



EMBODIED CARBON OF BUILDINGS AND INFRASTRUCTURE

INTERNATIONAL POLICY REVIEW

September 2017

“Embodied Carbon of Buildings and Infrastructure—International Policy Review” was commissioned by Forestry Innovation Investment Ltd (FII). It may be electronically downloaded for information only, and without charge, from naturallywood.com.

Disclaimer

The opinions and recommendations in this report are those of the authors, and in no way should be taken to represent the views of FII, the report reviewers, or any of the subject-matter experts consulted during the course of the research. This report was commissioned by FII to better understand international actions to address embodied carbon, and is intended to be purely informational in nature and FII does not assume any responsibility for the accuracy or completeness of the information in this published work or its fitness for any particular purpose.

This published work is designed to provide authoritative information, but is not intended to provide professional advice. Users are responsible for exercising professional knowledge and judgement in the application and use of the information contained in this published work. Under no circumstances will any one or more of FII, the report reviewers, or any of the subject-matter experts consulted during the course of the research be liable to any person or business entity for any loss, costs or damages of any kind resulting from their use of this published work.



**Forestry Innovation
Investment**

naturally:wood[®]

British Columbia wood. Sustainable by nature. Innovative by design.

AUTHORS

Authors
Ryan Zizzo, Zizzo Strategy Inc.
Joanna Kyriazis, Zizzo Strategy Inc.
Helen Goodland, Brantwood Consulting

Contributors
Panu Pasanen, Bionova Ltd.

Cover image: Grandview Heights Aquatic Centre, Surrey, B.C.

Photographer: Ema Peter Photography. Image Courtesy of HCMA Architecture + Design

ACKNOWLEDGEMENTS

The authors would like to thank the following individuals for providing information and insight during the research and drafting of this report.

Jennifer O'Connor, Athena Sustainable Materials Institute

James Salazar, Athena Sustainable Materials Institute

Agnes Schuurmans, member of technical committee of Stichting Bouwkwiteit (SBK), The Netherlands

Dr. Tanja Brockmann, Division Construction and Environment, Federal Institute for Building, Urban Affairs and Spatial Development (BBSR), Germany

Nicolas Kerz, Federal Institute for Building, Urban Affairs and Spatial Development (BBSR), Germany

Catherine De Wolf, PhD Candidate, Massachusetts Institute of Technology (MIT) (assisted with research on Belgium)

Lisa Wastiels, Deputy Head of Lab of Sustainable Development, Belgian Building Research Institute

Flavie Lowres, British Research Establishment (BRE), UK

Susanna Toller, Swedish Transport Administration (Trafikverket)

Severin Lenel, Intep, Switzerland

Laurent Guldner, Florian Piton and Mickaël Thiery, Ministère de l'Environnement, de l'Énergie et de la Mer et Ministère du Logement et de l'Habitat Durable, France

Cécile Beaudard, Solinnen, France

Kate Simonen, University of Washington, USA

Craig Boyle, Public Services and Procurement Canada

Andrew Pape-Salmon, Government of British Columbia

Bill MacKinnon, B.C. Housing

Sean Pander and Patrick Enright, City of Vancouver

EXECUTIVE SUMMARY

Addressing greenhouse gas (GHG) emissions from buildings and infrastructure is a key component of the global fight against climate change. Increasingly, the importance of taking a life-cycle view towards reducing total construction-sector GHG emissions is being acknowledged. This involves considering embodied GHG emissions (commonly referred to as “embodied carbon”) *in addition to* the current focus on operational GHG emissions. Embodied carbon in construction refers to the GHG emissions associated with the manufacturing, maintenance, and decommissioning of a structure.

It has been estimated that approximately 20% of GHG emissions are embodied in the construction sector.¹ This report was commissioned by Forestry Innovation Investment Ltd. to better understand the approaches by leading countries to addressing embodied carbon and the best practices that could be applied elsewhere. The findings and recommendations in this report are based on a review of seven leading examples (Belgium, France, Germany, The Netherlands, Sweden, Switzerland, and the United Kingdom) that have implemented policies and programs that are intended to reduce embodied GHG emissions of buildings and infrastructure projects. Two more examples (Finland and Singapore) that are in the process of development are also examined. The report offers best practices for consideration and a potential menu of policy options that could reduce the impacts of buildings on the environment over their life cycle.

This report is of interest for any jurisdiction that has responsibility for the development and construction of buildings and/or for sustainability and climate change issues. It is also relevant to those responsible for the procurement of public construction projects and civic infrastructure projects. Finally, this report may also be of interest to businesses, design professionals, building product manufacturers and suppliers, non-governmental organizations, and other stakeholders who are involved in the design and construction of green buildings and infrastructure.

Throughout this report, a broad definition for the term “policy” has been used. In other words, the review has not been limited to government regulatory instruments. Market mechanisms, calls-to-action, and overarching stated intentions are included where appropriate and have shown to be influential.

Based on the review of international best practices, an embodied carbon framework may be structured to support the following aspirations:

1. Support climate-change mitigation commitments.
2. Address GHG reductions not currently included in the context of buildings and infrastructure.

¹Tatsuo, O. et al. 2014. "Introduction of Annex 57 – Evaluation of Embodied Energy and Carbon Dioxide Emissions for Construction Worldwide". Proceedings SB 14, Barcelona.
www.irbnet.de/daten/iconda/null_DC28086.pdf

3. Establish performance criteria and incentives to drive measurable reduction in embodied carbon in new construction and retrofits.
4. Leverage best practices and experiences from international leaders to promote understanding of embodied and life-cycle carbon.
5. Build industry capacity for making informed decisions about the impacts of embodied carbon in buildings and for performing whole-building Life Cycle Assessment (LCA).
6. Complement and build upon existing energy/GHG policy goals and standards.

Jurisdictions could achieve various climate-change and other goals by adopting an embodied carbon initiative for construction. The benefits of adopting such a policy could include, but would not be limited to:

- Support of municipal, provincial, state or federal goals for climate-change mitigation.
- Achievement of measurable, short-term GHG reductions.
- Reduction of other environmental impacts of construction besides carbon.

KEY FINDINGS

The following insights from the review of global best practices and the assessment of the current domestic policy environment could provide insights into the development of an embodied carbon initiative.

1. Life-cycle perspectives are key to understanding the long-term impacts of construction-related GHG emissions.

Many recent climate-change policies reference “net-zero” (either energy or carbon) for buildings. However, a building is not truly “net-zero” until it has paid back or offset its initial carbon debt (i.e., the embodied GHG emissions associated with materials, manufacturing, and other processes that are upstream of building occupancy) and has considered its future carbon emissions in terms of end-of-life decommissioning. Jurisdictions with policies that are driving towards sustainable consumption and production goals or towards a “circular economy” are on the path towards addressing embodied carbon because these policies demonstrate an understanding of the importance of having a life-cycle perspective in order to reduce GHG emissions in absolute terms rather than by merely shifting GHG emissions between life-cycle phases.

2. An embodied carbon policy tackles GHG emissions reductions not currently being addressed in the context of buildings and infrastructure on the scale and in the time frame required to meet national and/or international GHG emissions reductions commitments.

Climate-change policies and programs generally do not account for embodied carbon in buildings and infrastructure despite embodied carbon being an important piece in the overall emissions profile of many jurisdictions. Not only is embodied carbon a significant proportion of a building’s overall carbon footprint, but reductions in embodied carbon are

realized in the short term, which is a critical consideration given that global carbon emissions need to be urgently reduced to meet international climate commitments.

3. In order to reduce embodied carbon in new and existing construction, carbon incentives should be tied to measurable performance outcomes.

Proxy measures and prescriptive solutions with a presumed GHG emissions reduction benefit should be replaced by incentives based on quantifiable and comparable results. Prescriptive sustainable design guidelines and incentives simplify decision-making but can limit creative problem-solving and may not deliver actual reductions in environmental impact. Prescriptive strategies also do not allow for design flexibility, are limited in scope, and are not tied to measurable performance outcomes. Whole-building LCA, on the other hand, is an internationally accepted science. It is intended to be used by project teams to quantify embodied carbon and other environmental impacts in buildings, and can be the basis of a life-cycle carbon policy.

4. Ample precedents of best practices and program design are available for jurisdictions to draw on.

The leading international jurisdictions reviewed in this report have explored a variety of approaches, thereby providing helpful test cases for all types of policies and programs—from voluntary reporting to mandatory performance standards. The following countries are taking significant action to reduce embodied carbon in construction, either through regulatory policy or strong incentives:

- **Belgium:** Has a national EPD database. Manufacturers wishing to make environmental marketing claims must submit an EPD to the database.
- **France:** Offers building labels and incentives for voluntarily meeting both embodied carbon and net-zero energy consumption targets. The voluntary pilot program is expected to become mandatory in 2020. France has a national EPD database. Manufacturers wishing to make environmental marketing claims must submit an EPD to the database.
- **Germany:** Whole-building LCA is required for new federal building projects as part of a green building rating program specific to government projects, with points awarded as a function of performance against a benchmark. A private-sector voluntary green building program has a similar LCA benchmark approach. Germany has a national LCA/EPD database and a free, national, whole-building LCA software tool.
- **The Netherlands:** Requires embodied carbon reporting at the building-permit-application stage for new residential and office buildings over 100 m². A building's total environmental profile (of which embodied carbon is one element) will have an upper limit, based on standardized weighting factors, as of 2018. The Netherlands also has a national EPD database, a standardized method for whole-building LCA, and several software tools that conform to the standardized method.
- **Sweden:** Large transportation infrastructure projects are required to calculate and report embodied carbon. There are incentives to reduce the embodied carbon below a target. Sweden has a national LCA-based tool to support its program.
- **Switzerland:** Whole-building LCA is required for all new government buildings in several municipalities, including Zurich, with an embodied carbon performance target for some building types. Switzerland has a national call-to-action (the “2000 Watt

Society”) to limit per-capita energy consumption and all GHG emissions, including embodied GHG emissions.

- **United Kingdom:** Voluntary green building rating programs have long included LCA, with increasing sophistication as the programs have been updated. Embodied carbon performance targets are now in place in a residential program and are anticipated in 2018 for a commercial/institutional program.

There are three precedent-setting efforts in Canada:

- **Vancouver:** As of May 2017, developers seeking a rezoning application need to comply with stringent sustainability requirements, including the reporting of whole-building embodied carbon.
- **Public Services and Procurement Canada:** Whole-building LCA is required for its new building projects.
- **Quebec:** Under Quebec’s Wood Charter, a comparative analysis of GHG emissions is required for structural materials in provincially funded new building projects.

Together, these efforts provide a sufficient range of precedents, expertise and experience for policymakers to make the case for further exploration of how embodied carbon policies can work in North America. Given the fact that the marketplace for construction materials is global, it is vital for North American jurisdictions to be familiar with international best practices. It is also important to harmonize standards and resources where possible, to improve clarity and simplicity in LCA application for the manufacturing and construction sectors.

5. Industry needs support and resources in order to engage with LCA software and data.

To complete a full LCA of a building in order to properly quantify and report the embodied carbon impacts requires several steps and the use of tools and resources that are largely the domain of technical specialists. Canada’s existing technical infrastructure is adequate for

- Providing the technical underpinnings of an embodied carbon framework, and
- Supporting awareness-building and skill development.

However, more work is required to develop the technical tools, systems and resources necessary to fully support the implementation of a rigorous embodied carbon policy and to ensure program consistency and integrity. When complete, the technical infrastructure of an embodied carbon policy could include:

- Consensus-based standards and methods.
- High-quality, publicly accessible data on energy, materials, products, and processes.
- Simplified LCA software tools tailored for design and construction projects.

6. Consideration of an embodied carbon framework should complement established operating energy / GHG goals and standards, and must be phased in.

In addition to ensuring compatibility with existing climate policies, it is also important to recognize that there may be concern that adding embodied carbon to existing GHG-emission reduction campaigns in the building sector could be a distraction and potentially derail important progress that is being made on improving the operational energy efficiency of buildings. Adding embodied carbon considerations may also overwhelm builders, designers, and developers with requirements. Respecting these concerns, taking a slower step-by-step approach, with low-risk early stages, will likely be most effective.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	iv
GLOSSARY AND ABBREVIATIONS	xi
1 INTRODUCTION.....	1
1.1 Study objectives	2
1.2 Research methodology	3
1.3 Opportunities for future research	3
2 EMBODIED CARBON AND THE LIFE CYCLE OF BUILDINGS.....	5
2.1 Definitions and principles	5
2.2 Design strategies for reducing embodied carbon in buildings	8
2.3 Measuring embodied carbon	9
2.4 Market readiness and state of embodied carbon policy development	10
3 LEADING GLOBAL PRECEDENTS IN EMBODIED CARBON POLICY	19
3.1 Leading examples of embodied carbon policy	19
Belgium	21
France	21
Germany	23
The Netherlands.....	24
Sweden	26
Switzerland.....	26
United Kingdom.....	28
3.2 Comparison of leading jurisdictions	29
3.3 Progress in North America	32
State of California, United States.....	32
International Green Construction Code (IgCC).....	33
City of Vancouver, Canada	33
Province of Quebec, Canada	33
CaGBC Zero Carbon Building Standard	33
LEED and Green Globes	34
Living Building Challenge.....	34
Elsewhere in North America	35
4 TECHNICAL RESOURCES FOR MEASURING EMBODIED CARBON	36
4.1 Standards.....	36
4.2 Impact evaluation process.....	37
4.3 Technical tools and resources	40
4.4 Performance benchmarking systems.....	44
5 FINDINGS AND RECOMMENDATIONS	46
APPENDIX 1: DETAILS OF EXISTING GLOBAL POLICIES	50
APPENDIX 2: DETAILS ON EXISTING TECHNICAL INFRASTRUCTURE	71
APPENDIX 3: DEFINING “NET ZERO”	89

LIST OF FIGURES

Figure 1: UBC Brock Commons Tallwood House.....	1
Figure 2: Life-cycle carbon emissions due to buildings.	5
Figure 3: Elements contributing to the embodied carbon impacts over the life cycle of a building product or assembly, or of a whole building.....	7
Figure 4: Design strategies for reducing embodied carbon in construction projects.....	8
Figure 5: Typical life cycles of buildings and their components.....	9
Figure 6: The life-cycle carbon emissions for a typical building over 60 years and over 10 years, illustrating the relative impacts based on the time frame of analysis. ...	10
Figure 7: Projected trend in life-cycle carbon in buildings in terms of scope and allocation.	11
Figure 8: Key phases of the whole-building LCA process.	37
Figure 9: How the key phases of whole-building LCA are connected	38
Figure 10: LCI for the LCA of a building.	39

LIST OF TABLES

Table 1: Groundwork for an embodied carbon action plan in Canada: some existing Canadian policies and programs.....	13
Table 2: Groundwork for an embodied carbon-action plan in Canada: some Canadian policies in development.....	18
Table 3: Leading embodied carbon policies: summary, by country.....	30
Table 4: Data quality indicators as per the 2016 US EPA guidance: summary.	42
Table 5: Selection of leading whole-building LCA tools.....	81
Table 6: Net-zero buildings: common definitions.....	89

GLOSSARY AND ABBREVIATIONS

Circular economy: refers to a closed-loop model of an economy where waste is eliminated. All waste products are either sold, consumed, collected and then reused, remade into new products, returned as nutrients to the environment or incorporated into global energy flows.²

Construction waste: refers to wastes that are derived from the process of building new structures, but excluding large civil and public infrastructure projects (dams, bridges, etc.), marine pilings, telephone infrastructure, rail infrastructure, land clearing, etc.

Design for disassembly: describes how a building is “designed with the end in mind” so that it can then be cost-effectively and rapidly taken apart at the end of life and components can be reused and/or recycled. The design team creates a disassembly plan that sets out the method of disassembly of major systems during renovations and end of life, and the properties of major materials and components.

Embodied carbon emissions in construction - commonly referred to as “**embodied carbon**” refers to the GHG emissions associated with the manufacturing, maintenance, and decommissioning of a structure.

Extended producer responsibility (EPR): is “a policy approach in which a producer’s responsibility (physical and/or financial) for a product is extended to the post-consumer stage of a product’s life cycle. EPR shifts responsibility upstream in the product life cycle to the producer and away from municipalities. As a policy approach it intends to provide incentives to producers to incorporate environmental considerations in the design of their products. EPR also shifts the historical public sector tax-supported responsibility for some waste to the individual brand owner, manufacturer or first importer.”³

Greenhouse gases (GHG): are gases that trap heat in the Earth’s atmosphere. Commonly these are carbon dioxide, methane, nitrous oxide, and fluorinated gases (such as CFCs, HCFCs, HFCs etc. found in refrigerants).

Net Zero: A net zero building, also known as a **zero net energy** (ZNE) building, **net-zero energy building** (NZEB), or **zero-energy** building, is “an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.”⁴ The fact that there are many terms, and many interpretations of those terms, is discussed throughout the report, and summarized in Appendix 3.

² CCME 2014 State of Waste Management in Canada report.

www.ccme.ca/files/Resources/waste/wst_mgmt/State_Waste_Mgmt_in_Canada%20April%202015%20revised.pdf

³ CCME, Canada-Wide Action Plan for Extended Producer Responsibility.

www.ccme.ca/files/current_priorities/waste/pn_1499_epr_cap_e.pdf

⁴ US Department of Energy definition, 2015. <https://energy.gov/eere/buildings/articles/doe-releases-common-definition-zero-energy-buildings-campus-and>

Net-zero-energy-ready or “zero energy ready”: a net-zero-energy-ready building is a high performance building which is so energy efficient, that a renewable energy system can offset all or most of its annual energy consumption. It is inferred that the renewable energy system itself is not included in the building, but the owner could add it at some future time and the building would then become a net zero building.

Operating emissions: in buildings refers to the GHG emissions that are generated from the burning of fossil fuels used to heat, cool and power a building during its service life.

Sustainable consumption and production (SCP): as defined by the Oslo Symposium in 1994, sustainable consumption and production is about "the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of further generations.”⁵

Sustainable materials management (SMM): is an approach to promoting sustainable materials use. It integrates actions targeted at reducing negative environmental impacts and preserving natural capital throughout the life cycle of materials, and takes into account economic efficiency and social equity.

⁵ <https://sustainabledevelopment.un.org/topics/sustainableconsumptionandproduction>

TERMINOLOGY RELATED TO THE MEASUREMENT OF EMBODIED CARBON

The following terms and definitions are taken from ISO 14040/44:2006 – Terms and Definition Section (4), (5):

Life cycle assessment (LCA): Compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle.

Life cycle impact assessment (LCIA): Phase of life-cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life cycle inventory (LCI): Phase of life-cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Type III environmental product declaration (EPD): Provides quantified environmental data using predetermined parameters and, where relevant, additional environmental information. (The predetermined parameters are based on the ISO 14040 series of standards. The additional environmental information may be quantitative or qualitative.)

Product category rules (PCR): A set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories.

Life cycle inventory (LCI) database: A database of LCI flows for individual unit processes or for a portion of a product life cycle. In the case of unit process data, the data includes intermediate flows of materials between processes, whereas system process data is a “black box” that does not specify intermediate flows. LCI databases track hundreds of inventory flows.

LCIA/EPD database: A database of results from LCA studies that does not contain a complete list of LCI flows and instead presents the calculated impact assessment results for a database of products that have previously completed LCAs often leading to published EPDs. These databases are typically based on EPDs and may differ in underlying methodology and assumptions depending on the PCRs that the EPDs are based on.

1 INTRODUCTION



Figure 1: UBC Brock Commons Tallwood House.⁶

When the University of British Columbia decided to build the 18-storey Brock Commons Tallwood House student residence as a hybrid mass timber, concrete, and steel building, the reasons were as much to do with advancing low-carbon building design as they were with promoting the possibilities of mass timber construction. The estimated avoided and sequestered greenhouse gases (GHGs) from the wood used in the building is equivalent to removing 511 cars off the road for a year. The total carbon dioxide equivalent avoided by using wood products over other materials is more than 2,432 tonnes.⁷ This example illustrates the tremendous potential for buildings to contribute to GHG emissions

⁶ Image source: www.naturallywood.com

⁷ www.naturallywood.com/resources/brock-commons-time-lapse

reduction goals. Because the significant impacts of construction materials remain largely overlooked in most climate change policies in North America, this report reviews current actions by leading countries aimed at addressing embodied carbon and presents options that could be considered.

Addressing carbon emissions from buildings has been identified as a key component of the global fight against climate change. However, the focus is typically limited to emissions due to burning fossil fuels for building operation. These operational emissions represent only part of a building's life cycle. The International Energy Agency (IEA) has stated that the reduction of embodied energy and GHG emissions from buildings “may have a tremendous effect on the reduction of global energy consumption and GHG emissions”.⁸ There is a growing understanding that it is important to take a full life-cycle view towards construction-sector carbon emission reductions, thereby addressing embodied emissions as well as operating emissions. In fact, it has been estimated that approximately 20% of global GHG emissions are embodied in the construction sector.⁹ These embodied GHG emissions —referred to as “embodied carbon emissions”— are produced from the construction, maintenance, and end-of-life decommissioning of the buildings.

1.1 STUDY OBJECTIVES

This report is intended to raise awareness of the importance of embodied GHG emissions associated with buildings and infrastructure projects. It was commissioned by Forestry Innovation Investment Ltd. to better understand the approaches by leading countries to addressing embodied carbon and the best practices that could be considered in the development of a carbon framework. The findings and recommendations in this report are based on a review of seven leading examples (Belgium, France, Germany, The Netherlands, Sweden, Switzerland, and the United Kingdom) that have implemented policies and programs that are intended to reduce embodied GHG emissions of buildings and infrastructure projects. Two more examples (Finland and Singapore) that are in the process of development are also examined. The policy examples comprise both mandatory policies and voluntary programs with high levels of industry uptake/influence.

The report offers policy considerations and a potential menu of options that could reduce the impacts of buildings on the environment over their life cycle. The intention is that the findings will bring a deeper understanding of the full climate-related impacts of buildings over their life cycle. By describing a relevant and robust collection of examples and experiences, it offers sufficient justification for policymakers to invest time and resources into research, with a view to incorporating embodied carbon considerations into existing climate-change-mitigation toolkits.

EMBODIED IMPACTS OF BUILDINGS

may have a
“tremendous effect on
the reduction of global
GHG emissions.”

⁸ IEA Evaluation of Embodied Energy and CO₂e for Building Construction (Annex 57), July 2016.
www.annex57.org

⁹ Source: Tatsuo, O. et al. 2014. Introduction of Annex 57 – Evaluation of Embodied Energy and Carbon Dioxide Emissions for Construction Worldwide. Proceedings SB 14, Barcelona.
www.irbnet.de/daten/iconda/null_DC28086.pdf

This report would be of interest to policymakers who have responsibility for the development and construction of buildings and for sustainability and climate change issues. It is also relevant to those responsible for public procurement of construction projects and civic infrastructure projects. This report may also be of interest to businesses, design professionals, building product manufacturers and suppliers, non-governmental organizations, and other stakeholders who are involved in the design and construction of green buildings and infrastructure.

1.2 RESEARCH METHODOLOGY

Investigation into the world-wide leading policies and programs was conducted via web searches, interviews with key contacts associated with each program and/or with the program users/stakeholders, and the authors' knowledge and expertise. A leading EU expert on embodied carbon policy, Panu Pasanen of Bionova Ltd., validated the European examples identified for further investigation and provided additional insights. The North American and other examples were drawn from the authors' own knowledge and their connections with governments and leading organizations in North America. Information gathering took place between November 2016 to May 2017.

Throughout this report, a broad definition for the term “policy” has been used. In other words, the review has not been limited to government regulatory instruments. Market mechanisms, calls-to-action, and overarching stated intentions are included where appropriate and have shown to be influential. The term “buildings” is used to refer to habitable structures as well as infrastructure such as roads and civil works, unless noted otherwise. While many of the policies referenced in this report relate to “large” buildings, a comprehensive embodied carbon would, eventually, include all buildings. Other important technical terms, abbreviations, and acronyms are described in the Glossary.

1.3 OPPORTUNITIES FOR FUTURE RESEARCH

Through the process of developing this report, the following opportunities for future investigation and reporting were identified:

- The full political context and history behind each of the policies discussed (e.g., which other foundational policies were already in place and for how long).
- Economic considerations of the policy examples, such as which authority/government department was financially responsible for the policy; the costs to develop, implement, and administer the policy; and how it is funded (e.g., by building permit fees or eco fees from products, or directly by government).
- The relationship between embodied carbon emissions and other environmental impacts (ozone depletion, air quality, etc.); how some of the technical tools for measuring embodied carbon can be used to evaluate a number of different environmental impacts in addition to embodied carbon, often as part of the same analytical process; and other opportunities available to policymakers by encouraging the use of these tools.

