Embodied Carbon in Construction

Policy Primer for Ontario

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This report and the associated case study can be downloaded at publications.zizzostrategy.com

1 Executive Summary

This policy primer is intended for design teams and policymakers interested in addressing embodied carbon, emissions associated with construction material extraction, manufacture, and transportation, and building and infrastructure construction, maintenance, and decommissioning in the Ontario context. It provides an overview of the concept of embodied carbon and describes how life cycle assessment (LCA) can be used to calculate and minimize life cycle GHG impacts from construction projects.

It draws on the lessons learned from a recent case study that calculated the embodied carbon of a new commercial building in Toronto and explores how LCA can be applied in Ontario to minimize life cycle GHG impacts from construction projects. The primer combines international best practices and an understanding of Ontario's specific technical, financial and political context to offer recommended actions that specific stakeholder groups can take to translate lessons learned from LCA research into concrete policy and processes.

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2 What is Embodied Carbon?

Buildings account for nearly one-quarter of Canadian greenhouse gas (GHG) emissions[1] making them a prime target for reduction strategies. Policymakers around the world have identified the reduction of GHGs from the construction sector as a key component in the global fight against climate change.

Estimates of buildings-related emissions generally relate to a building's annual operations, that is, energy consumed for heating, cooling, ventilation, and plug loads. These emissions are generally the best understood, the easiest to measure and, in turn, the most feasible to reduce. Operational emissions have also traditionally accounted for a significant majority of a building's measured carbon emissions, and thus have been the focus of most energy conservation and/or carbon reduction strategies. However, a building's operations are just one phase of its life cycle, and each other phase also results in emissions which are typically ignored.

In the building context, embodied carbon[2] refers to emissions other than operational emissions. These include emissions associated with construction material extraction, manufacturing, and transportation to site, on-site construction processes, as well as building maintenance, repair, refurbishment, and decommissioning (end-of-life including demolition, recycling, and landfill). See Figure 1, which shows the various life cycle stages of a building.

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[1] Environment and Climate Change Canada (2017) Canadian Environmental Sustainability Indicators: Greenhouse Gas Emissions. Available at: www.ec.gc.ca/indicateurs-indicators/default.asp?lang=En&n=FBF8455E-1. (Including electricity)

[2] Numerous variations on the name exist, including: scope 3 emissions, embodied emissions, embodied GHGs, embodied CO_2, or more broadly, embodied energy (related, but not equivalent as depends on carbon content of energy source).

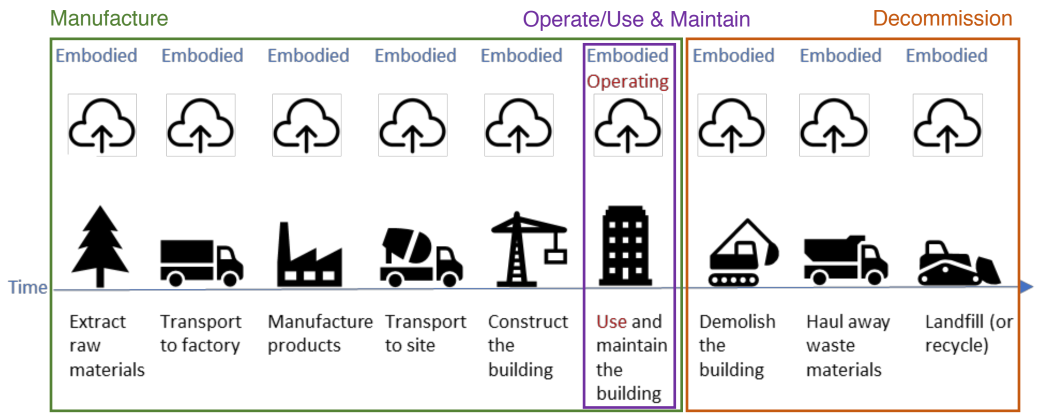

Figure 1: Life cycle GHG emissions from various building life cycle stages

Construction material manufacture, transportation to site, and the construction process result in a "carbon debt" before day one of operations, which isn't considered in most green or net-zero buildings policy, design, tracking or reporting, nor is it considered in most energy reporting and tracking.

3 Why is Embodied Carbon in Buildings Important?

There are at least three reasons why addressing embodied emissions associated with non-operational phases of construction is important.

First, the dominance of operational GHGs is shrinking. Buildings are becoming increasingly energy efficient, with "net-zero" buildings on the horizon. Many jurisdictions are also reducing the carbon intensity of their energy sources (for instance, Canada recently announced new natural gas performance standards, and efforts continue to generate electricity from lower-carbon processes). As buildings become more efficient and energy sources become lower carbon, annual operational GHGs will decrease over time, while embodied emissions will remain largely unaddressed. If these trends continue as expected, in the not-so-distant future embodied emissions are likely to become the dominant source of building emissions (see Figure 2).

