOR ACHIEVING CARBON REDUCTIONS

Many of the systems provide some form of an incentive for applying the prescribed carbon reduction policies. Most common incentive are certification points towards a better rating. The incentives identified in this study can be grouped into one of the following categories:

INCENTIVE	DESCRIPTION	USED IN
1. Rating points	Systems that award rating points for the application of LCA, or achieving savings quantifiable with LCA.	LEED v4, DGNB 2018, BREEAM International 2016
2. Funding condition	Public funding program or state procurement setting it a funding condition to achieve carbon target.	State policy in Minnesota and California, United States
3. Density bonus	Meeting a carbon performance level may make a project eligible for additional gross floor area rights.	French E+C- scheme's good performance level (when enacted by city-level plan)
4. Cash impact	Either carbon offsetting funded by the constructor, thus ensuring carbon emissions lead to real cash cost for project; or a carbon performance payment.	Decarbonization e.g. Living Building Challenge, and carbon performance payment Rijkswaterstaat
5. Mandatory	Carbon criterion is a simple requirement. The criterion itself can be set up differently in different systems where it's mandatory.	Dutch MPG regulation and allowed level of the French E+C- scheme (when the law enters in vigor)

The chart below shows the popularity of each of these incentives.

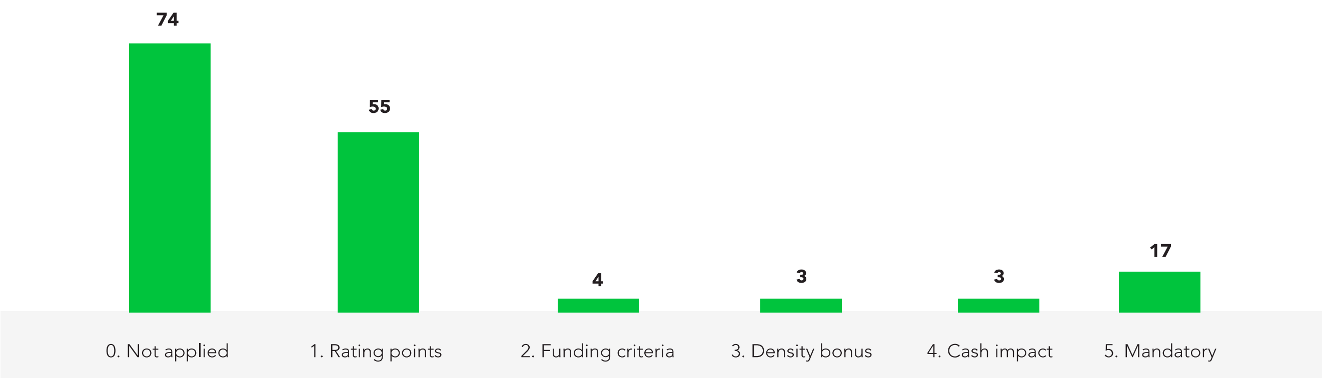


***Illustration**: popularity of different types of carbon reduction incentives*

The French E+C- regulation has both the highest allowed and good carbon performance levels, together with related energy efficiency levels. Achieving good carbon and energy performance levels allows a project to achieve a government label for performance, which in turn can be enabled by the local city masterplan to allow up to 15% density bonus. So far in the pilot phase of the system, no city has applied this density bonus in their masterplan.

4.7 CHOOSING LOW-CARBON PRODUCTS USING EPDS

Environmental Product Declaration (EPD) is a tool for reporting product environmental performance, including carbon and other LCA-relevant information. EPD is always third-party verified and follows a minimum set of ISO standards as well as specific Product Category Rules. European, and many international EPDs also comply with EN 15804. EPDs can be used as a basis for choosing between products, subject to limits of comparability.

All things being equal, selecting a product with lower carbon emissions for a project is a good choice. However, all things are not always equal – for example, one product might make for thicker structures and thus increase the use of other materials. This chapter will not discuss the limits of comparability at length, so this is to be understood as a case of choosing between two technically comparable products, for example, two different concrete mixes or two different insulation materials with similar thickness and thermal performance.

In addition to comparisons, EPDs are essential building blocks for building level assessments. They provide detailed information about specific products that improves the accuracy of building LCAs. Comparisons between products that have an impact on the whole building need to apply a comparative analysis for the building level impacts using LCA methodology. The different types of applications for EPDs identified in this study are the following:

METHOD	DESCRIPTION	WHERE THIS IS USED
1. Documentation	Document that project has purchased products that have product-specific EPDs.	BREEAM International
2. Use in LCA	Use product-specific EPD data in your building level LCA	Miljöbyggnad 3
3. Buy low-carbon	Additional requirement separately of LCA to compare and choose products that have EPD, and that are comparatively better	LEED v4

The graph below shows the prevalence of the different product selection methods.

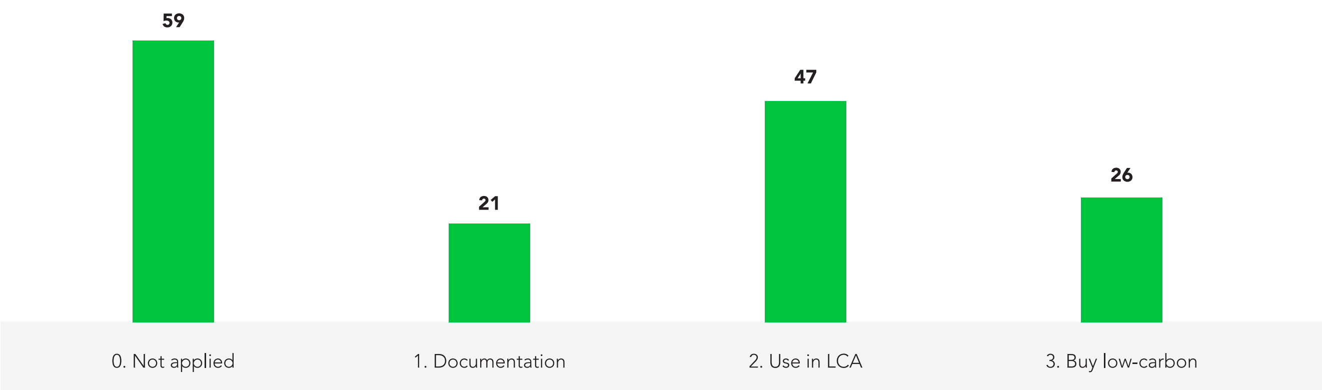


***Illustration**: use of EPD in different green building systems*

5 BUILDING EMBODIED CARBON REDUCTION SYSTEMS

Systems are listed by geographic region. Europe was split into two regions, on one hand be able to contrast the differences between Northern and Continental Europe and to be able to have approximately similar sized datasets for each of the main regions. This was found pertinent as the use of embodied carbon in certification and regulations clustered along these regional lines. All systems focused on infrastructure works are listed in **section 6**.

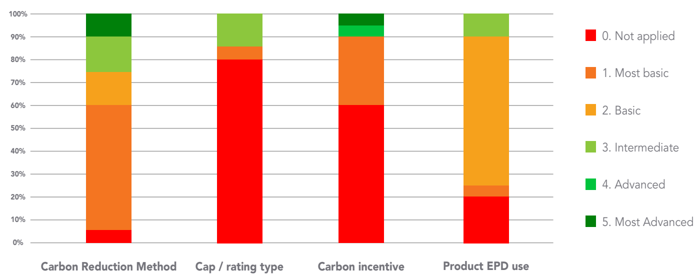
The legend for reading the data tables in this chapter is provided below.

LEGEND	INTERPRETATION
Type	This explains what is the legal status of the system is in question. It can be either a Certification, Regulation, Standard or Guideline.
Embodied carbon	If embodied carbon or LCA is addressed by the system directly, and whether it is a requirement or an optional criteria. When a simplified approach is used, it's documented with 'No - Simplified', and when it is one of possible methods, it's recorded as 'No - May use'.
Carbon reduction by	The embodied carbon reduction methodology the system is using. The definitions for these options are provided in **chapter 4.1.**
Cap / rating type	The mechanism for setting embodied carbon cap or rating (if applicable for the system). These options are defined in **chapter 4.5.**
Carbon incentive	If there is an incentive available for embodied carbon performance, this field explains what it is. These options are defined in **chapter 4.6.**
Product EPD use	Besides building level performance, many systems also promote specifying better products. These options are defined in **chapter 4.7.**

Reading the 'Level of sophistication' graphics

The chart shows the regional level of sophistication of studied embodied carbon: Carbon reduction method, cap/rating type, carbon incentive, and product EPD use. For each of these categories, every system is evaluated on a scale from 0 (Not applied - visualized with red) to 5 (Most advanced - visualized with dark green).

LEVEL OF SOPHISTICATION OF CARBON REDUCTION



5.1 INTERNATIONAL AND EUROPEAN LEVEL

This study identified 20 systems used internationally, or at least at a pan-European level. All these systems include LCA using one of the methodologies except One Planet Living, which is not prescriptive by nature. After the cut-off date of this report, LEED Zero certification outline from the USGBC was published. The key parameters outlining how embodied carbon reductions are driven by these systems are shown in the following.

Active house specification
Europe

Level(s)
Europe

DGNB International
International

HQE International
International

Living Building Challenge
International

SB Tool
International

Zero Carbon Certification
International

BREEAM International
International

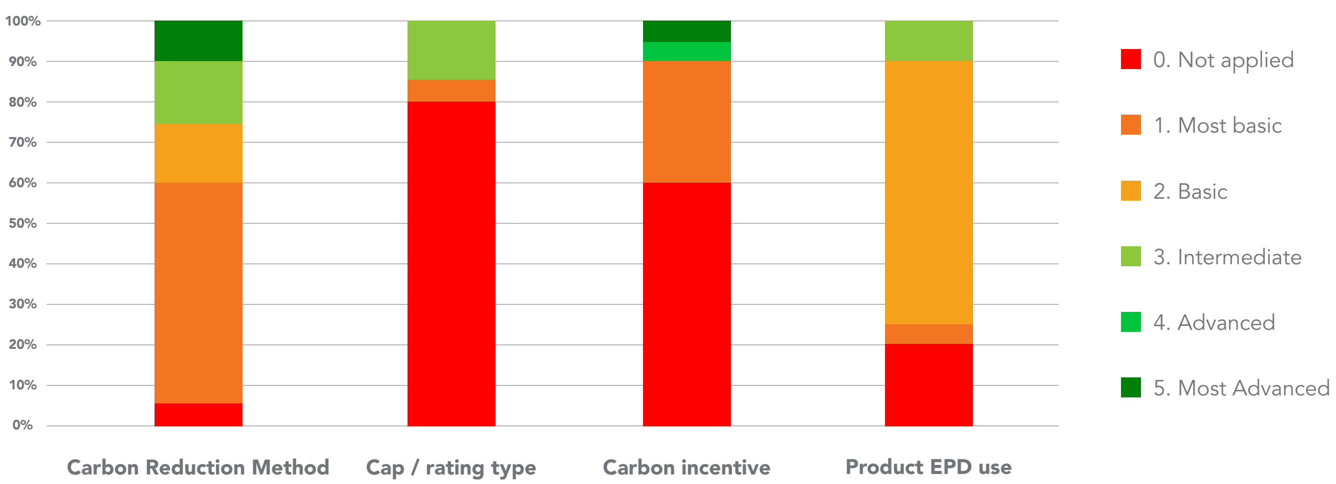
EDGE
International

LEED
International

Illustration: *systems using embodied carbon internationally. Trademarks owned by their respective owners.*

The figure below shows the level of sophistication of the region's approach in carbon reduction using the data in the table on the following page. For decoding the visual refer to the beginning of **chapter 5**.

LEVEL OF SOPHISTICATION OF CARBON REDUCTION METHODS, INTERNATIONAL/EUROPE



SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP / RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
Active house specification	Europe	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	-
Level(s)	Europe	Certification	Optional	1. Carbon reporting	-	-	2. Use in LCA
EN 15978	Europe	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
EN 15804	Europe	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
EN 15643-5	Europe	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
LEED v4	International	Certification	Optional	2. Carbon comparison	1. Self-declared	1. Rating points	3. Buy low-carbon
BREEAM International	International	Certification	Optional	1. Carbon reporting	-	1. Rating points	1. Documentation
Living Building Challenge	International	Certification	Required	5. Decarbonize	-	4. Cash impact	-
EDGE	International	Certification	Optional	2. Carbon comparison	-	-	-
HQE International	International	Certification	Optional	2. Carbon comparison	-	1. Rating points	3. Buy low-carbon
SBTool	International	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
DGNB International	International	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
Zero Carbon Certification	International	Certification	Required	5. Decarbonize	-	5. Mandatory	2. Use in LCA
ISO 14040	International	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
ISO 14044	International	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
ISO/FDIS 21929-1	International	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
ISO FDIS 21931-1	International	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
ISO 21930	International	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
One Planet Living	International	Certification	No - May use	Not determined	-	-	-

***List**: International systems and their key embodied carbon reduction information*

5.2 NORTHERN EUROPE: NORDIC COUNTRIES, UK AND IRELAND

The study identified 24 systems used in this region, which makes it the most active region in the development of green building systems on a per capita basis. Nordic countries are moving forward with regulatory development for embodied carbon. This region has enough experience to start moving to more efficient carbon reduction methods. Some of the regulations in this region have not yet entered in force.