- The processes and tactics for developing the policies in the Canadian context, considering each jurisdiction's individual circumstances and stages of development.
- The results of the policies in terms of:
 - Building performance data (i.e., whether projects are achieving the performance goals, the extent to which the policies are having a meaningful impact on the levels of embodied carbon in buildings).
 - Feedback from industry (i.e., capacity and technical issues related to the introduction of LCA).
 - Implementation bottlenecks and/or unforeseen consequences.

2 EMBODIED CARBON AND THE LIFE CYCLE OF BUILDINGS

2.1 DEFINITIONS AND PRINCIPLES

Embodied carbon emissions are produced during the manufacture, transportation, installation, maintenance, and disposal of the products and materials that go into buildings. A recent study that just looked at non-residential building construction, estimated that Canada's annual embodied carbon emissions just due to that sector are at least 2.3M tonnes of CO₂e.¹⁰ The urgency of addressing embodied carbon emissions due to construction will escalate as low-carbon energy capacity increases and building operational energy efficiency improves. The significance of a building's embodied carbon impacts is best appreciated when considered over the building's life cycle, which encompasses construction, operation, and eventual disposal. The life-cycle carbon emissions due to buildings are described in Figure 2.

LIFE- CYCLE

perspectives are key to ensuring long-term emissions reductions

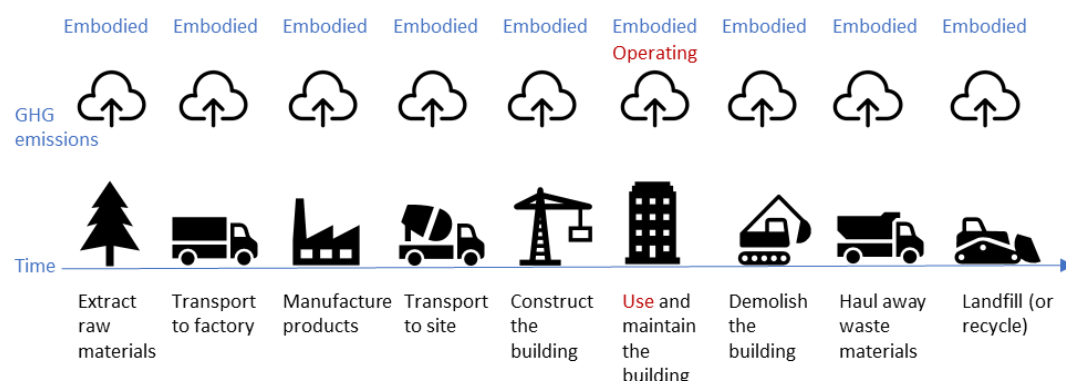


Figure 2: Life-cycle carbon emissions due to buildings.

Along with the carbon emissions produced from the operation of the building—referred to as the “operating carbon” (that is, the GHG emissions that result from burning fossil fuels to heat, cool, light, and ventilate buildings)—embodied carbon contributes to the total life-

¹⁰ This GHG emission estimate is equivalent to 487,000 cars driving for a year and would cost \$46M (Canadian currency) in purchased offsets. Our calculation is based on the following sources:

- Average non-residential starts floor area is derived from CanaData, as cited in a 2011 blog post by Alex Carrick of CMD (formerly Reed Construction Data).
- Average carbon footprint per square foot of construction is derived from Tatsuo, O. et al. 2014 (see Footnote 1).
- Car equivalencies are per US EPA GHG equivalencies online calculator.
- Carbon cost is calculated at \$20/tonne, (sourced from <http://www.offsetters.ca>).

cycle “carbon footprint” of a building is measured kg CO₂e/m² gross floor area/yr and described by the following equation:

$$\text{Life-cycle carbon footprint} = \text{embodied carbon} + \text{operating carbon}$$

Today, the term “carbon footprint” in the context of buildings is almost always applied – incorrectly—to just the process of operating the building (i.e., to the exclusion of embodied impacts). In addition to heating and lighting, etc., operating plugged-in equipment like computers may be included, and occasionally GHG emissions from commuter or business travel is considered. All of these sources of emissions fall under “operating carbon” but they represent only part of the building’s total life-cycle carbon footprint. Embodied carbon comprises the GHG emissions from all other stages of the building’s life cycle including resource extraction (e.g., mining and harvesting), processing and manufacturing of materials, building construction, building maintenance and repair, demolition, and disposition of materials at the project’s end of life (e.g., landfilling and recycling). These emissions are sometimes referred to as “Scope 3 emissions”.¹¹ For most types of building (inhabited or civil infrastructure), embodied carbon accounts for a significant amount of the building’s total GHG emissions, the majority of which occur **upstream of** (that is, prior to) building occupancy.¹²

The scope of embodied carbon over a building’s life is illustrated in Figure 3. This diagram is a typical depiction for the life cycle of products, assemblies, and whole buildings. It highlights how three different aspects of a building contribute to embodied GHG emissions: material use, operational energy use, and operational water use. Material-related impacts are the building’s embodied impacts, represented by the green boxes in the figure.

¹¹ Scope 3 emissions are those for which an organization is responsible but which happen outside of the organization itself; for example, the emissions related to products purchased and disposed of. For more information, go to www.ghgprotocol.org.

¹² For more information about the importance of embodied energy and carbon in relation to energy consumed in building operation in the context of life-cycle environmental impacts, see the International energy Association’s “Guidelines for Policy Makers” (2016), available at www.annex57.org.

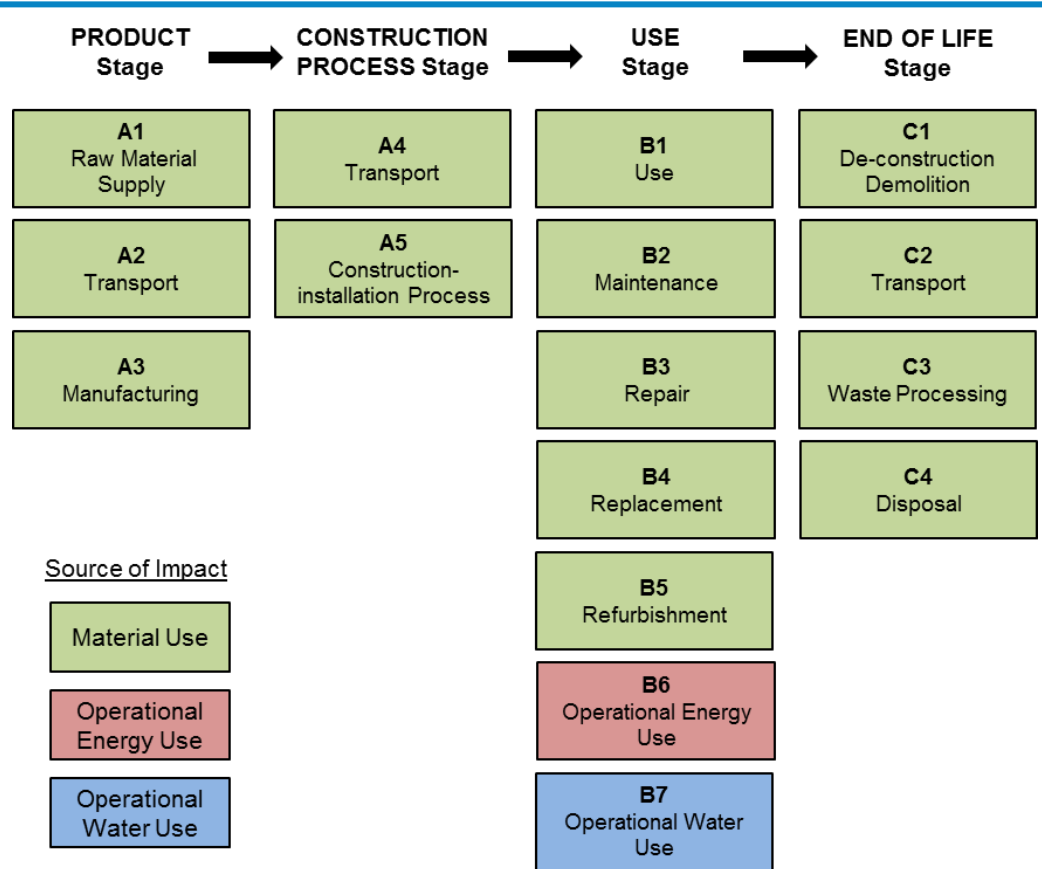


Figure 3: Elements contributing to the embodied carbon impacts over the life cycle of a building product or assembly, or of a whole building.¹³

¹³ Per EN 15804/5978. See Appendix 2 for full citations of all ISO and EN standards referenced in this report.

2.2 DESIGN STRATEGIES FOR REDUCING EMBODIED CARBON IN BUILDINGS

Multiple tactics for reducing embodied carbon are available to the designers of building projects (Figure 4).

1. Substitution of materials

- Natural materials
- Recycled and reused materials and components
- Innovative materials

2. Reduction of resource use

- Lightweight constructions
- Building form and design of layout plan
- Design for flexibility and adaptability
- Low-maintenance need
- Design for service life extension
- Reuse of building structures

3. Reduction of construction impacts

- Reduction of construction-stage impacts

4. Design for low end-of-life impacts

- Design for disassembly
- Design for recyclability

Figure 4: Design strategies for reducing embodied carbon in construction projects.¹⁴

While it is important to note that, for many reasons, buildings frequently do not last as long as the designed service life,¹⁵ Figure 5 illustrates the range of typical life cycles of buildings and their various components. It shows how designers can take a holistic approach to minimizing the embodied carbon impacts whereby the ease and frequency with which products can be replaced is considered at the design stage in order to optimize the building's useful life.

¹⁴ IEA, "Evaluation of Embodied Energy and CO₂eq for Building Construction (Annex 57)", 2017, www.annex57.org.

¹⁵ J. O'Connor. 2004. Survey on actual service lives for North America buildings. Presented at Woodframe Housing Durability and Disaster Issues Conference, Las Vegas, October 2004. http://cwc.ca/wp-content/uploads/2013/12/DurabilityService_Life_E.pdf.

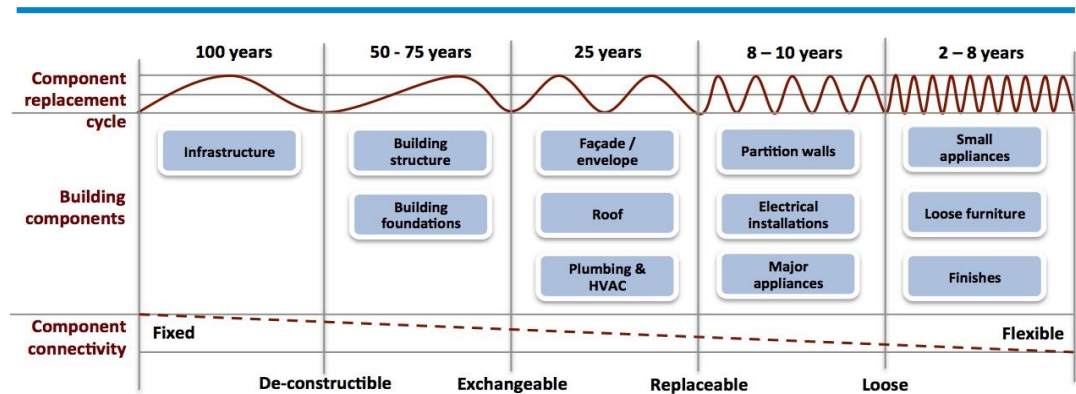


Figure 5: Typical life cycles of buildings and their components.¹⁶

2.3 MEASURING EMBODIED CARBON

Life cycle assessment (LCA) is the internationally accepted science of measuring a product's potential environmental impacts on air, land, and water over its entire life cycle, from resource extraction to its end-of-life disposition. LCA reports lifetime environmental burdens like smog creation, water pollution, and waste generation.¹⁷ Embodied carbon is one of the most important impact categories in LCA.

EMBODIED CARBON

is usually overlooked in current GHG-reduction strategies.

LCA has been used for decades in many different industrial sectors, often by manufacturers who wish to understand—and reduce—the environmental impacts of their products.¹⁸ Applied to buildings, LCA is the tool needed to calculate the environmental impacts due to manufacturing and transporting the construction materials, the process of construction, activities related to building occupancy and maintenance, demolition, and final waste disposal. Resources are consumed and emissions are produced during every life-cycle phase. LCA measures all flows between a product and nature, estimates the potential environmental impact, and helps identify opportunities for reducing impacts.

Because LCA is the necessary tool for addressing embodied carbon, and because carbon is often the primary focus of LCA studies, the policy review for this report includes policies related to whole-building LCA or to environmental product declarations (EPD). Typically, LCA results for a project are assembled in the form of a written report. More

¹⁶ Diagram based upon Durmisevic, E. and Brouwer, J. (2002), "Design aspects of decomposable building structures" in Chini, A.R. and Schultmann, F. (eds) "Design for Deconstruction and Materials Reuse", CIB Publication 272, TG39 Meeting, 9 April 2002, Karlsruhe, Germany.

¹⁷ Specifically, the typical LCA impact categories that are most commonly assessed within the construction sector are: global warming potential, acidification, eutrophication, smog, ozone depletion; depletion of non-renewable and renewable energy resources, depletion of non-renewable and renewable material resources, and water consumption.

¹⁸ "Guidance on Life Cycle Thinking and Its Role in Environmental Decision Making," Sustainable Materials Management Coalition, March 2014.

www.michaeldbaker.com/wp-content/uploads/2014/03/Guidance-on-Life-Cycle-Thinking-031014.pdf

details about LCA and other important tools and resources necessary for measuring embodied carbon are presented in Section 4 along with info about when they should be deployed, the compliance standards, and who should conduct the analysis.

2.4 CANADA'S MARKET READINESS AND EXISTING SUPPORTING POLICIES

Policies aimed at the carbon impacts of the built environment have historically focussed on addressing the operating emissions of buildings and embodied carbon has largely been overlooked. The reasons for this include:

- Operating carbon has historically comprised by far the largest portion of the total carbon footprint of buildings.
- There have been minimal or no incentives to reduce embodied carbon.
- To be able to incorporate LCA in their building projects involves a steep learning curve for building designers.

However, the situation is changing and there are several important drivers that suggest Canada's design and construction industry may be ready to address embodied carbon in buildings. These include:

- Climate change policies are starting to prioritize those GHG emission strategies that can deliver results quickly. As the timeframes to achieve GHG emission reduction targets get shorter, so the embodied carbon portion becomes a much larger slice of the overall carbon emissions “pie” (Figure 6).

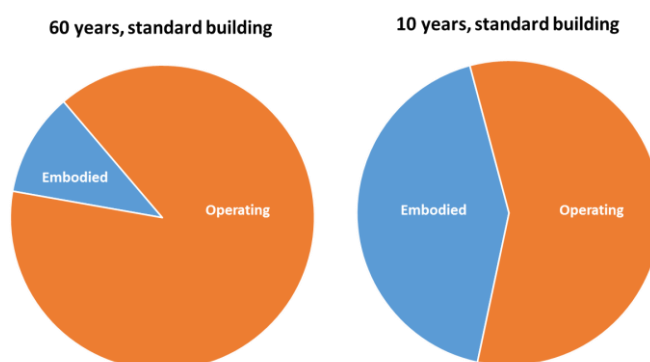


Figure 6: The life-cycle carbon emissions for a typical building over 60 years and over 10 years, illustrating the relative impacts based on the time frame of analysis.¹⁹

¹⁹ The source of this data is an extensive Athena Institute/Morrison Hershfield LCA study of mid-rise concrete buildings (Marceau, M., L. Bushi, J. Meil, and M. Bowick. 2012. Life cycle assessment for sustainable design of precast concrete commercial buildings in Canada. 1st International Specialty Conference on Sustaining Public Infrastructure). The study is highly conservative because it covers strictly core and shell and does not include finishes, furnishings, HVAC, and so forth—otherwise the actual embodied numbers would be significantly higher. The pie charts show the carbon footprint for a typical new 5-storey building in Toronto (a typical North American energy grid) over 60 years and 10 years of operation.

- Canada's construction industry is modernizing. This substantial transformation is epitomized by unprecedented investment in new processes and technologies such as virtual design and construction tools aimed at modernizing the entire design and construction supply chain.²⁰ As a consequence, readiness for embodied carbon policies and the potential to establish reduction targets for buildings may be emerging. Policies and programs that send clear long-range market signals will be important in laying out the path forward.
- The sustainable design community is aiming for a scenario whereby the operating energy of buildings is drastically reduced and further GHG emissions savings must be sought from the building's embodied carbon footprint (Figure 7).

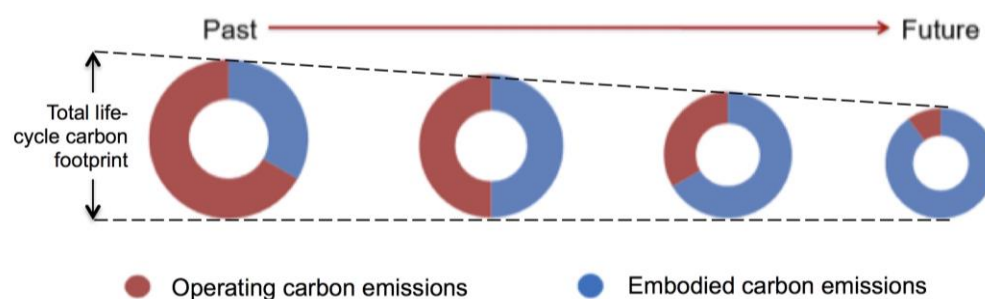


Figure 7: Projected trend in life-cycle carbon in buildings in terms of scope and allocation.

- Design teams are increasingly accustomed to the use of complex modelling during design (e.g., to estimate operating energy consumption). And increased use of sophisticated tools like building information modelling (BIM) may make it easier to collect the detailed materials information needed for LCA. Leading policymakers are becoming aware that addressing only operating carbon may lead to a zero-sum game, or worse, if it merely shifts operating carbon to embodied carbon without a net life-cycle reduction in carbon. For example, adding more materials to a building (for instance, insulation) will shift emissions between life-cycle phases, thus reducing operating emissions while increasing embodied emissions. The resulting energy savings need to pay back the initial increase in environmental impacts in a reasonable period. A total life-cycle carbon calculation solves the problem of “burden-shifting” from one life-cycle phase to another by ensuring that design choices result in a truly optimized carbon solution that takes a holistic view. Indeed, policies involving carbon pricing in the manufacturing sector are also an incomplete tactic for reducing embodied emissions in construction.²¹

²⁰ www.weforum.org/press/2016/05/the-long-overdue-transformation-of-the-construction-industry

²¹ While carbon taxes or cap-and-trade regulations are felt by manufacturers of construction products, they are not currently priced high enough to shift consumer demand to lower carbon products. In addition, carbon pricing is generally only applied within jurisdictional borders; such schemes typically do not apply to imported products. Canadian construction uses many imported products, which means that Canadian carbon-pricing mechanisms, as currently designed, are not sufficient tools for shifting purchasing decisions away from high-carbon imports.

In light of the above, policymakers around the world are recognizing that climate change policies for the construction sector that focus entirely on operating carbon are only a partial solution. In fact, they may even be counterproductive if new high-performance construction is favoured over preservation and improvement of existing building stock.

Awareness of the impacts of materials choices on the environment has been growing steadily in Canada. Green building rating programs, such as LEED, have found their way into 34 Canadian municipal policies in six provinces and one territory²² as well as into public sector procurement standards across the country. While LEED now has a high-value incentive for whole-building LCA, it is important to note that whole-building LCA is still but one of the various credit options a project team can take to achieve LEED certification.

There are also numerous programs and regulations in place across the country that might be viewed as proxy or precedent measures with respect to embodied carbon. These policies include: carbon-pricing mechanisms; GHG reporting programs; green building codes and/or the requirement to achieve certification under green building rating systems, which encourage the choice of local and/or recycled materials; green or social public procurement programs; extended producer responsibility (EPR) programs; and policies that aim to reduce and divert construction, renovation, and demolition waste from landfills.

There is good evidence that the groundwork is in place for consideration of embodied carbon for the building sector. The move towards performance-based building codes and support for “net-zero” and “circular economy” goals are important catalysts because they can impose metrics related to GHG emissions, start to consider the impacts of construction materials, and also empower design teams to seek the best solution for their projects. Table 1 summarizes relevant Canadian policies and programs that would support an embodied carbon action plan. Table 2 offers a further selection of initiatives that are in development. Various initiatives of industry and thought leaders are considering tools, best practices, and policy approaches to address embodied carbon. Table 2 details a few such initiatives that could have an influence on policymakers and/or the market going forward.

Although many of these policies do not generally deliver quantifiable results (e.g., in terms of tonnes of embodied carbon reduced) they are important precursors to embodied carbon policies because they help to build industry capacity, introduce new terminology, and “warm the market” for low-carbon products, data about environmental impacts of material and investment in market infrastructure that helps to “close the loop” on construction waste.

²² LEED in Motion Canada: 2017. Canada Green Building Council.
http://www.cagbc.org/cagbcdocs/advocacy/LEED_IN_MOTION_CANADA_2017_UPDATE.pdf

Table 1: Existing policies and programs in Canada

Select Policies and Programs	Relevance to Embodied Carbon
Pan-Canadian Framework on Clean Growth and Climate Change ²³	<p>In December 2016, Canada's First Ministers released a plan to meet Canada's emissions reduction target. The Framework provides that federal, provincial, and territorial governments will work to:</p> <ul style="list-style-type: none"> • Develop and adopt increasingly stringent model building codes, aiming towards a net-zero energy-ready model building code by 2030. • Collaborate to encourage the increased use of wood products in construction, on the basis of carbon storage in wood. • Modernize procurement practices to support the adoption of clean energy and technologies. <p>The final framework document does not explicitly mention embodied carbon, but the net-zero and wood references are an implied acknowledgement. Note that the Framework was developed after an extensive effort by four working groups, one of which focused on "specific mitigation opportunities". That working group's report²⁴ recommended that embodied carbon should be considered as part of the Pan-Canadian approach to climate change.</p>
Canada Federal Sustainable Development Strategy 2016–2019 ²⁵	<p>Every three years, the federal government updates its Sustainable Development Strategy. The Strategy sets priorities and goals; federal departments then align their departmental sustainability plans with the federal Strategy.</p> <p>The 2016–2019 Strategy sets targets to reduce GHG emissions from federal government buildings but focuses on operational energy. With respect to buildings, the Strategy sets the following goals for the federal government:</p> <ul style="list-style-type: none"> • Will be an early adopter of building standards per the Pan-Canadian Framework for all new government buildings and leases, where applicable. • Will establish a complete and public inventory of federal GHG emissions and energy use. • Will review procurement practices to align with green objectives. <p>The Strategy also commits funding to green infrastructure (which includes but is not limited to reducing GHG emissions). The links to the Pan-Canadian Framework and the commitment to GHG reduction goals set the stage for future embodied carbon reference in this federal Strategy.</p>
PSPC Sustainable Development and Green Building Strategies ^{26,27}	<p>Public Services and Procurement Canada (PSPC) – the federal department formerly known as Public Works and Government Services Canada (PWGSC) – requires its major projects to perform LCA, a policy in place since 2004.</p>

²³ "Pan-Canadian Framework on Clean Growth and Climate Change," Government of Canada, December 2016.

²⁴ "Specific Mitigation Opportunities Working Group Final Report," (part of the Pan-Canadian Framework process), Government of Canada, December 2016.

²⁵ "Achieving a Sustainable Future: A Federal Sustainable Development Strategy for Canada 2016–2019," Government of Canada, 2016.

²⁶ Public Works and Government Services Canada, Sustainable Development Strategy 2003.

²⁷ Public Works and Government Services Canada, A Green Building Implementation Guide, 2012.

Table 1 - continued.

Select Policies and Programs	Relevance to Embodied Carbon
National Round Table on the Environment and the Economy Report²⁸	In 2012, the National Round Table on the Environment and the Economy ²⁹ published an in-depth research project and policy guidance piece that lays out strong arguments for life-cycle assessment in sustainable development and for the creation of the necessary technical infrastructure.
Federal requirement to assess upstream GHG emissions for some projects³⁰	In January 2016, the Ministry of Environment and Climate Change and the Ministry of Natural Resources made a joint announcement on an interim approach to principles and plans for major projects. The approach requires an assessment of upstream GHG emissions (i.e., embodied carbon) for major projects that are under environmental review.
British Columbia's Climate Leadership Plan³¹	<p>British Columbia's Climate Leadership Plan puts embodied carbon on the table by "promoting the use of low carbon and renewable materials in public sector infrastructure". This strategy is put forth with an embodied carbon rationale (although the word embodied is not used). Two materials are specifically named: Portland-limestone cement (which has lower embodied carbon than traditional cements) and wood products (which typically have lower embodied carbon than competing materials). This suggests that British Columbia has acknowledged embodied carbon as a target. The plan also discusses implementing a number of policies to encourage the development of net-zero buildings, including:</p> <ul style="list-style-type: none"> • Accelerating increased energy requirements in the B.C. Building Code by establishing incremental performance steps to make buildings ready to be net zero by 2032 (see below regarding the B.C. Energy Step Code). • Developing energy-efficiency requirements for new buildings that go beyond those in the B.C. Building Code-called Stretch Codes-which interested local governments could implement in their communities. • Creating innovation opportunities and financial incentives for advanced, energy-efficient buildings, including an increase in funding for design and innovation.