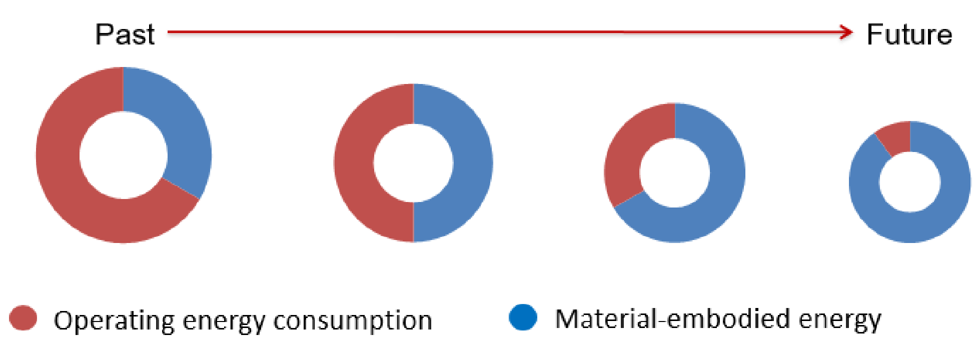

Figure 2: Trend in life cycle energy/carbon in buildings

To address the construction phases that will most likely be responsible for the bulk of life cycle emissions in the future, policies should be developed now that tackle embodied carbon and work to offset the carbon debt associated with construction.

Second, in some jurisdictions targeting operational emissions may already have limited impacts on GHG reduction because buildings are operated using already-clean electricity grids. Many Canadian regions, including Ontario, British Columbia and Quebec, have low-carbon electricity grids. Reducing operational energy from electricity in buildings, while helpful, will not get at the most significant portion of buildings-related emissions in those regions.

Figure 3 graphs cumulative GHG emissions over 60 years of a modelled typical Vancouver mid-rise building. Because BC has a very low-carbon electricity grid and a relatively low heating demand (meaning less natural gas is used for heating than in other Canadian regions), GHG emissions from building operations are relatively low compared to the GHG emissions related to materials manufacturing, construction, repair, and decommissioning. In fact, for the modelled building, cumulative operating carbon does not exceed embodied carbon until year 60, which is longer than many buildings stay in service. In Ontario, certain types of high performance buildings cross this threshold after roughly ten years (as determined in this study) since the operating energy requires more carbon due to a more carbon-intensive electricity grid, and significantly higher heating demands in the winter.

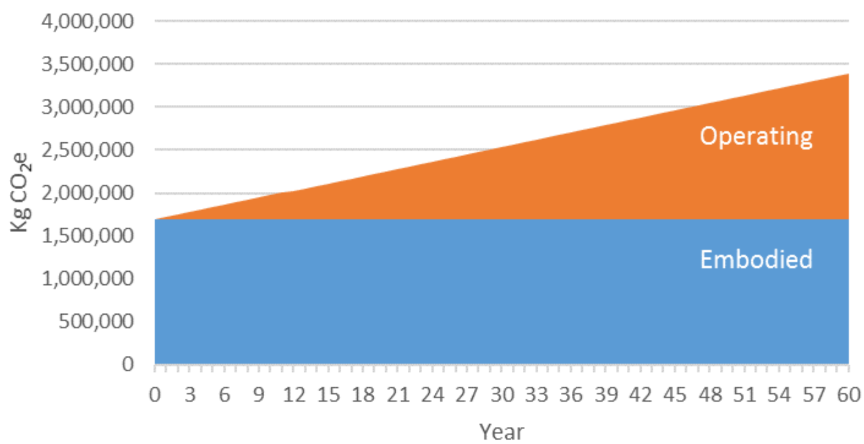

Figure 3: Operating versus embodied carbon, typical five-storey Vancouver mid-rise building[3]

Finally, policies aimed at reducing embodied carbon can address emissions in the building and construction sector that are not yet being tackled by other carbon policies and can do so in the timeframes needed to meet reduction targets. Large-scale emission reductions are required in the short-term to meet emission reduction targets at the municipal, provincial and national scales. Embodied carbon policies can help achieve these goals, as they focus on the short-term (i.e. initial procurement) and offer immediate results. Operational savings, on the other hand, are measured annually, and build up over a longer timescale.

[3] Marceau, M., L. Bushi, J. Meil, M. Bowick, 2012. Life cycle assessment for sustainable design of precast concrete commercial buildings in Canada. 1st International Specialty Conference on Sustaining Public Infrastructure.

4 What is Life Cycle Assessment and How Can It Help?

Life cycle assessment is the science of measuring environmental impacts on air, land and water from a material or product over its entire life cycle—from resource extraction to its end-of-life decommissioning. It is used to quantify embodied carbon of individual materials and their associated processes.