DK-DGNB
Denmark

RT Ympäristötyökalu
Finland

Home Performance Index
Ireland

Powerhouse
Norway

BREEAM NOR
Norway

Futurebuilt
Norway

Miljöbyggnad
Sweden

BREEAM SE
Sweden

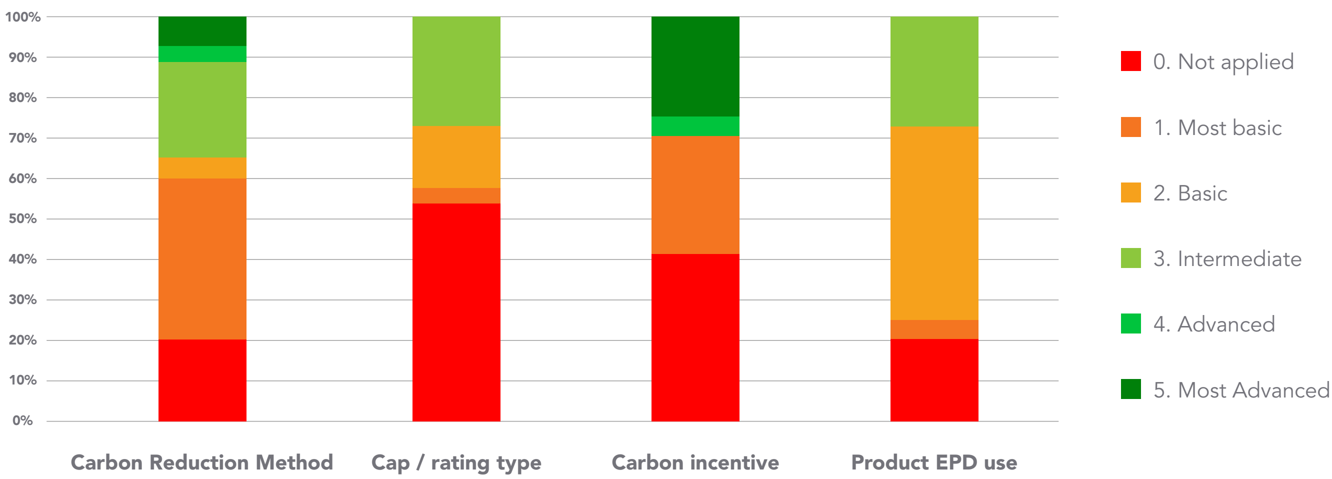
BREEAM UK
UK

Home quality mark
UK

Illustration: *embodied carbon in Northern Europe. Trademarks owned by their respective owners.*

The figure below shows the level of sophistication of the region's approach in carbon reduction using the data in the table on the following page. For decoding the visual refer to the beginning of **chapter 5**.

LEVEL OF SOPHISTICATION OF CARBON REDUCTION METHODS, NORTHERN EUROPE



SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP/RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
DK-DGNB	Denmark	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
Bolig+	Denmark	Certification	No	-	-	-	-
RT Ympäristötyökalu	Finland	Certification	Optional	3. Carbon rating	3. Fixed scale	1. Rating points	-
Rakennusten elinkaariarviointi	Finland	Regulation	Required	Not determined	Not determined	Not determined	2. Use in LCA
Building Performance Metrics	Finland	Standard	Optional	1. Carbon reporting	-	-	2. Use in LCA
Home Performance Index	Ireland	Certification	Optional	1. Carbon reporting	-	1. Rating points	3. Buy low-carbon
Powerhouse	Norway	Certification	Required	5. Decarbonize	3. Fixed scale	5. Mandatory	2. Use in LCA
BREEAM NOR	Norway	Certification	Optional	3. Carbon rating	2. Methodology	1. Rating points	3. Buy low-carbon
FutureBuilt	Norway	Certification	Required	3. Carbon rating	2. Methodology	5. Mandatory	2. Use in LCA
Statsbygg requirements	Norway	Regulation	Required	4. Carbon cap	2. Methodology	5. Mandatory	3. Buy low-carbon
NS 3720	Norway	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
NollCO2	Sweden	Certification	Required	5. Decarbonize	3. Fixed scale	4. Cash impact	2. Use in LCA
Miljöbyggnad	Sweden	Certification	Required	1. Carbon reporting	1. Self-declared	1. Rating points	2. Use in LCA
BREEAM SE	Sweden	Certification	Optional	1. Carbon reporting	-	1. Rating points	3. Buy low-carbon
Klimatdeklaration av byggnader	Sweden	Regulation	Required	1. Carbon reporting	Not determined	Not determined	2. Use in LCA
Swan Label for Buildings	Sweden	Certification	No	-	-	-	-
DREAM	UK	Certification	No - Simplified	Simplified method	3. Fixed scale	1. Rating points	-
BREEAM UK	UK	Certification	Optional	2. Carbon comparison	3. Fixed scale	1. Rating points	3. Buy low-carbon
Home Quality Mark	UK	Certification	Optional	3. Carbon rating	3. Fixed scale	1. Rating points	1. Documentation
London Plan 2018	UK	Regulation	Optional	1. Carbon reporting	-	5. Mandatory	-
Whole life carbon assessment for the built environment	UK	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
PAS 2080	UK	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
PAS 2050	UK	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
SKA Rating for Fit-outs	UK	Certification	No	-	-	-	3. Buy low-carbon

List: *Northern European systems and their key embodied carbon reduction information*

5.3 CONTINENTAL EUROPE

This study identified 38 systems used in this region, which are listed below. France, the Netherlands, and Belgium are moving forward at a fast pace with regulatory development in this area, with each having legislation in place aimed at reducing embodied carbon in construction. Here there are two regulations that target materials when used in buildings. There are also city-level requirements that have already been applied in this region, for example the Hamburg HafenCity certification, and others are in preparation. However, these are not in the scope of this review.

IBO ÖKOPASS
Austria

Klimaaktiv
Austria

ÖGNI
Austria

ÖGNB / TBQ
Austria

SBToolCZ
Czech Republic

Bâtiment à Énergie Positive & Réduction Carbone
France

Bâtiment Bas Carbone
France

BEPOS & BEPOS+ Effinergie 2017
France

Bâtiment Durable Francilien
France

Bâtiment Durable Méditerranéen
France

Haute Qualite Environnementale
France

DGNB-DE
Germany

Nachhaltiger Wohnungsbau
Germany

BNB
Germany

BREEAM DE NC 2018
Germany

BREEAM NL
Netherlands

GPR
Netherlands

Green Homes Romania
Romania

Verde
Spain

BREEAM ES
Spain

2000-Watt-Gebäude
Switzerland

Minergie Eco and A
Switzerland

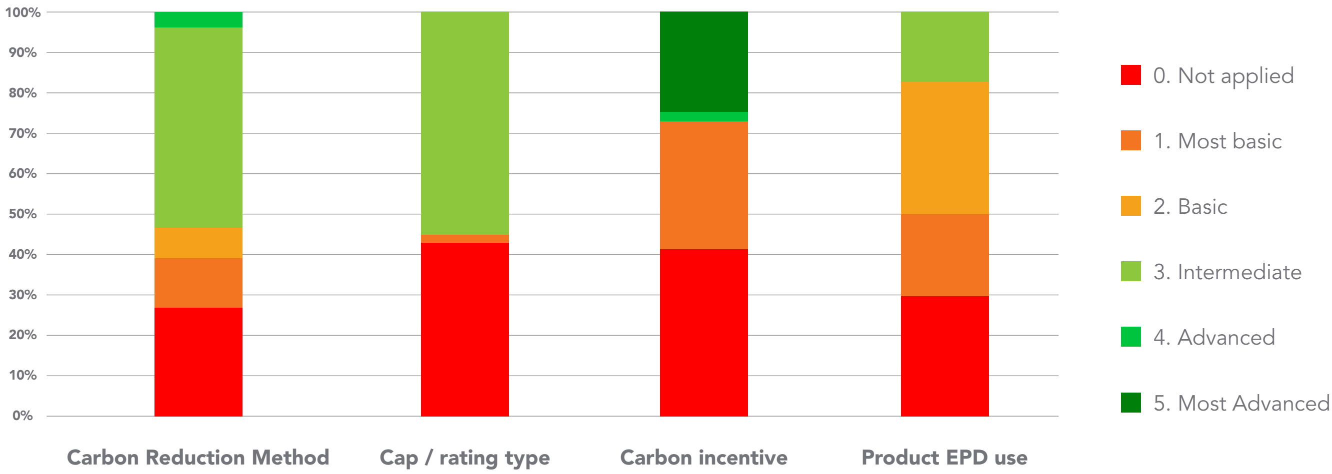
SGNI (DGNB-CH)
Switzerland

SNBS
Switzerland

Illustration: *systems using embodied carbon in Continental Europe. Trademarks owned by their respective owners.*

The figure below shows the level of sophistication of the region's approach in carbon reduction using the data in the table on the following page. For decoding the visual refer to the beginning of **chapter 5**.

LEVEL OF SOPHISTICATION OF CARBON REDUCTION METHODS IN CONTINENTAL EUROPE



SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP/ RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
IBO ÖKOPASS	Austria	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	3. Buy low-carbon
Klimaaktiv	Austria	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
ÖGNB / TQB	Austria	Certification	Optional	3. Carbon rating	3. Fixed scale	1. Rating points	1. Documentation
ÖGNI	Austria	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
2014-05-22/34 Arrêté royal fixant les exigences minimale	Belgium	Regulation	Required	Simplified method	-	5. Mandatory	1. Documentation
Milieugerelateerde materiaalprestatie van gebouwelementen	Belgium	Regulation	Required	3. Carbon rating	3. Fixed scale	5. Mandatory	2. Use in LCA
SBToolCZ	Czech Republic	Certification	Optional	3. Carbon rating	3. Fixed scale	1. Rating points	-
Arrêté du 9 juillet 2014 modifiant l'arrêté du 23 décembre 2013	France	Regulation	Optional	Simplified method	-	5. Mandatory	1. Documentation
Bâtiment à Énergie Positive & Réduction Carbone	France	Certification	Required	3. Carbon rating	3. Fixed scale	3. Density bonus	2. Use in LCA
Bâtiment Bas Carbone	France	Certification	Required	3. Carbon rating	3. Fixed scale	5. Mandatory	2. Use in LCA
Bâtiment Durable Francilien	France	Certification	Optional	2. Carbon comparison	3. Fixed scale	1. Rating points	3. Buy low-carbon

***List 1/2**: Continental European systems and their key embodied carbon reduction information*

SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP/ RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
Bâtiment Durable Méditerranéen	France	Certification	Optional	2. Carbon comparison	3. Fixed scale	1. Rating points	3. Buy low-carbon
BEPOS & BEPOS+ Effinergie 2017	France	Certification	Required	3. Carbon rating	3. Fixed scale	5. Mandatory	2. Use in LCA
Haute Qualite Environnementale	France	Certification	Optional	2. Carbon comparison	-	1. Rating points	3. Buy low-carbon
BNB	Germany	Certification	Optional	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
BREEAM DE NC 2018	Germany	Certification	Optional	1. Carbon reporting	-	1. Rating points	1. Documentation
DGNB-DE 2018	Germany	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
Nachhaltiger Wohnungsbau	Germany	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA
Casaclima Nature	Italy	Certification	No	-	-	-	1. Documentation
Criteri ambientali Minimi	Italy	Certification	No - May use	Not determined	-	-	1. Documentation
GBC Home	Italy	Certification	No - May use	Not determined	-	-	1. Documentation
Sistema Edificio	Italy	Certification	No	-	-	-	-
Protocollo ITACA	Italy	Certification	No	-	-	-	3. Buy low-carbon
Bepalingsmethode Milieuprestatie Gebouwen en GWW-werken	Netherlands	Standard	Required	1. Carbon reporting	-	-	2. Use in LCA
Bouwbesluit 2012 (Building Act 2012)	Netherlands	Regulation	Required	4. Carbon cap	3. Fixed scale	5. Mandatory	2. Use in LCA
BREEAM NL	Netherlands	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	-
GPR	Netherlands	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	-
LiderA	Portugal	Certification	No	-	-	-	-
Green Homes Romania	Romania	Certification	Required	1. Carbon reporting	-	5. Mandatory	-
Green Zoom	Russia	Certification	No	-	-	-	-
BREEAM ES	Spain	Certification	Optional	1. Carbon reporting	-	1. Rating points	3. Buy low-carbon
VERDE	Spain	Certification	Required	3. Carbon rating	1. Self-declared	1. Rating points	3. Buy low-carbon
2000-Watt-Gebäude	Switzerland	Certification	Required	3. Carbon rating	3. Fixed scale	5. Mandatory	-
Minergie Eco and A	Switzerland	Certification	Required	4. Carbon cap	3. Fixed scale	5. Mandatory	-
SGNI (DGNB-CH)	Switzerland	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	-
SIA merkblatt 2032	Switzerland	Standard	Required	1. Carbon reporting	-	-	-
SNBS	Switzerland	Certification	Required	3. Carbon rating	3. Fixed scale	1. Rating points	2. Use in LCA