²⁸ "Canada's Opportunity: Adopting Life Cycle Approaches for Sustainable Development," National Roundtable on the Environment and the Economy, 2012.

²⁹ The NRTEE was an independent policy advisory agency to the Government of Canada from 1987 to 2013.

³⁰ See news release, January 27, 2016: "Government of Canada Moves to Restore Trust in Environmental Assessment" <http://news.gc.ca/web/article-en.do?nid=1029999>

³¹ [Climate Leadership Plan](#), August 2016, Government of British Columbia.

Table 1 - continued.

Select Policies and Programs	Relevance to Embodied Carbon
The B.C. Energy Step Code ³²	<p>Brought into effect in April 2017, the B.C. Energy Step Code is a voluntary roadmap that establishes progressive performance targets (i.e., steps) that support market transformation from the current energy-efficiency requirements in the BC Building Code to net-zero energy-ready buildings.</p> <p>It does not mention embodied carbon but does take a new, performance-based approach rather than the traditional prescriptive approach. This means the BC Energy Step Code does not specify <i>how</i> to construct a building, but identifies an energy-efficiency target that must be met and lets the designer/builder decide how to meet it.</p> <p>It establishes a set of incremental performance steps for new buildings that aims to communicate the future intent of the Building Code and improve consistency in building requirements across British Columbia to transition to net-zero energy-ready buildings by 2032. It is a voluntary tool that local governments across British Columbia can use to encourage—or require—the construction of more energy-efficient buildings in their communities, and in a consistent, predictable way.</p> <p>Establishing performance over prescription as the basis sets the stage for future application of embodied carbon policy.</p>
Quebec Charte du bois ³³	<p>The Quebec Wood Charter promotes the use of wood, primarily on the basis of climate-change mitigation. A requirement to report embodied carbon is currently in the rollout process and is expected to be fully active in 2018-2019. Project managers will be required to perform a comparative emissions analysis between different construction materials in publicly funded construction projects. The emissions data will be required at the funding application stage.</p> <p>Projects are not required to meet carbon targets, but carbon data must be submitted to secure project funding. A GHG calculation tool is currently under development specifically to support this requirement and is expected to be ready in 2019.</p>
City of Vancouver Zero Emissions Building Plan ³⁴	<p>This Plan's target is to reduce emissions from new buildings by 90% by 2025, relative to emissions in 2007, and to achieve zero emissions for all new buildings by 2030. It acknowledges that:</p> <ul style="list-style-type: none"> • Embodied emissions will become an increasingly significant portion of overall building life-cycle emissions as operational emissions decline. • New research and software tools have been developed specifically for the Canadian construction sector, to quantify the embodied emissions from buildings on a detailed project basis for all building components and materials. <p>It recommends that:</p> <ul style="list-style-type: none"> • “In anticipation of the near-term importance of measuring and reducing the embodied emissions of building materials, it is essential that the City begin collecting data from new developments on their estimated embodied carbon in order to inform future incentive, policy, and potentially regulatory mechanisms targeted at reducing the embodied emissions of new buildings.”

³² www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/energy-efficiency/energy-step-code

³³ www.mffp.gouv.qc.ca/publications/forets/entreprises/charte-du-bois-anglais-Web.pdf

³⁴ <http://council.vancouver.ca/20160712/documents/rr2.pdf>

Table 1 - continued.

Select Policies and Programs	Relevance to Embodied Carbon
City of Vancouver Green Buildings Policy for Rezoning³⁵	<p>One of the first-embodied carbon policies in North America, Vancouver's Green Building Policy introduces requirements to report embodied emissions associated with the construction of a building in certain cases.</p> <p>Requires projects applying for rezoning to be:</p> <ul style="list-style-type: none"> designed to and apply for "near-zero emissions" building standard (Passive House and International Living Building Institute's Zero Energy Certification are mentioned); OR designed to and apply for and meet numerous "low-emissions green building" requirements, including being designed to and registering for LEED Gold, and reporting life-cycle equivalent carbon dioxide emissions (i.e., global warming potential impacts, or "embodied carbon") of each building, in kgCO₂e/m², as calculated by a whole-building LCA. <p>Even more strenuous requirements are imposed upon projects that fall under the "General Policy for Higher Buildings", which applies to projects over 500 ft (152 m) tall.³⁶</p>
Canada Green Building Council's Zero Carbon Building Standard³⁷	<p>The CaGBC Zero Carbon Buildings Standard champions the move to lower-carbon buildings in support of Canada's efforts to reduce GHG emissions by 30 per cent by 2030.</p> <p>The Standard provides a path for both new and existing buildings to reach zero carbon and be certified as Zero Carbon – Design (for new construction) and Zero Carbon – Performance (for existing) It also offers Zero Carbon – Design + Performance whereby building that has achieved Zero Carbon Building - Design certification can apply for Zero Carbon Building - Performance certification any time after one year of building performance data has been collected.</p> <p>It establishes five key components for the evaluation of building carbon footprints, one of which is embodied impacts:</p> <ul style="list-style-type: none"> The ZCB Standard requires applicants to report their Energy Use Intensity (EUI) to provide transparency and enable the industry to learn from each zero carbon building. Reporting EUI also enables the operators of a building to gauge the effectiveness of energy conservation measures and demonstrate progress over time.
Extended Producer Responsibility programs	<p>Jurisdictions that have these programs are applying a life-cycle perspective to products. For example, British Columbia's Recycling Regulation,³⁸ under authority of the Environmental Management Act,³⁹ sets out the requirements for product stewardship and indicates recognition of the full life-cycle impacts of certain products (car tires, batteries, etc.) but, as yet, does not include construction materials.</p>

³⁵ Green Buildings Policy for Rezoning, November 29, 2016 amendment, City of Vancouver. <http://vancouver.ca/files/cov/G002.pdf>

³⁶ <http://former.vancouver.ca/commssvcs/guidelines/H005.pdf>

³⁷ "Zero-Carbon Buildings Standard," Canada Green Building Council, 2017. <http://www.cagbc.org/zerocarbon>

³⁸ www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/449_2004

³⁹ www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/03053_00

Select Policies and Programs	Relevance to Embodied Carbon
Architecture 2030/2030 Challenge⁴⁰	<p>The Challenge calls on the global building community to progressively reduce operating carbon emissions of new buildings, to achieve zero carbon by 2030.</p> <p>As well, the Challenge calls for strong advocacy for addressing embodied carbon, although this is not yet a formal part of the zero-carbon target for buildings due to concerns that it will complicate buy-in. Architecture 2030 is focused on building awareness of embodied carbon at the level of whole buildings.</p> <p>Meanwhile, a “2030 Challenge for Products” calls on manufacturers to reduce the embodied carbon of construction products and calls on architects to specify low-carbon products. Architecture 2030 acknowledges this is not enough to substantially reduce the embodied carbon of buildings.</p>
LEED and Green Globes	<p>Leading voluntary green building rating system LEED and competing system Green Globes are used in Canada (and elsewhere). Both have similar strategies for using LCA to inform/optimize a final building design that has a smaller embodied impact than a reference building, with an emphasis on embodied carbon.⁴¹</p> <p>They are voluntary standards that act as a “call-to-action” and an indicator that the market is ready for embodied carbon measurement.</p> <p>Numerous Canadian cities have incorporated LEED into their green building policies. Some provinces and municipalities require new government buildings to be LEED certified.</p>
The Living Building Challenge	<p>This is a niche program based in the United States; it also used in Canada and elsewhere. It explicitly acknowledges the importance of embodied carbon in that it requires calculation of embodied carbon and the purchase of an offset.⁴²</p>
Envision	<p>Envision is a green rating system for infrastructure; it has an LCA component.</p>

⁴⁰ Architecture 2030 is a “non-profit think tank transforming climate change problems into solutions through the design of the built environment” with a strong sustainability voice in the United States. The organization has a solid track record of influencing policy in the United States. <http://architecture2030.org/>

⁴¹ LEED v4 Materials and Resources credit “Building life-cycle impact reduction” (option 4). Green Globes Materials and Resources, Performance Path for Building Core and Shell. See current reference guides and online resources for details.

⁴² Living Building Challenge – Materials, Embodied Carbon Footprint. See current reference guide and on-line resources for details.

Table 2: Policies in development

Select Policies and Programs	Relevance to Embodied Carbon
Ontario Green Procurement Roundtable	This Roundtable consists of group of industry leaders in the Ontario market. Facilitated by Evergreen, its objective is to identify best practices and draft a report with recommendations and next steps for the Ontario government. The group met in January 2017 and is hoping to provide recommendations in mid 2017.
Carbon Impact Initiative⁴³	The Initiative is a construction industry-led action plan (developed by EllisDon) in support of Canada's international climate-change commitments. The plan was launched in 2016 and includes four action items. Action Item 2 is Carbon Accounting and includes the goal of developing a tool to allow for GHG emissions tracking on construction sites. This tool will follow the GHG Protocol. The creation of this tool remains at the idea generation phase.
Carbon Leadership Forum / Embodied Carbon Network⁴⁴	Based in the United States, this virtual group advocates for a total carbon focus (embodied plus operating) and to facilitate actions that reduce embodied carbon. Its efforts are aimed at building awareness, creating knowledge, and facilitating collaborations and communication.
Carbon Leadership Forum / Structural Engineers 2050 Commitment Initiative⁴⁵	This group aims to address the missing embodied carbon component in the Architecture 2030 challenge, and hopes to develop carbon-benchmarking resources.

⁴³ <http://lowcarbonagenda.ellisdon.com>

⁴⁴ <http://swarmdev2.be.washington.edu/embodied-carbon-network/>

⁴⁵ www.carbonleadershipforum.org/2017/02/09/structural-engineers-2050-commitment-initiative/

3 LEADING GLOBAL PRECEDENTS IN EMBODIED CARBON POLICY

This section introduces seven leading national examples of policies from Europe (Belgium, France, Germany, The Netherlands, Sweden, Switzerland, and the United Kingdom) that have been designed to measure and/or report embodied carbon. For each policy, a summary of key features is presented, followed by further commentary. Technical details can be found in Appendix 1a. These precedents range from mandatory requirements (such as codes and regulations) to voluntary guidelines that include green building ratings systems, and calls to action. Where mandatory requirements exist in a given jurisdiction, those are focused on because they are considered to be the most advanced. This section concludes with a comparison of the seven leading examples. Two additional examples of “jurisdictions to watch” (Finland and Singapore) are set out in Appendix 1b.

This section then illustrates progress in North America with a selection of examples at the local and provincial/state level—including the State of California, the City of Vancouver, and the Province of Quebec—followed by a discussion of what is happening elsewhere across the continent.

3.1 LEADING EXAMPLES OF EMBODIED CARBON POLICY

The following leading policy examples (organized alphabetically) were all developed within the context of a Europe-wide commitment to address climate change that, for the built environment, is primarily captured under (1) the European Union’s 2010 Energy Performance of Buildings Directive (latest version 2016), which generally requires that member states establish quantitative metrics for primary energy (kWh/m²/yr)⁴⁶ and (2) the European Union’s cap and trade system.⁴⁷

⁴⁶ In January 2012, the European Parliament adopted a supplement to the Energy Performance of Buildings Directive (2010), which establishes a comparative methodology framework for calculating cost-optimal levels of minimum energy-performance requirements for buildings and building elements. Specifically, the directive requires that member states must establish quantitative metrics for primary energy (kWh/m²/yr) thereby formalizing the concept of energy system boundaries and principles of primary, secondary, and site energy.

See <https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings>.

Primary energy is an important factor when calculating embodied carbon (e.g., in the preparation of EPDs and source data for LCA). It is defined as the raw energy found in nature that has not been subject to any technical conversion process or transportation. Primary energy can be non-renewable or renewable. Non-renewable primary energy is found in sources that are finite like oil, uranium, or coal. Renewable primary energy is found in virtually endless sources like water, solar radiation, or wind. Primary energy is sometimes referred to as “source energy”.

⁴⁷ https://ec.europa.eu/clima/policies/ets_en

Established in 2005, the European Union's carbon market is the world's largest. It covers most construction material sectors, including iron and steel, aluminum, bricks, metals, cement clinker, glass, ceramics, and others. The European Union aims to link its system with other compatible systems around the world in the future. Some exceptions apply; for instance, certain small emitters (those emitting <25 kT CO₂e/yr) can be excluded if governments put in place fiscal measures that will cut emissions by an equivalent amount.

As a result, EU member countries have been working together, in groups and independently, to advance and harmonize GHG emission reduction policies for over a decade. The range of protocols, agreements, tools, standards, and other mechanisms that are now in effect are too long to list.⁴⁸ It is sufficient to say that the efforts are spread broadly to include initiatives such as developing criteria for "secondary materials" which defines when a waste ceases to be a waste and becomes a secondary product,⁴⁹ and modernizing the construction procurement process to better accommodate the new technologies and processes required to achieve environmental performance goals.⁵⁰

Also supporting the adoption of embodied carbon policies are a suite of standards written by the European Committee for Standardization (CEN) Technical Committee. When countries choose to adopt formal reporting requirements for LCA-based building performance, they typically follow the standards written by this committee (described in Section 4.1).

⁴⁸ A summary of current climate policies in the European Union and member states is provided by Entracte, <http://entracte-project.eu/research/report-current-policies>.

⁴⁹ Delgado, L. Catarino, A.S. Eder, P. Litten, D. Zheng Luo, Villanueva, A. "End-of-Waste Criteria", JRC Scientific and Technical Reports, 2009. <http://ftp.jrc.es/EURdoc/JRC53238.pdf>. This document for the European commission looks at how to determine when certain specified waste ceases to be waste, which is an important concept for reducing the carbon impacts of buildings. Briefly, the report proposes that waste becomes a secondary material when it has undergone a recovery operation and complies with specific criteria developed in accordance with the following conditions:

- The substance or object is commonly used for specific purposes.
- A market or demand exists for such a substance or object.
- The substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products.
- The use of the substance or object will not lead to adverse environmental or human health impacts.
- Values for pollutants will be limited where necessary and shall take into account any possible adverse environmental effects of the substance or object.

⁵⁰ For example, the "Construction 2025" industrial strategy developed in partnership by the UK government and the Confederation of British Industries (CBI) establishes a long-term vision for the British construction industry whereby projects will be built 30% cheaper and 50% faster, and with 50% fewer GHG emissions (www.gov.uk/government/publications/construction-2025-strategy). This "call to action" has stimulated over £150M in investment in R&D and new technologies. A government building information modelling Mandate (www.bimtaskgroup.org) requires all public projects over £50M to be completed using virtual design and construction tools. Collectively, these efforts put in place the systems, standards, and industry capacity needed to implement embodied carbon policies and to meaningfully reduce the embodied carbon in buildings.

Belgium

Key features:

- The Belgian EPD Program, or “B-EPD”, requires EPDs for all construction products that make environmental marketing claims, with specified exceptions.
- Regional governments are cooperating to develop a voluntary LCA-based methodology to calculate building-level impacts, which may evolve into future regulation.

Belgium has taken several steps towards developing an LCA-based embodied carbon policy, both at the national level and within the three regions (Brussels, Flanders, and Wallonia).

At the national level, activity is focused on environmental product declarations (EPDs). A legislative document (Royal Decree) sets out rules and infrastructure around EPDs and environmental claims. The Royal Decree establishes a national EPD database, which is aligned with international standards. Any manufacturer that wishes to make an environmental claim about a product must first perform an LCA and upload an EPD to the database. The national database is also intended for use in whole-building LCA, in coordination with a future LCA assessment tool for building elements known as “MMG”. This tool will be aligned with the LCA methodology currently being created by the regions.

OVAM, the public waste agency for Flanders, has created a program (guidelines and education) that addresses the embodied environmental impacts of construction, with a focus on waste reduction. The intention is to create a permanent supported framework for cooperation between the public and stakeholders of the construction industry to give further shape to sustainable materials management from a life-cycle perspective. The program includes a limited LCA database of 115 building elements, and a hope that this work will lead to eventual development of government policy regarding material selection and sustainable design. However, questions arise over the potential for such a limited program to offer an “apples-to-apples” comparison of buildings. Further, there is a risk of backlash from the providers of targeted materials over possible market distortions and unfair trading practices (whereby they are required to provide information while others are not).

France

Key features:

- A voluntary national building pilot program offers incentives to builders and developers in exchange for meeting certain energy- and carbon-performance benchmarks, including embodied life-cycle carbon. Incentives include:
 - An award of the national building label “Energie Carbone” (E+C-), indicating high performance.
 - Additional density incentives in exchange for meeting certain tiers.
 - Financial assistance for builders/developers to support LCA studies and additional costs.

- The national pilot program includes two requirements: one for energy (four tiers), and another for carbon (two tiers).
- The carbon label tier (either the lower performance “Carbon 1”, or higher performance “Carbon 2”) is based on a building’s combined calculations in two indicators—(1) life-cycle carbon and (2) embodied carbon in building materials and equipment—each of which must be below a maximum value.
- The program relies on the national EPD database. Manufacturers wishing to make environmental marketing claims must submit an EPD to the database.
- The plan is for the pilot program to become mandatory in the early 2020s, after which incentives will be removed and life-cycle carbon-performance requirements will be imposed on all new buildings.

France has been using LCA since 2004 to combat greenwashing by product manufacturers. A series of laws were enacted involving EPDs, eventually resulting in the requirement that any manufacturer wishing to make an environmental claim about a product or communicate about a product’s environmental aspects must submit an EPD to the national EPD database.

France’s Energy Transition Law (Transition Énergétique pour la Croissance Verte, or TECV)⁵¹ encourages new construction to be low energy and low carbon. In November 2016, France launched a pilot program called “Energie Positive et Réduction Carbone”⁵² (formerly “Energie Carbone” or E+C-). France’s Ministry of the Environment, Energy and the Sea, and the Ministry of Housing and Sustainable Habitat, appear to be the administrators of the program.

Under Energie Positive et Réduction Carbone, the government offers various incentives to motivate builders and developers to meet energy and carbon-performance benchmarks. For instance, new buildings that opt in to the pilot program can apply for additional rights to construction density above zoning limits if they show proof of meeting energy and life-cycle carbon (including embodied) performance targets. They may also receive financial assistance to support LCA studies or receive the national label of E+C-. The program includes one new building label with two components or requirements: one for energy (four tiers) and another for carbon (two tiers). This label is issued by accredited certifiers (e.g., Cofrac⁵³ or its European counterparts). It is expected that this pilot policy will become mandatory in the early 2020s, with life-cycle carbon requirements imposed on all new buildings.

Benchmarking programs are also underway in France. The HQE Performance initiative is a pilot project (by the same organization that administers the HQE green building rating program,⁵⁴ which has an LCA component) to establish whole-building LCA benchmarks, beginning with office buildings and multi-unit residential buildings.

⁵¹ www.gouvernement.fr/action/la-transition-energetique-pour-la-croissance-verte

⁵² www.batiment-energiecarbone.fr

⁵³ www.cofrac.fr

⁵⁴ www.hqegbc.org/batiments/certifications

Germany

Key features:

- Whole-building LCA is required for new federal construction as part of the mandatory Assessment System for Sustainable Building (Bewertungssystem Nachhaltiges Bauen or BNB) green building certification system. Buildings can achieve more points (and potentially a higher certification level) with better LCA results.
- The voluntary green building certification system called Deutsche Gesellschaft für Nachhaltiges Bauen (German Sustainable Building Council, DGNB)⁵⁵ has a LCA performance strategy that is similar to BNB and also has an embodied carbon ceiling.
- Both BNB and DGNB include pre-determined standard embodied carbon performance benchmarks and award points based on relative performance against these benchmarks.
- German embodied carbon programs are supported by strong technical infrastructure such as a free national LCA/EPD database and a free national whole-building LCA software tool.

Germany has been driving towards leadership in greening its economy for decades. Over ten years ago, the German Sustainable Building Council (DGNB)⁵⁶ rolled out a voluntary green building system that has been adopted by all German-speaking countries. It has 45 sustainability criteria, seven of which are assessed by performing whole-building LCA. This provides a strong platform from which to establish LCA-oriented policies.

A policy adopted in 2010 requires that the design of federal buildings over 2M EUR (roughly \$2.8M CDN) must achieve a silver certification under BNB certification system.⁵⁷ This is notable because BNB requires whole-building LCA. Therefore, new federal building construction in Germany must perform a whole-building LCA. Buildings can achieve more points (and potentially a higher certification level) with better LCA results.

The BNB system is supported by a strong national LCA infrastructure, specifically a harmonized database and a free whole-building LCA tool. The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety provides a free online national LCA EPD database called ÖKOBAUDAT,⁵⁸ which contains data for at least 700 building products, including generic materials data as well as specific data from EPDs. The data are provided in the widely used ILCD data format (with EPD-relevant extensions), an approach that is currently being adopted by a growing number of European countries. In addition, the Ministry provides a free LCA software tool for buildings, called eLCA,⁵⁹ which is directly connected to ÖKOBAUDAT.

⁵⁵ This acronym is used for both the national green building rating system, and the body which oversees it, the German Sustainable Building Council (Deutsche Gesellschaft für Nachhaltiges Bauen or DGNB).

⁵⁶ www.dgnb-system.de/en/system/criteria/core14

⁵⁷ www.bnb-nachhaltigesbauen.de

⁵⁸ www.oekobaudat.de

⁵⁹ www.oekobaudat.de/en/database/browse-oekobaudat.html

The Netherlands

Key features:

- New residential and office buildings over 100 m² applying for a building permit are required to calculate a series of LCA-based metrics known as the “environmental profile”, which includes requirements to report on global warming potential (including embodied carbon) and depletion of raw materials and fossil fuels.
- National cost per kg equivalent weighting factors⁶⁰ exist to turn the environmental profile into one single monetary cost per m² of construction (i.e., the “shadow cost”). A ceiling on this shadow cost of 1 EUR/m² of construction is proposed to take effect in January 2018 (pending final government approval).
- This policy is supported by strong technical infrastructure such as a national EPD database, a standardized method for whole-building LCA, and several software tools that conform to the standardized method.

The Netherlands’ embodied carbon policy has been in place since 2013 and it is the first known instance of public policy specifically requiring whole-building LCA for non-government buildings.

In requiring embodied carbon reporting prior to issuing a building permit for certain types of buildings, the Netherlands arguably has the most broadly applicable and robust policy in the world on whole-building LCA. Three LCA indicators must be reported:

1. global warming potential, which is based on total (including embodied) carbon;
2. depletion of raw materials; and
3. depletion of fossil fuels.

The Netherlands first attempted such a policy in 2003. It was not successful at the time due to significant resistance from major stakeholders, including the real estate sector and contractors who objected to the additional cost required to carry out the analysis. However, the next decade saw significant advancements, many of which were actively developed together with the same stakeholders who had originally pushed back, which helped to achieve their buy-in.

Over that time, life-cycle assessment activity in manufacturing and building design became more prevalent. A number of whole-building LCA tools emerged and manufacturers began publishing EPDs through various private Dutch EPD programs. In 2010, a government-led project was started to harmonize EPD programs and whole-building LCA tools. The aim of this initiative was to develop a single framework for both data suppliers (e.g., product manufacturers) and data users (e.g., building design professionals), in order to provide clarity and transparency in the market. An independent association called Stichting Bouwkwality (SBK)⁶¹ was appointed to compile a single, national LCA database on materials and to establish a standard national method for whole-building LCA practice.

⁶⁰ These factors give relative weighting to different LCA-based *environmental effect categories*. See Appendix 1a.

⁶¹ www.bouwkwality.nl

SBK launched the National Environmental Database (NMD)⁶² in 2012, based on the existing Dutch standard for EPDs (NEN 8006), and then updated it in 2014 to align with the new European standard EN 15804.⁶³ A standardized whole-building LCA method called the Assessment Method: Environmental Performance Construction and Civil Engineering Works (GWW)⁶⁴ was then published; it is based on the EN 15804 and EN 15978 standards. Three whole-building LCA software tools for buildings conforming to the method have been approved by SBK. These tools draw on the national database.

In 2012 the Netherlands introduced Article 5.9 of the Building Code (Bouwbesluit 2012), which requires new residential buildings and office buildings (with a floor area >100 m²) seeking a construction permit to calculate 11 different LCA-based metrics and report total global warming potential, as well as depletion of raw materials and fossil fuels. These estimates are to be calculated with data from the national database and using the national method for whole-building LCA. The policy became mandatory January 1, 2013. Operational energy impacts are excluded from the calculation, and there are no specific minimum performance criteria. National cost per kg equivalent weighting factors exist to turn the 11 metrics into one single monetary cost per m² of construction called the “shadow cost”. A ceiling on this shadow cost of 1 EUR/m² of construction is expected to take effect in January 2018 (pending final government approval). So far, the Dutch program does not impose a binding target and there are no penalties tied to non-compliance.