Product manufacturers can use LCA to measure and reduce the environmental impacts of products, and might publicly disclose this information in a publicly available document called an environmental product declaration (EPD). EPDs contain data on the LCA-based quantification of a specific product. Whole building LCA design tools allow users to estimate their building's life cycle impacts by making use of these product-level EPDs. These design tools work by matching user material selection and quantity inputs to international EPD databases where the underlying environmental impacts for each phase of a material's life cycle are stored. Users can estimate the environmental impact of each material entered, and the software will combine them into whole-buildings results. In this way, building designers can use LCA-based EPDs to determine the environmental footprint of a whole building and search for ways to reduce life cycle GHG emissions and other impacts through strategies such as:

- Ensuring efficient use of materials (i.e. "right-sizing")
- Selecting materials with more efficient manufacturing processes
- Minimizing transportation impacts through use of local materials
- Using robust materials that require less maintenance, repair, and refurbishment
- Choosing materials that can be reused or recycled instead of landfilled

As detailed in the sections below, employing one or more of these strategies can deliver material life cycle GHG emissions reductions.

5 State of Play on Embodied Carbon Policy

Although the concept of LCA has been around for decades, it has gained prominence in recent years. LCA-related global standards have been developed, more EPD data has become publicly available in online databases, and, most importantly, design tools and software have advanced to allow for smart LCA-based design optimization. In North America, this effort is being led by the Athena Sustainable Buildings Institute, a Canadian not-for-profit organization providing LCA tools, EPD data, and associated research and resources.

5.1 Internationally

Several European jurisdictions have embodied carbon policies. Highlights of the strongest strategies are provided in Table 1.

Table 1: Leading examples of embodied carbon reduction strategies

The Netherlands	• Embodied carbon reporting required at building permit application for new residential and office buildings over 100 m^2 • A building's total environmental profile (of which embodied carbon is one piece) will have an upper limit as of 2018 • National EPD database, standardized method for whole-building LCA, and several software tools that conform to the standardized method
Germany	• Whole-building LCA required for new federal building projects as part of a mandatory green building rating program • Points are awarded as a function of performance against a benchmark • National LCA / EPD database and free national whole-building LCA software tool
France	• Voluntary building labels and incentives for embodied carbon and net-zero energy consumption targets • Voluntary program expected to become mandatory in 2020 • Manufacturers wishing to make environmental marketing claims must submit an EPD to the national database
Switzerland	• Whole-building LCA required for all new government buildings in several Swiss municipalities, including Zurich, with an embodied carbon performance target for some building types • National call-to-action (the "2000-Watt Society") limits per-capita energy consumption and GHG emissions, including embodied GHGs
Sweden	• Large transport infrastructure projects (roads, rail, tunnels) required to calculate and report embodied carbon • Monetary incentives awarded if embodied carbon is below a specified target. • National LCA-based tool / database
Belgium	• Manufacturers making environmental marketing claims must submit an EPD to the national database

5.2 Canada

Currently, our research has found no mandatory policies regarding embodied carbon in Canada. However, several voluntary initiatives exist, as illustrated in Table 2.

Table 2: Canadian Embodied Carbon Policies (Voluntary)

Vancouver Green Buildings Policy for Rezoning	• As of May 2017, developers seeking a rezoning application need to comply with one of two stringent sustainability requirements. One option includes requirement for whole-building embodied carbon reporting.*
LEED	• The most recent version of the influential LEED Building Design and Construction (v4) green building rating system includes whole building LCA-optimization as a strategy for the first time. This includes meeting a 10% reduction in embodied carbon from a project-specific baseline.
Zero Carbon Building Standard	• The Canada Green Building Council (CaGBC)'s new zero carbon building standard includes a requirement to report a building's embodied carbon.*

Public Services & Procurement Canada (PSPC)	• PSPC requires whole-building LCA for its new building projects, however it is unclear whether this requirement is typically followed.*
Quebec's Wood Charter	• Quebec requires a comparative analysis of GHG emissions for structural materials in provincially-funded new building projects.*

*Note, these are reporting requirements, where no performance targets are required to be met.

6 Towards LCA-based Decisions in Ontario

Addressing embodied carbon presents an opportunity for Ontario to make significant progress on its ambitious emissions reduction targets.[4] Recent policy developments and discussions with government and industry indicate that Ontario is well-positioned to start exploring next steps towards the implementation of LCA to minimize life cycle GHG impacts from construction projects.

The release of the Pan-Canadian Framework on Clean Growth and Climate Change, and major impending federal and provincial infrastructure spending, have highlighted the need to move quickly to reduce GHG emissions and reform procurement policies to align with international and federal obligations while ensuring taxpayer dollars are being spent effectively. Procurement reform using LCA-informed decision-making is currently a topic of particular interest among provincial and federal Ministries across Canada. A group of industry leaders in the Ontario market have been meeting for Ontario Green Procurement Roundtable discussions, facilitated by the Ministry of Infrastructure, with the objective to identify best practices and draft a report with recommendations and next steps for the Ontario government.

