1 INTRODUCTION

The purpose of this report is to describe the results of a proof-of-concept study for an "Embodied Carbon Policy Reduction Calculator" designed to support city policymakers pursuing policies and programs that aim to reduce embodied carbon.

1.1 Why Embodied Carbon?

The buildings and infrastructure that define our cities are also one of the largest sources of greenhouse gas (GHG) emissions. Embodied carbon is the GHG emissions arising from the extraction, manufacturing, transportation, installation, maintenance, and disposal of construction materials. These emissions are primarily released across building material supply chains before a building even opens. Embodied carbon is measured as **global warming potential (GWP)** using a methodology called **life cycle assessment (LCA)**.

Embodied carbon is significant: embodied carbon associated with the built environment accounts for at least 20% of total global GHG emissions[4]. Additionally, embodied carbon disproportionately impacts frontline communities. When cities work to reduce embodied carbon, they are working to eliminate the environmental and public health burden placed on frontline communities that suffer most from both global impacts related to climate change and local impacts related to fossil fuel use in transportation and manufacturing across construction supply chains, like smog and diesel emissions.

Beyond the direct benefits to the climate and public health due to GHG emissions reductions, policies can have significant potential co-benefits depending on the policy, such as:

Reducing industrial emissions from material manufacturing, resulting in significant environmental and public health co-benefits such as improving air quality in fenceline communities and reducing energy use, water use, ozone depletion, smog formation, and eutrophication;

- Extending the life of existing materials, reducing the environmental damage and community health impacts from landfilling construction materials;
- Incentivizing reuse and material or space efficiency, saving money and reducing waste;
- Rewarding locally sourced materials and products that promote the local economy;
- Creating markets for lower-carbon materials and technologies and signaling manufacturers to decarbonize their products and processes;
- Supporting preservation of cultural resources and heritage through extending the life of existing buildings;
- Discouraging environmental damage from new construction on greenfield (i.e., previously undeveloped) sites by encouraging reuse and increased density in already developed portions of cities; and
- Promoting better access to transit and city services through increased density, resulting in a wide range of environmental and public health benefits from less driving for commuting and other travel.

Global warming potential

The potential climate change impact of a product or process as measured by an LCA, reported in units (typically kg) of carbon dioxide equivalent (CO_2e). This report uses "GWP", "carbon", and "embodied carbon" interchangeably to refer to these impacts.

Life cycle assessment (LCA)

LCA is a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy, and the associated environmental impacts directly attributable to a building, infrastructure, product or material throughout its lifecycle (ISO 14040: 2006).

4 United Nations Environment Programme. (2021). *2021 Global Status report for Building and Construction: Toward Zero-emissions, Efficient and Resilient Buildings and Construction Sector.* Nairobi. https://globalabc.org/sites/default/files/2021-10/GABC_Buildings-GSR-2021_BOOK.pdf

1.2 Why an Embodied Carbon Policy Calculator?

A handful of cities have already made the commitment to address these emissions through their policies and programs, such as those who have signed on to the Clean Construction Declaration,[5] but more cities will need to adopt a whole life-cycle approach to the built environment that addresses both operational and embodied carbon to reach global decarbonization targets.

A wide variety of paths for reducing embodied carbon are available to cities. For example, the City Policy Framework for Dramatically Reducing Embodied Carbon provides model language for 52 policies to reduce embodied carbon.[6] Similarly, the C40 Clean Construction Policy Explorer[7] and Carbon Leadership Forum Policy Toolkit[8] showcase the many ways in which cities around the world are currently taking action.

Examples of existing policies to reduce embodied carbon include:

- Building reuse and expanded historic preservation incentives;
- Setting life-cycle carbon intensity limits for buildings (i.e., limiting kgCO2e/m2);
- Setting product carbon intensity limits for construction materials, such as concrete or steel;
- Wood or bio-based building material incentives; and
- Deconstruction or salvage requirements for demolition permits.