The Netherlands has a strong history in sustainable materials management and has developed an effective, integrated, policy-driven life-cycle approach. The embodied carbon policy has informed (and is informed by) a suite of other supporting policies such as the cross-cutting Chain-Oriented Waste policy, which aims to address the environmental impacts acting across the whole material chain from the end-of-life stage and back up the supply chain. The Netherlands’ National Waste Management Plan 2009–2021, called “Towards a Material Chain Society”,⁶⁵ describes the government’s ambitions to minimize environmental pressures over the whole supply chain and to harmonize policy in different areas (e.g., natural resources, products/design, waste management, and concepts such as cradle-to-cradle) by means of a chain-oriented waste policy. Fundamentally, a chain approach considers the entire material chain, including all the stages in the life cycle of a product or material, from raw material mining, production, and use, to waste and possible recycling, as opposed to concentrating on “end-of-pipe” solutions.⁶⁶

⁶² www.milieudatabase.nl

⁶³ All major standards referenced in this section are explained in Appendix 2.

⁶⁴ www.milieudatabase.nl/imgcms/SBK_Assessment_method_version_2_0_TIC_versie.pdf

⁶⁵ A summary is available in English; www.eea.europa.eu/publications/managing-municipal-solid-waste/netherlands-municipal-waste-management/at_download/file. The Dutch Waste Management Plan, “Landelijk afvalbeheerplan 2009–2021” (LAP, 2009) is available at: www.lap2.nl/default.asp

⁶⁶ For example, see OECD “Sustainable Materials Management Making Better Use of Resources”, P162 – 165. <http://www.oecd.org/environment/waste/smm-makingbetteruseofresources.htm>

Sweden

Key features:

- The Swedish Transport Authority requires carbon accounting for new projects over 50M SEK (\$7.5M CDN).
- Sweden's voluntary national green building rating system, Miljöbyggnad v2, does not include LCA; however, the next version (v3) will.⁶⁷
- Stockholm has a suggested a LCA calculation guideline for construction over 10M SEK (\$1.5M CDN), but no requirements or enforcement mechanisms currently exist.

One tactic Sweden is using to work towards a goal of net-zero GHG emissions by 2050 is to address the embodied impacts in transportation infrastructure construction. Since 2015, all transportation projects over 50M SEK (\$7.5M CDN) have been required to calculate their embodied carbon at various points during design and construction. Contractors can receive bonus monetary incentives if they can further reduce emissions-through low-carbon material selection-below the already optimized value calculated during the design phase. It should be noted that Sweden was one of the first countries in the world to adopt a carbon tax (in 1991),⁶⁸ which has sent strong long-range market signals to industry of its commitments to address climate change.

The Swedish Transportation Administration ruling TDOK 2015:0007 explains the importance of recognizing embodied carbon and describes a carbon tool provided by the transportation administration, called Klimatkalkyl (“climate calculator”).⁶⁹ Klimatkalkyl is a web-based LCA tool that includes a database with the embodied energy and GHG emissions per linear unit of 94 different transportation infrastructure types. It is intended to be used as a decision support tool, providing the basis for project improvements in both early and late planning stages.

LCA is not yet part of Sweden’s green building rating program, Miljöbyggnad, which is administered by the Swedish Green Building Council. However, the next version (v3) is said to include a voluntary LCA strategy. Projects targeting Gold certification would be subject to a minimum LCA-based performance requirement. Further details of LCA in Miljöbyggnad 3 are not yet available.

Switzerland

Key features:

- Minergie⁷⁰ is the most widely used Swiss national green building rating system, which is also used in other German-speaking countries. Numerous versions of this standard exist. One of them, Minergie-Eco, includes a performance target or whole-building, LCA-based embodied energy.

⁶⁷ www.sgbc.se/var-verksamhet/miljoebyggnad

⁶⁸ Sweden’s—and other countries’—carbon tax efforts are briefly summarized at www.carbontax.org/where-carbon-is-taxed.

⁶⁹ www.trafikverket.se/tjanster/system-och-verktyg/Prognos--och-analysverktyg/Klimatkalkyl

⁷⁰ www.minergie.ch

- Other rating systems used in Switzerland include SGNI, which is based on the German DGNB system; SNBS; and 2000-Watt-Areale. All of them use the same methodology and data for a whole-building LCA calculation.
- Several hundred buildings have been certified based on LCA calculations. The approach reportedly works well and generates only moderate additional work.
- The City of Zurich requires all new government buildings to obtain Minergie-Eco certification.
- Minergie-Eco is voluntary; however, some public and private organizations (e.g., the Zurich Cantonal Bank) have made it a requirement for new buildings or major renovations.

The Swiss Federal Institute of Technology has developed a concept called the 2000 Watt Society⁷¹ that seeks to limit the daily rate of energy consumption per capita to 2,000 watts (48 kWh/day) as a means to reduce energy consumption and GHG emissions. Adopted by over 100 cities, towns, and cantons across Switzerland and Germany, this initiative recognizes that embodied carbon, which the Swiss refer to as “grey energy/grey emissions”, is important to understanding the true impacts of consumption.

While the 2000 Watt Society vision has not yet been translated into clear requirements for every sector at the national level, it is meant to act as a “north star” for energy policy and has been implemented to varying degrees in several Swiss jurisdictions, including Zurich, Basel, and Geneva.

The City of Zurich has come the closest to turning this pledge into policy. In 2008, a referendum in Zurich was held, asking for public support for achieving the 2000 Watt Society goal by 2050, and 75% voted “yes”. Thus, the pledge is documented in Zurich’s municipal code, which akin to a city constitution.⁷² Zurich has since committed to the vision of the 2000 Watt Society and has set a 2050 target of 8.5 kg CO_{2e}/m² for life-cycle embodied carbon in residential buildings. Zurich now requires compliance with the Minergie-Eco standard for new construction of city buildings. This standard includes a performance target for whole-building LCA. Other cities, cantons, and communities are following Zurich’s example and anchoring the 2000 Watt Society concept in their municipal codes and energy-usage policies.

For guidance on implementation, Zurich is looking to their city’s existing Energy Master Plan, which largely focuses on conservation and fuel switching, but makes a soft reference to embodied energy and the general idea that the consumption of goods has environmental impact due to embodied effects.

⁷¹www.swissinfo.ch/eng/politics/energy-efficiency_2000-watt-society--when-the-future-becomes-a-reality/41958718

⁷² www.stadt-zuerich.ch/portal/en/index/portraet_der_stadt_zuerich/2000-watt_society.html

United Kingdom

Key features:

- There are a number of aspirational goals at the national, regional, and local levels with ambitious targets to reduce the energy consumption and GHG emissions of buildings.
- BREEAM, the voluntary green building rating system, has an LCA component.
- There is a national materials LCA database—the ICE database—which provides data on energy and carbon.

The United Kingdom has taken substantial steps towards developing the infrastructure required for implementing embodied carbon policy, although as of yet no hard policies appear to be in place. Currently there are a number of aspirational goals at the national, regional, and local levels, with ambitious targets to reduce the energy consumption and GHG emissions of buildings. These goals also seek to reduce impacts from the consumption of construction materials and construction waste. In addition, as with LEED in North America, voluntary green building certifications are highly influential in the British construction sector and can therefore function as de facto policy.

A proposed zero-carbon building policy was repealed in 2015, which included various potential “allowable solutions”—one of which was based on reducing embodied carbon. The repeal was due to a hard-fought political campaign in which the winning party promised to “cut red tape” and streamline approvals for housing.

The United Kingdom’s dominant voluntary green building rating system, Building Research Establishment Environmental Assessment Method (BREEAM), has long had an LCA component. Specifically, some of the points are calculated as a function of LCA-based ranking of building elements in the Building Research Establishment (BRE) Green Guide to Specifications. The credit is called “Mat 01 Life cycle impacts” and is worth up to six points. The aim of this credit is to “recognise and encourage the use of construction materials with a low environmental impact (including embodied carbon) over the full life cycle of the building.” If products with EPDs are specified, they too can boost the score. In addition, BREEAM gives “innovation” points when design teams perform whole-building LCA.⁷³

Points in BREEAM can also be earned by specifying products certified to BRE’s BES 6001: Framework Standard for Responsible Sourcing,⁷⁴ which provides product ratings using a multi-attribute system that includes LCA. As part of BREEAM’s incentive for whole-building LCA, BRE is working with collaborators to create the infrastructure for a

⁷³ This text refers to the current version of BREEAM used in the United Kingdom (BREEAM New Construction UK 2014). Various versions (referred to as *schemes*) of BREEAM exist, including New Construction, In-Use (for existing building), Communities, and Refurbishment. In addition, there are versions of BREEAM specific to other countries, and an international version for countries without their own systems. The various schemes are updated and reissued on different schedules. Requirements vary in each scheme, but all include LCA based strategies. More information at www.breeam.com.

⁷⁴ www.bre.co.uk/page.jsp?id=1514

benchmark system.⁷⁵ Such a system would enable the evolution of BREEAM's LCA credit towards a comparative requirement. (BREEAM 2018 is targeting this feature, with a concurrent downgrading or elimination of its Green Guide within the current Mat 01 credit.) Meanwhile, a residential program in the BRE family, Home Quality Mark,⁷⁶ already includes benchmarking in its LCA component.

The United Kingdom has a national materials LCA database which focuses on energy and carbon (it does not include data on other environmental impacts). The database was developed at the University of Bath and known as ICE (Inventory of Carbon and Energy). There is also an embodied carbon database for buildings,⁷⁷ commissioned by the UK Green Building Council and WRAP, a non-profit organization focused on waste reduction. In fact, the UK Green Building Council is also developing a Client Brief for embodied carbon. Embodied Carbon: Developing a Client Brief hones in on the client sector that has the most potential to drive embodied carbon reductions by demanding that their development projects address reductions. This guidance aims to smooth the pathway to measuring and reducing embodied carbon in new developments by providing practical guidance specifically designed to be used by clients in development briefs.⁷⁸

3.2 COMPARISON OF LEADING JURISDICTIONS

Table 3 on the following pages summarizes the information on the leading jurisdictions discussed in this section.

⁷⁵ www.impactwba.com/page.jsp?id=21

⁷⁶ www.homequalitymark.com

⁷⁷ <http://ecdb.wrap.org.uk/Default.aspx>

⁷⁸ www.ukgbc.org/resources/publication/embodied-carbon-developing-a-client-brief

Table 3: Leading embodied carbon policies: summary, by country.

Country	Overview	Policy Name	Policy Type/Phase	Referenced Dataset	Tools	Scope	Performance Requirements
Belgium	Publishing to national EPD database is mandatory for all construction products making environmental marketing claims. National LCA calculation methodology in development.	B-EPD.	Requirement for EPD publishing. Voluntary calculation methodology in development for buildings to use EPD database to run WB-LCA.	B-EPD Database.	Voluntary national calculation methodology and tool in development; expected to be launched by 2018.	Construction products making environmental marketing claims.	No.
France	National program on energy and life-cycle carbon (including embodied carbon) performance in buildings. Voluntary now during pilot, but expected to become mandatory ~2020. Creation of EPDs mandatory for products using environmental labels.	Pilot program Energie Positive et Réduction Carbone includes embodied carbon calculations.	Regulatory building label pilot program. Expected to become mandatory in future.	INIES. LCA results uploaded to national E+C- database.	Various tools have been validated under the program.	New buildings. Does not apply to renovations unless project requires new permits. Includes operational energy.	Program has two levels of LCA-based performance requirement benchmarks, also called thresholds (Carbon 1, low performant. Carbon 2, high performance). An LCA is required and all impacts are calculated (same impacts as on EPD) but only energy and carbon have relevant thresholds.
Germany	BNB (Bewertungs-system Nachhaltiges Bauen) (which includes whole-building LCA) Silver certification required.	BNB Assessment System for Sustainable Building.	German government custom building rating program (similar to DGNB, the most popular voluntary German building rating program).	ÖKOBAUDAT. Building performance results to be shown in future site “eBNB”.	eLCA: free LCA software for federal buildings.	New federal government buildings over 2M EUR (~\$2.8M CDN).	No. Higher points achieved through higher LCA performance, but no minimum performance required.

Table 4 – continued.

Country	Overview	Policy Name	Policy Type/Phase	Referenced Dataset	Tools	Scope	Performance Requirements
The Netherlands	Required to submit 11 LCA-based metrics, including total life-cycle embodied carbon.	Dutch Building Code (Bouwbesluit 2012), Article 5.9.	Required for building permit.	Milieudatabase.	National Assessment Method (GWW). At least four national LCA tools exist.	New residential & office buildings over 100 m ² (and extensive renovations).	Not yet. To be introduced in future.
Sweden	Transport Authority requires carbon accounting for projects.	Ruling TDOK 2015:0007.	Policy applies during transportation infrastructure planning, design, and construction.	Klimatkalkyl makes use of pre-calculated embodied carbon calculations for 94 transportation infrastructure solutions, on a unit basis.	Klimatkalkyl ("climate calculator") is an LCA-based design tool for infrastructure (e.g., roads, bridges, rail).	Transportation Authority requirement applies to projects over 50M SEK (\$7.5M CDN).	Not specified. However, monetary incentives are offered to contractors who can reduce embodied carbon below design calculation through low-carbon material selection.
Switzerland	City of Zurich requires that all new government buildings be Minergie-Eco standard certified, which requires an LCA calculation (i.e., of embodied energy).	2000 Watt Society vision anchored in municipal code. Minergie-Eco certification.	Mandatory municipal policy. Voluntary national building certification program (Minergie) is used to support policy directive. Only Minergie-Eco (one of several versions of Minergie) requires LCA.	Swiss KBOB dataset (national dataset), based on ecoinvent data.	There are multiple tools available.	Mandatory policy is applicable to new government buildings in Zurich. Minergie-Eco is applicable to new and existing buildings of all types. Not applicable to infrastructure.	Minergie-Eco has "deep grey energy" (Swiss term for "embodied energy") performance standards for six building categories.
United Kingdom	No requirements exist. Voluntary rating system and embodied carbon-related aspirational goals in place.	Green building rating system: BREEAM.	Voluntary standards: BREEAM (buildings), CEEQUAL (infrastructure), and Home Quality Mark (residential) include LCA options.	ICE database.	BRE's "Impact" method.	Some municipalities require BREEAM, but not all BREEAM projects must do LCA.	No. Home Quality Mark provides additional points for higher LCA performance, but no minimum performance is required.

3.3 PROGRESS IN NORTH AMERICA

State of California, United States

California is at the forefront of green building regulations and standards in the United States. The California green building code, CalGreen, includes an optional LCA path,⁷⁹ along with a range of performance measures related to energy efficiency, solid waste diversion, etc.

The state also recently introduced a bill (AB 262 – Public contracts: lowest responsive bidder: eligible materials⁸⁰) that would require all prospective bidders on state public works projects using eligible materials to disclose the Scope 1, 2, and 3 emissions generated in the manufacture of those materials (which would include embodied carbon). By January 2019, the state will establish the maximum acceptable global warming potential for each category of eligible materials. The latest amendment (July 2017), classifies the following eligible materials and has added a requirement for EPDs.⁸¹

- carbon steel rebar
- flat glass
- mineral wool board insulation
- structural steel

The *State Contract Act* and other California laws generally require that bids be awarded to the “lowest responsible bidder”. This new bill would modify the way that the “lowest responsible bidder” is determined by requiring the awarding department to use GHG emissions information to calculate the lowest bid. While the formula has yet to be determined, the following high-level three-step process was set out in Bill AB 262:

- Step 1: Quantify the social cost of one unit of Scope 1, Scope 2, and Scope 3 GHG emissions in consultation with the California Air Resources Board.
- Step 2: Develop a formula to quantify emissions associated with transporting eligible materials from the manufacturer to the project site. (The formula will multiply fuels used or miles transported by a standard emissions factor for fuel type or distance travelled and the form of transportation used).
- Step 3: Multiply the per unit “social cost” by the amount of GHGs emitted in the manufacture of the eligible materials as disclosed by the bidder.

The intention of Bill 262 is to mitigate the impacts of climate change caused by greenhouse gases.

⁷⁹ The relevant part of the code is Section A5.409.2. The code and all its various versions and components is available at www.bsc.ca.gov/Home/CALGreen

⁸⁰ http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB262

⁸¹ The bill requires that the bidder on a project must submit a facility-specific EPD prior to installing any eligible materials on a project.

Vancouver's

new rezoning policy may provide a pulse check of market readiness.

International Green Construction Code (IgCC)

The International Green Construction Code (IgCC)⁸² is a model code that includes optional whole-building LCA components. It is available for adoption by any jurisdiction; a handful of US states and local jurisdictions have adopted it to date. It is intended to set a minimum level of performance, and thus local adoption of more stringent requirements will override these provisions. Like CalGreen in California, IgCC puts the LCA provisions in an elective portion of the codes so they can be adopted at the discretion of the local jurisdiction.

It is a voluntary performance-path alternative to prescriptive material requirements (where they apply). This may be seen by design teams as an incentive to avoid the restrictions and documentation inherent in prescriptive requirements. Compliance requires that the “final design” have lower impacts than a “reference design” for at least three LCA measures.

City of Vancouver, Canada

In 2016 the City of Vancouver introduced a new rezoning policy. It includes a compliance path that requires reporting of embodied emissions, as calculated by a whole-building LCA. Under its Green Buildings Policy for Rezoning,⁸³ projects applying for rezoning are required to either: (1) be designed to and apply for an emissions building standard like Passive House;⁸⁴ or (2) meet numerous low-emissions green building requirements, including being designed to and registering for LEED Gold and reporting the embodied carbon emissions of each building in kgCO₂e/m², as calculated by a whole-building LCA (along with a number of other requirements). Vancouver's is the first policy requiring whole-building LCA in North America that our research has identified to date.

Province of Quebec, Canada

The Quebec Wood Charter is an initiative that aims to increase the use of wood in construction. It requires a comparative analysis of GHG emissions for structural materials in provincially funded projects. The emissions data will be required at the funding application stage, not the building permit stage. Moreover, funding is dependent on the analysis being conducted and not on the project manager ultimately choosing lower carbon materials. A GHG calculation tool is currently under development and is expected to be ready in 2019.

CaGBC Zero Carbon Building Standard

In May 2017, the Canada Green Building Council launched its Zero Carbon Building Standard,⁸⁵ which is a voluntary leadership program that will ultimately lead to Zero Carbon certification for both new and existing buildings, with unique requirements for

⁸² www.iccsafe.org/codes-tech-support/codes/2015-i-codes/igcc

⁸³ Available at <http://vancouver.ca/home-property-development/general-policies-guidelines.aspx>

⁸⁴ www.passivehousecanada.com

⁸⁵ www.cagbc.org/zerocarbon

each. New construction projects earn Zero Carbon Building – Design certification by modelling a zero-carbon balance, highly efficient envelope and ventilation systems to meet a defined threshold for thermal energy demand intensity, and onsite renewable energy systems capable of providing a minimum of 5% of building energy consumption.

Project teams are required to evaluate energy use holistically, including impacts on peak electricity, and determine the embodied GHG emissions associated with structural and envelope materials. While the program requires applicants to conduct a “cradle-to-grave” LCA of the project, the embodied carbon requirement has been limited to reporting and does not set any performance targets. There is a group of 16 projects that are participating in a 2-year pilot of the program. Registration will open to the market in September 2017.

LEED and Green Globes

LEED is the dominant voluntary green building rating system in North America and is also used extensively around the world. The newest Building Design & Construction (BD+C) version is LEED BD+C v4. It contains a new materials credit—Building Life Cycle Impact Reduction. Option 4 (Whole Building Life-Cycle Assessment), which is worth at least three points (out of 110) and serves as incentive for design teams to undertake whole-building LCA. The three points are awarded provided that the “final design” has at least 10% lower impacts than a “reference design” for at least three LCA measures, and no measure performs 5% worse than the reference design.⁸⁶ Two additional points can also be achieved through exemplary performance and regional priority. The competing program Green Globes has a similar incentive.

Living Building Challenge

The Living Building Challenge⁸⁷ is a niche green building rating system developed in the United States and administered by the International Living Future Institute. It is primarily used in the United States and Canada, although the system is intended for international applicability.

Within the materials requirements, projects must calculate the total embodied carbon due to construction materials and processes, and purchase an offset from an approved provider of offset credits. This task requires whole-building LCA, although only the carbon portion is reported. This may be the only green building rating program with a requirement to measure—and offset—embodied carbon.

⁸⁶ Whether referenced in policy or not, LEED influences international construction practices and standards. To date, over 1B square feet of construction in Canada has been LEED-registered. As an example of market penetration, 22% of all new commercial buildings, and approximately 30% of all new institutional buildings, constructed in Canada in 2014 were LEED certified. Source: LEED in Motion: Canada, Green Business Certification Inc., 2017.

www.cagbc.org/cagbcdocs/advocacy/LEED_IN_MOTION_CANADA_2017_UPDATE.pdf

⁸⁷ Living Building Challenge 3.0, International Living Future Institute, 2014.

https://living-future.org/sites/default/files/15-1215%20Living%20Building%20Challenge%203_0_forweb.pdf

CANADA COULD BENEFIT

in a variety of ways
from an embodied
carbon plan.

Elsewhere in North America

While many jurisdictions have implemented green building policies,⁸⁸ research suggests that most jurisdictions in North America have not yet directly addressed embodied carbon in policy or in building codes, and there is no indication that Canada is considering embodied carbon for upcoming building code revisions. However, there are examples of life-cycle awareness and policy recommendations in Canada (see Section 2.4) and one existing policy within the federal department Public Services and Procurement Canada (see Table 1 for details on precedents). In addition, when green building codes, standards, and rating programs are adopted in policy or regulations, there is an indirect link to embodied carbon.

⁸⁸ The US Green Building Council has a searchable database of green building policies that have been adopted by municipal and state/provincial government across the US and Canada.
www.usgbc.org/search/public%20policy?page=0&filters=type:public_policy

4 TECHNICAL RESOURCES FOR MEASURING EMBODIED CARBON

4.1 STANDARDS

Standardization is necessary to ensure that the environmental impacts of products and buildings are consistently and accurately calculated and presented. The standards development process for life-cycle assessment addresses what implications the methodological requirements will have on the practicality of completing LCAs, as well as how an LCA methodology requirement may affect an industry's results. The participation of many experts with different interests in standards development ensures broad credibility of the developed standards.

The International Organization for Standardization (ISO) publishes the most high-level consensus-based international standards related to LCA. The consensus nature of ISO standards means that they define the minimum requirements for LCA globally. ISO standards have been developed for LCA practice in general, as well as for LCA studies that are specific to building products and construction works. Given the global marketplace for construction products and materials, harmonization of standards across regional and national boundaries is important.

The European Committee for Standardization (CEN) is an EU organization. It develops its own suite of standards that complement the ISO standards by providing more detailed requirements for topics not specified in ISO standards, thus facilitating harmonization. In particular, CEN TC 350 "Sustainability of construction works"⁸⁹ provides a system for the sustainability assessment of buildings using a life-cycle approach. The purpose of this series of European standards is to enable comparability of the results of assessments. However, this series does not set benchmarks or levels of performance (see Section 4.4).

The technical participants in CEN standard development are typically also involved in developing ISO standards, and thus there is overlap between CEN and ISO standards development whereby CEN standards can serve as pilots for ISO standards. It is important to note that ISO standards are being revised to conform with the CEN standards, making future comparisons between North America and the European Union possible.

Currently, in North America, the CEN standards are being used to further the goals of harmonization of building sector LCAs. The overall structure and scoping rules for completing LCAs on building products and whole buildings are equally applicable to the North American context and have been widely adopted (through the development of Product Category Rules (PCRs), described under Environmental Product Declarations (EPDs) in Appendix 2).

⁸⁹ http://portailgroupe.afnor.fr/public_espacenormalisation/centc350/standards_overview.html

The forthcoming revision to ISO 21930, which defines the principles and requirements for building product EPDs, does adopt many of the elements of the CEN standards. This may diminish the importance of the European standards to harmonizing PCRs. For a description of standards developed by ISO and CEN relating to LCA, EPDs, and communication, as well as whole-building LCA, see Appendix 2.

4.2 IMPACT EVALUATION PROCESS

The procedures necessary to complete a full LCA of a building in order to quantify and report the embodied carbon impacts requires several steps and the use of a range of tools and resources. Figure 13 illustrates the key phases of LCA and Figure 14 is a schematic of how the key elements of LCA tie together.

The timing of when the LCA is completed is important. It is sometimes said that 90% of design decisions are typically made during the first 10% of the design process. Certainly the opportunity to make changes diminishes as the project approaches the start of construction. For the findings from a LCA process to meaningfully inform the design of a building (as opposed to simply documenting the resulting impacts), analysis should commence as early as possible and be iterated as the project design evolves.