Ontario's Energy and Water Reporting and Benchmarking rules were recently introduced with requirements to begin reporting in 2018. These requirements could start priming the market for eventual embodied carbon policies by building the market's acceptance of enhanced quantification and reporting practices.

Finally, the province has previously updated the Ontario Building Code to incorporate climate change considerations and has plans to do so again by 2030 at the latest. This could present a clear opportunity to workshop and integrate embodied carbon quantification, reporting and even potential performance targets into Code improvement considerations.

The following subsections briefly discuss the technical, policy and financial factors that should be considered in future steps towards addressing embodied carbon in Ontario buildings and construction.

[4] In the Climate Change Mitigation and Low-carbon Economy Act, 2016, Ontario has committed to
1. A reduction of 15 per cent by the end of 2020.
2. A reduction of 37 per cent by the end of 2030.
3. A reduction of 80 per cent by the end of 2050.

6.1 Technical Factors

To implement LCA-based decision making in the Ontario context, the proper technical infrastructure must be in place. Jurisdictions with successful embodied carbon policies can point to the importance of robust LCA-based resources to support the policy, including:

- A centralized, public, life cycle inventory databases and EPD repositories to provide standardized and reliable underlying data for whole-building LCA
- Easy to use, accessible, whole-building LCA tools for architects and engineers
- Standardized methods and guidance for whole-building LCA calculation and reporting
- Data collection on process and results to improve the system and eventually create performance benchmarks, best-practice guidelines, and a system for measuring success

The above resources take significant investment and time to create. An alternative streamlined approach can also be taken, where Ontario-specific average embodied carbon values could be calculated for the most dominant materials such as concrete, steel, glazing, asphalt, timber, insulation, etc. This would provide easy-to-use values that all design teams could employ to provide a first-level of embodied carbon estimates, while a more robust LCA-based infrastructure is being developed.

While Canada's existing technical infrastructure provides a solid foundation, more work is required to develop the tools, systems and resources necessary to fully support the quantification and reporting of embodied carbon impacts of buildings and construction. Currently, the Ontario Ministry of Infrastructure is leading the provincial effort to determine how Ontario will integrate LCA-based decision making into future infrastructure decisions. Similar efforts are occurring in other provinces and at the federal level, signaling a need for coordination and sharing best-practices going forward.

6.2 Financial Factors

Although there may be a learning curve and increased costs initially to incorporate embodied carbon into construction decisions, it appears that the incremental costs of incorporating this analysis is comparatively small for the potential benefit it could provide. Baking these considerations into the designs from the outset can lead to cost efficiencies.

No data was identified which provides a robust understanding of cost impacts of incorporating LCA-based decisions making at the onset – and costs will depend on the availability of tools and data that are applicable to the region. Some European regions have developed free tools and database, so the only additional cost for analysis is the time spent by the designers. Currently, the Athena whole building LCA tool is free. The European tool used in the case study (One Click LCA) costs approximately $1,000 for a one-year license.

Construction costs to implement the findings of an LCA optimization depend on the strategies being employed. For example, a change to the concrete mix may have no financial impact, while changing the structural system to mass timber (for high-rise construction) could carry significant costs (up to a 10% cost of construction premium, based on our investigation). More research is required to better understand what specific factors these costs can be attributed to (e.g. labour, materials, etc) and how higher premium materials can be made to be most cost-competitive.

6.3 Policy Factors

Introducing embodied carbon policies for buildings and/or infrastructure will require leadership from policy makers to ensure that industry has clear direction, predictability and the resources it needs. In Ontario, this effort is currently being led by the Ontario Ministry of Infrastructure, with cooperation from Ministry of Environment and Climate Change and the Treasury Board. This multi-ministerial approach is critical for decisions to permeate throughout government and builds familiarity and ownership of the policy in multiple government circles.

Embodied carbon policies would also need to align with planned or existing policies aimed at reducing operational energy and GHG emissions in the construction sector and beyond. Consideration should be given to how embodied carbon policies would interact with other policies and programs such as the Ontario cap and trade regime, Ontario's energy reporting regulations, the Ontario Building Code, provincial and municipal procurement policies and third-party certification programs such as LEED, among others.

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 efforts in the building sector in the near-term could overwhelm builders, designers, and developers with requirements. Respecting these concerns, and taking a slower phase-in approach (i.e. whereby a policy starts with a smaller scope and less ambitious targets and then ramps up over time) will likely be most effective and avoid industry push-back. Additionally, starting with voluntary requirements that are paired with monetary incentive for compliance, has been found to be an effective approach. These policies can then be made mandatory in future, once the market has become familiar with them.