As more cities take steps towards enacting policies and regulations to reduce embodied carbon for their new buildings, retrofits, and infrastructure, policymakers need tools to estimate the potential impact of different policy opportunities. With limited time to act, pursuing the most impactful strategies to reduce embodied carbon is key, given the limited political will and financial resources available.

Currently, embodied carbon is primarily measured at the scale of a building or project (by design teams) or at the material scale (by manufacturers and construction teams). This has resulted in a plethora of tools for individual projects or products, but a severe lack of tools for considering embodied carbon at the scale of a city. Cities are restricted in their ability to lead this analysis on their own, as data collection and analysis can cost valuable time and resources.

The lack of city-level data on the embodied carbon emission in the built environment is a barrier to action that adds to the typical political and other challenges faced by policymakers. Policymakers can better champion and prioritize embodied carbon policies when they have better data to communicate the magnitude of potential for impact.

The goal of developing an embodied carbon policy reduction calculator for embodied carbon (EC) is to fill this gap by creating a calculator for cities to estimate the carbon reduction potential of embodied carbon policies. This calculator would:

5 C40 Cities. (n.d.). *Clean Construction Declaration*. https://www.c40.org/declarations/clean-construction-declaration/

6 Carbon Neutral Cities Alliance, One Click LCA, Architecture 2030. (2020). *City Policy Framework for Dramatically Reducing Embodied Carbon.* http://carbonneutralcities.org/wp-content/uploads/2021/02/City-Policy-Framework-for-Dramatically-Reducing-Embodied-Carbon.pdf

7 C40 Clean Construction Team. (October 2021). *C40 Clean Construction Policy Explorer*. https://www.c40knowledgehub.org/s/article/Clean-Construction-Policy-Explorer?language=en_US

8 Carbon Leadership Forum. (2021). *CLF Embodied Carbon Policy Toolkit*. https://carbonleadershipforum.org/clf-policy-toolkit/

- Establish a simple way for planners and policymakers to model the carbon savings potential of EC policies for a specific city;
- Allow for comparison of emissions reduction policies for EC by key target dates (2030 and 2050) to assess the largest opportunities for impact;
- Provide customized estimates of carbon savings associated with each policy to give cities the values they need to make a case for action;
- Evaluate which policies may be required to meet embodied carbon reduction targets, such as those set by city or regional climate action plans.

1.3 Proof-of-Concept Study

The Carbon Leadership Forum and C40 Clean Construction teams collaborated to develop a proof-of-concept for an embodied carbon policy reduction calculator, described in this report.

The team developed four prototype calculators to estimate emissions from four types of embodied carbon policies (summarized in Figure 1):

1. Reducing the embodied carbon footprint of entire buildings
2. Limiting the embodied carbon footprint of concrete
3. Increasing adaptive reuse
4. Evaluating the carbon impact of housing policy