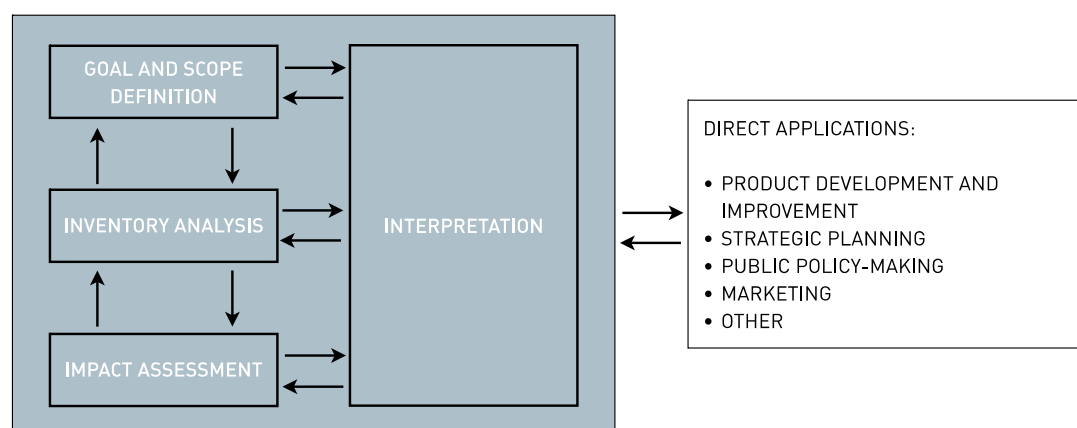
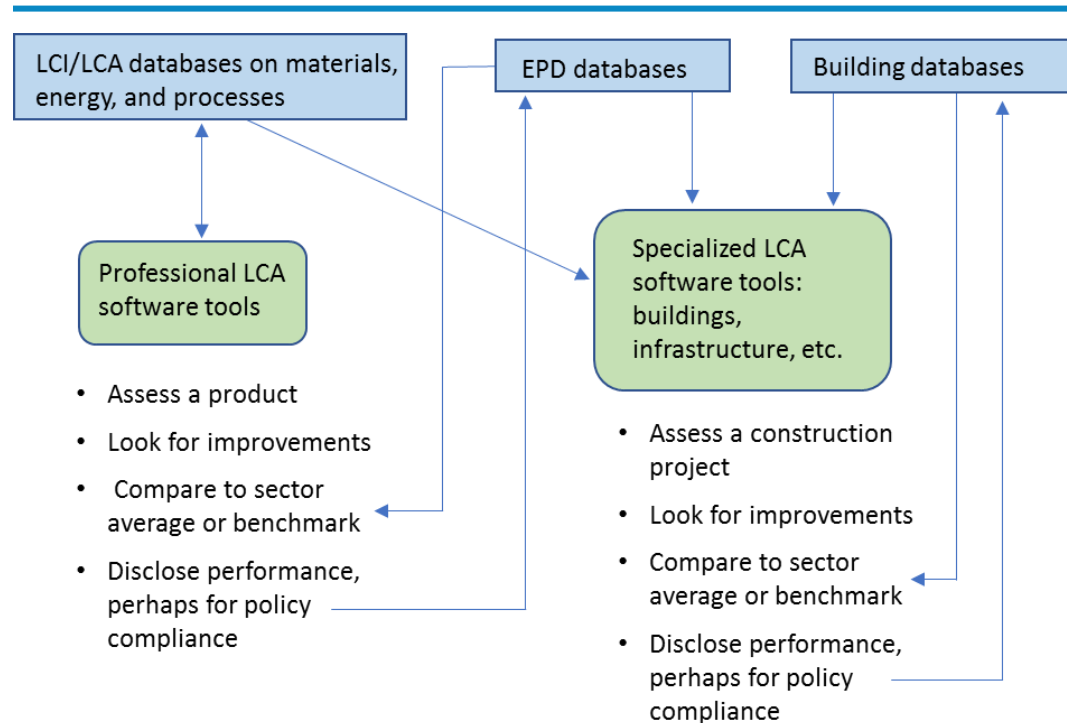


Figure 8: Key phases of the whole-building LCA process.⁹⁰

⁹⁰ Credit: ISO 14040:2006.



All guided by national and international standards

Figure 9: How the key phases of whole-building LCA are connected

Step 1: Goals and scope

The first step in the LCA is to establish the goals and scope of the assessment. Because it is impractical (and sometimes impossible) to include every aspect of a building in an assessment, system boundaries, assumptions, and limitations are developed as part of establishing the goals and scope of the assessment. For example, mechanical and electrical equipment and systems are frequently omitted from the analysis due to their complexity (which is significant) relative to their overall share of the building impacts (which is small). The impacts of the planning and design process (which are also usually very small relative to other factors) are also omitted.

Allocation procedures, as well as the required quantity and quality of data also need to be defined at this stage. Unit process data and resulting life-cycle inventory information need to be up to date, complete, reliable, regionally derived (or adjusted), and transparent to allow for a clear definition of goal and scope.

Step 2: Inventory analysis

Once the goals and scope are set, the life-cycle inventory (LCI) analysis process then serves to quantify overall cradle-to-grave inputs (e.g., resources, land use, transportation, etc.) and outputs. For embodied carbon, the outputs are GHG emissions but most LCA software tools also allow for a range of other impacts to be considered such as ozone depletion, water pollution, etc.

The LCI phase of an LCA links the building life-cycle stages to the inputs from nature and emissions to nature (elementary flows) that are affected by upstream and downstream cause–effect chains (ISO 14040). Figure 15 is a schematic representation of a complete LCI model for a building life cycle. For each stage in the building life cycle, data are required to model the intermediate inputs and outputs back to the boundary with nature.

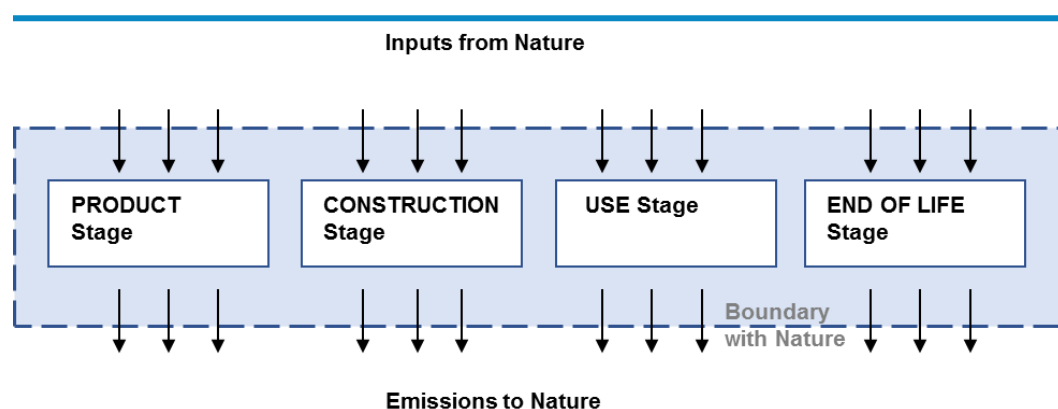


Figure 10: LCI for the LCA of a building.⁹¹

The LCI analysis is accomplished through the collection of unit process data for products and processes with the help of existing datasets and tools (see Section 4.3). Three types of data are needed to model the life cycle of a building or other construction project:

- **Material takeoffs**, used to create a bill of materials, are data which list the material components that comprise the project.
- **Scenario information** are the assumptions about the material inputs such as supply chain characteristics, transportation, replacement rates, and end-of-life fate.
- **LCI process data** are the individual datasets for modelling the material inputs and processes identified in the material takeoffs and scenario information.

The analyst for a whole-building LCA may develop material takeoff data and scenario information that are specific to the project, or the analyst may rely on defaults for these data as provided in various whole-building LCA software packages. In both cases, the underlying LCI databases may comprise “unit process” data that make the various

⁹¹ Per EN 15978 / ISO 14040

underlying processes within a modelled system, as well as the “system process” data in which the inventory is only presented cumulatively, transparent.

Unit process-level data are treated as modules that are linked together in process-flow models in which the output of one process becomes the input into another. In both cases, the LCI modelling is complete when all process flows link back to the boundary with nature in the form of raw material inputs and emissions to air, water, and land.

Step 3: Impact assessment

Finally, the life-cycle assessment (LCA) of the building project is performed based on previously generated LCI results. This should be completed in accordance with ISO 14044, which sets out procedures for:

- the selection of impact categories and classification, category indicators, and characterization models;
- the assignment of LCI results (classification); and
- the calculation of category indicator results (characterization).

The LCA involves first quantifying the materials used and then tracing the supply chain of those materials back to the system boundary with nature (i.e., energy and resource flows from nature as well as air, water, and land emissions back to nature). The system of processes that comprise the upstream and downstream cause–effect chains of the life cycle may include hundreds if not thousands of individual unit processes. To complete the life-cycle inventory, the individual unit process data must be scaled in process–flow models in order to relate the inputs and outputs of a process to the specific amounts of these flows that are caused by the building life cycle.

Once complete, the life-cycle inventory of the building is then related to the potential environmental impacts that are caused by the flows across the boundary with nature.⁹² These impacts are calculated based on cause–effect models developed by scientists with expertise in sustainability issues (e.g., climate-change experts, toxicologists, ecologists, etc.).

A summary report is generated. The information can be compared to a benchmark, such as industry averages, to a baseline established for the project in question, or to a series of design alternatives.

4.3 TECHNICAL TOOLS AND RESOURCES

While the LCA procedure has long been held up as complex and the domain of academics, the advent of easy-to-use software, backstopped by improved data (quantity

⁹² Note: per ISO 14044, LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

and quality) and access to unprecedented computing power, are rapidly changing the perceptions of industry practitioners.

The inter-linked components that comprise the underpinning of the LCA process are described below to assist policymakers in understanding what industry would be expected to take on in terms of investment in technical tools, and to give a sense of the training needed to manipulate them.

NATIONAL TECHNICAL RESOURCES

are required to ensure program consistency and integrity.

LCI databases

There are several comprehensive and reliable databases that are curated and administered by well-funded and reputable research organizations. Several of these databases are based on a for-profit model, while others are voluntary and funded by government organizations or groups representing building product manufacturers who are seeking to publish their industry data. The two main global-level LCI databases are **ecoinvent** and **GaBi** and these supply a good deal of the data currently being accessed in Canada.⁹³ As LCA grows in stature, more locally specific data will invariably follow.

In addition, there are several European and national-level LCI databases that are publicly available and of suitable quality to develop LCAs for construction projects. However, there is currently no long-term, well-funded caretaker(s) of Canada's databases. Details about these and other databases are provided in Appendix 2.

Increasingly, these databases support the requirements of widely accepted standards (such as those published by ISO and CEN), and will work consistently regardless of the software package that is used. However, ensuring data meet the quality requirements described in these standards can be costly. For this reason, voluntary LCI databases such as the U.S. Life Cycle Inventory Database⁹⁴ (another source of data used in Canada) must be managed for quality by consultancies that use the data or by software providers that have an interest in ensuring that their software users can confidently and reliably access high-quality data.

Because LCI data are essentially the result of different LCA studies, a given database may contain data that are of varying quality and applicability to a construction-related LCA. LCI data used in a whole-building LCA must meet a reasonable level of data quality to ensure that the LCA results are credible. Table 4 provides a summary of the data quality indicators of a given LCI dataset as identified in ISO 14044:2006, Clause 4.2.3.⁹⁵ and in the 2016 data quality guidance from the US Environmental Protection Agency (EPA).⁹⁶


⁹³ The Canadian Interuniversity Research Center for the Life Cycle of Products (CIRAIG), started the development of a life-cycle inventory databank for Québec in 2011 and currently partners with ecoinvent.

⁹⁴ www.nrel.gov/lci

⁹⁵ ISO 14044:2006 "Environmental management — Life cycle assessment — Requirements and guidelines" www.iso.org/obp/ui/#iso:std:iso:14044:ed-1:v1:en

⁹⁶ "EPA/600/R-16/096: Guidance on Data Quality Assessment for Life Cycle Inventory Data". June 2016, accessed from www.epa.gov/research.

Table 4: Data quality indicators as per the 2016 US EPA guidance: summary.⁹⁷

		Highest score 				Lowest score
Indicator		1	2	3	4	5 (default)
Flow reliability		Verified data based on measurement.	Verified data based on a calculation, or non-verified data based on measurement.	Non-verified data based on a calculation.	Documented estimate.	Undocumented estimate.
Flow representativeness	Temporal correlation	<3 years of difference.	<6 years of difference.	<10 years of difference.	<15 years of difference.	Age of data unknown, or >15 years.
	Geographical correlation	Data from same resolution and same area of study.	Within one level of resolution and a related area of study.	Within two levels of resolution and a related area of study.	Outside of two levels of resolution but a related area of study.	From a different or unknown area of study.
	Technological correlation	All technology categories are equivalent.	Three technology categories are equivalent.	Two technology categories are equivalent.	One technology category is equivalent.	None of the technology categories is equivalent.
	Data-collection methods	Representative data from >80% of the relevant market over an adequate period.	Representative data from 60–79% of the relevant market over an adequate period, or representative data from >80% of the relevant market over a shorter time period.	Representative data from 40–59% of the relevant market over an adequate period, or representative data from 60–79% of the relevant market over a shorter time period.	Representative data from <40% of the relevant market over an adequate period, or representative data from 40–59% of the relevant market over a shorter time period.	Unknown, or data from a smaller number of sites and from shorter periods.

Notes:

- **Verification** may take place in several ways, e.g., by on-site checking, by recalculation, or through mass balances or crosschecks with other sources. For values calculated from a mass balance or another verification method, an independent verification method must be used in order to qualify the value as verified.
- **Temporal difference** refers to the difference between date of data generation and the date of representativeness as defined by the scope of the project.
- A **related area of study** is defined by the user and should be documented in the geographical metadata. The relationship established in the metadata of the unit process should be consistently applied to all flows within the unit process. Default relationship is established as within the same hierarchy of political boundaries.
- **Technology categories** are process design, operating conditions, material quality, and process scale.
- The **relevant market** should be documented. The default relevant market is measured in production units. If the relevant market is determined using other units, this should be documented. The relevant market established in the metadata should be consistently applied to all flows within the unit process.
- **Adequate time period** can be evaluated as a time period long enough to even out normal fluctuations. The default time period is 1 year, except for emerging technologies (2-6 months) or agricultural projects >3 years.

⁹⁷ https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=528687

LCIA and LCA databases

Life cycle impact assessment (LCIA) and life cycle assessment (LCA) databases are used for similar purposes to LCI databases but, rather than contain inventory data on flows between a product and nature (Figure 10), these databases are made up of LCA results for products. Many of these databases have been designed with ease of use as the priority over comprehensiveness, in order to encourage industry practitioners to get to grips with LCA. As a result, some databases may be limited to just a few categories of products (e.g., plastics), or they may focus only on certain impacts (e.g., carbon and energy) or on construction typologies (e.g., roads).

LCIA and LCA databases are sometimes considered “LCA Lite” because some of them may not be suitable for executing the comprehensive impact LCAs of buildings, they offer valuable rough guides to designers early in the project development when the design is still in flux—particularly when the databases can be accessed via easy-to-use software interfaces (such as Excel spreadsheets, online catalogues of assemblies, etc.). More details and examples are provided in Appendix 2.

Life cycle assessment software

The only practical way to manage the LCI data and calculate the impacts of the complex “product system” is to use specialized LCA software. LCA software automates the process flow calculation and the “characterization” of inventory flows into impact results. There are several general-use LCA software platforms available for developing life-cycle inventory models and calculating impact assessment results. However, these powerful but highly technical products are typically used only by LCA professionals, who require their inherent flexibility in order to develop life-cycle inventory models from scratch.

Recently, several whole-building and infrastructure LCA tools have been developed to bridge the gap between construction-sector professionals and the complexity of the background LCI data and methodologies required for LCA. These tools simplify the process in user-friendly, construction-specific interfaces. LCI data and methods are embedded in the software which also incorporates LCA scenario data and, in some cases, assists the user in material takeoff calculations. Underlying data can come from public and proprietary databases and from EPDs. Whole-building LCA tools are organized in a building context (e.g., by material assemblies and building sub-components). These tools are commonly restricted to particular geographic regions based on their underlying data, although some tools claim global coverage. See Appendix 2 for details and examples.

It is worth noting that where embodied carbon policies have been implemented, a range of software tools and resources were developed early on to encourage industry acceptance of LCA. These tools, which most commonly comprise technical libraries and catalogues of pre-evaluated materials, products, and assemblies, etc., generate outputs that are quick to access and easy to understand. Although they do not on their own necessarily deliver complete measures of embodied carbon, they serve other important purposes such as educating industry stakeholders, boosting technical capacity,

encouraging the development of new systems and assemblies, and building familiarity with the principles and terminology associated with the embodied impacts of buildings. For example, the online Swiss catalogue of building assemblies “Bauteilkatalog”⁹⁸ was created to support the rollout of the 2040 Energy Efficiency Path technical specification from the Swiss Society of Engineers and Architects (SIA)⁹⁹ (see the example of Switzerland in Section 4). It can generate outputs for typical structural systems, which include the heat transfer coefficient (e.g., U-value) and embodied energy (referred to as grey energy) with associated embodied carbon emissions.

Environmental Product Declaration programs

An Environmental Product Declaration (EPD) is a set of environmental impact data for a product based on an LCA that has been conducted in compliance with applicable ISO standards. EPDs are a rapidly growing trend due to market demands for manufacturer “transparency” related to sustainability claims.

As of January 2017, over 6,000 construction product EPDs had been published globally.¹⁰⁰ There are at least ten EPD programs currently in operation in North America. But, because EPDs are still relatively new, standards, harmonization, and alignment across programs are still developing. Several of the leading North American EPD program operators are working together to harmonize the way product category rules are developed. More details are provided in Appendix 2.

4.4 PERFORMANCE BENCHMARKING SYSTEMS

Embodied carbon policies should ideally include performance targets. However, when performance targets are put in place, incentives or requirements are keyed to a benchmark and projects need to achieve a certain level of performance. The precedent for this approach has been the implementation of operating energy performance incentives and regulations where benchmark systems are already in use.

However, benchmarking embodied construction carbon is complicated. Whole-building LCA involves so many variables that achieving “apples-to-apples” comparisons can be difficult. An effective whole-building LCA benchmarking system requires a great deal of standardization and oversight to ensure that comparison of a building’s performance to a benchmark value is fair and accurate. A new standard in development, ISO 21678,¹⁰¹ will tackle methodological principles for building LCA benchmarks.

As a first pass at understanding the range of possible embodied carbon performance, two “embodied carbon databases” have been developed. The first was in the United Kingdom, commissioned by the UK Green Building Council and WRAP (a non-profit

⁹⁸ www.bauteilkatalog.ch

⁹⁹ <http://shop.sia.ch/collection%20des%20normes/architecte/sia%202040/e/F/Product>

¹⁰⁰ Jane Anderson, Construction LCA, 2017, as presented at: <https://info.gr.am/47216efb-7256-4a5e-acc3-04ce046cbdf8>

¹⁰¹ www.iso.org/standard/71344.html

organization focused on waste reduction).¹⁰² More recently, a US effort has assembled a large collection of whole-building LCA results.¹⁰³ The primary finding from the US work is the importance of identifying the need for quality control and standardization before assembling such a database, in order to reduce the large degree of uncertainty and non-comparability of the data. For this reason, neither of these databases is suitable for benchmarking.

Another relevant effort is the self-generated, whole-building, LCA benchmark approach in the North American green building rating programs LEED and Green Globes. These programs have an LCA incentive based on achieving better performance in a final design compared to a baseline design. Allowing users to define their own baselines outside of any standards or oversight is problematic; the system is easy to abuse and it cannot provide verifiable metrics on the success of the incentive in reducing environmental impacts.

Robust whole-building LCA benchmarking efforts are underway in Europe. A breakdown of these efforts by country is presented in Appendix 2.

¹⁰² <http://ecdb.wrap.org.uk/About.aspx>

¹⁰³ Simonen, K., Rodriguez, B., McDade, E., Strain, L. (2017). *Embodied Carbon Benchmark Study: LCA for Low Carbon Construction*. Available at <http://hdl.handle.net/1773/38017>

5 FINDINGS AND RECOMMENDATIONS

Based on the review of international best practices, an embodied carbon framework may be structured to support the following aspirations:

1. Support climate-change mitigation commitments.
2. Address GHG reductions not currently included in the context of buildings and infrastructure.
3. Establish performance criteria and incentives to drive measurable reduction in embodied carbon in new construction and retrofits.
4. Leverage best practices and experiences from international leaders to promote understanding of embodied and life-cycle carbon.
5. Build industry capacity for making informed decisions about the impacts of embodied carbon in buildings and for performing whole-building Life Cycle Assessment (LCA).
6. Complement and build upon existing energy/GHG policy goals and standards.

Jurisdictions could achieve various climate-change and other goals by adopting an embodied carbon initiative for construction. The benefits of adopting such a policy could include, but would not be limited to:

- Support of municipal, provincial, state or federal goals for climate-change mitigation.
- Achievement of measurable, short-term GHG reductions.
- Reduction of other environmental impacts of construction besides carbon.

The following insights from the review of global best practices and the assessment of the current domestic policy environment could provide insights into the development of an embodied carbon initiative.

1. Life-cycle perspectives are key to understanding the long-term impacts of construction-related GHG emissions.

Many recent climate-change policies reference “net-zero” (either energy or carbon) for buildings. However, a building is not truly “net-zero” until it has paid back or offset its initial carbon debt (i.e., the embodied GHG emissions associated with materials, manufacturing, and other processes that are upstream of building occupancy) and has considered its future carbon emissions in terms of end-of-life decommissioning. Jurisdictions with policies that are driving towards sustainable consumption and production goals or towards a “circular economy” are on the path towards addressing embodied carbon because these policies demonstrate an understanding of the importance of having a life-cycle perspective in order to reduce GHG emissions in absolute terms rather than by merely shifting GHG emissions between life-cycle phases.

2. An embodied carbon policy tackles GHG emissions reductions not currently being addressed in the context of buildings and

infrastructure on the scale and in the time frame required to meet national and/or international GHG emissions reductions commitments.

Climate-change policies and programs generally do not account for embodied carbon in buildings and infrastructure despite embodied carbon being an important piece in the overall emissions profile of many jurisdictions. Not only is embodied carbon a significant proportion of a building's overall carbon footprint, but reductions in embodied carbon are realized in the short term, which is a critical consideration given that global carbon emissions need to be urgently reduced to meet international climate commitments.

3. In order to reduce embodied carbon in new and existing construction, carbon incentives should be tied to measurable performance outcomes.

Proxy measures and prescriptive solutions with a presumed GHG emissions reduction benefit should be replaced by incentives based on quantifiable and comparable results. Prescriptive sustainable design guidelines and incentives simplify decision-making but can limit creative problem-solving and may not deliver actual reductions in environmental impact. Prescriptive strategies also do not allow for design flexibility, are limited in scope, and are not tied to measurable performance outcomes. Whole-building LCA, on the other hand, is an internationally accepted science. It is intended to be used by project teams to quantify embodied carbon and other environmental impacts in buildings, and can be the basis of a life-cycle carbon policy.

4. Ample precedents of best practices and program design are available for jurisdictions to draw on.

The leading international jurisdictions reviewed in this report have explored a variety of approaches, thereby providing helpful test cases for all types of policies and programs—from voluntary reporting to mandatory performance standards. The following countries are taking significant action to reduce embodied carbon in construction, either through regulatory policy or strong incentives:

- **Belgium:** Has a national EPD database. Manufacturers wishing to make environmental marketing claims must submit an EPD to the database.
- **France:** Offers building labels and incentives for voluntarily meeting both embodied carbon and net-zero energy consumption targets. The voluntary pilot program is expected to become mandatory in 2020. France has a national EPD database. Manufacturers wishing to make environmental marketing claims must submit an EPD to the database.
- **Germany:** Whole-building LCA is required for new federal building projects as part of a green building rating program specific to government projects, with points awarded as a function of performance against a benchmark. A private-sector voluntary green building program has a similar LCA benchmark approach. Germany has a national LCA/EPD database and a free, national, whole-building LCA software tool.
- **The Netherlands:** Requires embodied carbon reporting at the building-permit-application stage for new residential and office buildings over 100 m². A building's total environmental profile (of which embodied carbon is one element) will have an upper limit, based on standardized weighting factors, as of 2018. The Netherlands

also has a national EPD database, a standardized method for whole-building LCA, and several software tools that conform to the standardized method.

- **Sweden:** Large transportation infrastructure projects are required to calculate and report embodied carbon. There are incentives to reduce the embodied carbon below a target. Sweden has a national LCA-based tool to support its program.
- **Switzerland:** Whole-building LCA is required for all new government buildings in several municipalities, including Zurich, with an embodied carbon performance target for some building types. Switzerland has a national call-to-action (the “2000 Watt Society”) to limit per-capita energy consumption and all GHG emissions, including embodied GHG emissions.
- **United Kingdom:** Voluntary green building rating programs have long included LCA, with increasing sophistication as the programs have been updated. Embodied carbon performance targets are now in place in a residential program and are anticipated in 2018 for a commercial/institutional program.