***List 2/2**: Continental European systems and their key embodied carbon reduction information*

5.4 NORTH AND SOUTH AMERICAN SYSTEMS

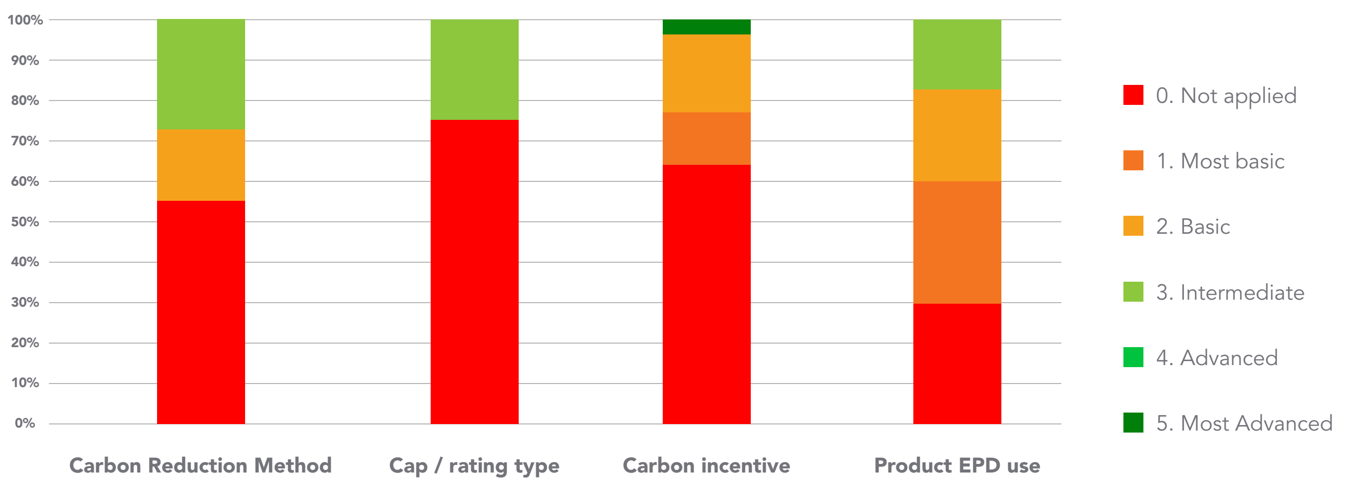
In this region, we identified 23 systems. The reader should note that systems such as LEED, Living Building Challenge, and Zero Certification, while originating from this region, are listed under International systems (**ref 4.1**). Additional provincial or state-level regulations are in use in the US and Canada. In addition, some cities, such as Vancouver, apply their own requirements. However, those are not in the scope of this review.

Aqua **Brazil**	**Zero Carbon Building Standard** **Canada**	**CES - Certificación de Edificios Sustentables** **Chile**	**BREEAM USA New Construction** **US**	**Minnesota B3 Guidelines** **US**
Buy Clean California Act (AB-262) **US**	**California Green Building Code 2016, Section 5.409 Life Cycle Assessment** **US**	**Green Globes** **US**	**International Green Construction Code** **US**	

Illustration: *systems using embodied carbon in North and South Americas. Trademarks owned by their respective owners.*

The below visual shows the level of sophistication of the region's approach in carbon reduction using the data below. For decoding the visual refer to the beginning of **chapter 5**.

Level of sophistication of carbon reduction methods in North & South America



SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP/RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
AQUA	Brazil	Certification	Optional	2. Carbon comparison	-	1. Rating points	2. Use in LCA
GBC Brasil Casa e Condomínio	Brazil	Certification	No	-	-	-	3. Buy low-carbon
GBC Brasil Zero Energy	Brazil	Certification	No	-	-	-	-
Built Green (Canada)	Canada	Certification	No	-	-	-	-
Public Services & Procurement Canada (PSPC)	Canada	Regulation	Required	1. Carbon reporting	1. Self-declared	2. Funding criteria	2. Use in LCA
Quebec's Wood Charter	Canada	Regulation	Required	2. Carbon comparison	1. Self-declared	2. Funding criteria	2. Use in LCA
Zero Carbon Building Standard	Canada	Certification	Required	1. Carbon reporting	-	5. Mandatory	2. Use in LCA
Certificación de Vivienda Sustentable	Chile	Certification	No	-	-	-	1. Documentation
CES - Certificación de Edificios Sustentables	Chile	Certification	Optional	1. Carbon reporting	-	-	3. Buy low-carbon
Casa Columbia	Colombia	Certification	No	-	-	-	3. Buy low-carbon
Criterios ambientales para el diseño y construcción de vivienda urbana	Colombia	Guideline	No	-	-	-	-
Codigo tecnico de construccion sostenible v2	Peru	Regulation	No	-	-	-	-
BREEAM USA New Construction	USA	Certification	Optional	Not determined	Not determined	Not determined	Not determined
Buy Clean California Act (AB-262)	USA	Regulation	Optional	Simplified method	-	2. Funding criteria	1. Documentation
ASTM E2921	USA	Standard	Optional	1. Carbon reporting	-	-	-
Built Green (United States) / Green Point	USA	Certification	No	-	-	-	-
California Green Building Code 2016	USA	Regulation	Optional	2. Carbon comparison	1. Self-declared	1. Rating points	1. Documentation
Green Globes	USA	Certification	Optional	2. Carbon comparison	1. Self-declared	1. Rating points	1. Documentation
Guiding Principles for Sustainable Federal Buildings	USA	Regulation	No - May use	Not determined	-	-	3. Buy low-carbon
International Green Construction Code	USA	Regulation	Optional	2. Carbon comparison	1. Self-declared	-	1. Documentation
LENSES	USA	Certification	No - May use	Not determined	-	-	-
Minnesota B3 Guidelines	USA	Regulation	Required	2. Carbon comparison	1. Self-declared	2. Funding criteria	2. Use in LCA
National Green Building Standard ICC-700	USA	Certification	No	-	-	-	-

List: *North & South American systems and their key embodied carbon reduction information*

5.5 ASIA-PACIFIC REGION SYSTEMS

In this region we identified 23 systems. In addition, some city-level requirements applied in Australian metropolises were excluded from the scope of this review. Furthermore, the Japanese Life Cycle Carbon Minus scheme was identified after the cut-off date of this report.

China Green Building Design Label (Three Star)
China

China Green Building Label (Three Star)
China

BEAM Plus
China

G-SEED
Korea

BCA Green Mark
Singapore

EEWH
Taiwan

EnviroDevelopment
Australia

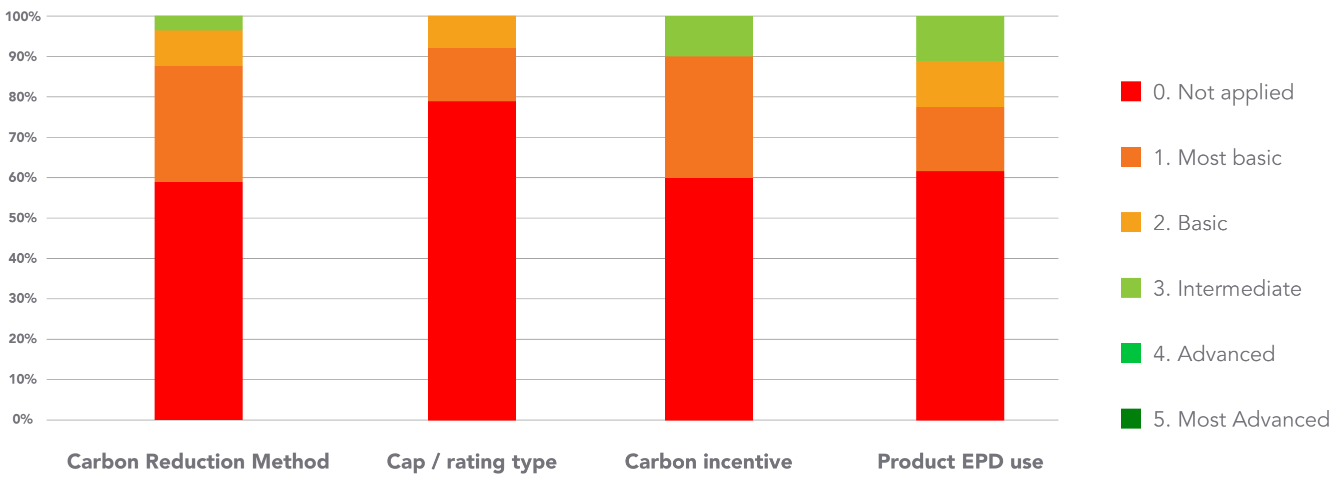
Green Star Australia
Australia

Green Star NZ
New Zealand

Illustration: *systems using embodied carbon in Asia-Pacific region. Trademarks owned by their respective owners.*

The below visual shows the level of sophistication of the region's approach in carbon reduction using the data below. For decoding the visual refer to the beginning of **chapter 5**.

Level of sophistication of carbon reduction methods in Asia-Pacific



SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP/RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
China Green Building Label (Three Star)	China	Certification	Optional	1. Carbon reporting	-	1. Rating points	-
China Green Building Design Label (Three Star)	China	Certification	Optional	1. Carbon reporting	-	1. Rating points	-
ESGB / GB/T 50378-2014	China	Standard	No	-	-	-	Not known
BEAM Plus	Hong Kong	Certification	Optional	1. Carbon reporting	-	3. Density bonus	-
IGBC Green New Buildings	India	Certification	No	-	-	-	1. Documentation
TERI-GRIHA	India	Certification	No	-	-	-	3. Buy low-carbon
GreenSHIP	Indonesia	Certification	No	-	-	-	Not known
CASBEE	Japan	Certification	No - Simplified	Simplified method	3. Fixed scale	1. Rating points	-
G-SEED	Korea	Certification	Optional	1. Carbon reporting	-	-	1. Documentation
Green Building Index	Malaysia	Certification	No	-	-	-	-
SEED-Sustainability in Energy and Environmental Development	Pakistan	Guideline	No	-	-	-	Not known
BERDE	Philippines	Certification	No	-	-	-	3. Buy low-carbon
BCA Green Mark	Singapore	Certification	Optional	1. Carbon reporting	-	3. Density bonus	1. Documentation
GreenSL	Sri Lanka	Certification	No	-	-	-	-
EEWH	Taiwan	Certification	Optional	Simplified method	3. Fixed scale	1. Rating points	1. Documentation
TREES Thailand	Thailand	Certification	No	-	-	-	-
LOTUS Rating system	Vietnam	Certification	No	-	-	-	-
Green Star Australia	Australia	Certification	Optional	2. Carbon comparison	1. Self-declared	1. Rating points	2. Use in LCA
EnviroDevelopment	Australia	Certification	Optional	3. Carbon rating	1. Self-declared	1. Rating points	2. Use in LCA
NABERS	Australia	Certification	No	-	-	-	-
National Carbon Offset Standard for Buildings	Australia	Certification	No	-	-	-	-
Green Star NZ	New Zealand	Certification	Optional	2. Carbon comparison	1. Self-declared	1. Rating points	3. Buy low-carbon
Home Star	New Zealand	Certification	No	-	-	-	-

***List**: Asian and Australasian systems and their key embodied carbon reduction information*

5.6 MIDDLE EAST AND AFRICAN SYSTEMS

In this region, we identified 9 systems. Use of LCA is an exception rather than the rule.

Konut
Turkey

***Illustration**: systems using embodied carbon in Middle East and Africa. Trademarks owned by their respective owners.*

SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP/ RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
Estidama Pearl Rating System	Abu Dhabi	Certification	No	-	-	-	-
Al Sa'fat - Dubai Green Building Evaluation System	Dubai	Certification	No	-	-	-	-
Green Building Standard SI-5281	Israel	Standard	No	-	-	-	-
Jordan Green Building Guide and Regulations	Jordan	Regulation	No	-	-	-	-
ARZ BRS	Lebanon	Certification	No	-	-	-	-
GSAS by GORD	Qatar	Certification	No - Simplified	Simplified method	-	1. Rating points	2. Use in LCA
GBCSA Net Zero/Net Positive Tool	South Africa	Certification	No - May use	Not determined	-	-	-
Green Star SA	South Africa	Certification	No	-	-	-	-
Konut	Turkey	Certification	Optional	1. Carbon reporting	-	1. Rating points	3. Buy low-carbon

***List**: Middle East and African systems and their embodied carbon reduction information*

6 CIVIL ENGINEERING EMBODIED CARBON REDUCTION SYSTEMS

The civil engineering works market differs in some respects from building construction. In many countries some types of infrastructure have a monopoly investor, usually a state agency or a state-owned company. Municipal infrastructure is typically invested in by the cities, as well as the local utilities (that may be also city-owned). This concentration of the market has led some infrastructure bodies to develop their own systems for embodied carbon reduction. In addition, some voluntary certification systems for infrastructure works are available.

This study identified 20 infrastructure-relevant systems consisting of 11 voluntary certifications, the balance consisting of 4 government-agency systems and 5 guidelines. Of the identified systems, 70% apply embodied carbon reduction or LCA methods. The most common approach is rating carbon performance compared to reference performance. In addition, 90% of the systems apply circular economy measures. The most common measures are promotion of recycled material use, waste reduction, and material efficiency.