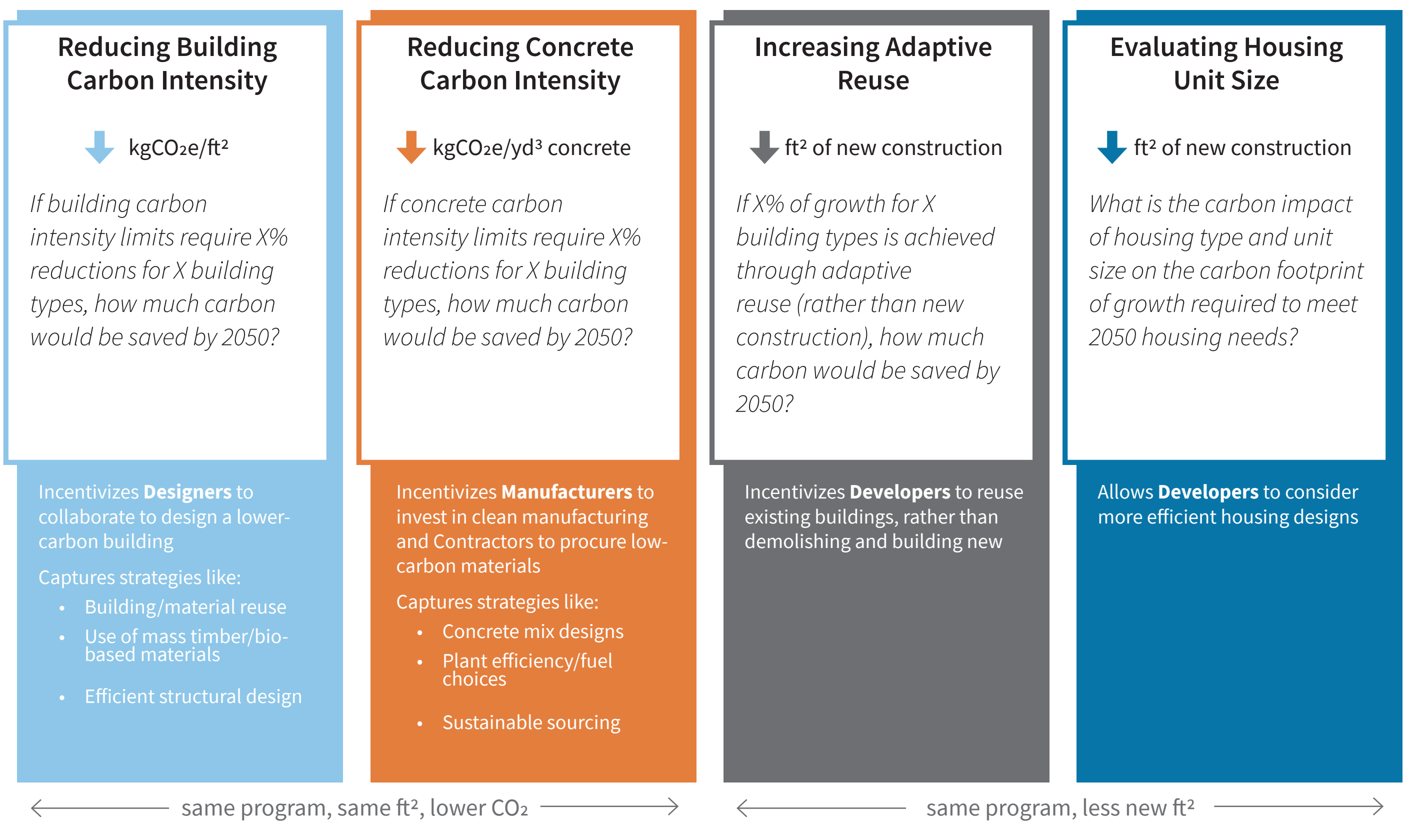

Figure 1. Summary of four types of policies assessed by prototype calculators, including primary stakeholders and potential strategies.

These policies were selected for the proof-of-concept because they met multiple or all of the following criteria:

- Policy framework or precedents already exist
- Pilot cities (and other C40 cities) expressed interest in this type of policy
- Adequate preliminary data available to support prototype calculator
- Political priority outside of embodied carbon

To test each prototype calculator, the team worked with three C40 North American cities: New York City, New York; Portland, Oregon; and Austin, Texas. For each city, the CLF used building stock and growth projections provided by the cities to assess the GHG emissions reduction potential for each policy. The findings from each city are shared in Section 3.

This study used many robust and well-researched datasets to determine the growth projections of cities and their resulting embodied carbon impacts. However, multiple assumptions and order-of-magnitude estimates were still required to fill gaps where insufficient data was available. It is important to remember that the calculators were intended as a proof-of-concept only, and not for comparative decision-making at this time. Appendix B lists the priorities identified by the authors, contributors, and pilot cities necessary for their future development.