There are three precedent-setting efforts in Canada:

- **Vancouver:** As of May 2017, developers seeking a rezoning application need to comply with stringent sustainability requirements, including the reporting of whole-building embodied carbon.
- **Public Services and Procurement Canada:** Whole-building LCA is required for its new building projects.
- **Quebec:** Under Quebec’s Wood Charter, a comparative analysis of GHG emissions is required for structural materials in provincially funded new building projects.

Together, these efforts provide a sufficient range of precedents, expertise and experience for policymakers to make the case for further exploration of how embodied carbon policies can work in North America. Given the fact that the marketplace for construction materials is global, it is vital for North American jurisdictions to be familiar with international best practices. It is also important to harmonize standards and resources where possible, to improve clarity and simplicity in LCA application for the manufacturing and construction sectors.

5. Industry needs support and resources in order to engage with LCA software and data.

To complete a full LCA of a building in order to properly quantify and report the embodied carbon impacts requires several steps and the use of tools and resources that are largely the domain of technical specialists. Canada’s existing technical infrastructure is adequate for

- Providing the technical underpinnings of an embodied carbon framework, and
- Supporting awareness-building and skill development.

However, more work is required to develop the technical tools, systems and resources necessary to fully support the implementation of a rigorous embodied carbon policy and to ensure program consistency and integrity. When complete, the technical infrastructure of an embodied carbon policy could include:

- Consensus-based standards and methods.
- High-quality, publicly accessible data on energy, materials, products, and processes.

- Simplified LCA software tools tailored for design and construction projects.

6. Consideration of an embodied carbon framework should complement established operating energy / GHG goals and standards, and must be phased in.

In addition to ensuring compatibility with existing climate policies, it is also important to recognize that there may be concern that adding embodied carbon to existing GHG-emission reduction campaigns in the building sector could be a distraction and potentially derail important progress that is being made on improving the operational energy efficiency of buildings. Adding embodied carbon considerations may also overwhelm builders, designers, and developers with requirements. Respecting these concerns, taking a slower step-by-step approach, with low-risk early stages, will likely be most effective.

APPENDIX 1: DETAILS OF EXISTING GLOBAL POLICIES

This appendix presents the details of the embodied carbon policies in the following jurisdictions:

APPENDIX 1A: LEADING JURISDICTIONS

- Belgium
- France
- Germany
- The Netherlands
- Sweden
- Switzerland
- United Kingdom

APPENDIX 1B: JURISDICTIONS TO WATCH

- Finland
- Singapore
- United Kingdom

APPENDIX 1A: LEADING JURISDICTIONS

1. BELGIUM

Overview

- EPD publishing is mandatory for any construction product manufacturer who makes environmental marketing claims, with specified exceptions (same as in France).
- Regional governments are cooperating to develop a voluntary calculation methodology, which uses the national EPD database to calculate building-level impacts.
 - There are potential plans for the Belgium Building Research Institute to launch building requirements around this, but no details are available yet.

Description

- Belgium EPD Program, or B-EPD, became law on December 7, 2016 through the Royal Decree on Environmental Messaging. Both the B-EPD and Belgian EPD database officially launched in February 2017.

Logistics

- B-EPD is run by the Federal Public Service of Health, Food Chain Safety and Environment.
- EPDs must be verified by approved inspectors before they will be published.
- Voluntary calculation methodology is being developed for building elements and whole-buildings. Expected to launch in fall of 2017. Led by Openbare Vlaamse Afvalstoffenmaatschappij (Public Waste Agency of Flanders),¹⁰⁴ and is supported by:
 - Brussels Instituut voor Milieubeheer (Brussels Institute for Management of the Environment)¹⁰⁵
 - Portail de l'énergie en Wallonie (Energy Portal in Wallonia)¹⁰⁶
- Draft version, including a proposed database and methodology, was developed in 2012¹⁰⁷ based on the EN standards. Specific changes include additional indicators and methodology to achieve a single score from various impact categories.

¹⁰⁴ www.ovam.be

¹⁰⁵ www.leefmilieu.brussels

¹⁰⁶ <http://energie.wallonie.be>

¹⁰⁷ www.ovam.be/sites/default/files/atoms/files/Environmental%20profile%20of%20buildig%20elements.pdf

1. BELGIUM - continued

Data Sources	<ul style="list-style-type: none"> • B-EPD website and documentation: www.environmentalproductdeclarations.be. This site will also link to the building calculation/assessment tool being developed, once complete. • B-EPD Database¹⁰⁸—live as of February 2017 • EPD rules are based on existing European and international standards (EN ISO 14025).
Tools	<ul style="list-style-type: none"> • MMG is a LCA tool currently under development. It uses the methodology currently being developed by the regions, and will make use of the national EPD database. More information available on website.¹⁰⁹
Intention/Goals	<ul style="list-style-type: none"> • Enable sustainable choice of construction materials and reduce greenwashing. • Implementation of environmental goals.
Scope	<ul style="list-style-type: none"> • EPDs required for all construction products making environmental claims, with some exceptions.
Tracking	<ul style="list-style-type: none"> • No national ongoing tracking of whole-building LCA results.

¹⁰⁸ www.health.belgium.be/en/belgian-epd-programme-b-epd

¹⁰⁹ www.ovam.be/afval-materialen/materiaalbewust-ontwerpen-produceren-en-aankopen/materiaalprestatie-gebouwen

2. FRANCE

Overview	<ul style="list-style-type: none"> Voluntary program that offers builders and developers incentives if they meet certain performance standards, which includes an embodied carbon calculation. Expected to become mandatory ~2020. Creation of EPDs is mandatory if environmental labels will be used on products.
Policy/Program	<ul style="list-style-type: none"> Energie Positive et Réduction Carbone (formerly Energie Carbone or E+C-) is a pilot program launched under the Energy Transition Law for Green Growth that builds on R.111-20-6 of the Building Code (du code de la construction).
Description	<ul style="list-style-type: none"> New buildings can receive incentives such as additional construction rights (right to build more floor area above zoning limits), financial assistance with LCA studies, and/or an E+C- building label if they opt-in and show proof of complying with performance benchmarks for energy and life-cycle carbon (including embodied). First national EPD standard created in ~2004. Products that wish to do green marketing must publish an EPD to the INIES database.
Logistics	<ul style="list-style-type: none"> Takes place at building permit stage. Applies to entire building permit site (building and plot). It can cover multiple buildings if they all apply using same building permit. There are two levels of embodied carbon performance: Carbon 1 (low performance), and Carbon 2 (high performance). <ul style="list-style-type: none"> Level is based on a building's combined calculations in two indicators: (1) life-cycle carbon, (2) embodied carbon in building materials and equipment—each of which must be below a maximum value. Calculation to determine benchmark is not straightforward. Requires calculations and looking up reference values to add modulation factors based on building type, surface and underground parking, floor area, building location, height, and surface area. <ul style="list-style-type: none"> There are building-specific benchmark targets; performance must be under for each target. Whole-building LCA results submitted by program participants are uploaded to national observatory.
Data Sources	<ul style="list-style-type: none"> National dataset: “environmental and health reference data for buildings” (INIES),¹¹⁰ contains over 1600 datasets <ul style="list-style-type: none"> Includes both national averages and manufacturer-specific data. To complete an LCA in accordance with the reference document, an applicant can use three types of data: (1) specific data supplied by an industrial EPD, (2) general data, or (3) fixed values to help simplify methodology calculation. Foreign EPD data cannot be used in the assessment.

¹¹⁰ www.inies.fr/home

2. FRANCE - continued

Tools	<ul style="list-style-type: none"> • Must use software validated by the Ministry of Environment and INIES data. Various tools have been validated under the program, including One Click LCA, ThermACV, ELODIE, ClimaWin, and NovaEQUER. • If an applicant wishes to use his or her own tool, they can contact the Ministry to explore potential validation. • The French government is committed to improving the control and verification of the central database and software used for assessments. • Recommendations aimed at improving software will be released in or around March of 2017.
Intention/Goals	<ul style="list-style-type: none"> • Reduce overall carbon and energy, including life cycle. • Evaluate the carbon footprint of buildings and construction. • Reduce greenwashing in the construction products sector. • Promote recyclable materials, innovation, and the circular economy.
Scope	<ul style="list-style-type: none"> • New buildings. • Does not apply to renovations at present, unless a renovation forces resubmission as a new building. • Includes operational energy.
Tracking	<ul style="list-style-type: none"> • All project reports are uploaded to a national observatory, which will likely be used to calculate statistics and will document best practices in the building sector.
Lessons	<ul style="list-style-type: none"> • This process has been pushed very hard by the French industry, which is keen on having this in place. The legislation has come much later; in some ways, a progressive industry program became legislative. • France is just at the beginning stages of the program, so not much to report yet. Most of the efforts have been focused on motivating participants to join. The program was based on extensive consultation with construction actors, so they expect a successful experience.

3. GERMANY

Overview	<ul style="list-style-type: none"> New federal buildings costing over 2M EUR (~\$2.8M CDN) are required to achieve a minimum Silver certification level under a custom rating system (BNB)—which requires whole-building LCA (as of 2010).¹¹¹
Policy/Program	<p>BNB: Assessment System for Sustainable Building (Bewertungssystem Nachhaltiges Bauen).¹¹²</p> <ul style="list-style-type: none"> An assessment system created by and for the national government. A slight variation of the voluntary national green building rating system (DGNB), which also requires whole-building LCA.
Description	<ul style="list-style-type: none"> BNB building design teams are required to calculate embodied carbon and other LCA metrics using whole-building LCA.
Logistics	<ul style="list-style-type: none"> BNB awards points based on LCA performance against pre-determined standard benchmark values. For example, a low, medium, and high benchmark for kg CO₂/m²/yr is provided. Projects earn some points for meeting the low benchmark, more points for the medium benchmark, and the most points for the high benchmark, as per the following, with linear interpolation for intermediate values: <ul style="list-style-type: none"> 100 points for ≤25 kg CO₂e/m²/yr 50 points = 41 kg CO₂e/m²/yr 10 points ≥ 66 kg CO₂e/m²/yr The LCA in DGNB has an embodied carbon ceiling, which the project must stay below. The further below this ceiling, the more points achievable. <ul style="list-style-type: none"> A project's LCA performance is compared against a standard pre-calculated “reference building” whose performance level is “R”, and corresponds to five points. The ceiling or limit “L” is calculated as 1.4R, and corresponds to zero points. The best performance, or target “T”, is 0.7R and corresponds to earning all ten available points.

¹¹¹ www.nachhaltigesbauen.de/fileadmin/pdf/Systainable_Building/LFNB_E_160309.pdf

¹¹² www.bnb-nachhaltigesbauen.de/

3. GERMANY - continued

Data Sources	<ul style="list-style-type: none"> • Free national LCA EPD database (ÖKOBAUDAT).¹¹³ Generic data is in German but English will also be offered starting in the latter part of 2017. <ul style="list-style-type: none"> ◦ Maintained by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety. ◦ Contains both generic (average) datasets and company or association-specific EPDs. ◦ Mandatory dataset for use with BNB. ◦ Contains over 700 building products. <p>Compliant with EN 15804 – “Sustainability of Construction Works. Environmental product declarations. Core rules for the product category of construction products” and uses ILCD data format.</p>
Tools	<ul style="list-style-type: none"> • BNB-compliant software must be used. Excel calculations using data from the national database is also acceptable. • Free LCA software for federal buildings (eLCA). (English version available.) • Software tool is taught and used in some university courses, so professionals are familiar and comfortable using it. • Other market-based programs are more widely used for other buildings.
Intention/Goals	<ul style="list-style-type: none"> • Reduce carbon. • BNB is a government version of the voluntary market-led rating system. Allows government to pursue green practices without involvement of private labels.
Scope	<ul style="list-style-type: none"> • BNB Silver certification is required only by new federal buildings over 2M EUR. • Voluntary building labels similar to BNB with points for meeting LCA benchmarks are available for single-family housing¹¹⁴ and for multi-family housing.¹¹⁵
Tracking	<ul style="list-style-type: none"> • All BNB projects total performance/scoring reside in a national repository (eBNB)—but, it does not show LCA results. • Database of BNB Certified Buildings.¹¹⁶ <ul style="list-style-type: none"> ◦ Currently 26 buildings (as of February 2017). • Currently roughly 50 additional buildings are in the process of certifying; evenly split between federal buildings (required) and state/community buildings (voluntary).

¹¹³ www.oekobaudat.de/

¹¹⁴ www.bau-irn.de/

¹¹⁵ www.bau-irn.de/

¹¹⁶ www.bnb-nachhaltigesbauen.de/zertifizierte-gebaeude.html

3. GERMANY - continued

Lessons

- The high level of market adoption is due to phased-in approach:
 - 2001: Design guidelines released.
 - 2007: Voluntary DGNB system launched.
 - 2009: Voluntary BNB system (for state buildings) launched.
 - 2010: Federal buildings required to achieve BNB Silver.
- Successful uptake is attributed to:
 - Broad outreach and stakeholder engagement during policy creation.
 - Government-run database which all are required to use—brings credibility and consistency.
 - Government-mandated requirement to calculate LCA.
 - Starting with government buildings.

Additional notes on Germany:

DGNB's Reference values¹¹⁷ are:

- Educational, office, hotel, residential
- 50-year study period, including construction, refurbishment, and end of life
- LCA Modules A1-A3, B2-B5, C, D
 - Global warming potential = 9.40 kg CO₂e/m²/yr
 - ODP = 5.30E-7 kg CFC₁₁e/m²/yr
 - POCP = 0.0042 kg C₂H₄ e/m²/yr
 - AP = 0.037 kg SO₂e/m²/yr
 - EP = 0.0047 kg PO₄⁻³e/m²/yr
 - PE_{nr} = 123 MJ/m²/yr
 - PE_{tot} = 151 MJ/m²/yr

The LCA performance levels for single-family housing are below.

(Note: these include both an LCA-based construction component, and an energy demand from an operations component, and are compared against a reference value of 17.84 kg CO₂e/m²/yr).

- 10 points ≤ 9.44 kg CO₂e/m²/yr (52.9% of reference value)
- 5 points ≤ 17.84 kg CO₂e/m²/yr (100% of reference value)
- 1 point ≤ 24.56 kg CO₂e/m²/yr (138% of reference value)

The multi-family housing LCA performance levels are:

- Clearly surpassed ≤ 12 kg CO₂e/m²/yr
- Surpassed ≤ 17 kg CO₂e/m²/yr
- Fulfilled ≤ 24 kg CO₂e/m²/yr

¹¹⁷ <http://www.eebguide.eu/?p=1015>

4. THE NETHERLANDS

Overview

- Since January 2013, it is mandatory to calculate 11 LCA-based parameters known as the “environmental profile” and report total global warming potential (includes life-cycle embodied carbon), and raw material and fossil fuel depletion, to obtain a construction permit for new residential and office projects over 100 m².

Policy/ Program

- Building Code 2012 (Bouwbesluit 2012), Article 5.9 requires the use of Assessment Method for Environmental Performance Construction and Civil Engineering Works—also known as GWW and The Assessment Method.

Description

- Requires whole-building LCA (including embodied carbon) to be performed at the time of building permit application.

Logistics

- This policy relies on two separate but related pieces:
 - Assessment Method (GWW)¹¹⁸
 - National Dataset¹¹⁹
- Custom national “weighting factors” have been developed (see table below from GWW) to give relative weighting to different LCA-based *environmental effect categories* (called the “environmental profile”), resulting in a single-score financial indicator called the “shadow cost”. A ceiling of 1 EUR/m² of construction is expected to be placed on this shadow cost in 2018.

Environmental effect categories	Equivalent unit	Weighting factors [€ / kg equivalent]	
Depletion of abiotic raw materials (excluding fossil energy carriers) – ADP	Sb eq	€ 0.16	Raw materials
Depletion fossil energy carriers – ADP	Sb eq ⁶	€ 0.16	
Climate change – GWP 100 j.	CO ₂ eq	€ 0.05	
Deterioration ozone layer – ODP	CFK-11 eq	€ 30	
Photochemical oxidant forming – POCP	C ₂ H ₄ eq	€ 2	
Acidification – AP	SO ₂ eq	€ 4	
Over-fertilization – EP	PO ₄ eq	€ 9	Emissions
Human toxicity – HTP	1,4-DCB eq	€ 0.09	
Fresh water aquatic ecotoxicity – FAETP	1,4-DCB eq	€ 0.03	
FAETP			
Marine aquatic ecotoxicity - MAETP	1,4-DCB eq	€ 0.0001	
Terrestrial ecotoxicity – TETP	1,4-DCB eq	€ 0.06	

1-points score

- Renovations are covered in a separate document: “Assessment of the environmental performance of the to-be renovated or transformed existing constructions” (“Bepaling van de milieuprestatie van te renoveren, of te transformeren, bestaande gebouwen”).

¹¹⁸ www.milieudatabase.nl/imgcms/SBK_Assessment_method_version_2_0_TIC_versie.pdf

¹¹⁹ www.milieudatabase.nl/index.php?q=english-documents

4. THE NETHERLANDS - continued

Data Sources	<ul style="list-style-type: none"> • Database and assessment method are based on EN 15804 and EN 15978. • National Dataset includes both generic and product-specific data, which have been reviewed according to a verification protocol.
Tools	<ul style="list-style-type: none"> • GPR Gebouw (LCA tool for buildings). • GPR Bouwbesluit (LCA tool for buildings). • DGBC tool (LCA tool for buildings). • DuboCalc (LCA tool for infrastructure).
Intention/ Goals	<ul style="list-style-type: none"> • To reduce emissions of GHGs and the depletion of raw materials due to building construction.
Scope	<ul style="list-style-type: none"> • New residential and office buildings over 100 m² applying for a building permit. <ul style="list-style-type: none"> ◦ Extensive renovations are also applicable. • Sometimes applied to large infrastructure projects on a case-by-case basis (no national requirement or law to apply to infrastructure). • Operational energy not included. Covered by separate assessment methods and regulations.
Tracking	<ul style="list-style-type: none"> • Calculated embodied carbon is not being tracked in a central database.
Lessons	<ul style="list-style-type: none"> • Hard to quantify the impacts of the policy, because results are not tracked. • The weighting factors are subjective and thus contentious. • Real estate sector and contractors pushed back. They did not like the extra cost required to carry out the analysis. Government made a large investment to support the initiative and educate how to comply. • This exercise was attempted and failed in 2003 due to industry resistance. Re-did the whole process again 10 years later, learning from mistakes, and was successful. • Manufacturers are supportive and appreciate the consistent use of EPD data. • Starting to gain traction in market, and value is being recognized.

4. THE NETHERLANDS - continued

Data Sources	<ul style="list-style-type: none"> • Database and assessment method are based on EN 15804 and EN 15978. • National Dataset includes both generic and product-specific data, which have been reviewed according to a verification protocol.
Tools	<ul style="list-style-type: none"> • GPR Gebouw (LCA tool for buildings). • GPR Bouwbesluit (LCA tool for buildings). • DGBC tool (LCA tool for buildings). • DuboCalc (LCA tool for infrastructure).
Intention/ Goals	<ul style="list-style-type: none"> • To reduce emissions of GHGs and the depletion of raw materials due to building construction.
Scope	<ul style="list-style-type: none"> • New residential and office buildings over 100 m² applying for a building permit. <ul style="list-style-type: none"> ◦ Extensive renovations are also applicable. • Sometimes applied to large infrastructure projects on a case-by-case basis (no national requirement or law to apply to infrastructure). • Operational energy not included. Covered by separate assessment methods and regulations.
Tracking	<ul style="list-style-type: none"> • Calculated embodied carbon is not being tracked in a central database.
Lessons	<ul style="list-style-type: none"> • Hard to quantify the impacts of the policy, because results are not tracked. • The weighting factors are subjective and thus contentious. • Real estate sector and contractors pushed back. They did not like the extra cost required to carry out the analysis. Government made a large investment to support the initiative and educate how to comply. • This exercise was attempted and failed in 2003 due to industry resistance. Re-did the whole process again 10 years later, learning from mistakes, and was successful. • Manufacturers are supportive and appreciate the consistent use of EPD data. • Starting to gain traction in market, and value is being recognized.

5. SWEDEN

Overview	<ul style="list-style-type: none"> • Transport authority started requiring carbon accounting for new projects over 50M SEK¹²⁰ (\$7.5M CDN) in 2015. • Sweden's voluntary national green building rating system, Miljöbyggnad v2¹²¹, does not currently include LCA. However, the next version (v3) will. • Stockholm has a suggested LCA calculation guideline for construction, but no requirement or enforcement.
Policy/Program	<ul style="list-style-type: none"> • The regulation TDOK 2015:0007 requires carbon calculation of transportation infrastructure projects over 50M SEK (\$7.5M CDN) at various phases of design and after construction. • The City of Stockholm's "Routine environmental calculations of larger construction projects with LCA" ("Rutin för miljöberäkningar av större byggprojekt med LCA")¹²² is a carbon footprint guideline for buildings over 10M SEK (\$1.5M CDN) that is established prior to construction. No requirement or enforcement yet.
Description	<ul style="list-style-type: none"> • Klimatkalkyl (climate calculator)¹²³ is a LCA tool provided by the transportation administration, to calculate embodied energy and GHG emissions of transportation infrastructure construction and maintenance. It is intended as a decision support tool. • Includes a website database that allows users to select the type of infrastructure they are designing, and provides typical embodied carbon of construction on a linear unit basis. • City of Stockholm has long-term plans to generalize carbon accounting for all construction projects; no public timeline. There are plans to develop this, and perhaps require it for larger and/or higher budget projects. Program in development. • The voluntary Miljöbyggnad v3 (not yet released) is proposed to include a LCA strategy. All projects targeting Gold certification (the highest level) are proposed to have a minimum LCA performance requirement.

¹²⁰ Swedish kronor.

¹²¹ www.sgbc.se/var-verksamhet/miljobyggnad

¹²² <https://insynsverige.se/documentHandler.ashx?did=1809007>

¹²³ <http://webapp.trafikverket.se/Klimatkalkyl/>

5. SWEDEN - continued

Logistics

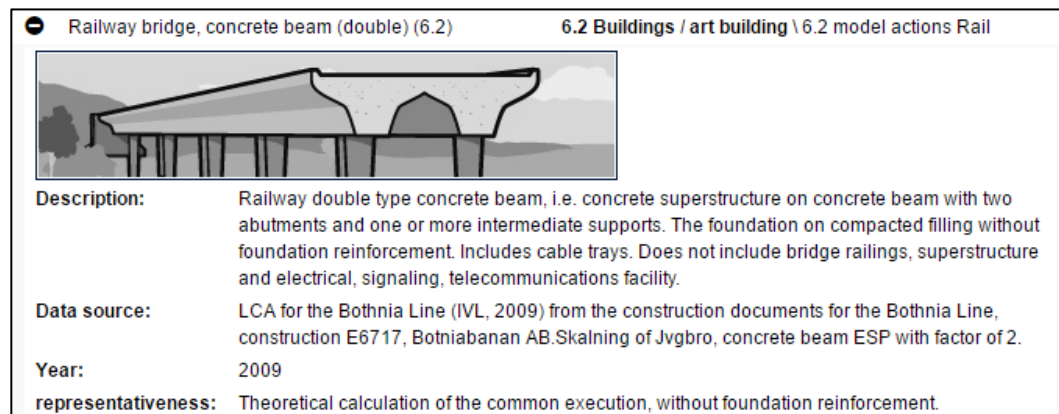
- The transport administration requires designers of infrastructure projects to use the Klimatkalkyl tool and submit calculations at various stages of the project. Over 150 projects have calculated their carbon with the tool since its launch in 2015. Hence, results from improvement measures are being tracked.
- Regulation requires a project's carbon calculations to be updated each time the cost calculations are updated.
- Miljöbyggnad v3's proposed LCA strategy is expected to require analysis of only the construction materials in the structure and building envelope.
 - Expected to require a calculation of reference-case CO₂e resulting from life-cycle stages A1 to A4 based on generic data, then compare against a design case using specific EPDs of higher-performing materials. Improvements of at least 10% are awarded the best Gold level.

Data Sources

- Engineers at WSP's Stockholm office¹²⁴ created the Klimatkalkyl tool from LCA data.
- Klimatkalkyl was developed to use the same formatting and methodology that cost calculations use. The idea is that any project that has proper cost calculations (i.e., has an accurate bill of materials) can also do carbon calculations with the tool.

Tools

- Klimatkalkyl is a free, web-based, voluntary, LCA-based design tool for transportation infrastructure (mainly roads, bridges, rail).
- Allows users in early planning phases to select their infrastructure type from a list of 94 potential construction solutions (e.g., one can select "railway bridge, concrete beam", see screen shot from Klimatkalkyl shown at right). The calculator provides an estimate of carbon accounting for this type of infrastructure on a unit basis, which is then multiplied by the length of the infrastructure. Users in later planning phases exchange the default values to project-specific values to obtain a increasing precision.