Infrastructure sustainability
Australia

Canadian guide to greener roads
Canada

CEEQUAL International
International

Infrastructure sustainability
International

BREEAM for Infrastructure
International

Transport Infrastructure Ireland
Ireland

Bca Green Mark For Infrastructure
Singapore

CEEQUAL UK & Ireland
International

Greenroads
US

BE2ST - in Highways
US

Envision
US

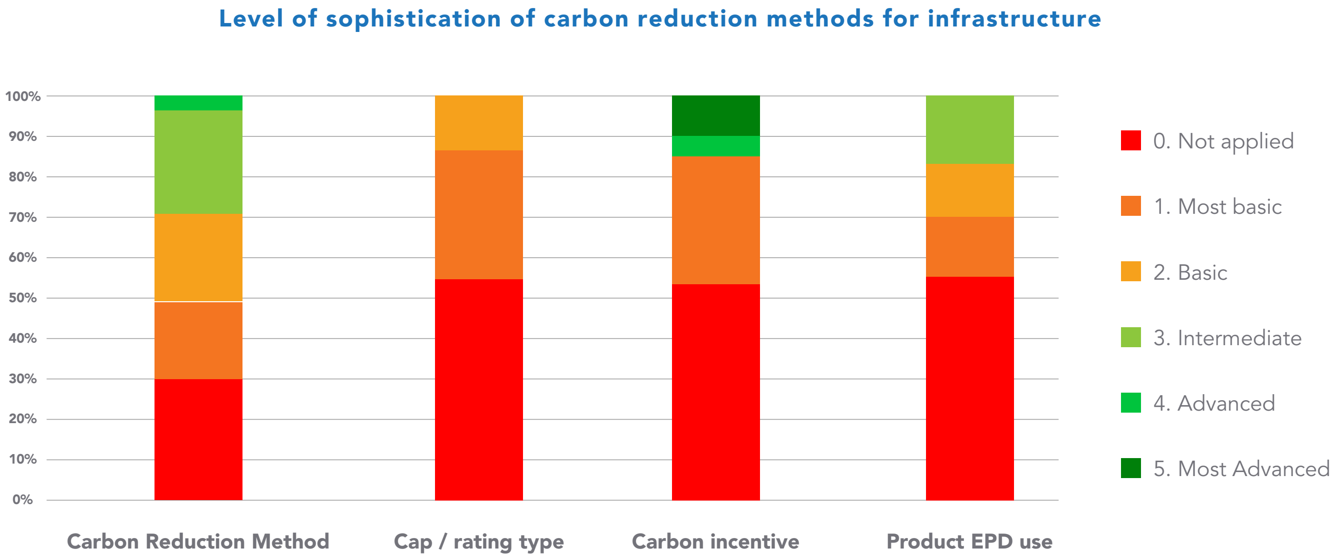
***Illustration**: infrastructure systems using embodied carbon internationally.*

Trademarks owned by their respective owners.

SYSTEM	COUNTRY	TYPE	EMBODIED CARBON	CARBON REDUCTION	CAP/RATING TYPE	CARBON INCENTIVE	PRODUCT EPD USE
Infrastructure Sustainability	Australia	Certification	Optional	3. Carbon rating	1. Self-declared	1. Rating points	1. Documentation
Canadian Guide for Greener Roads	Canada	Guideline	Optional	Not known	-	-	-
CWA 17089 Indicators for the sustainability performance of roads	Europe	Guideline	Required	1. Carbon reporting	-	-	2. Use in LCA
HQE Infrastructure	France	Certification	No	-	-	-	-
CEEQUAL International	International	Certification	Required	2. Carbon comparison	1. Self-declared	1. Rating points	-
Infrastructure Sustainability	International	Certification	Optional	3. Carbon rating	1. Self-declared	1. Rating points	1. Documentation
BREEAM for Infrastructure	International	Certification	Optional	1. Carbon reporting	-	1. Rating points	1. Documentation
Transport Infrastructure Ireland	Ireland	Regulation	Required	1. Carbon reporting	-	1. Rating points	-
Rijkswaterstaat procurement policy	Netherlands	Regulation	Required	3. Carbon rating	2. Methodology	4. Cash impact	3. Buy low-carbon
GSAS - Districts & Infrastructure & Railways	Qatar	Certification	No - Simplified	Simplified method	-	1. Rating points	2. Use in LCA
BCA Green Mark for Infrastructure	Singapore	Certification	Optional	2. Carbon comparison	-	1. Rating points	-
TDOK 2015:2017	Sweden	Regulation	Required	2. Carbon comparison	2. Methodology	5. Mandatory	3. Buy low-carbon
CEEQUAL UK & Ireland	UK	Certification	Required	2. Carbon comparison	1. Self-declared	1. Rating points	-
HS2 Technical Standard - Carbon footprinting and life cycle assessment	UK	Regulation	Required	4. Carbon cap	2. Methodology	5. Mandatory	2. Use in LCA
GreenLITES	USA	Guideline	No	-	-	-	-
STARS (Sustainable Transportation Analysis & Rating System)	USA	Guideline	No	-	-	-	-
INVEST (Infrastructure Voluntary Evaluation Sustainability Tool)	USA	Certification	No	-	-	-	-
Greenroads	USA	Certification	Optional	1. Carbon reporting	-	1. Rating points	-
BE2ST-in-Highways	USA	Guideline	Required	3. Carbon rating	1. Self-declared	1. Rating points	-
Envision	USA	Certification	Required	3. Carbon rating	1. Self-declared	1. Rating points	3. Buy low-carbon

***List**: Infrastructure systems and their key embodied carbon reduction information*

The below visual shows the level of sophistication of the region's approach in carbon reduction using the above data. For decoding the visual refer to the beginning of **chapter 5**.



7 COMPARISON OF REGIONAL DIFFERENCES

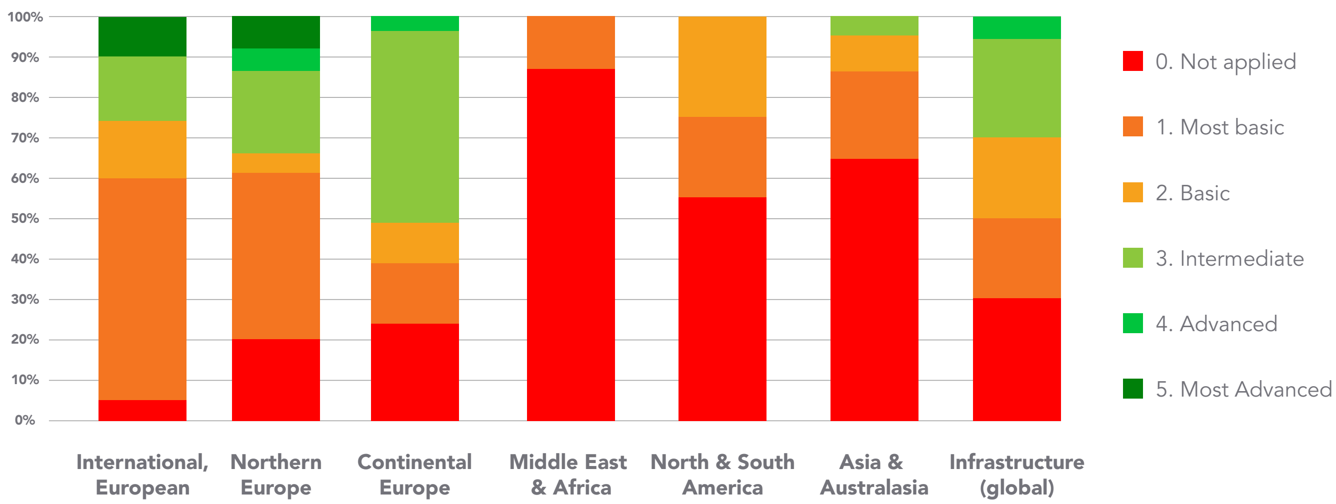
Reading the 'Relative share of ... by geography' graphics

The application of the embodied carbon reduction aspects for the systems vary geographically. The visuals in this section show the regional differences in the level of sophistication in the four embodied carbon reduction aspects studied for all systems: Carbon reduction method, cap/rating type, carbon incentive, and product EPD use. Each column shows the regional distribution for the methods in the systems used for buildings. The two rightmost columns show the global distribution for the methods for buildings and infrastructure, respectively.

7.1 CARBON REDUCTION METHODS APPLIED BY GEOGRAPHY

Regions vary in the use of efficient methods for reducing carbon impacts. For example, in Northern Europe, several embodied carbon cap and carbon rating systems are in place in locally used systems. The detailed explanations of the methods are in the **chapter 4.1**.

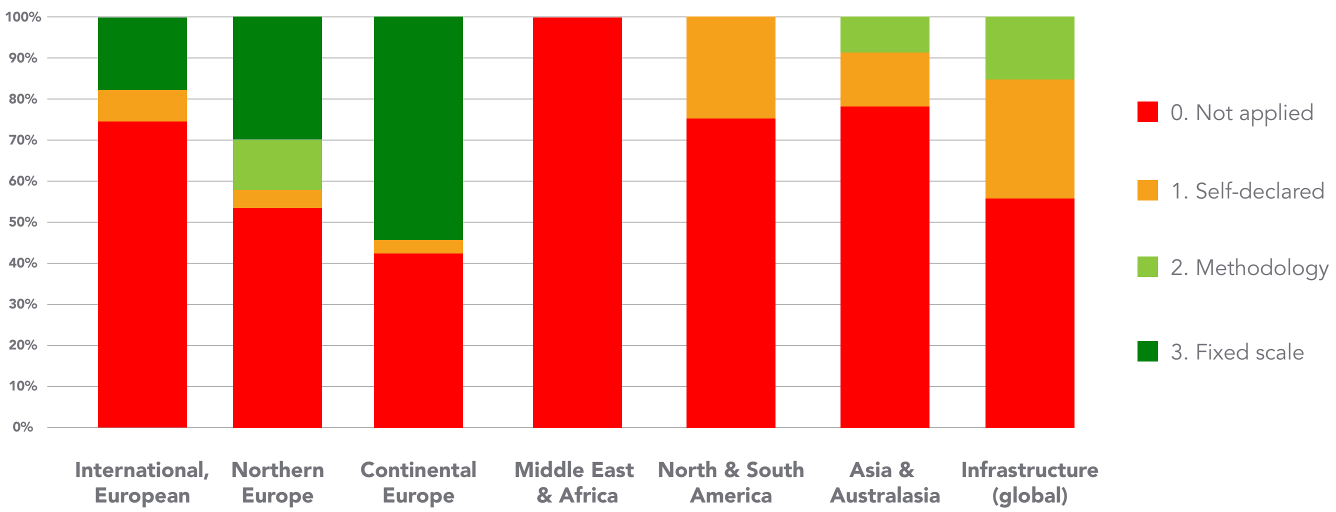
Relative share of different carbon reduction methods by geography



7.2 CARBON CAP/RATING METHODS APPLIED BY GEOGRAPHY

Continental Europe, followed by Northern Europe, is the leader in setting effective carbon caps or applying carbon ratings, as shown in the visual below. Definitions of the carbon cap/rating systems are given in **chapter 4.5.**

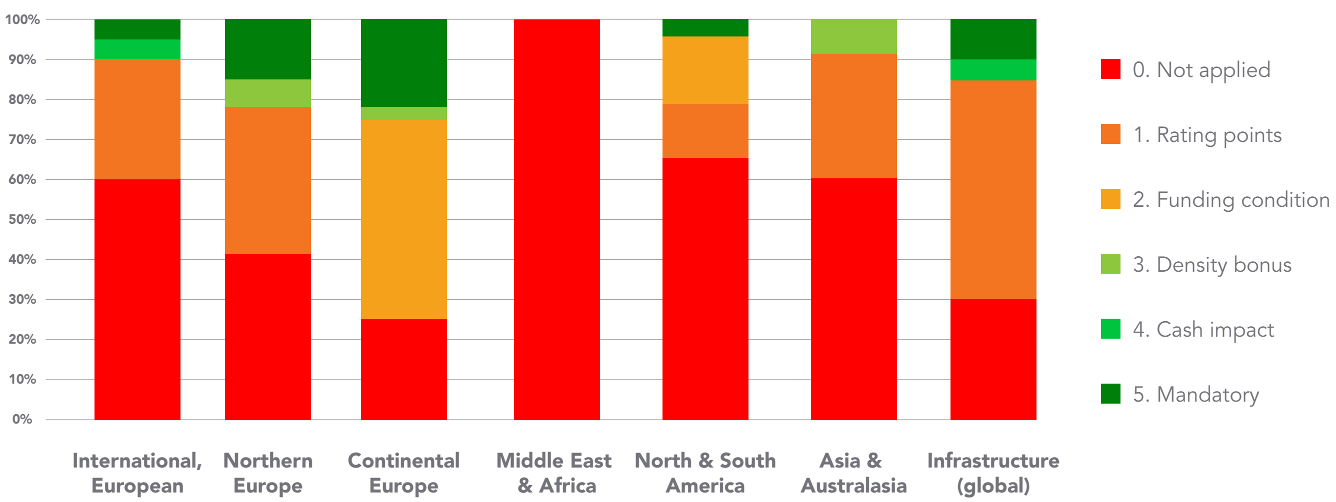
Relative share of different carbon cap / ratings by geography



7.3 CARBON INCENTIVES APPLIED BY GEOGRAPHY

The most effective carbon reduction incentives are applied in Continental Europe, while overall the global status is still rather applying for rating points in a certification system. North American systems apply this as a funding condition as well. These are outlined in **chapter 4.6**.