2 CALCULATING THE EMBODIED CARBON REDUCTION POTENTIAL OF CITY POLICIES

This section provides an overview of four prototype calculators developed to evaluate the impact of the following policies:

1. Requiring reductions in building embodied carbon intensity;
2. Limiting the carbon content of concrete;
3. Increasing **adaptive reuse;** and
4. Evaluating the carbon impact of housing policy.

Adaptive reuse

The renovation and reuse of pre-existing structures for new purposes. In this report, adaptive reuse also refers to the use of a vacant existing building for the same purpose.

Quantifying the embodied carbon of buildings requires multiple sets of data for the physical, temporal, and environmental scales. This pilot study focuses on embodied carbon impacts for a limited scope of building typologies which can be used to estimate the impacts of future growth scenarios.

The prototype calculators rely on currently available life cycle assessment (LCA) data for buildings and products, typical material quantities for certain products per building type, benchmarks for buildings and products, and typical construction type data for North American cities. Appendix A contains a full overview of the methodology, background data, and uncertainties built into the calculators.

While there are many factors that contribute to the carbon impacts of the built environment, this study was limited in its physical, life cycle, and environmental scope:

- **The physical scope** of all calculators is limited to buildings—particularly the structure, enclosure, and interior finishes. The calculators do not include impacts of other systems such as the mechanical, electrical, and plumbing systems (MEP), nor do they include impacts of infrastructure, such as roadways, parking lots, sewer and water systems, and power distribution networks, which can all contribute to the carbon footprint of cities and significantly alter the results of the current calculators.
- **The life cycle scope** is limited to the product stage of a full life cycle (A1-A3) due to the limitations in available data for use across the prototype calculators. This means that impacts from construction operations, use and replacement, demolition, and end-of-life are not included. These stages are critical to include in future stages of developing these calculators to provide cities with estimates that include the entire life cycle. The estimates in Section 3 for each pilot city are therefore conservative, in that they capture reductions from only a portion of the embodied carbon associated growth in each city. The actual emissions are likely to be much higher.
- **The environmental scope** of all calculators is limited to embodied carbon. They do not include other global environmental impacts such as smog or acidification, nor do they include local impacts such as noise, air pollution, or land use changes. The calculators do not measure social, economic, or other non-environmental indicators.

The results from the calculators are intended as a proof-of-concept for functionality, and are directionally accurate but not yet reliable estimates for informing decision-making. Additional research could improve the accuracy, scope, and functionality of the calculators. Appendix B lists the priorities identified by the authors, contributors, and pilot cities for future development.

2.1 Requiring reductions in building embodied carbon intensity

Calculator 1, or the "Building Embodied Carbon Intensity (BECI) Reduction Policy Calculator," was designed to answer the following question:

If a city required **reductions in building embodied carbon intensity for certain building typologies,** what would be the potential carbon savings by 2050 based on their current growth projections?

Answering this question would help policymakers calculate the potential for policies that limit **building embodied carbon intensity (BECI)** through either:

- Requiring percentage (%) reductions in BECI from a baseline over time; or
- Setting maximum allowable BECI values per floor area ($kgCO_2e/m^2$ or similar).

BECI reduction policies allow for the broadest range of embodied carbon reduction strategies of any of the policies explored in this proof-of-concept. For example, a BECI reduction policy would incentivize the following strategies:

- Building and/or material reuse;
- Efficient structural or building design (i.e., using less of a material, rather than choosing the lowest carbon version of a material);
- Selection of lower-carbon systems and materials, such as sustainably sourced mass timber and other bio-based materials; and
- Use of lower-carbon concrete mixes (similar to policies addressed in Section 2.2).