¹²⁴ WSP is an international engineering firm headquartered in Canada www.wsp.com

5. SWEDEN - continued

Intention/Goals	<ul style="list-style-type: none"> • Transportation policy has a goal of 15% carbon reduction in projects by 2020. • To encourage the market to disclose environmental impacts of construction products. • To implement climate goals.
Scope	<ul style="list-style-type: none"> • Klimatkalkyl must be used for all road and railway projects over 50M SEK (\$7.5M CDN). <ul style="list-style-type: none"> ◦ Does not include operational energy. • Stockholm guidelines are for all building construction projects over 10M SEK (\$1.5M CDN). <ul style="list-style-type: none"> ◦ Only CO₂e calculation is required. ◦ Includes construction materials and transportation. Does not require inclusion of use or demolition phase, which can voluntarily be added.
Tracking	<ul style="list-style-type: none"> • Embodied GHG data for transport infrastructure are collected.
Lessons	<ul style="list-style-type: none"> • Klimatkalkyl allows users to apply specific material EPDs when available. There is a risk for inconsistencies due to different interpretations of the EPD standards by the program operators. • For some observations and recommendations, see a recent conference paper by the project team.¹²⁵

¹²⁵ Toller, S. and M.Larsson, 2017. Implementation of life cycle thinking in planning and procurement at the Swedish Transport Administration. Proceedings of the Pavement Life-Cycle Assessment Symposium, Champaign, Illinois, 12-13 April 2017

6. SWITZERLAND

Overview	<ul style="list-style-type: none"> Minergie¹²⁶ is a series of voluntary building rating systems used throughout Switzerland. The Minergie-Eco standard requires a calculation of embodied energy and includes a performance target for whole-building LCA. City of Zurich requires all new government buildings to obtain Minergie-Eco certification.
Policy/Program	<ul style="list-style-type: none"> The City of Zurich has anchored the 2000 Watt Society vision¹²⁷ in its municipal code and set a 2050 target for embodied life-cycle GHG emissions from residential buildings at 8.5 kg CO₂e/m²/yr. While Minergie is a voluntary building rating system, certain cities and cantons have integrated Minergie standards by requiring their own buildings to achieve Minergie certifications, by subsidizing certified buildings, or by providing additional density incentives for those buildings that do. Private firms have also integrated Minergie into their corporate social responsibility (CSR) or other standards. For instance, Zurich Cantonal Bank, a large Swiss bank, made Minergie-Eco standard for all new buildings.
Description	<ul style="list-style-type: none"> Minergie has various classes of application (Minergie, Minergie-P, Minergie-A). They each have an “Eco” variant, including (among other requirements) a calculation of embodied energy (called “grey energy” in Swiss parlance). Minergie was first launched in 1997, at which time it was not yet looking at embodied energy. The other classes of Minergie certification were launched as follows: <ul style="list-style-type: none"> 1997: Minergie-Standard 2003: Minergie -P: the Swiss equivalent to the Passivhaus 2006: Minergie -Eco 2011: Minergie -A Minergie-Eco has “deep grey energy” performance standards for six building categories, according to the Swiss Engineering Association (SIA) standard SIA 380/1 edition 2009.
Logistics	<ul style="list-style-type: none"> Minergie uses a LEED-like process. There are two milestones at which an applicant submits documentation: (1) after design is complete and (2) after construction is complete. The applicant is required to submit further information after the second phase only if major changes occurred between the first and second phases.
Data Sources	<ul style="list-style-type: none"> Swiss KBOB dataset¹²⁸ (national dataset, based on ecoinvent data), which is incorporated in most Swiss energy-calculation applications (providing regulatory required calculations).

¹²⁶ www.ecolabelindex.com/ecolabel/minergie

¹²⁷ www.swissinfo.ch/eng/politics/energy-efficiency_2000-watt-society--when-the-future-becomes-a-reality/41958718

¹²⁸ www.kbob.admin.ch/kbob/de/home.html

6. SWITZERLAND - continued

Tools	<ul style="list-style-type: none"> The most common multinational tool used for these calculations is the Lesosai tool.¹²⁹ Some tools allow for the simultaneous calculation of operational energy and embodied energy. Minergie encourages users to combine energy modelling with the LCA calculation in order to facilitate the process. Grey energy calculations follow SIA-Merkblatt 2032.¹³⁰
Intention/Goals	<ul style="list-style-type: none"> Reduce embodied and operational energy and carbon. To implement climate goals. Minergie was initially launched to reduce energy demand and elevate the comfort level of buildings. The Minergie-Eco standard focuses on ecology and well-being.
Scope	<ul style="list-style-type: none"> The City of Zurich's requirements apply to all new government buildings. The voluntary Minergie certification can be used for new and existing buildings of all types. It does not apply to infrastructure.
Tracking	<ul style="list-style-type: none"> Minergie data are centralized to the certification organisation. Minergie has certified approximately 1,334 Minergie (P-/A-) Eco buildings and 40,001 buildings in total (Minergie (-P/-A) certified).
Lessons	<ul style="list-style-type: none"> The program has worked well thus far and has received very wide industry support. The representative at Minergie said that, while the program has worked well in Switzerland, it is always difficult to recommend a program to other countries due to different contexts, norms, construction types, etc. He was less interested in policies that required calculation of embodied carbon emissions (the number of new buildings some cantons are building is small) and was more interested in the private sector adoption of Minergie. (A Cantonal Bank made Minergie-Eco a requirement, which had a much broader impact.) The representative also advised that any program should make things as simple as possible. That is, the emphasis should be less on calculating values exactly and more on a simple, usable method that will ensure broader uptake. This is why, for instance, Minergie has tried to combine energy modelling with the embodied energy calculation (i.e., because much of the information needed for the LCA calculation comes out of the energy-modelling exercise).

¹²⁹ www.lesosai.com/en

¹³⁰ Merkblatt SIA 2032 «Graue Energie von Gebäuden», available for purchase from www.sia.ch

7. UNITED KINGDOM

Overview	<ul style="list-style-type: none"> Voluntary rating systems (BREEAM, Home Quality Mark) have embodied carbon goals in place, but no requirements.
Policy/Program	<ul style="list-style-type: none"> Voluntary BREEAM green building rating system includes two LCA-based incentives: the “Mat 01” credit which rewards selection of low-impact building elements, and “innovation” points for performing whole-building LCA. The residential program Home Quality Mark (part of the BRE family) has a whole-building LCA benchmark incentive. BREEAM 2018 will go this way too. There was previously an option being created for an embodied carbon “allowable solution” as part of the zero-carbon policy¹³¹ goal, which aimed to make all domestic buildings zero carbon by 2016 and commercial buildings by 2019. However, this goal was repealed in 2015.
Description	<ul style="list-style-type: none"> BREEAM has programs for new construction and renovation and fit-outs, as well as a Home Quality Mark program for homes and CEEQUAL for infrastructure. All incorporate LCA methodology. All are voluntary. In some cities, achieving BREEAM for municipally owned buildings is a planning requirement. However, LCA is just one of the available strategies and is not strictly required. BREEAM has been in place since 1990. It has incorporated an LCA perspective since 1996 (indirectly via the BRE Green Guide product rating system) and has increasingly emphasized more sophisticated whole-building LCA.
Logistics	<ul style="list-style-type: none"> BREEAM certification is sought by project teams. It has design phase certification and final certification. Various different versions (or schemes) of BREEAM exist, for different project types and for different countries.
Data Sources	<ul style="list-style-type: none"> Certified BREEAM Assessments database.¹³² BRE Green Guide and the GreenBookLive database.
Tools	<ul style="list-style-type: none"> BREEAM New Construction 2016¹³³ scheme document. Various LCA tools are certified for the BRE “Impact” methodology.
Intention/Goals	<ul style="list-style-type: none"> BREEAM has an overall sustainability goal rather than single target. Strengthening sustainable construction.

¹³¹ www.zerocarbonhub.org/zero-carbon-policy/zero-carbon-policy

¹³² www.greenbooklive.com/search/scheme.jsp?id=202

¹³³ www.breeam.com/new-construction

7. UNITED KINGDOM - continued

Scope	<ul style="list-style-type: none">• BREEAM can be applied to all types of projects.• Includes operational energy for LCA purposes.
Tracking	<ul style="list-style-type: none">• BRE.
Lessons	<ul style="list-style-type: none">• Cities are using their planning-review and/or permit-issuing powers to strengthen green construction. Cities have adopted BREEAM as a tool towards this end, as it has broad industry support.

APPENDIX 1B: JURISDICTIONS TO WATCH

8. FINLAND

Overview	<ul style="list-style-type: none">• No requirements for embodied carbon calculations or EPDs.• All state (national) construction projects are encouraged to use life-cycle calculators during design.• Regulation currently being prepared that will require the use of life-cycle calculators in future, but details not yet developed.¹³⁴ This regulation will not apply to municipalities or private construction.• Voluntary life-cycle carbon metrics exist but are not yet widely used.
Policy/Program	<ul style="list-style-type: none">• Green Building Council Finland (FiGBC) has a voluntary guideline called Building Performance Indicators,¹³⁵ which includes life-cycle carbon.• Finnish Building Information Foundation (Rakennustieto, or RTS) has created the RTS Environmental Classification Certificate (RTS-Ympäristöluokitussertifikaatti),¹³⁶ which incorporates the FiGBC Indicators. This labelling system is starting to be used for most state construction projects.
Logistics	<ul style="list-style-type: none">• FiGBC Voluntary Building Performance Indicators.<ul style="list-style-type: none">○ Eight indicators broken into two categories: Design Phase, and Use Phase—each having four sub-indicators.○ Life-cycle carbon footprint (CO₂e) is one of the Design Phase Indicators.○ Methodology based on EN 15978.○ Includes all life-cycle phases, including operational energy.• Voluntary programs currently in place have limited impact. Future regulations are currently under development and are not yet well defined.
Data Sources	<ul style="list-style-type: none">• FiGBC Life Cycle Carbon Footprint Guide (well-written explanation).¹³⁷

¹³⁴ [www.ym.fi/fi-FI/Maankaytto_ja_rakentaminen/Rakentamisen_ohjaus/Tiekartta_rakennusmateriaalien_hiilijala\(40813\)](http://www.ym.fi/fi-FI/Maankaytto_ja_rakentaminen/Rakentamisen_ohjaus/Tiekartta_rakennusmateriaalien_hiilijala(40813))

¹³⁵ <http://figbc.fi/en/building-performance-indicators/>

¹³⁶ www.rakennustieto.fi/index/english/productsandservices/finnishbuildingclassificationsystem.html

¹³⁷ <http://figbc.fi/en/building-performance-indicators/calculation-guide/life-cycle-carbon-footprint-guide/>

8. FINLAND - continued

Tools	<ul style="list-style-type: none"> • RT-Environmental Tool (RT-ympäristötyökalu)¹³⁸ is a free tool to help in the calculation of building performance in line with the requirements of the RTS Environmental Classification Certificate (no LCA capability). • One Click LCA—a subscription based, online whole-building LCA calculation tool.
Intention/Goals	<ul style="list-style-type: none"> • Reduce embodied carbon. • Rationale: to implement climate goals.
Scope	<ul style="list-style-type: none"> • Future regulation will be binding for national/state bodies only, but not businesses or municipalities. • New projects and large-scale renovations.
Tracking	<ul style="list-style-type: none"> • No national tracking of life-cycle carbon performance of buildings.
Lessons	<ul style="list-style-type: none"> • Voluntary mechanisms have had very limited impact in the market so far.

¹³⁸ <http://glt.rts.fi/etusivu/rt-hankeohjaustyokalu/>

9. SINGAPORE

Overview	<ul style="list-style-type: none"> Green Mark building rating system¹³⁹ includes an optional LCA-based strategy.
Policy/Program	<ul style="list-style-type: none"> Singapore's Building & Construction Authority (BCA) has operated the Green Mark green building rating system since 2005. It is mandatory for all projects over 2,000 m².
Description	<ul style="list-style-type: none"> Program requires projects to register and pass through certain steps. One of the criteria addresses materials. Materials criteria include materials selection guidance as well as quantification of embodied carbon. In some cases, for higher ratings, incentives may be applied for.
Logistics	<ul style="list-style-type: none"> Various versions of Green Mark exist for different building types. Non-residential buildings (NRB): 2015 includes embodied carbon. <ul style="list-style-type: none"> A total of 140 points are available. Section 3.02: Materials is worth 18 points, including: <ul style="list-style-type: none"> 3.02b: Embodied Carbon (2 points) <ul style="list-style-type: none"> 0.25 points per material for using materials that report their “material emission factors” 2 points for full carbon footprint of development including all materials
Tools	<ul style="list-style-type: none"> BCA's Carbon Calculator helps “identify carbon debt and quantify environmental impact and embodied energy, as well as allow benchmarking over time.” The calculator could not be found online but may be available to registered projects.
Intention/Goals	<ul style="list-style-type: none"> Green Mark has the intention of ensuring a sustainable, self-sufficient country.
Scope	<ul style="list-style-type: none"> New building, addition or extension of existing building, or major renovation—over 2,000 m²
Tracking	<ul style="list-style-type: none"> BCA Green Mark Directory is a free, publicly available, online directory showing all Green Mark buildings with descriptions of their features. LCA results not provided in this directory.
Lessons	<ul style="list-style-type: none"> The scheme has been very successful. It is not clear that the scheme is replicable elsewhere as the economy in Singapore is under different kinds of resource constraints than most others, and has, politically, a very homogeneous structure. Although embodied carbon is a voluntary strategy in Green Mark, its weighting is miniscule (2 points available for a whole-building LCA, out of a total 140 potential points), thus there is not sufficient incentive for the strategy to be widely adopted.

¹³⁹ www.bca.gov.sg/green_mark/

APPENDIX 2: DETAILS ON EXISTING TECHNICAL INFRASTRUCTURE

This appendix covers details on the following key technical infrastructure elements, worldwide:

- standards
- life-cycle inventory (LCI) databases and life-cycle impact assessment (LCIA) databases
- life-cycle assessment (LCA) software—general (professional) tools
- whole-building and infrastructure LCA software usable in North America
- environmental product declaration (EPD) programs and databases

DISCLAIMER: The information presented here represents current global LCA practices. It is presented only to identify for readers the most prominent and widely used infrastructure, globally.

Standards

These two documents from the International Standards Organization (ISO)¹⁴⁰ are the universally accepted foundational LCA standards:

- ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework.
- ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines.

In 2006, ISO 14025 was published to specify the application of the ISO 14040 series of standards in developing EPDs and outline the procedures for establishing an EPD program. All EPD programs cite ISO 14025 as a governing standard in their program-operator documents and in all EPDs that they publish:

- ISO 14025:2006 Environmental labels and declarations – Type III environmental declarations – Principles and procedures

In addition to the foundational LCA standards described above, ISO has also sought to provide standardization that is specific to the completion of carbon footprints of products through the publication of ISO 14067 in 2013. ISO 14067 draws heavily on ISO 14044 as a normative reference for scoping and modelling the life cycle of a product, but does provide specific carbon footprinting guidance not found elsewhere in the ISO standards. ISO 14067 is sometimes cited in LCA studies as a supplementary guidance document for topics for which no other standards apply:

- ISO 14067:2013 Carbon footprint of products — Requirements and guidelines for quantification and communication

¹⁴⁰ All of the ISO standards cited in this document are available from www.iso.org

ISO has further sought to supplement the existing suite of standards through several works that are currently in progress. ISO 14026 applies to the following generation of EPDs:

- ISO/DIS 14026 Environmental labels and declarations — Principles, requirements, and guidelines for communication of footprint information (under development)

ISO 14027 also applies to the following generation of EPDs:

- ISO DTS 14027 Environmental labels and declarations — Development of product category rules (PCRs) (under development)

In addition to the generic LCA standards, Subcommittee 17 (SC 17: Sustainability in building and civil engineering works¹⁴¹) was established by the ISO Technical Committee TC 59: Buildings and civil engineering works,¹⁴² which has published several standards that define the LCA framework as it applies to buildings and building materials. Subcommittee 17 has developed the following standards:

- ISO 15392:2008 Sustainability in building construction, General principles
- ISO 21929-1:2011 Sustainability in building construction, Sustainability indicators -- Part 1: Framework for the development of indicators and a core set of indicators for buildings
 - Purpose: provides criteria and indicators regarding building sustainability.
- ISO 21929-2:2015 Sustainability in building construction, Sustainability indicators -- Part 2: Framework for the development of indicators for civil engineering works
- ISO 21930:2007 Sustainability in building construction, Environmental declaration of building products
 - Purpose: provides criteria, indicators, and reporting regarding LCA of building products.
- ISO 21931-1:2010 Sustainability in building construction, Framework for methods of assessment of the environmental performance of construction works, Part 1: Buildings
 - Purpose: provides requirements beyond ISO 21930, regarding environmental sustainability of buildings.
- ISO 21931-2 Sustainability in buildings and civil engineering works, Framework for methods of assessment of the sustainability performance of construction works, Part 2: Civil engineering works (under development)

ISO 21930 was originally published in 2007 and reflected the lack of consensus around several material-specific modelling issues that are known to be significant to the outcomes of LCA studies of buildings. These issues include the treatment of recycling, biogenic carbon storage in wood products, and carbonation in concrete products, as well as data-quality standards and the breadth of impacts that are to be addressed in a building product LCA. In the 9 years since ISO 21930's publication, LCA developers have looked elsewhere (e.g., to European standards) to produce LCAs and EPDs of building products.

ISO 21930 has been under revision by Technical Committee 59 for the past several years and is currently a Draft International Standard, which means that all technical issues have been settled. The Draft

¹⁴¹www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?coid=322621

¹⁴²www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?coid=49070

International Standard of ISO 21930 is expected to be published in 2017 and will reclaim its place as the consensus international standard for conducting building product and whole-building LCA and EPDs.

Technical Committee 59 is also currently developing another standard that will standardize the benchmarking of buildings to determine sustainability in construction. This standard, ISO 21678, was approved for development in September 2016. Initial drafting of the standard is currently underway:

- ISO 21678 Sustainability in buildings and civil engineering works -- Methodological principles for the development of benchmarks for sustainable buildings (under development)

The ISO standards for LCA described here have received international consensus. The requirement of consensus, however, means that ISO does not address some of the modelling and reporting elements that are required for consistent LCA practice. The European Commission recognized the lack of harmonization and in 2005 established the European Committee for Standardization (CEN) Technical Committee 350 (TC 350) to address LCA and EPD standards for construction works.¹⁴³ CEN/TC 350 has since developed a series of standards¹⁴⁴ to address environmental sustainability issues that mirror those developed by ISO. These are:

- EN 15643-2:2010 Assessment of buildings – Framework for the assessment of environmental performance
- EN 15804:2012 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products
- EN 15978:2011 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method

Similar to the relationship between the building and construction ISO standards, EN 15643-2 is the highest-level standard and defines the criteria and indicators for building sustainability, while EN 15804 applies to building products and EN 15978 applies to whole buildings. EN 15978 defers to EN 15804 for the system boundary definition for the various building products that comprise a building.

The areas in which the CEN standards have been particularly useful in supplementing ISO standards are the more detailed descriptions and modular structure of processes to be included in the system boundary and the environmental indicators to be reported. As noted previously, the revised ISO 21930 has adopted many of the specifications in EN 15804.

LCI DATABASES

There are several European and national-level LCI databases that are publicly available and of suitable quality for developing LCAs for construction projects. The two leading global-level LCI databases are ecoinvent and GaBi. These and other important LCI databases are summarized below. Prices are as of March 2017.

¹⁴³ http://portailgroupe.afnor.fr/public_espacenormalisation/CENTC350/index.html

¹⁴⁴ All of the published CEN standards cited in this document are available for purchase.

https://standards.cen.eu/dyn/www/f?p=204:32:0:::FSP_ORG_ID,FSP_LANG_ID:481830,25&cs=117375B165644AAC954DDC63B921F43EF

ecoinvent

ecoinvent claims it is the world's largest, most consistent, comprehensive, and transparent life-cycle inventory database. Administered by a non-profit association in Switzerland, the ecoinvent database is used worldwide.

- **Administrator:** ecoinvent Association¹⁴⁵
- **Website:** www.ecoinvent.org
- **Geographic applicability:** global/regional; ecoinvent is European-focused but some datasets are specific to North America (i.e., they reference Canadian and US electricity grids), and global datasets are mostly presented as unit process data so they can be customized to North American conditions.
- **Size:** 12,800 LCI datasets (some datasets are duplicative but specific to different regions).
- **Sectors:** comprehensive; e.g., includes energy supply, agriculture, transport, biofuels and biomaterials, bulk and specialty chemicals, construction materials, wood, and waste treatment.
- **Transparency:** most datasets are available as both unit process data and system process data; a limited number of datasets are available as system processes only to retain confidentiality.
- **Price:** direct access by purchasing a license (3,800 EUR for single user) with an annual update fee (650 EUR) or, more commonly, access via an LCA software tool that has ecoinvent embedded in the background.
- **Integrated with:** all major professional LCA software tools and several simplified LCA-based tools.

GaBi

Like ecoinvent, Gabi claims to be the world's largest LCI database. The GaBi database was developed by a group called thinkstep (formerly PE International) and is available for use in the similarly named GaBi LCA software that is also offered by thinkstep. Thinkstep is a for-profit consultancy and software provider.

- **Administrator:** thinkstep
- **Website:** www.gabi-software.com/canada/index
- **Geographic applicability:** global/regional; many datasets are specific to North America.
- **Size:** Approximately 30,000 LCI datasets. (Some datasets are duplicative but specific to different regions.)
- **Sectors:** comprehensive.
- **Transparency:** provides data at both the unit process and system process level.
- **Price:** GaBi Database is available in sector-specific modules. The first user for "US Extension" database costs \$4,550 USD + \$1,138 USD annually. The "Construction Materials" database costs \$3,900 USD + \$975 USD annually. Additional users cost extra.
- **Integrated with:** thinkstep software such as GaBi and Tally.

¹⁴⁵ The ecoinvent Association, previously known as the Swiss Centre for Life Cycle Inventories, was founded by five organizations: the Swiss Federal Institute of Technology Zurich (ETH Zurich) and Lausanne (EPF Lausanne), the Paul Scherrer Institute (PSI), the Swiss Federal Laboratories for Materials Science and Technology (Empa), and Agroscope, Institute for Sustainability Sciences.

USLCI

The USLCI Database provides individual gate-to-gate, cradle-to-gate, and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the United States.

- **Administrator:** US Department of Energy (NREL)
- **Website:** www.nrel.gov/lci
- **Geographic applicability:** United States.
- **Size:** 2,500 LCI datasets.
- **Sectors:** comprehensive.
- **Transparency:** most datasets are available as unit process data; a limited number of datasets are available as system processes only to retain confidentiality. Some datasets are incomplete (i.e., some process flows are terminated prior to their boundary with nature) and the data gaps must be filled with data from other sources.
- **Price:** free.
- **Integrated with:** all major professional LCA software tools.

ELCD – European Reference Life Cycle Database 2.0

The ELCD Database was first released in 2006 and is comprised of data from EU-level business associations and other European sources for key materials, energy carriers, transport, and waste management.

- **Administrator:** European Commission – Joint Research Centre
- **Website:** <http://eplca.jrc.ec.europa.eu/ELCD3>
- **Geographic applicability:** Pan-Europe.
- **Size:** 509 LCI datasets. Background data are from GaBi and ecoinvent.
- **Sectors:** General but limited coverage.
- **Transparency:** 437 of the 509 LCI datasets are available as system process data only; a limited number of datasets are available as unit process data.
- **Price:** free.
- **Integrated with:** all major professional LCA software tools.

Eco-Profiles of the European Plastics Industry

PlasticsEurope maintains a database of Eco-profiles for plastic products manufactured in Europe. Eco-profiles are a combination of life-cycle inventory datasets and environmental product declarations (EPDs).

- **Administrator:** PlasticsEurope (Association of Plastics Manufacturers in Europe)
- **Website:** www.plasticseurope.org/plastics-sustainability-14017/eco-profiles.aspx
- **Geographic applicability:** Pan-Europe.
- **Size:** 30 LCI datasets.
- **Sectors:** the European plastics industry; background data are from GaBi.

- **Transparency:** All datasets are system process data only.
- **Price:** free.
- **Integrated with:** all major professional LCA software tools.

LCIA AND LCA DATABASES

Rather than contain inventory data on flows between a product and nature, LCA or LCIA databases contain LCA results for products. The primary LCA databases are summarized below alphabetically. Prices are as of March 2017.

AusLCI

The Australian National Life Cycle Inventory Database is a major initiative currently being delivered by the Australian Life Cycle Assessment Society (ALCAS). The aim is to provide and maintain a national, publicly accessible database with easy access to authoritative, comprehensive, and transparent environmental information on a wide range of Australian products and services over their entire life cycle.