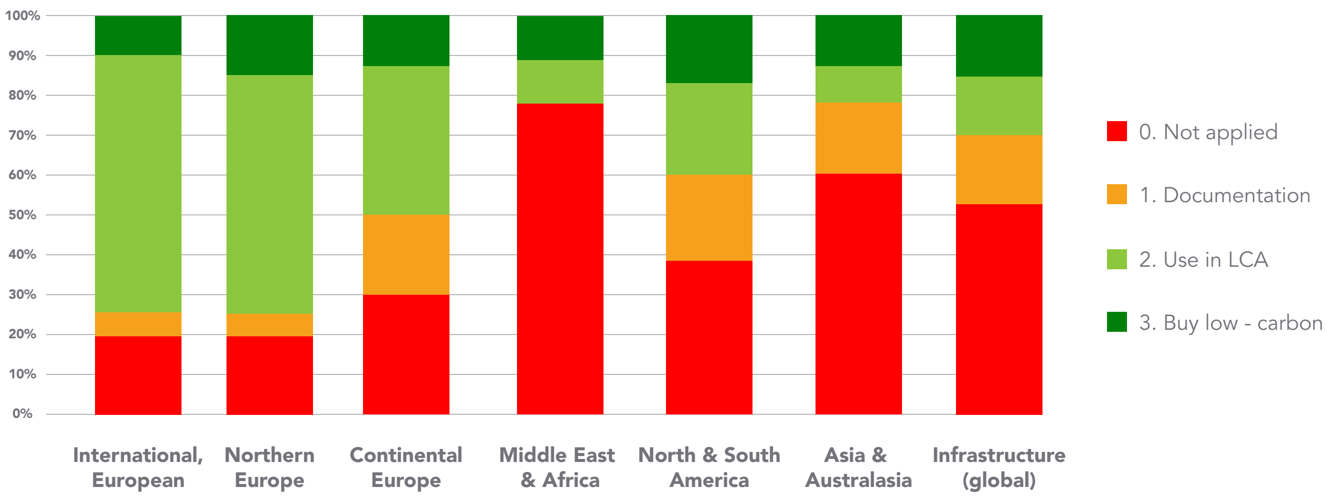
Relative share of different carbon incentives by geography

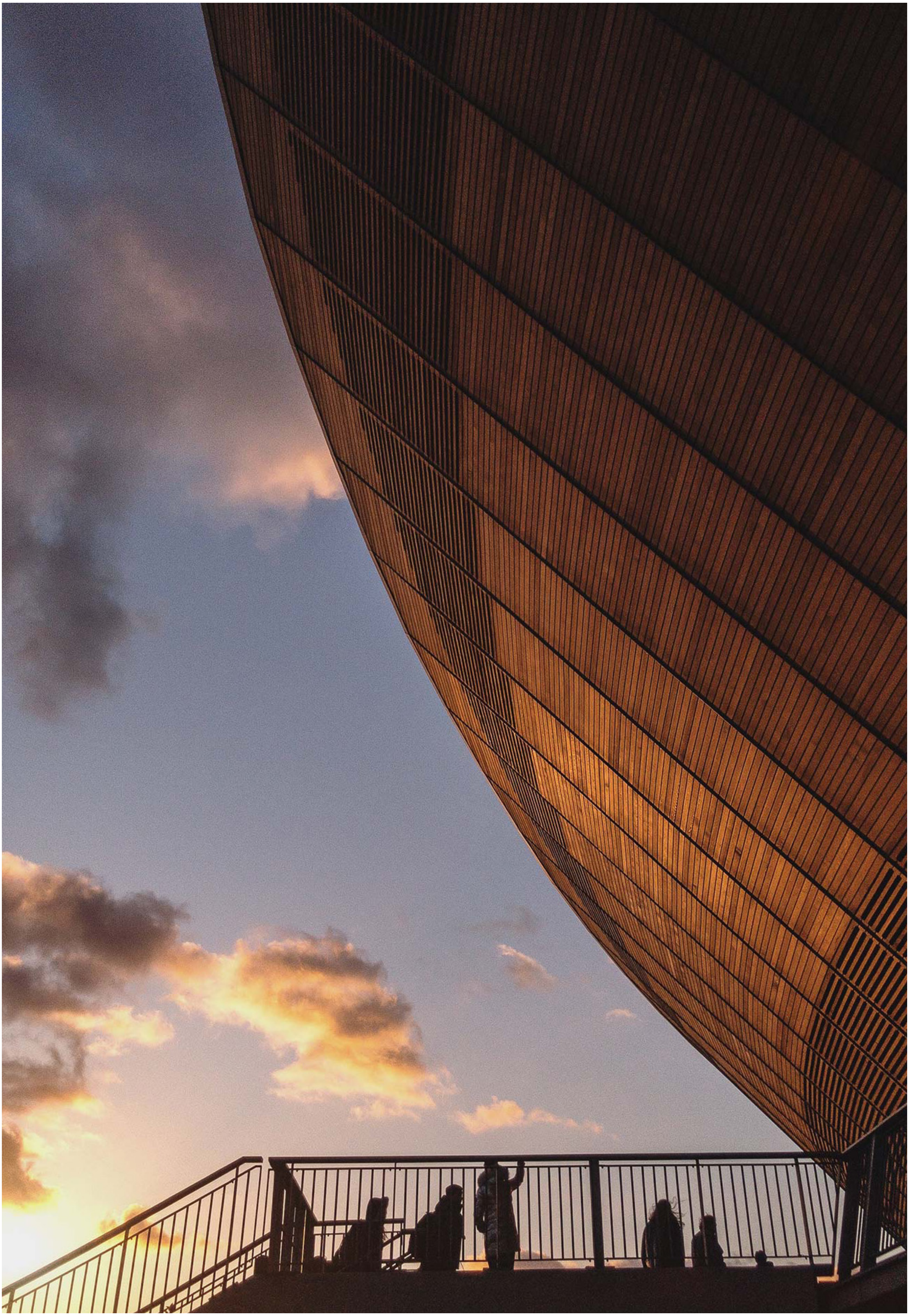


7.4 PRODUCT EPD USE BY GEOGRAPHY

Product EPD use is one of the more commonly-used best practices in all international systems as well as the European systems. The differences in the use of product EPDs in different systems are explained in **chapter 4.7**.

Relative share of different product EPD by geography





8 BEST PRACTICES FOR DESIGNING CARBON REDUCTION SYSTEMS

This review aims to promote the best practices in embodied carbon reduction, and this chapter explains them in detail. Each of these best practices has been applied by a large number of systems over a period of time, so they are all proven in practice. Besides these methods, other good practices also exist; however, they were not as useful or as proven.

8.1 TARGET THE EARLY PHASE OF THE PROJECT

Policies and measures targeting embodied carbon need to target the early phase when possible – for example, before planning permission. This is because low-carbon design practices, especially when they target embodied carbon, are the most efficient as well as most cost-effective in the early phases of a project. By introducing this requirement early on, it is possible to encourage materials awareness when designing structures and areas. The early phases of a project lock in the range of possible embodied carbon impacts, for better or worse. There are still opportunities to reduce the impacts later on, but their overall impact tends to be more limited, and bigger changes will be less cost-efficient.

When a carbon target has been set in the earliest phases of a project, it becomes a design target for the designers working on the project, and sets the embodied carbon constraints the design team needs to achieve. As the project progresses, carbon and cost are known in more detail, but also start to get locked in. This is visualized in the graphic below.

Project carbon performance and cost of changes

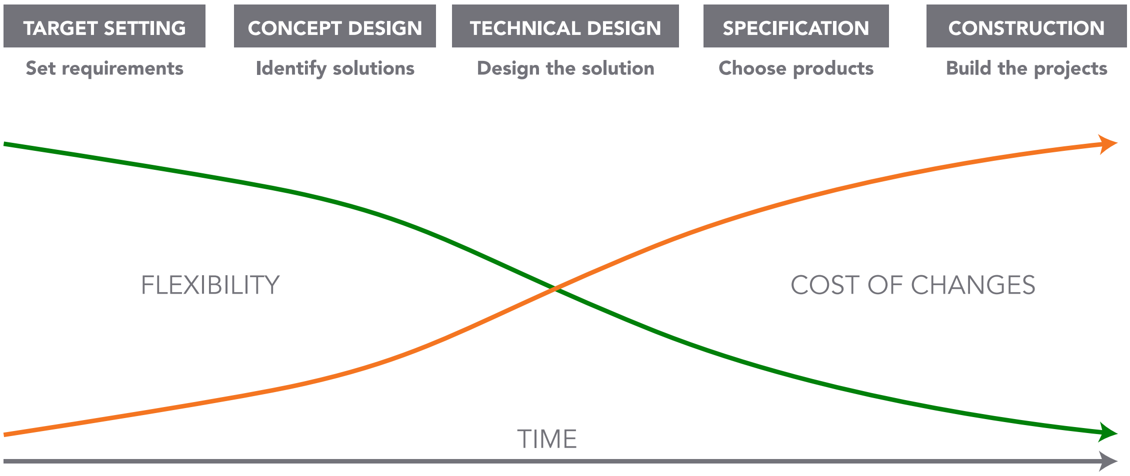


Illustration: *starting early is crucial to be able to reduce carbon emissions from a project*

This practice is applied well in the BREEAM UK NC 2018 certification, for example. This scheme requires users to submit both the concept phase baseline LCA analysis and design options before applying for planning permission from the council.

As a practical example, changing the site of the building later in the process is impossible. However, choosing a site requiring very deep foundations can more than double a project's embodied carbon emissions.

8.2 SET AN EMBODIED CARBON CAP FOR COMMON BUILDING TYPES

A total of 39 systems identified in this study have an effective carbon cap. Having a cap ensures all projects have to consider embodied carbon very early on. Performance targets are the kind of requirements that clients are used to set for their design teams. Besides setting the caps or rating levels, the way they are set matters. This is discussed in the next chapter.

Carbon impacts, embodied as well as operational, vary based on shape, size, site, and building type. Setting energy ratings and mandatory maximum energy consumption for buildings has been an effective means of reducing energy consumption of new buildings. The same logic applies to embodied carbon reductions. The caps can be initially set only for common building types, as those are the ones with the largest overall construction volume.

Caps will limit the use of carbon-intensive designs and constructions, and also incentivize decarbonization for projects whose carbon impacts almost reach the maximum allowed threshold. Setting caps should allow almost any well-managed project (i.e. one that is mindful of the cap) to meet the targets, leaving only designs and projects with very high impacts outside their scope. To achieve best results, it is advisable to combine the cap with carbon performance ratings or incentives.

A good example of this practice is the French government label system, Énergie Carbone, which includes mandatory caps and good performance target levels for both embodied carbon and life-cycle carbon.

For the purposes of embodied carbon reductions, it is more efficient to set reductions for carbon only. The use of LCA in several green building systems takes multiple environmental impact categories into consideration. Other impact categories may well be reported and considered, but to achieve climate goals the best practice is to set the targets only for carbon reduction. Having multiple optimization targets makes both the efficiency of analysis and the resulting decision-making harder. Moreover, it should be noted that some of the impacts are local (like the ones on water bodies) and are effectively regulated. Thus, this type of impact benefits less from marginal improvement than carbon impacts, which are not subject to effective regulations.

One approach to help countries to develop sufficient data for setting caps for common building types is the Carbon Heroes Benchmark Program, **www.carbonbenchmark.com**. The program collects data from building-level LCAs carried out by the industry and processes them to building-type specific regional averages. Partners of this program include the Irish, Dutch, Italian, Hungarian, and Romanian Green Building Councils, as well as Statsbygg of Norway and several private companies. The program creates benchmark levels for embodied carbon from A to G. The created benchmarks are building type- and region-specific.

8.3 APPLY A FIXED METHOD FOR SETTING RATING OR CARBON CAP VALUES

Effective rating or cap values work as targets which are taken into target setting by the construction client's initial brief, or are otherwise included into the early concept design. This means that they need to be predictable, targetable as well as achievable. The different methods to set the threshold values are explained in the **chapter 4.5**.

For systems working in a single country or context, best practice is to apply either a fixed scale for the threshold values, or a clear and normative methodology to develop those on a project level. Fixed threshold values will simplify the process from the point of view of the project team, as targets are given, but this comes at the cost of flexibility. The lost flexibility may mean that specific types of projects will be getting either an advantage or a disadvantage.

For systems working across a range of countries or contexts, a normative and verifiable methodology for defining threshold values for the projects is recommend. This allows for example accounting for differences to carbon performance arising from other building code, such as acoustic, fire-proofing, seismic and structural norms. Key parameters for designing a good methodology for threshold values are clarity, verifiability and sufficient, yet not burdensome level of detail.

8.4 PROVIDE INCENTIVES FOR ACHIEVING CARBON REDUCTIONS

This chapter discusses external incentives for carbon reduction policies. Reducing inefficient material use and wastage has a very direct financial benefit for construction management businesses. However, other players in the value chain do not directly share these benefits, so e.g. investors and designers have less incentive to design for material efficiency. The different types of incentives have been explained earlier in the **chapter 4.6**.

Ideally, the incentives should be proportional to the effort. Calibrating the incentives is demanding, and will in practice require simplified rules to allow project developers to target a specific performance level to unlock the incentive.

Many of the incentives identified work as part of a voluntary certification system by providing points. From decarbonization point of view, the optimal design for a voluntary certification design would be to make carbon reporting mandatory, and award points for better performance.

Incentives with direct financial value linked to carbon reduction are rare. The only cases with direct cash impact were identified in the public procurement domain from the Swedish Trafikverket and the Dutch Rijkswaterstaat, where carbon performance may unlock a cash bonus. More often, the incentive takes the form of a density bonus (additional construction rights). Cash bonuses were found in the social housing programs in Italy and Austria. However, those are not directly linked to carbon, but overall environmental performance.