LCA in Toronto

Toronto is emerging as a sustainability and technology hot-spot and therefore is well placed to lead in the development and implementation of LCA policies and practices. Toronto already has innovative and industry-leading requirements including the Toronto Green Standard, that could be leveraged to show continued leadership and incorporate LCA considerations.

The Toronto Green Standard is a set of green building design and site requirements that new buildings in Toronto must meet to obtain a building permit. It includes mandatory requirements (Tier I), and more stringent voluntary requirements (Tier II). Developments meeting the Tier II level are eligible for monetary incentive through a partial development charge refund. Toronto Green Standard could be expanded to include embodied carbon elements, particularly in Tier II. For instance, embodied carbon reporting could be added as a Tier II strategy.

Other potential policy insertion points in the City of Toronto include the Toronto Municipal Code (for instance, Chapter 363, Schedule D could be considered for the potential insertion of embodied carbon reporting requirements) and the Toronto Zoning Bylaw 569-2013 (for instance, the building or energy requirements sections of each zoning category could be considered for potential insertion of embodied carbon performance standards).

7 Recommended Actions

This section offers recommended actions that specific stakeholder groups can take to translate lessons learned from the LCA research into concrete policy, projects and programs in Ontario. Some of recommended actions will be applicable across stakeholder groups (all stakeholders can help promote data collection and pilot projects, for example). These recommendations should not be considered comprehensive, but can help spur discussion and increased update of LCA analysis in buildings.

7.1 Asset Owners (including the YMCA), and their New Construction Design Teams

Asset owners can show leadership by requiring their new construction design teams to calculate, report, and reduce embodied carbon before any official policy requirements come into place. Building and design teams can raise awareness and encourage consideration of embodied carbon in the sector, cultivating the skill sets needed to apply LCA to decision making and streamlining the LCA process through smart management. Specific recommended actions include:

- Calculate and report the embodied carbon associated with construction projects. Design teams should be required to perform this type of analysis and reporting. This will start to move the industry towards better practices which will simplify future LCA, including ensuring material quantities and descriptions are adequately entered into building design computer models (BIM).

- Consider ways to reduce embodied carbon in design. For future sites which have not yet started detailed design, consider hosting a design charrette meeting where team members can brainstorm ways to reduce embodied carbon, yet still meet building

programming requirements. The earlier in the design these conversations occur, the more likely that they can be applied and the large impact possible. Suggestions include:
  - Using timber as a main structural material, or a major structural component material (such as designing a wood roof)
  - Material minimization (avoiding over-sizing)
  - Maximizing use of timber in non-structural applications (stairs, finishes, etc.),
  - Specifying concrete that uses Portland-limestone cement (GUL) and high-supplemental cementitious material (SCM) content
  - Reduced floor to ceiling heights,
  - Use more robust materials,
  - Specify materials with high recycled content and that are easily recyclable
  - Specify local materials

- Pilot low-embodied carbon buildings and infrastructure projects. Show leadership by calculating and reporting the embodied carbon of their buildings and piloting strategies to reduce embodied carbon in their projects.

- Discuss embodied carbon strategies during early design. Design team should discuss ways to minimize embodied carbon during conceptual and schematic design phase. The later in the design processes these conversations occur, the smaller the potential to make changes.

- Include LCA consultant in the design team, introducing to multiple design and construction team members, and set embodied carbon information sharing, quantification, reporting, and reduction as project goals. As LCA is not yet a typical component of building design and construction, some team members are not used to providing the information required for LCA. Have the project owner introduce the LCA consultant to multiple contacts with architect, structural engineer and construction team consultants. Introduction to multiple team members in each discipline is important to avoid bottlenecks with unexpected vacation or illness. The project owner should also set the expectation that consultants are to be responsive to the LCA consultant and provide the requested information in a timely manner.

- Ensure building simulation (BIM) has accurate material details from start of project. The BIM should include proper material descriptions such that accurate quantity take-offs for the LCA can be achieved from the BIM. This can greatly reduce the time and effort required to perform LCA.

7.2 Municipal Governments

Municipalities can act as leaders in promoting embodied carbon calculations and reporting through innovative policies and building standards. Specific recommended actions include:

- Incorporate embodied carbon performance goals and reporting requirements in procurement policies for construction projects. Options could include requiring whole-building LCA, reporting, performance targets or material specifications such as concrete with high SCM percent and Portland-limestone cement for all new municipal building and infrastructure projects.