- **Administrator:** Australian Life Cycle Assessment Society
- **Website:** www.auslci.com.au
- **Geographic applicability:** Australia.
- **Size:** 460 datasets.
- **Sectors:** multiple.
- **Transparency:** some unit process data, some system process data.
- **Price:** free.
- **Integrated with:** SimaPro, GaBi.

BP LCI

The Building Products Life Cycle Inventory is an Australian LCI database specifically for construction products. It is more or less consistent with AusLCI.

- **Administrator:** Building Products Innovation Council
- **Website:** www.bpic.asn.au/lci/thebuildingproductslifecycleinventory
- **Geographic applicability:** Australia.
- **Size:** over 100 generic construction products.
- **Sector:** building construction.

GEMIS

The International Institute for Sustainability Analysis and Strategy (IINAS), an independent transdisciplinary research organization based in Darmstadt (Germany), is the host of GEMIS (Global

Emissions Model for integrated Systems), a public domain life-cycle and material flow analysis model and database that IINAS provides freely. IINAS also collaborates with the German Environment Agency (UBA) to produce ProBas, a web-based tool for GEMIS data.

- **Administrator:** The International Institute for Sustainability Analysis and Strategy (IINAS)
- **Website:** GEMIS: <http://iinas.org/gemis.html>
- **Geographic applicability:** global (used in 30 countries).
- **Size:** 10,000 LCI datasets.
- **Sectors:** comprehensive.
- **Transparency:** unit process data.
- **Price:** free.
- **Integrated with:** ProBas web-based LCI data-exploration tool. Data must be uploaded into LCA software to complete LCI modelling.

ICE

The United Kingdom has a national LCA materials database (partial: just energy and carbon), which was developed at the University of Bath¹⁴⁶ and is known as ICE (inventory of carbon and energy).

- **Administrator:** Circular Ecology
- **Website:** www.circularecology.com/embodied-energy-and-carbon-footprint-database.html
- **Geographic applicability:** tailored to the United Kingdom; suitable as proxy data for other regions.
- **Size:** 200 embodied carbon and energy profiles for building materials.
- **Sectors:** building products.
- **Transparency:** embodied carbon and energy profiles only.
- **Price:** free.
- **Integrated with:** available for download. Not suitable for comprehensive impact LCAs of buildings because the scope is limited to carbon and energy.

Nationale Milieudatabase

In 2010, the Dutch government established a single LCA database comprising EPDs and generic LCA data, and it established a whole-building LCA method for use in The Netherlands. Stichting Bouwkwaliiteit (SBK)¹⁴⁷ first released the National Environmental Database (NMD) in 2012, based on the existing Dutch standard for EPDs (NEN 8006), and then updated it in 2014 to align with EN 15804.

- **Administrator:** Stichting Bouwkwaliiteit (SBK)
- **Website:** www.milieudatabase.nl/index.php?q=english-documents
- **Geographic applicability:** The Netherlands.
- **Size:** 950 LCA datasets (not complete LCI, reports 11 impact categories including raw materials, global warming, ozone depletion, etc.).

¹⁴⁶ www.bath.ac.uk

¹⁴⁷ www.milieudatabase.nl

- **Sectors:** construction products. Background data are from ecoinvent.
- **Transparency:** about half the datasets are unit process data, and the other half of the datasets are system process data.
- **Price:** multi-level subscription service (complex pricing scheme).
- **Integrated with:** stand-alone database available online and compatible with SimaPro; integrated with Dutch whole-building LCA tools.

ÖKOBAUDAT

Germany's Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety¹⁴⁸ provides a free national LCA/EPD database called ÖKOBAUDAT, which contains data for at least 700 building products, including generic materials data as well as specific data from EPDs. In addition, the ministry provides a free LCA software tool for buildings called eLCA that is directly connected to ÖKOBAUDAT.

- **Administrator:** Germany's Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
- **Website:** www.oekobaudat.de/en
- **Geographic applicability:** Germany.
- **Size:** 1,006 LCIA profiles.
- **Sectors:** construction products. Background data are from GaBi.
- **Transparency:** only system-level LCIA results are available. The complete LCI is not available as unit process data nor system process data.
- **Price:** free.
- **Integrated with:** eLCA Building LCA Software.

LCA SOFTWARE

LCA software packages facilitate LCI model development by providing an interface in which the LCA developer can create new unit processes to model foreground processes and then relate these processes to secondary data sources by using the output of one process as an input to another process. LCA software also automates the process flow calculation and the “characterization” of inventory flows into impact results.

General LCA tools

There are several general-use LCA software platforms available for developing life-cycle inventory models and calculating impact assessment results. These software packages allow the user to integrate published LCI databases with material takeoffs and scenario information specific to a given project. This type of LCA software is typically used only by LCA professionals, who require the inherent flexibility in

¹⁴⁸ www.bmub.bund.de/en

these tools to develop life-cycle inventory models from scratch. With these tools, the interface and models can be very complex, and therefore users need an advanced understanding of LCA. These types of LCA software tools are used in the development of LCI datasets that are in the background of more user-friendly, whole-building LCA software applications.

Two main software platforms, SimaPro and GaBi (summarized below), have dominated the general LCA software space for some time. As an alternative, an up-and-coming, open-source tool called OpenLCA¹⁴⁹ is gaining increased attention due to recent improvements and the ability to integrate it into custom LCA software tools. The following list of LCA software presents the five most widely used platforms in North America and globally. Prices are as of March 2017.

GaBi

- **Administrator:** thinkstep
- **Website:** www.gabi-software.com
- **Price:** \$5,850 USD single-user annual license. \$11,700 first user + \$5,850 per additional user for first year, and \$2,925 + \$1,463 per additional user annual fee.

OpenLCA

- **Administrator:** Green Delta
- **Website:** service packages available for a fee.

Quantis Suite

- **Administrator:** Quantis
- **Website:** <https://quantis-suite.com>
- **Price:** 1,000 EUR per user per year.

SimaPro

- **Administrator:** PRé Sustainability
- **Website:** <https://simapro.com>
- **Price:** \$4,600 USD single-user annual license. \$10,925 to \$14,375 first user + \$8,050 to \$10,925 per additional user, indefinite license.¹⁵⁰

Umberto NXT

- **Administrator:** IFU Hamburg
- **Website:** www.ifu.com/en/umberto
- **Price:** available on request.

¹⁴⁹ www.openlca.org

¹⁵⁰ Lower cost estimate is for the “Analyst” version of software. Higher cost is for the “Developer” version, which contains more features. Both versions are satisfactory for building product and whole-building LCA development.

LCA tools for construction projects

These tools simplify the LCA process in user-friendly, construction-specific interfaces. The background LCI data and methods are embedded in the software, plus these tools incorporate LCA scenario data and, in some cases, assist the user in material takeoff calculations. Underlying data can come from public and proprietary databases and from EPDs. Whole-building LCA tools are organized in a building context (e.g., by material assemblies and building sub-components). These tools are commonly restricted to particular geographic regions based on their underlying data, although some tools claim global coverage.

These tools differ in terms of their alignment to standards, the scope of the life cycle that they address, and their regional applicability. Two whole-building software packages are currently available for specific application in North America: the Impact Estimator for Buildings from the Athena Institute, and Tally from KT Innovations (described below). Two other software tools (one originating in Finland and one in Australia) are marketed as global in applicability and are therefore listed here as well. (Note that global tools typically employ a “regionalization” method that involves applying local energy-grid information to foreign manufacturing data when local manufacturing data are missing from the tool). The following tools attempt North American regionalization.

Athena Impact Estimator for Buildings

- **Administrator:** Athena Sustainable Materials Institute
- **Website:** <http://calculatelca.com/software/impact-estimator>
- **Price:** free.
- **Source of underlying data:** Athena Institute customized industry data (internal LCA studies) and scenario data, USLCI database profiles, ecoinvent, and other publicly available data such as industry LCAs.
- **Platform:** desktop software for Windows.
- **Geographic applicability:** United States and Canada (highly regionalized tool, supports numerous North American cities).

Tally

- **Administrator:** KT Innovations
- **Website:** <http://choosetally.com>
- **Price:** US \$695 per year (requires Autodesk Revit, for additional cost).
- **Source of underlying data:** thinkstep GaBi data customized for use in Tally. The data also include some EPDs.
- **Platform:** Revit plugin.
- **Geographic applicability:** United States.

One Click LCA

- **Administrator:** Bionova Ltd.
- **Website:** www.oneclicklca.com
- **Price:** starting around CAN \$500 per year (for a module limited to carbon accounting).
- **Source of underlying data:** primarily relies on EPDs. Supplemented with generic data.

- **Platform:** web-based application. Also has plugins for Revit, Tekla, and ArchiCAD.
- **Geographic applicability:** global.

E-Tool

- **Administrator:** E-Tool ECD
- **Website:** <http://etoolglobal.com>
- **Price:** free for unassisted use. \$400 AUD for the software plus training and the use of their LCA reporting template.
- **Source of underlying data:** unclear.
- **Platform:** web-based application.
- **Geographic applicability:** global.

Pavement LCA

- **Administrator:** Athena Sustainable Materials Institute
- **Website:** <https://calculatelca.com/software/pavement-lca>
- **Price:** free.
- **Source of underlying data:** Athena Institute customized industry data (internal LCA studies) and scenario data, USLCI database profiles, ecoinvent, and other publicly available data such as industry LCAs.
- **Platform:** desktop software for Windows and a web-based application.
- **Geographic applicability:** United States and Canada (highly regionalized tool, supports multiple North American cities).

Table 6 summarizes a selection of leading whole-building LCA tools that are specific to another country but do not attempt North American regionalization at this time.

Table 5: Selection of leading whole-building LCA tools

Whole-building LCA tool	Website
France	
ELODIE	http://editions.cstb.fr/Products/Elodie.html
ClimaWin	www.bbs-logiciels.com/clima-win
ThermACV	www.logicielsperrenoud.com/catalog/thermacv
NovaEQUER (PEBN)	www.izuba.fr/logiciel/novaequer
Germany	
eLCA	www.bauteileditor.de
The Netherlands	
GPR Gebouw	www.gprsoftware.nl/gpr-bouwbesluit
GPR Bouwbesluit	www.gprsoftware.nl/gpr-bouwbesluit
DGBC tool	www.dgbc.nl/materialentool

Table 6 – continued

Whole-building LCA tool	Website
MRPI MPG	www.mrpi-mpg.nl
DuboCalc, for civil engineering works	www.rijkswaterstaat.nl/zakelijk/zakendoen-met-rijkswaterstaat/inkoopbeleid/duurzaam-inkopen/duurzaamheid-bij-contracten-en-aanbestedingen/dubocalc/index.aspx
Sweden	
Klimatkalkyl (transportation infrastructure)	www.trafikverket.se/tjanster/system-och-verktyg/Prognos--och-analysverktyg/Klimatkalkyl/
Switzerland	
LESOSAI	www.lesosai.com/en
Thermo	www.thermo-bauphysik.ch/cms
EnerHaus	www.enerweb.ch
Greg	www.energiekonzepte.ch/greg
United Kingdom	
IES Impact	www.iesve.com/software/ve-for-engineers/module/IMPACT-Compliant-Suite/3273

ENVIRONMENTAL PRODUCT DECLARATION PROGRAMS AND DATABASES

An environmental product declaration (EPD) is a set of environmental impact data for a product. The dataset is based on an LCA that has been conducted in compliance with an industry consensus-based set of product category rules (PCR) and with applicable ISO standards. Once completed, an EPD is verified by and registered with an EPD program operator.

The PCRs set out the reporting requirements and LCA methods for developing ISO Type III environmental product declarations as per ISO 14025. ISO 14025 draws heavily on two other ISO LCA standards (ISO 14040 and ISO 14044) to determine system boundaries, a functional or declared unit, inventory input and output flows, and the reporting of life-cycle impact indicators.

Globally, the development of EPDs is rapidly accelerating. In the 10 years since the publication of ISO 14025, more than 50 EPD programs have been established across the globe. As of 2015, these EPD programs had published more than 2,200 PCR documents and thousands of EPDs.¹⁵¹ As of January 2017, over 6,000 construction product EPDs had been published globally; 3,500 of these EPDs were developed according to EN 15804, while 2,500 EPDs had been published in accordance with ISO

¹⁵¹ Passer et al. Environmental product declarations entering the building sector: critical reflections based on 5 to 10 years' experience in different European countries. *Int J Life Cycle Assess* (2015) 20:1199–1212.

21930.¹⁵² Some jurisdictions collect EPDs in central databases to ensure public access and to facilitate the use of EPD data as one source of input for whole-building LCA. During the 10-month period between March 2016 and January 2017, about 1,500 EN 15804-compliant EPDs were published. Over many years prior to that, only about 2,000 such EPDs had been published, which means the total number has nearly doubled in the last year.

North America

North America is a hotspot of EPD development, with at least ten EPD programs currently in operation. EPDs are still relatively new in North America, which means standards, harmonization, and alignment across programs are still developing. Several of the leading North American EPD program operators are working together towards harmonization of product category rules development. Harmonization is being addressed through the Program Operator Consortium. The Program Operator Consortium comprises six EPD program operators and is administered by the Sustainable Minds EPD Program. The Program Operator Consortium and Sustainable Minds have developed a two-part PCR template (Part A and Part B)¹⁵³ that harmonizes many of the scoping and modelling decisions that are required to develop a PCR. The Program Operator Consortium/Sustainable Minds Part A 2016 conforms to the Guidance for Product Category Rule Development, v1.0, established by the Product Category Rule Guidance Development Initiative and developed by the American Center for Life Cycle Assessment PCR subcommittee.

Current North American EPD program operators:

ASTM International EPD Program

Administrator: ASTM International

Website: www.astm.org/EPDs

Program Operator Consortium member

Carbon Leadership Forum EPD Program

Administrator: Carbon Leadership Forum

Website: www.carbonleadershipforum.org/Carbon_Leadership_forum/PCR.html

CSA (Canadian Standards Association)

Administrator: CSA Group

Website: www.csaregistrars.ca/epd/about_epd_pcrs_e.cfm

Earth Sure

Administrator: Institute for Environmental Research and Education (IERE)

Website: <http://iere.org/programs/earthsure/>

FPIInnovations EPD Program

Administrator: FPIInnovations

¹⁵² Jane Anderson, Construction LCA, 2017, as presented at:

<https://info.gr.am/47216efb-7256-4a5e-acc3-04ce046cbdf8>

¹⁵³ Part A contains generic LCA scoping rules while Part B is specific to the product category that is the subject of the PCR.

Website: <https://fpinnovations.ca/ResearchProgram/environment-sustainability/epd-program/Pages/default.aspx>

ICC Evaluation Service EPD Program

Administrator: ICC Evaluation Service, LLC

Website: www.icc-es.org/ep/epd-index.shtml

Program Operator Consortium member

National Ready Mixed Concrete Association (NRMCA) EPD Program

Administrator: NRMCA

Website: www.nrmca.org/sustainability/epdprogram/index.asp

NSF International National Center for Sustainability Standards EPD Program

Administrator: NSF International

Website: www.nsf.org/business/sustainability_ncss/index.asp?program=SustainabilityNcs

Program Operator Consortium member

SCS Global Services

Administrator: SCS

Website: www.scsglobalservices.com/environmental-product-declaration

Program Operator Consortium member

Sustainable Minds Transparency Report Program

Administrator: Sustainable Minds

Website: www.sustainableminds.com/transparency-report-program

Program Operator Consortium member and administrator

UL Environment EPD Program

Administrator: UL Environment

Website: <http://industries.ul.com/environment/certificationvalidation-marks/environmental-product-declarations>

Europe

Similar to the Program Operator Consortium in North America, the **ECO Platform** is an international non-profit established by European EPD program operators, trade associations, and LCA practitioners to harmonize EPD development. The following EPD program operators actively participate in and support the ECO Platform:

- Asociación Española de Normalización y Certificación (AENOR)
- Association HQE – Programme FDES INIES
- Bau EPD GmbH
- Building Research Establishment Limited (BRE)
- Col·legi d'Aparelladors, Arquitectes Tècnics i Enginyers d'Edificació (CAATEEB)
- EPD Danmark
- EPD International AB

- ICMQ S.p.A.
- Institut Bauen und Umwelt e.V. (IBU)
- Instytut Techniki Budowlanej, ITB (Building Research Institute)
- Plataforma para a Construção Sustentável
- Stichting MRPI (Milieurelevante Productinformatie)
- The Norwegian EPD Foundation (EPD-Norge)
- Zavod za gradbeništvo Slovenije
- PEP ecopassport

In 2013, the European Council invited the European Commission to "develop a common methodology on the quantitative assessment of environmental impacts of products, throughout their life cycle, in order to support the assessment and labelling of products."¹⁵⁴ The result of this directive is the Product Environmental Footprint project or PEF initiative, which seeks to go beyond EPDs to dictate how LCA-based information is presented on product packaging.

Product environmental footprints mirror environmental product declarations in that Product Environmental Footprint Category Rules, or PEFCRs, dictate the scope of the underlying LCA and the presentation of the LCA results. The difference with product environmental footprints is that they aggregate and weight environmental impacts into a single sustainability metric. Weighting obfuscates the underlying LCA results and is reliant on subjective valuation of impacts. The development of weighting factors is so contentious that pilot versions of the Product Environmental Footprint project have decided to weight all impacts equally to avoid the difficult task of ranking environmental significance. This arbitrary equal weighting is, of course, equally subjective as assigning a random weight to a given impact category.

It remains to be seen whether product environmental footprints will begin to replace EPDs in Europe as the ongoing pilot projects reach their conclusion in the next few years. It is important to note that product environmental footprints do carry the weight of the EU directive that kick-started their development and the project is generally well-funded.

The European EPD programs of most interest to the purpose of this study are described in further detail below.

EPD program: Bauen und Umwelt eV (IBU)

The IBU EPD Program was developed in close interaction with the construction and environmental authorities in Germany and in conjunction with the international standardization process.

- **Program operator:** Institute Construction and Environment e.V.
- **Website:** <http://ibu-epd.com/en/epd-program/>
- **Member of Eco Platform:** yes.
- **Geographic applicability:** global.

¹⁵⁴ Commission recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations (Text with EEA relevance) (2013/179/EU) <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013H0179>

EPD database: Fiches de Déclaration Environnementale (FDES INIES)

France's national construction materials EPD database is called INIES. Since 2011, the Association HQE, a recognized public interest group, has served as owner–manager. As of 2014 the database contained over 1,500 EPDs covering more than 27,000 commercial references, and it has been growing at about 200 or 300 new EPDs per year. The EPDs are being used in labelling schemes (e.g., HQE – see the review of France's policies in Section 3) and in building LCA tools (e.g., ELODIE) through XML export of the database. The database is linked to regulations to which manufacturers must comply if they wish to make green marketing claims.

- **Administrator:** INIES
- **Website:** <http://www.inies.fr/produits-de-construction>
- **Member of Eco Platform:** yes.
- **Geographic applicability:** France.

EPD Program: PEP ecopassport®

French program specifically for electrical, electronic, and HVAC products.

- **Administrator:** Association P.E.P.
- **Website:** <http://www.pep-ecopassport.org>
- **Member of Eco Platform:** yes.
- **Geographic applicability:** France.

EPD Database: B-EPD

A recently launched national EPD database in Belgium, linked to regulations to which manufacturers must comply if they wish to make green marketing claims, and to be linked with a whole-building LCA tool (in development).

- **Administrator:** Federal Public Service of Health
- **Website:** www.environmentalproductdeclarations.be
- **Member of Eco Platform:** no.
- **Geographic applicability:** Belgium.

EPD Program: The International EPD System

Global program based in Sweden, with 700 EPDs for a wide range of product categories by companies in 35 countries.

- **Administrator:** International EPD AB
- **Website:** <http://www.environdec.com>
- **Member of Eco Platform:** yes.
- **Geographic applicability:** global.

EPD Program and database: Stichting MRPI (Milieurelevante Productinformatie)

National database in The Netherlands.

- **Administrator:** Stichting Bouwkwiteit
- **Website:** www.milieudatabase.nl

- **Member of Eco Platform:** yes.
- **Geographic applicability:** The Netherlands.

EPD Program: The Norwegian EPD Foundation (EPD-Norge)

Program primarily active in the Nordic countries.

- **Administrator:** Norwegian EPD Foundation
- **Website:** <http://epd-norge.no>
- **Member of Eco Platform:** yes.
- **Geographic applicability:** Pan-Europe.

Other European EPD program operators include:

- Asociación Española de Normalización y Certificación (AENOR)
- Bau EPD GmbH
- Building Research Establishment Limited (BRE)
- Col·legi d'Aparelladors, Arquitectes Tècnics i Enginyers d'Edificació (CAATEEB)
- EPD Danmark
- EPD International AB
- ICMQ S.p.A.
- Institut Bauen und Umwelt e.V. (IBU)
- Instytut Techniki Budowlanej, ITB (Building Research Institute)
- Plataforma para a Construção Sustentável
- The Norwegian EPD Foundation (EPD-Norge)
- Zavod za gradbeništvo Slovenije

LCA BENCHMARKING PROGRAMS AND INITIATIVES

Robust whole-building LCA benchmarking efforts are underway in Europe. The following summaries describe a range of these efforts by country:

France

- The HQE Performance initiative is a pilot project (by the same organization that administers the HQE green building rating program,¹⁵⁵ which has an LCA component) aimed at establishing whole-building LCA benchmarks, beginning with office buildings and multi-unit residential buildings.

¹⁵⁵ www.hqegbc.org/accueil

Germany

- The voluntary green building rating program DGNB awards points for performance against whole-building LCA benchmark values. Benchmark values were developed based on LCA performance of theoretical archetype buildings for various building types such as office, industrial, etc. There are three levels of performance, with increasing points available: minimum, average, and state-of-the-art.
- The BNB green program, which is mandatory for federal buildings, similarly awards points for performance against three different benchmark levels.
- Voluntary green labeling programs for residential buildings have a similar system.

Switzerland

- Minergie-Eco, SNBS, SGNI, and 2000-Watt-Areal all have a LCA benchmark system already in place. Threshold values are based on building type, among other things.
- New building types will be added and the benchmark thresholds evaluated in 2018.

United Kingdom

- The Building Research Establishment (BRE) has a whole-building LCA benchmark system already in place in the residential green program Home Quality Mark.¹⁵⁶
- It is expected that BREEAM 2018 will do the same, and will completely replace the existing Mat 01 credit with a benchmark-based LCA credit.
- The BREEAM update will likely be supported by BRE's "Impact project", which is currently working on whole-building LCA benchmarks based on archetypes (a sample are combined into a single benchmark representing average performance) and intended for integration into BREEAM. Archetypes are being collected via the current LCA credit in BREEAM. The expectation is that the benchmark is dynamic, reflecting the current average performance, and will therefore become increasingly more challenging as buildings get better.¹⁵⁷

¹⁵⁶ www.homequalitymark.com/filelibrary/HQM-Beta--England--2015_SD232_r1.0.pdf

¹⁵⁷ <http://www.impactwba.com>

APPENDIX 3: DEFINING “NET ZERO”

Energy efficiency and sustainability policy across North America is increasingly referencing net-zero buildings (whether net-zero energy or net-zero carbon) as a goal. However, there are several approaches to net zero, which is creating confusion and misalignment in the industry.

Further, many net-zero initiatives focus only on operational energy and energy-efficiency measures, leaving the embodied emissions associated with building materials—such as those that occur because of resource extraction, production, transportation, repair and maintenance, and end-of-life recycling/landfill unaccounted—for. The narrow focus on operational energy thus results in an underestimation of the true emissions profile of the construction sector. As such, net-zero policies that address only operating energy are a partial solution. Table 7 offers a range of common definitions for zero-energy buildings. As can be seen, none of these common definitions of zero-energy buildings typically include the embodied carbon of materials. However, net-zero source energy and net-zero energy emissions move closer to this concept, and indeed “net-zero energy emissions” can be revised to “net-zero emissions” (removing the focus on energy alone) for a more complete quantification of a project’s life-cycle carbon impacts.

Table 6: Net-zero buildings: common definitions

Concept	Definition ¹⁵⁸	Includes embodied carbon?
Net-zero site energy	Produces at least as much energy as it uses in a year, when accounted for at the site.	No.
Net-zero source energy	Produces at least as much energy as it uses in a year, when accounted for at the source. ¹⁵⁹	No. However, this definition gets closer to the concept of “life-cycle” impacts. (Includes extraction, processing, and transportation phases, but limited to total energy consumed, not carbon or materials.)
Net-zero energy costs	The amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.	No.
Net-zero energy emissions	Produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.	Not typically. Some frameworks expand the scope of emissions to include embodied carbon in materials, and/or the emissions associated with occupant travel to and from the building site.

¹⁵⁸ Zero Energy Buildings: A Critical Look at the Definition, National Renewable Energy Laboratory, 2006.

¹⁵⁹ Source energy refers to the primary energy used to generate and deliver the energy to the site.