Furthermore, several cities and systems provide benefits or requirements for projects that achieve a minimum level of green building rating (e.g. for LEED or BREEAM certification). When the rating system in question awards credits for carbon LCA performance, these credits allow an increase in the level of rating. Rating systems typically allow achieving the rating with multiple different methods, not just carbon. Therefore, this is an indirect method of promoting better carbon performance, and may not lead to substantial improvement.

Cities can promote carbon reduction more efficiently by, for example, providing an expedited permitting process for low carbon projects, and by requiring carbon performance reporting or meeting performance thresholds in tenders, land sales competitions, and zoning. Additionally, density bonus (or corresponding discount from municipal permitting fees) can be awarded for good performance.

8.5 SET RULES AND REQUIREMENTS BASED ON OFFICIAL STANDARDS

Standards provide comparability, trust and efficiency. In most countries, the role of official standards is enshrined in law for public procurement. Applying official standards benefits contractors as well as construction product manufacturers. Contractors benefit, as they can be ensured of a fair and comparable basis of assessment when evaluating solutions, and they can leverage standards-based solutions, processes, and methods when working with a variety of clients.

Construction products are traded internationally, and hence it's essential that manufacturers are able to report on and prove their product performance using International and European standards, without having to recreate the data and certifications for each country to which they introduce their products. This makes markets more competitive and reduces the cost of compliance to manufacturers, which also lowers costs for buyers.

The most used and robust standards for construction LCA available today are the ones developed by the CEN/TC 350, which include the EN 15804 for construction products and EN 15978 for buildings. A standard for civil engineering is in preparation. Besides being used in Europe, they are also applied in North America, Australia, the Middle East, and Asia. Recently, ISO 21930 was published, and its key technical provisions align with the EN 15804. This provides a basis of broad international comparability and conformity. **[6]**

Relying solely on ISO 14040 and ISO 14044 standards for construction works LCA is not advisable, as it leaves a great deal of room for interpretation and implementation of choices, thus preventing result comparability as well as allowing for greenwashing.

In this area, BREEAM and DGNB are exemplary at applying the standards-based assessments. In addition, all the countries where LCA is broadly adopted (see **7.1.**) are applying this practice.

8.6 SET OPEN COMPLIANCE REQUIREMENTS AND VERIFY OUTCOMES

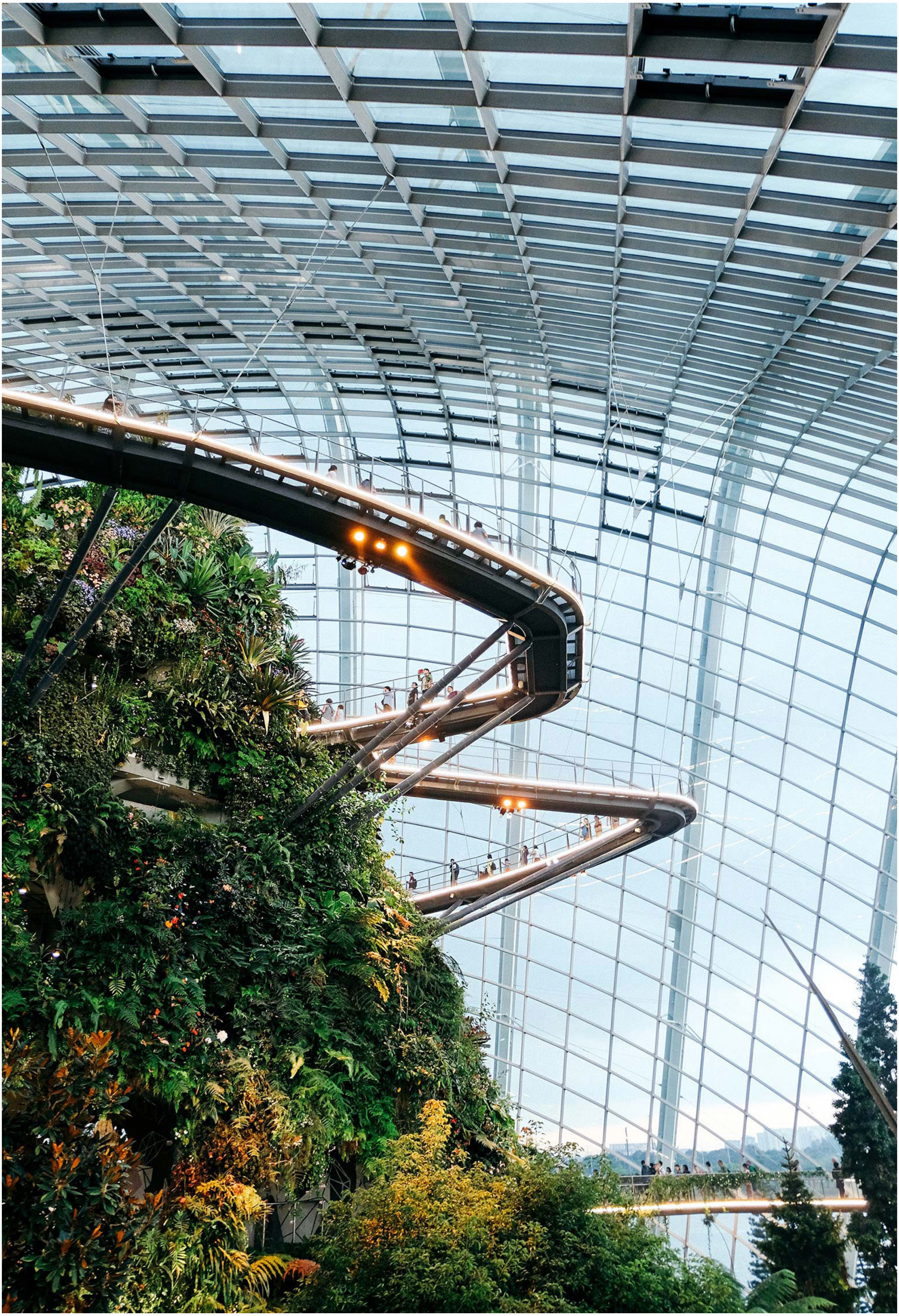
Open compliance requirements are a public assessment methodology which anyone can access and implement. This allows for innovation and market-driven improvement. Closed systems limit innovation, in particular the development of digital design technologies including building information models (BIM), parametric design and optimization, and integrated design processes. Closed systems may not have public methodology documents, and, in particular, they often limit the software and solutions that can be used for assessment.

As with any incentive, 'trust, but verify' is a solid practice. The verification is not a necessary component in reporting-only systems, but is a valuable component for systems where competitive advantage is influenced by embodied carbon. The verification can target the calculation tools, as well as LCA results. Some systems identified in this study appear open, yet work as partially closed systems in practice.

Verification of calculation tools ensures that all solutions implement the methodology exactly as required. This does not impose a single solution to the end users. This kind of mandatory verification for calculation tools is in place in France, the Netherlands, Switzerland, and the UK (BREEAM) for their respective national methodologies. These verifications are performed by appointed experts and necessary before the market introduction of any LCA software. **[7]**

For clarity, LCA software pre-verification is not a mandatory characteristic for an open system. For example, the Australian Green Star provides all information required, and does not require pre-approval of software solutions. Instead they inspect calculation results.

All the countries where LCA is broadly adopted (see **7.1.**) are fully open, with the exception of Austria's Ökoindex 3's rating scale, which is proprietary to IBO and not disclosed/available. BREEAM, Énergie Positive & Réduction Carbone and the Dutch MPG are very open systems.



9 SUCCESS CASES: COUNTRIES, BUILDINGS AND INFRASTRUCTURE

Despite the fact that embodied carbon reduction is relatively new, a number of green construction systems and governments have crafted solutions that combine numerous best practices and that have been shown to work in practice. This chapter shares some of those success cases.

9.1 SUCCESS CASES – DEVELOPING NATIONAL CAPABILITY

A few countries have been able to create a market environment where LCA is used for instructing building design in both public and private sector projects. In these countries it's a commonly available and requested analysis service, performed on a large number of construction projects, with experts and tools readily available. Governments have also played a role in this development, implementing policies that work together with the marketplace players. The methods have propagated and gained broader acceptance over a period of time.

The countries below were identified as good examples. In this section, we'll cover the Netherlands and Austria in more detail as France and Norway are covered partially via systems used in the building sector.

COUNTRY	# SYSTEMS	GOVERNMENT CONTRIBUTION	BUSINESS CONTRIBUTION
Austria	4	Housing subsidy and funds tied to green building methods that use LCA.	Development of building product environmental data, use of green building certifications.
France	7	The government has passed a law to regulate embodied carbon by 2020, this is now being piloted.	Development of building product EPDs, use in green building certifications, training programs.
Netherlands	5	Regulatory requirement to use LCA on new buildings since 2013.	Wide consensus on application, development of product information, training programs.
Norway	6	Requirement for government projects for LCA since a decade, boost to market development.	Wide consensus on application, development of product information, training programs.

9.1.1 THE NETHERLANDS – A REGULATORY CAP ON EMBODIED IMPACTS

The essential provisions of the Dutch construction regulations are set by the Building Act (Bouwbesluit), which consists of a law and a technically more detailed decree. The version of the Building Act that entered into force in January 2013 required all residential and office buildings whose surface exceeds 100m2 to account for their embodied impacts in the form of an LCA using the national assessment method and associated database. The method is based on EN 15804 and EN 15978 with national adaptations, including health impact accounting.

The assessment method applied converts the 11 LCA impact categories to a shadow price which is expressed in EUR. For example, the shadow price of carbon is 50 EUR/ton. This method does not consider use of energy or water during the building's life cycle. All impacts are transformed into a single monetary value, which is divided by the building gross floor area and assessment period length. The assessment period is 75 years for residential, 50 for offices. Combining the metric with different impacts reduces its decarbonization efficiency.

The regulation was revised with effect from January 2018 to set a mandatory environmental impact cap for buildings at 1.00 EUR per square meter and year. It is the first national regulation of this type in the world. This regulation applies only to new construction. The methodology is also applied to the commercial certifications used in the Netherlands, and will be soon used by the national infrastructure projects.

Both the national assessment method (Bepalingsmethode Milieuprestatie Gebouwen en GWW-werken) and the national environmental database (Nationale Milieudatabase) are published and updated by Stichting Bouwkwaliteit. Applying the method to a project requires the use of software that has been previously verified and approved. Approved tools are listed on the organization's **website**.

The shadow price weighing factors for different environmental impacts are shown below:

ENVIRONMENTAL IMPACT CATEGORIES	UNIT	WEIGHING (€/UNIT)
Depletion of abiotic resources (excluding fossil fuels)	**Sb eq**	**0,16 €**
Depletion fossil fuels	**Sb eq**	**0,16 €**
Global warming	**CO2 eq**	**0,05 €**
Depletion ozone layer	**CFK-11 eq**	**30 €**
Photochemical oxidant creation	**C2H4 eq**	**2 €**
Acidification	**SO2 eq**	**4 €**
Eutrophication	**PO4 eq**	**9 €**
Human toxicity	**1,4-DCB eq**	**0,09 €**
Fresh water aquatic eco toxicity	**1,4-DCB eq**	**0,03 €**
Marine aquatic eco toxicity	**1,4-DCB eq**	**0,0001 €**
Terrestrial eco toxicity	**1,4-DCB eq**	**0,06 €**

Illustration: *the Dutch shadow price weighing for the LCA impact categories*

9.1.2 AUSTRIA – VOLUNTARY APPLICATION IN A FEDERAL COUNTRY

Austria is a federation consisting of nine states. These states and the larger cities apply their own requirements and incentive policies. While there is no formal government-set methodology, IBO – Österreichisches Institut für Baubiologie und -ökologie has published what constitutes the nearest to a national embodied impact evaluation methodology. The name of this methodology is Ökoindex 3 (Ökologischer Kennwert der thermischen Gebäudehülle). This methodology is a weighted score of global warming potential (carbon footprint), primary energy depletion, and acidification, expressed as an A to E rating. The scale of performance has been fixed by IBO. The calculation data applied for these analyses are provided by Baubook, which is a limited company owned by a regional energy association and IBO. There are demands to revise this methodology to be in line with EN 15804 as well as to make public the method which has been used to establish the performance scales.

Austria has a governmental environmental rating system called klimaaktiv, which applies the Ökoindex 3 as the methodology for the building materials environmental impact assessment. Materials assessment is a mandatory part of the certification. Performing well in this certification can make residential buildings eligible for an additional environment-related subsidy. This certification has been applied to over 500 buildings.

Six of the nine Austrian states have applied Ökoindex 3 to their housing subsidy mechanisms alongside energy-related performance and features. These are Kärnten, Niederösterreich, Salzburg, Steiermark, Tirol, and Vorarlberg. The regulations are defined and managed at the level of the individual states, so they vary greatly. For example, in Tirol the embodied impact performance improvement is translated into cash using a scoring scheme, whereas in Vorarlberg, performance improvements release a 35-year low-interest loan.

All of these schemes are managed for specific policy purposes. Selected aspects of the Vorarlberg social housing funding scheme are shown below by way of example.

The funding scheme is for building new houses for low-income households, and consists of a 35-year loan with a fixed 1.75% interest rate. The loan has a fixed basic value, incremented by the number of children, and an additional bonus for low income families. There is an income limit for eligibility, and the maximum area covered by the scheme is 110 m2.