2.1.1 Policy advantages and co-benefits

Requiring reductions in building embodied carbon intensity is a promising policy solution for delivering large savings in embodied carbon across a variety of building typologies. Policies targeting entire buildings have multiple advantages in that they:

- Give architects, engineers, and contractors the most flexibility in meeting reduction targets;
- Allow for capturing reductions from design in addition to material specification, procurement, and construction;
- Can apply to the broadest range of building typologies;
- Can incentivize building and material reuse and efficiency, which can save money and reduce waste;
- Can support the creation of markets for new materials (such as bio-based alternatives to existing materials);
- Can support the creation of city benchmarking databases to support further analysis and identification of the highest-impact opportunity for reductions; and
- Signals manufacturers (indirectly) and supply chains to decarbonize their products and processes.

Building embodied carbon intensity (BECI)

Building embodied carbon intensity refers to the typical GWP per floor area ($kgCO_2e/m^2$) for an entire building under typical design and construction practices.

2.1.2 Policy precedents

There are a growing number of policy precedents for limiting a building's embodied carbon intensity. Policies targeting reductions in BECI are best suited to policy levers early in the design process, such as zoning and permitting, to allow for holistic design approaches to carbon reduction. These policies most directly target architects and engineers.

In North America, the first precedent was the Green Building Rezoning Requirements in Vancouver, B.C.,[9] which requires the disclosure of a building's embodied carbon footprint and will soon require percentage reductions in total embodied carbon.

In Europe, the first precedent was the Netherlands' Building Decree established in 2012,[10] which requires new residential and office buildings to meet environmental performance (including embodied carbon) targets per square meter of floor area. Similar policies have now been introduced or planned in many other European countries, including Belgium, Germany, France, Sweden, Denmark, and Finland.[11]

The BECI Reduction Policy Calculator could also help cities estimate the potential impact of requiring projects to meet the building life-cycle impact reduction credit included in LEEDv4 for New Construction, which requires teams to reduce the life cycle impacts of their buildings (including embodied carbon) by 10% from a baseline building.[12]

2.1.3 Calculator functionality

To calculate the baseline scenario, the calculator multiplies the BECI values for each **building typology** with the expected building typology growth projected for that city, and then applies the percentage reduction selected by the calculator user. See Appendix A Section A.3 for additional methodology details.

The BECI Reduction Policy Calculator requires users to input **building use**, **building size** for that building use, and expected area of growth by 2050 (in m²) for building typologies being assessed. Then, users can select a percentage (%) embodied carbon reduction requirement.

After entering this information, the calculator provides an estimate of projected embodied carbon by 2050 for a baseline scenario and the selected reduction scenario(s), as well as the total carbon savings potential by 2050. Figure 2 provides an illustrative example of the BECI Reduction Policy Calculator inputs and resulting outputs.

Building typology

In this report, building typology refers to a category of buildings with the same building use and building size. For example, 'commercial' is a building use, whereas 'commercial mid-rise (6-10 stories)' is a building typology.

Building use

Building use refers to the primary function of the building. Examples include commercial, multifamily residential, institutional, or retail. The building use names vary for different cities, and may or may not be tied to specific zoning names.

Building size

Building size refers to the range of building levels. For example, low-rise, mid-rise, 6-10 stories, or very large (>10 stories). The typical range of levels for a building use is typically limited by zoning and varies for each city.

9 City of Vancouver Planning, Urban Design and Sustainability Department. (2010). *Green Buildings Policy For Rezoning - Process And Requirements*. Available at https://bylaws.vancouver.ca/Bulletin/G002_2017April28.pdf

10 Netherlands Ministry of the Interior and Kingdom Relations. (2012). *Building Decree 2012.* https://www.rijksoverheid.nl/onderwerpen/bouwregelgeving/bouwbesluit-2012.

11 WBCSD and OneClickLCA. (2020). *Decarbonizing construction: Guidance for investors and developers to reduce embodied carbon.*

12 United States Green Building Council. (n.d.). *Building product disclosure and optimization - environmental product declarations.* https://www.usgbc.org/credits/new-construction-schools-new-construction-retail-new-construction-data-centers-new-3?return=/credits/new-construction/v4. Accessed February 2022.