- Replicate and expand municipal green standards to include embodied carbon elements. For example, in Toronto, the Toronto Green Standard is a set of green building design and site requirements that new buildings must meet to obtain a building permit. It includes mandatory requirements (Tier I), and more stringent voluntary requirements (Tier II). Developments meeting the Tier II level are eligible for monetary incentive through a partial development charge refund. Embodied carbon elements could be added to the TGS. For instance, the City may start by requiring concrete with high SCM percent and Portland-limestone cement under Tier I and/or by adding a requirement to report embodied carbon emissions as a strategy under Tier II. It could then explore minimum thresholds for embodied carbon as a next step.

- Consider adding embodied carbon reporting requirements to zoning or other building-related bylaws. While the Ontario Building Code would offer the preferred policy for embodied carbon quantification, reporting and potential performance targets due to its broad reach, municipalities can also consider potential policy “insertion points” such as zoning policies to help get the market ready. In the City of Toronto, relevant policies that could be explored for potential insertion points are the Toronto Municipal Code (see Chapter 363, Schedule D in particular) as well as the Toronto Zoning Bylaw 569-2013 (see the building and energy requirements sections of each zoning category in particular).

Key Questions and Considerations Going Forward

The following are key questions to be considered in the development and implementation of an embodied carbon policy in Ontario:

- What opportunities are there for skills training on LCA and embodied carbon?
- Which level(s) of government, third party certification bodies or other spheres of influence are best-placed to promote lower embodied carbon materials and approaches?
- How would the City of Toronto, the Province of Ontario or other actors go about promoting lower carbon materials and approaches where significant cost premiums exist for certain types of buildings?
- Are there opportunities to reduce these premiums (e.g. through lower labour costs due to prefab)?
- Are there non-financial market drivers that could help enhance uptake of lower embodied-carbon materials and approaches despite higher costs?
- How will carbon pricing affect the business case for material substitution at different price levels?

7.3 Provincial Governments

Provincial governments are well-placed to take meaningful action on embodied carbon through policy and the collection and promotion of data, tools and best practices. In an Ontario-context, specific recommended actions include:

- Promote Ontario-specific tools, standards and data for whole-building LCA. The provincial government could conduct or support a state of play study that seeks to clarify the most appropriate tools and data sources for Ontario, and to revise existing or develop new resources where required. A next step could be the creation of a central database that houses Ontario-specific data and EPDs, and to perform a 'validity check' on current leading LCA tools as applied to the Ontario market. Official guidance should be given by the provincial Ministries on the calculation methodology and specific factors, tools and benchmarks to apply on future LCAs for consistency across projects. This effort could be led by either the Ministry of Environment and Climate Change, or the Ministry of Infrastructure. Alternatively, national data and tools could be provided by the National Resource Council (NRC).

- Require projects to quantify and report their total carbon footprint, including both operational and embodied carbon, under the Ontario Building Code, and consider potential future performance targets. This policy could apply to new buildings and/or infrastructure projects. It could also start out with a more limited scope (i.e. only new government projects, only new buildings provided through Infrastructure Ontario, only projects over a certain size, or only Alternative Finance Projects, etc.) and later be expanded.

- Incorporate embodied carbon performance goals and reporting requirements in procurement policies for construction projects. Options could include requiring whole-building LCA reporting, performance targets or material specifications such as concrete with high SCM percent and Portland-limestone cement for all new provincial building and infrastructure projects.

7.4 Industry Associations and Design Community

Industry associations can help to build relevant skillsets, promote best practices and facilitate sharing of better data among its members. Specific recommended actions include:

- Offer training and education on embodied carbon and LCA. Industry associations (for example, construction material manufacturers) and other organizations in the design community could offer webinars, workshops or other training opportunities to build awareness of embodied carbon; train designers how to use LCA-based decision making; prepare industry for future policy moves in this direction; and cultivate the skills needed to respond to these policy developments. Education and outreach efforts could be targeted at improving industry knowledge about the benefits of lower-carbon materials and the whole-building LCA literacy of developers, manufacturers, designers, architects, engineers and contractors.

- Work towards providing LCA-relevant information or industry average values. Obtain industry-wide acceptable concrete-to-rebar ratios, or ask structural engineer to track estimated total amount of rebar and post-tensioning cable during design process and to provide to LCA consultant. Rebar quantities are typically not included in design documents, with final rebar quantities only being available post-construction (quantities are tracked as they arrive to site).

- Commission an Ontario-specific ready-mix concrete EPD. In January of 2017, The Canadian Ready-Mix Concrete Association released EPD10092. It represents the best publicly-available Canadian concrete EPD data, however, it uses Canada-wide averages. Isolating the Ontario-specific data that went into EPD10092 would likely be a relatively simple task. EPD providers have estimated this work could be completed for the range of $20,000 - $30,000. Proposed leaders could be Concrete Ontario (participants in CRMCA EPD) or Ready Mixed Concrete Association of Ontario.

- Commission an Ontario-specific rebar EPD. There does not appear to be an EPD available for Canadian-made rebar (concrete reinforcing steel). Proposed leaders could be Reinforcing Steel Institute of Canada (RSIC) or Ontario Cast-in-Place Concrete Development Council (OCCDC).