Voralberg energy and environmental bonuses for housing subsidies includes, for example:

- Improvement compared to reference heating: up to 180 € / m2
- Improvement of energy use carbon impacts: up to 180 € / m2
- Improvement compared to ÖköIndex 3 reference: up to 150 € / m2
- Wooden façade: 20 € / m2
- Renewable insulation: 30 € / m2

As shown above, the application of this policy involves a mix of performance-based and characteristic-based (type of material) criteria. However, Ökoindex 3 as such is purely performance-based.

9.2 SUCCESS CASES – BUILDING CERTIFICATION SYSTEMS

Several building certification systems have proven to be effective at promoting embodied carbon reduction. The systems here were selected because they apply different approaches and use the identified good practices for emissions reduction, yet are all effective.

SYSTEM	SUMMARY OF THE SYSTEM	STRENGTHS AND WEAKNESSES
BREEAM UK New Construction 2018, UK	Method to calculate building performance vs. benchmarks and encourage extensive optioneering. Exemplary credit available for additional work.	Reference values are clear and options are required before planning permission, making change possible. On the other hand, complex scheme and many separate requirements.
Energie+ Carbone-, France	Method to calculate carbon performance, report, and benchmark it. Combined to building energy regulation.	References are solid and clear, buildings can meet the "standard" level or the "low carbon" ambition. Calculation method slightly complex.
Futurebuilt, Norway	Method to get buildings to reduce life-cycle carbon by 50% calculated from national reference values, with third party verification at the end.	Clear and solid reference values for reduction. Verification in the end creates credibility. Starts very early in the process as well.

Other building certification systems applying good practices for embodied carbon reduction include the Swedish NollCO2, the German DGNB 2018, and Living Building Challenge, among others.

The key embodied carbon reduction parameters of these chosen systems are shown in the table below. Some of these systems also use a combination of different methods.

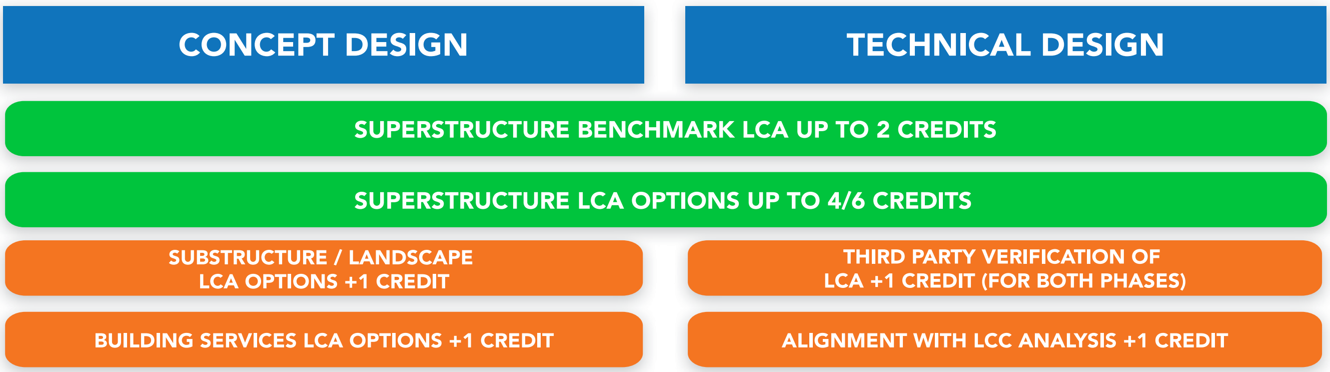
EMBODIED CARBON REDUCTION APPROACH	BREEAM UK NEW CONSTRUCTION 2018	ENERGIE+ CARBONE-, FRANCE	FUTUREBUILT, NORWAY
Carbon reduction	2. Carbon comparison	3. Carbon rating	3. Carbon rating
Cap/rating type	3. Fixed scale	3. Fixed scale	2. Methodology
Carbon incentive	1. Rating points	3. Density bonus	5. Mandatory
Product EPD use	1. Rating points	2. Use in LCA	2. Use in LCA

9.2.1 BREEAM UK NC 2018: BENCHMARKING AND EARLY PHASE FOCUS

BREEAM UK New Construction 2018 is a green building certification scheme created by BRE for non-residential construction in the UK. The BREEAM UK New Construction 2018 'Materials' category builds on BRE's long history of using LCA to assess environmental impacts of construction products in buildings. BREEAM UK New Construction 2018 incentivizes projects to start materials design at the 'Concept Design' stage and before planning permission is applied for, which allows for easy design adjustment when improvements are identified. The BREEAM Mat 01 Environmental impacts from construction products - Building life cycle assessment provides project teams credits for following:

1. Comparison of the LCA results with a benchmark during Concept Design and Technical Design (only offices, retail and industrial buildings)
2. Comparison of the LCA results with a benchmark during Technical Design
3. Comparing concept-level superstructure options during Concept Design
4. Comparing detailed superstructure options during Technical Design
5. Comparing concept-level substructure and hard landscaping options
6. Comparing concept-level core building services options (an exemplary credit)
7. Aligning LCA and Life-Cycle Costing for the options (an exemplary credit)
8. Third party verification of the accuracy of the LCA work (an exemplary credit)

The sequencing and credits for this analysis are shown in the visual below.



BREEAM LCA requirements are based on European Standard 15978, and BRE approves LCA tools prior allowing their use for BREEAM, using an objective, science-based methodology ensuring quality of data and assessment methods. Comparisons to the benchmarks are based on a normalized environmental impact methodology called Ecopoints, which is part of BRE's IMPACT LCA methodology. There is no mandatory minimum LCA performance requirement. The options comparisons can be based on carbon performance.

Overview of the identified best practices and their application in BREEAM UK New Construction 2018:

BEST PRACTICE	APPLIED?	HOW IT IS APPLIED
Target the early phase of the project	Yes	BREEAM does this by allowing parts of the credit to be achieved only if studies are done during the concept design stage and before planning permission is applied for.
Set embodied carbon cap for common building types	No	
Fixed method for setting rating or carbon cap values	Yes	Carbon rating applies BRE's IMPACT methodology and fixed scope of analysis.
Incentives for applying carbon reduction policies	Yes	Materials Life-Cycle Assessment is contributing up to 10% of the total credits in the system, thus, providing project teams with an incentive to focus on materials.
Set requirements based on official standards	Yes	BRE methodology is directly based on EN 15978 and related standards.
Set open compliance requirements and ensure they are upheld	Yes	BRE verifies all software and tools allowed for the certification, thus making sure comparisons are of sufficient quality to be robust support for decision making.

Further good practices in BREEAM 2018 are the added incentive of aligning LCA with LCC, as well as the incentive for having the LCA work third-party verified for accuracy. BREEAM requires results to be submitted in a technically processable format, which allows their easy verification and their use for future research, including further benchmark development.

However, the scope of the credit and incentive system creates inherent complexity, and rolling this out has required lot of communication and education effort from BRE as well as the industry. Furthermore, as the credit uses Ecopoints instead of carbon for the benchmark comparisons, it is not fully aligned with decarbonization objectives. Ecopoints does include global warming potential as its single most important contributor out of 11 components.

9.2.2 E+C- FRANCE: CARBON INTEGRATED INTO ENERGY REGULATION

The French government has primary legislation in place requiring regulation of carbon footprint of new buildings. Before acting the secondary legislation (decree), the government has prepared a pilot programme called Énergie Positive & Réduction Carbone (E+C-) for the regulatory method and tools. The methodology has two performance levels regarding carbon, one entry level and an improved performance level. The improved performance level can be used as criterion in public procurement or zoning, in effect working as a density bonus to build additional surface on the plot.

Key parameters and components of this methodology are:

- Methodology is issued by the French Ministry of Ecology, Energy, Sustainable Development and Spatial Planning. It has been developed together with the industry.
- Methodology requires the use of French generic data as well as INIES database, which gathers EPDs abiding by the European Standard 15804 and its French annex, and does not allow use of any other data for these assessments.
- Software tools implementing the methodology are verified and approved by government
- Energy performance of buildings calculations is a mandatory input for the LCA. This means that the LCA always integrates the energy assessments.
- Results are submitted to the government as online documents containing the essential inputs as well as the results in a technically analysed format. The result files are automatically verified for completeness of the content by upload portal. Result third-party verification is only done for projects applying for E+C- label.

The system provides a degree of adjustment to the carbon performance targets for projects with underground car parking, as well as high altitude projects. “Carbone 1” is the entry level, whereas “Carbone 2” is the good performance level. The values are given for single-family homes, multi-family residential, offices and as single group for all other building types. The methodology covers the entire building and its entire life-cycle, and allows use of fixed default values for simplifying assessment e.g. for electrification. The methodology has two types of carbon values, one for embodied carbon and another encompassing both embodied carbon and operational carbon. Both must be met at once. The embodied carbon caps are increased by 700 kg CO2e for each above-ground parking place and by 3000 kg CO2e for each underground parking place the local zoning bylaws require from the project (as long as those places are also built by the builder). The methodology calculates the values for a 50-year period, and divides it by total building area.

The embodied carbon limit values by building type are shown in the table below.

BUILDING TYPE	ENTRY LEVEL: CARBONE 1 – KG CO2E / M2	GOOD PERFORMANCE: CARBONE 2 – KG CO2E / M2
Single family or row houses	700	650
Apartment buildings	800	750
Office buildings	1050	900
Other regulated building types	1050	750

The application of this methodology is presently voluntary during the pilot period. It's included in the draft energy and environmental regulation for 2020. The methodology can also be used by willing cities to provide a 15% density bonus for projects meeting the carbon performance threshold. Cities make this decision independently.

Overview of the identified best practices and their application in E+C-:

BEST PRACTICE	APPLIED?	HOW IT IS APPLIED
Target the early phase of the project	No	
Set embodied carbon cap for common building types	Yes	Carbon caps are defined for building types in the methodology.
Fixed method for setting rating or carbon cap values	Yes	Methodology for setting the carbon cap and rating values is well defined.
Incentives for applying carbon reduction policies	Yes	Incentives can be created by city level decisions; the methodology enables this. Financial incentives for social housing were implemented in 2017 and 2018. A law requires new public constructions to assess their environmental performance according to E+C- methodology.
Set requirements based on official standards	Yes	Methodology is based on EN 15978 with some local adaptations.
Set open compliance requirements and ensure they are upheld	Yes	Methodology is fully open and all software tools are pre-verified.

9.2.3 FUTUREBUILT, NORWAY: 50% LIFE-CYCLE CARBON REDUCTIONS

FutureBuilt is a decade-long pilot program in Norway to provide skills, experience, and proof on how to design and construct buildings and halve their life-cycle emissions. The FutureBuilt program aims to include at least 50 projects and share experiences and results from these to the construction branch, and to a wider audience as well. The program is a result of cooperation with several municipalities, state bodies and financing organisations as well as industry associations.

FutureBuilt program's 2018 version is based on the Norwegian Standard NS 3720 Method for greenhouse gas calculations for buildings. The calculations are done for a 60-years period.

Each project shall have (at a minimum) four calculations, including:

- Reference building in the beginning of concept design (as explained below)
- Targeted building, in the early design phase. This has to show at least a 50% reduction in greenhouse gas emissions compared to the reference building.
- Actual building – as built. In this phase, all products sourced with EPDs must use EPDs for the calculation.
- Extended commissioning status – two years in use. Here, all energy use and transport emissions must be using the realized consumption and actual travel pattern data.

FutureBuilt methodology provides specific rules for calculating the baseline emissions (referansebyg), from which the emissions reductions are calculated. The reference building calculation method is very detailed, and consists of both process rules as well as calculation mechanism supporting it. The reference performance is based on energy regulation for building types, building size, floor number and type-specific material use for each part of the building, and location and type specific transport patterns as well as other choices allowing adjusment of, for example, foundation work due to site specific foundation conditions..

Uniquely, the FutureBuilt scope includes also transport of the users of the buildings in the use phase, 60 years, which makes the selection of a site close to a public transport hub/city center essential for the carbon performance of the building. FutureBuilt demands the project to appoint an emissions tracking expert, and they have to report the greenhouse gas emissions of the project at various stages, including at completion (as built).

The visualization below shows how this is achieved in the different stages of a project:

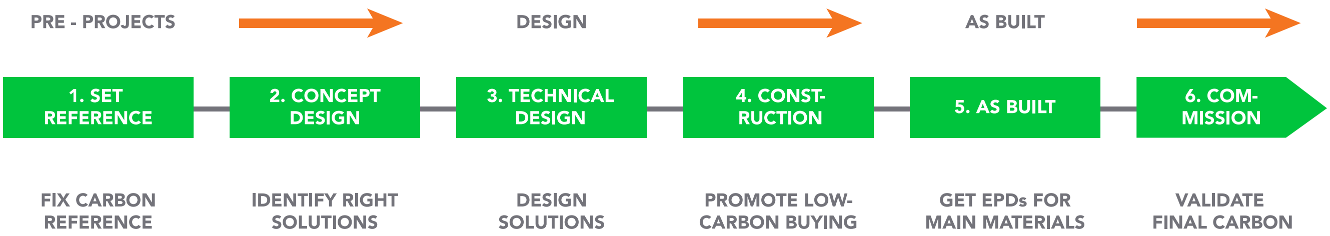


***Illustration**: The FutureBuilt process outline to implement carbon reductions*

The Norwegian government property arm Statsbygg implements a similar process for improving its own projects. This type of methodology is also used by other Norwegian investors. Some of the FutureBuilt projects also received energy investment subsidies.