Building Embodied Carbon Intensity (BECI) Reduction Policy Calculator

Step 1: Name Reduction Scenario: Scenario A2, 40% Multifamily

Step 2: Enter Projected Growth Data

Building Use	Building Size	2050 Expected Area of Growth (million m²)
Multifamily	1-7 Stories	5.3
Multifamily	> 7 Stories	12
Multifamily	Very Large	7.8

Step 3: Select Reduction Requirement

Percentage (%) Reduction Required
40%
40%
40%

CALCULATE

Results: Carbon Savings Potential by 2050

Baseline Scenario	8.5 million mtCO2e
Scenario A2	7.7 million mtCO2e
Total Savings Potential	**0.8 million mtCO2e**

Key

Indicates user input

Indicates tool output

Figure 2. Illustrative example of the BECI Reduction Policy Calculator demonstrating user inputs and outputs.

2.2 Limiting the Carbon of Concrete

Calculator 2, or the "Low-Carbon Concrete Policy Calculator," was designed to answer the following question:

If a city **limited the maximum allowable embodied carbon intensity of concrete for certain building typologies,** what would be the potential carbon savings by 2050 based on their current growth projections?

Answering this question would help policymakers calculate the potential for policies that limit **concrete embodied carbon intensity (CECI)**. This would also be helpful for cities to understand what magnitude of reduction targets for their policies would result in achieving their carbon reduction goals.

2.2.1 Policy advantages and co-benefits

Cement, a key ingredient of concrete, is responsible for approximately 7% of global greenhouse gas (GHG) emissions, making this a critical sector for GHG reductions.[13] Requiring reductions in concrete embodied carbon intensity is often referred to as "low-hanging fruit" for embodied carbon policies, since there are already a wide range of available strategies for reducing the carbon of concrete.[14,15]

Concrete embodied carbon intensity (CECI)

Concrete embodied carbon intensity refers to the average carbon intensity in $kgCO_2e/yd^3$ of concrete for specific regions of the USA.

13 IEA and Cement Sustainability Initiative. (2018). *Technology Roadmap: Low-Carbon Transition in the Cement Industry.* https://www.wbcsd.org/contentwbc/download/4586/61682/1

14 Cannon, C., Guido, V., and Wright, L. (2021). *Concrete Solutions Guide: Actionable Solutions to Lower the Embodied Carbon of Concrete*. https://rmi.org/insight/concrete-solutions-guide

15 Fransen, T., Lebling, K., Weyl, D., and Kennedy, K. (2021). *Toward A Tradable, Low-Carbon Cement Standard: Policy Design Considerations For The United States.* https://doi.org/10.46830/wriwp.20.00112

Benefits of policies targeting reduction in the embodied carbon intensity of concrete include:

- Helps create markets for lower-carbon materials and technologies across the concrete supply chain;
- Relative ease of implementation, by focusing on one type of carbon-intensive material;
- Can apply to roads, bridges, and other civil works in addition to buildings;
- Can incentivize material efficiency (e.g., reductions in total cement use), reducing waste;
- Can reward locally sourced materials and products that promote the local economy;
- Signals manufacturers and supply chains to decarbonize their products and processes; and
- Reduces industrial emissions that have significant co-benefits beyond carbon, such as improving air quality in **fenceline communities** and reducing energy use, water use, ozone depletion, smog formation, and eutrophication.

2.2.2 Policy precedents

Low-carbon concrete policies are growing rapidly at the local, state, and federal level across the United States and globally. In the United States, concrete is included in existing state and federal policies targeting procurement—such as the Buy Clean Colorado Act, the New York Low Embodied Carbon Concrete Act, and Executive Order 14057—as well as a growing number of state procurement bills, such as those introduced in 2021 New Jersey, California, Massachusetts, Washington, Minnesota, and Oregon that did not pass. Concrete was also included in the Federal Buy Clean program proposed in the CLEAN Future Act in Congress in March 2021.