Appendix

Case Study: New YMCA Community Centre in Toronto

About the Study

The YMCA of Greater Toronto's new community centre at 907 Kingston Road[5] in Toronto was used as a pilot project to investigate the scale of potential embodied carbon reductions through structural material substitutions for an institutional or commercial building in Ontario. The study aimed to:

- Inform the YMCA of Greater Toronto on how it could reduce embodied carbon at future centres
- Conduct a gap-analysis and identify where improvements in data sources, methodology, information sharing, and software tools are required to improve consistency and validity
- Determine how the results from a leading European LCA tool (using North American data where available, and location corrections where needed) compare to results from the leading Canadian tool
- Provide a 'proof-of-concept' that structural material-based substitutions can lead to non-trivial embodied carbon reductions, and therefore should be considered by Ontario policy makers as a future strategy to reduce carbon emissions from the construction sector

These results are meant to inform policy makers and building design teams and help scale-up embodied carbon optimizations in the Ontario construction market.

Case Study Results

The case study modeled four building design cases, calculated the embodied carbon of each building and compared them using two different LCA tools. The building designs modeled were as follows:

- Baseline: Represents the actual materials and processes used for the design and construction of the building (concrete used: 25-34% Supplementary Cementitious Material (SCM)[6] + Portland cement)
- Optimized: All concrete substituted for the lowest-environmental-impact concrete available in the Ontario market (green concrete used: 35-50% SCM + Portland-limestone cement)
- Timber: Replacing the concrete structural system with cross-laminated timber (CLT)
- Timber, including carbon sequestration

The results from the case study are summarized in Table 3, and show that timber construction is approximately 20%-50% lower embodied carbon than the baseline case. Results also varied by up to 60%, depending on case, between the two software tools used. The large range of results highlights the need for a detailed review of each tool's calculation methodology to determine which is most appropriate and accurate for Ontario.

5 As of July 2017, the building excavation is complete and foundations are being poured. The building is expected to be operational in summer of 2018.
6 SCMs replace cement in concrete mixes with a lower-carbon substitution.

Table 3: Embodied carbon calculations (T CO_2 e)

Case	Scenario	Baseline	Optimized	Timber	Timber w Sequestration
A	Athena IE4B With Local Compensation (Toronto)	5,151	4,670	4,010	1,660
B	One Click LCA Without Local Compensation	3,903	3,515	1,915	(627)
C	One Click LCA With Local Compensation (Ontario)	2,928	2,640	1,509	(1,034)

The results from case C in Table 3 are shown graphically in Figure 4.

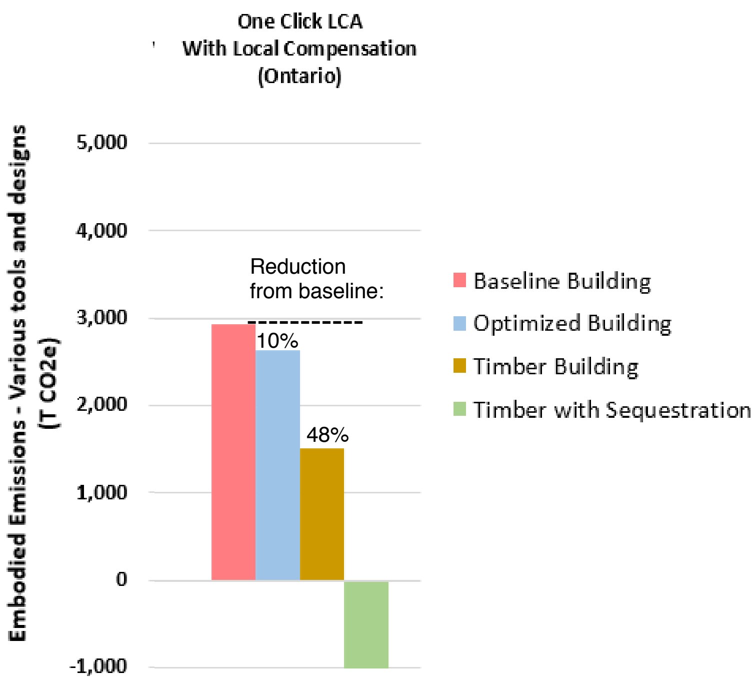

Figure 4: Embodied emission comparison

Financial Impacts and Potential Scale of Carbon Reduction

In conversation with building designers, it was found that specifying the lower carbon concrete (using Portland-limestone cement and high SCM-content) has minimal impact on concrete performance and cost, while leading to a roughly 10% reduction in embodied carbon.