BEST PRACTICE	APPLIED?	HOW IT IS APPLIED
Target the early phase of the project	Yes	Projects have to decide to become FutureBuilt project very early on.
Set embodied carbon cap for common building types	No	
Fixed method for setting rating or carbon cap values	Yes	Method for setting rating or carbon cap values is well defined.
Incentives for applying carbon reduction policies	Yes	FutureBuilt covers some external expert costs and provides broad communication. The municipalities give these projects a 'fast track'/priority to get building permits and other allowances needed, in addition to reduced fees for building permits.
Set requirements based on official standards	Yes	FutureBuilt refers to NS 3720 standard (based on EN 15978) from the time when NS 3720 is available.
Set open compliance requirements and ensure they are upheld	Yes	Methodology is open, and process includes several verification points, including publishing the actual results.

9.3 SUCCESS CASES – CIVIL ENGINEERING DESIGN AND PROCUREMENT

In the civil engineering field, projects are difficult to compare. This makes a carbon reduction system broadly as strong as its ability to drive actual impact reductions as opposed to notional reductions. In this area, three systems stand out. These are all operated by governmental clients and are High Speed Two from UK, Trafikverket from Sweden, and Rijkswaterstaat from the Netherlands. The first two are selected here as examples, as the detailed process documentation for the Dutch methodology was not available.

9.3.1 HIGH SPEED TWO, UK: CONTRACTUAL CARBON REDUCTION

High Speed 2 (HS2) is a high-speed railway under construction in the United Kingdom which, when completed, will connect London, Birmingham, the East Midlands, Leeds, and Manchester. The project is estimated to cost £56 billion and it's developed by a government- owned company. The carbon impact of the project has been subjected to several studies, especially since train travel speeds will reach up to 360 km per hour, creating substantial drag.

The London to West Midlands Environmental Statement published in 2013 reported a range of values for the embodied carbon impacts of the scheme; between 3.7 and 4.7 MtCO2e for construction products and between 1.6 and 1.8 MtCO2e from transport and construction process activities.

HS2 construction projects are awarded to a number of joint ventures, who each are required to report on LCA performance of the assets under construction, and deliver verified impact reduction requirements. Joint ventures are also required to achieve certified PAS 2080 compliance to show carbon management capability. The joint ventures have developed baselines and are required to report to HS2 periodically on the advancement of the design.

HS2 has written its own LCA methodology, which is based on EN 15804 and EN 15978 standards, PAS 2080 Carbon Management in Infrastructure, and applies elements of BREEAM certification. The methodology considers the full life-cycle of an asset over 120 years, and covers 11 life-cycle impact categories and four materials efficiency metrics. These also include use phase energy consumption, repair and replacement activities.

HS2 reduction requirements for joint ventures for carbon reduction from the baseline values are 50% for civils, stations and rail systems. Good performance against these reduction requirements puts joint ventures at an advantage for winning new tenders from the HS2 program. It is worth noting that while the HS2 methodology covers other LCA impact categories, the performance evaluation is based on carbon reduction.

9.3.2 TRAFIKVERKET, SWEDEN: CARBON IN PUBLIC PROCUREMENT

Swedish Trafikverket is the national transport agency, in charge of national road and rail transport infrastructure. Trafikverket has implemented since 2015 a policy to require all new projects whose investment budget is at least 50 million Swedish crowns (4,8 M€ or $5,5M) to report, reduce and document greenhouse gases and energy use from design to delivery. This is part of Trafikverket's work to meet overall goal to reduce emissions by 30% by 2025 compared to year 2015, and to achieve climate neutral infrastructure construction by 2045.

The analyses are conducted alongside investment cost assessments through several stages, ranging from consideration of different system solutions to concept design, detailed design, contracting, construction, and acceptance of delivery. In the initial phase, several different options could be evaluated. The initial analyses are done by Trafikverket internally, whereas the contractor is responsible for delivering the final resulting embodied energy and carbon performance data.

The analyses carried out internally at Trafikverket are carried out using Trafikverket own tool, which includes generic default LCA data that is appropriate for Swedish infrastructure works. Contractors are allowed to design and quantify the emissions using such means as they wish to until the final results are submitted. Submitting this uses again the Trafikverket tool. The contractors are allowed to use verified EPDs complying with EN 15804 for products used, and in absence of EPDs for specific products, the average database can be used.

Trafikverket policies regarding climate calculations and climate requirements are defined in two guidelines. Those are Klimatkalkyl- infrastrukturhållningens energianvändning och klimatpåverkan i ett livscykelperspektiv (TDOK 2015:0007) and Klimatkrav I planläggning, byggskede, Underhåll och på tekniskt godkänt järnvägsmateriel (TDOK 2015:0480).

At level of individual tenders, the methodology has also been used to set and follow up climate requirements in terms of contract clauses. A baseline is then predefined by Trafikverket, and a certain reduction in greenhouse gas emissions compared to that baseline is required. Beating the target carbon performance may award a bonus.

Trafikverket has further policies to reduce climate impacts from materials, which were first introduced to the procurement of concrete sleepers, and has now been extended to steel and fuels. These requirements may be further extended also to other product groups.

For product groups, where climate requirements are set, suppliers must perform better than required performance level. Further financial incentives are possible for achieving significant improvements. However, there is no fixed mechanism for this.

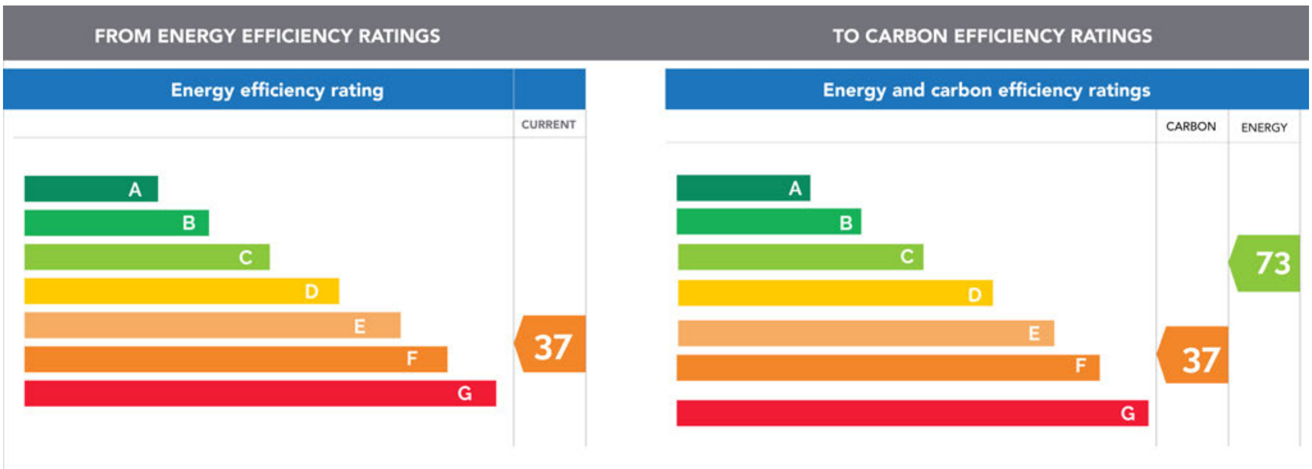
10 OUTLOOK FOR EMBODIED CARBON REDUCTION POLICIES

The past five years have seen embodied carbon and LCA become a standard feature of commercial as well as governmental green building systems. In all likelihood, when you are reading this study, at least one new system addressing embodied carbon has been launched somewhere. While this field is still relatively recent, best practises have started to emerge.

UNTIL EMBODIED CARBON IS REGULATED, IT'S UP TO CITIES AND OWNERS TO ACT ON IT

The first regulatory limits for LCA-based materials impacts are in force in the Netherlands, with several other countries following suit. France and the Nordic countries in particular are developing new regulations to address embodied carbon. Some countries intend to combine materials regulation with energy regulation, whereas others maintain the two separated.

Whether the two are separated or not, the overarching theme of the regulatory development is to eventually be able to handle embodied carbon as a regulated aspect in the same way as energy efficiency ratings are, for example, under European and other regulations, with highly standardized calculation methods and cost-efficient and robust processes. These systems in turn are well suited also for setting e.g. city level requirements that are stricter than the requirements of the legislation, possibly granting a density bonus or other benefit.



Voluntary green building certification systems can be expected to become more demanding in terms of transparency, methodologies, and compliance of the embodied carbon and LCA methods applied. This move is motivated by the need to have a robust basis to rate projects based on carbon performance. Some systems have started verifying and approving LCA tools, allowing for innovation and competition, while ensuring verified quality for users.

Eventually this capability will be integrated to other design tools used for code compliance such as energy performance tools and building design tools, such as architectural or structural software packages, eventually moving to computerized design optimization. Leading software solutions enable this already today.

Managing embodied carbon is a new skill. As with all skills, it needs to be learned and applied in practice before being mastered. Experience from voluntary certifications, pilot programs and projects that adopt the defined best practices prepares market players effectively for applying it in a large scale as part of building regulations.

The need for reducing embodied carbon is the most pressing where population grows. However, as some of fastest growing countries lack mandatory energy codes, it seems probable that the initial development will happen via voluntary certifications, or be driven by cities and investors.

This leaves large cities and investors an extraordinary opportunity to drive the change for the better via their own requirements and policies, and in case of cities, via zoning regulations, land use and green development policies.

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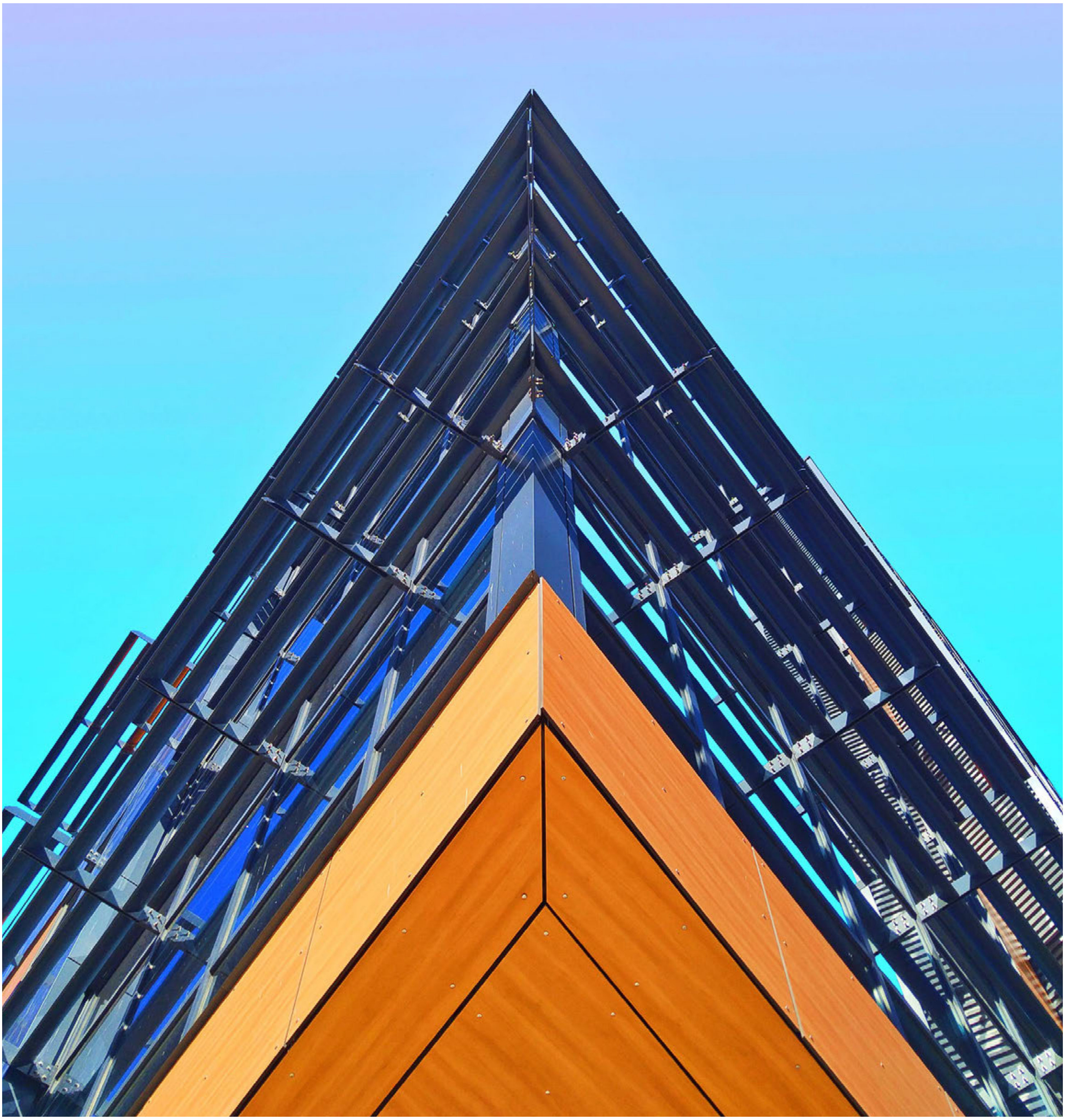

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