Altering building design from the standard reinforced concrete to CLT provides greater opportunity for carbon reduction, but also carries a price premium. Discussions with Ontario-based cost consultants familiar with the relative cost of these building systems estimate CLT-based construction to currently carry a price premium of roughly 5-10% over typical reinforced concrete.

Table 4 provides the potential scale of the savings that could be achieved if these strategies or requirements are applied to all new commercial/institutional building construction in Ontario –

that is, if all new commercial/institutional buildings are built with low-impact concrete mixes, or with timber. These calculations assume an annual amount of new commercial/institutional construction of 4.6143 M m^2[8], and total emissions from Ontario's commercial/institutional building sector of 13 Mt CO_2e[20] and entire provincial emissions of 169.8 Mt CO_2e[9].

Table 4: Potential scale of impacts if applied across Ontario

	Embodied carbon reduction (kg CO_2e/m^2)	Potential annual avoided carbon if applied to all new commercial and institutional construction in Ontario	% of total annual operational **emissions from Ontario's** commercial/institutional buildings
Baseline to Optimized	48	0.22 Mt CO_2e	2%
Baseline to Timber	235	1.08 Mt CO_2e	8%

Therefore, if all new commercial/institutional construction in Ontario was mandated to be built with low-embodied carbon concrete, or CLT-based timber, embodied emissions have been estimated to be decreased by an amount equivalent to approximately 2% or 8% respectively, of that sector's operational emissions, and total provincial emissions could be reduced by 0.13% or 0.64% respectively.

Lessons Learned

The following are lessons learned from the case study, which can be used by building design teams and policymakers who are interested in applying LCA in other contexts.

- There are multiple options for reducing embodied carbon in buildings in Ontario, including:
  - Using timber as a main structural material, or a major structural component material (such as designing roof systems using wood)
    - In the case study, substituting the structural material form reinforced concrete to timber (cross laminated timber) resulted in a roughly 50% drop in embodied emissions
  - Specifying concrete that uses Portland-limestone cement (GUL) and high-supplemental cementitious material (SCM) content
    - In the case study, making these substitutions resulted in a roughly 10% drop in embodied emissions.
  - Material minimization (ensuring structural systems aren't over-sized)
  - Maximizing use of timber in non-structural applications (stairs, finishes, etc.)
  - Reduced floor to ceiling heights
  - Using more robust materials
  - Specifying materials with high recycled content and that are easily recyclable
  - Specifying local materials

[8] Ontario commercial/institutional sector 2013-2014 added floor space (most recent year data is available for): http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive/trends_com_on.cfm

[9] Environmental Commissioner of Ontario. 2016 Annual GHG Report, Chapter 2: https://media.assets.eco.on.ca/web/2016/11/2016-Annual-GHG-Report_Chapter-2.pdf.

- For high-performance commercial/institutional buildings in Toronto, the embodied carbon is on the same magnitude as approximately ten years of operational carbon emissions.
    - Note that the relative impacts between embodied and operational emissions are specific to a given building and climate, and cannot be extrapolated to all construction. Factors that impact this relationship include:
        - Climate zone (heating and cooling demands and the relative amounts of natural gas (heating) and electricity (cooling) required for thermal comfort.
        - Other building loads and uses of energy (gas vs electricity split)
        - Emission factor / carbon intensity of the electricity grid (provincially dependent)
        - Use of on-site renewable energy systems
        - Building equipment and envelope thermal characteristics

- Small design changes can have significant impacts. A simple concrete design change such as requiring concrete with high SCM content and Portland-limestone cement can lead to a 10% reduction in embodied carbon emissions with minimal impact on costs or concrete properties. In this study, that is equivalent to eliminating an entire year's worth of operating carbon.

- Reducing environmental impacts in one area could lead to increased impacts in other areas. Policy makers and building designers should be aware of and consider the environmental trade-offs when selecting their building materials.
    - The case study found that moving from the baseline to optimized design reduced the environmental impact for each of the six impact categories studies, however changing to a timber design results in reduced environmental impacts for only half the impact categories, while the other half actually had higher environmental impacts. For example, Eutrophication is significantly higher for timber than concrete due to the impacts of fertilizers and other forest management practices that may be associated with the forestry industry that isn't used to produce concrete.

- Design team training and education can help to streamline future LCAs. Industry groups including construction material manufacturers will need further support and resources to better engage with LCA software and data and incorporate this thinking into the various stages of their design and construction processes.

- Ontario-specific data, tools and processes are lacking. This research highlighted the significant range in results of current LCA tools, even when large investments of time and effort were applied to selecting the most appropriate data sources and applying Ontario-specific correction factors. A typical construction project would unlikely be able to spend this amount of investment to check and confirm data sources so it's important to have trusted defaults and/or obvious 'Ontario-specific' options without confirming validity. Ontario-specific LCA tool verification, industry-average EPD data development, benchmark data, and emissions factors and corrections are needed.