At the local level, there are even more examples. Two of the first in the United States are Marin County's Low Carbon Concrete Code, which requires concrete to be below either maximum cement values or maximum GWP values per cubic yard of concrete ($kgCO_2e/yd^3$) by strength class,[16] and the City of Portland's Low Carbon Concrete Purchasing Policy, which will require ready mix concrete products used on city projects to be below a maximum GWP value per cubic yard of concrete ($kgCO_2e/yd^3$) by strength class.[17]

2.2.3 Calculator functionality

To calculate the baseline scenario, the Low Carbon Concrete Policy Calculator uses data on the **construction type**, concrete material quantity per construction type, and regional embodied carbon intensity values for concrete to estimate the embodied carbon associated with the projected growth. Baseline values are representative of typical construction practices and typical concrete production for each region. The percentage reduction selected is then applied to the baselines values to calculate the reduction scenario. See Appendix A Section A.4 for additional methodology details.

While the background calculations are different, the Low Carbon Concrete Policy Calculator requires similar inputs from users as the BECI Reduction Policy Calculator (e.g., building use, size, and expected growth) and communicates results in a similar

Fenceline communities

Fencline communities are communities of increased health risk due to their proximity to a major source of pollution. Fenceline communities are often disproportionately inhabited by people of color and the working poor.

Construction type

In this report, construction type refers to the primary structural system, such as concrete, steel/concrete hybrid, or mass timber. This is important because the structural system of a building, whether it be steel, concrete, or wood, is also an important indicator of the total volume of concrete a building will use.

16 County of Marin Sustainability Department. (2021). *Low-Carbon Concrete Requirements.* https://www.marincounty.org/depts/cd/divisions/sustainability/low-carbon-concrete.

17 City of Portland Procurement. (n.d.). *Current Sustainable Procurement Initiatives.* https://www.portland.gov/omf/brfs/procurement/sustainable-procurement-program/sp-initiatives#!/

format. This calculator could also be adjusted to allow users to select GWP values, rather than percentage reductions, to more directly match the structure of many policies.

Figure 3 shows an illustrative example of the Low Carbon Concrete Policy calculator inputs and resulting outputs.

Low Carbon Concrete Policy Calculator

Step 1: Name Reduction Scenario: Scenario B, Commercial

Step 2: Enter Projected Growth Data

Step 3: Select Reduction Requirement

Building Use	Building Size	2050 Expected Area of Growth (million m²)	Percentage (%) Reduction Required
Commercial	1-7 Stories	2.1	40%
Commercial	> 7 Stories	4.8	40%
Commercial	Very Large	3.1	20%

CALCULATE

Results: Carbon Savings Potential by 2050

Baseline Scenario	4.9 - 6.4 million mtCO2e
Scenario B	4.4 - 5.8 million mtCO2e
Total Savings Potential	**0.5-0.6 million mtCO2e**

Key

Indicates user input

Indicates tool output

Figure 3. Example of the Concrete Embodied Carbon Intensity Calculator inputs and outputs.

2.3 Increasing Adaptive Reuse

Calculator 3, or the "Adaptive Reuse Policy Calculator," was designed to answer the following question:

If a city **incentivized the adaptive reuse of a percentage of existing building stock** rather than demolishing and building new, what would be the potential carbon savings by 2050 based on their current growth projections?

Answering this question would help policymakers advocate for policies that encourage developers and building owners to extend the life of existing buildings through adaptive reuse rather than building on greenfield sites or demolishing and building new.

2.3.1 Policy advantages and co-benefits

Extending the life of the physical resources already invested in a city's existing buildings and materials through adaptive reuse reduces embodied carbon through avoiding the release of emissions for the manufacturing and construction of new materials. Policies incentivizing adaptive reuse can:

- Avoid carbon emissions from manufacturing new materials for new construction;
- Reduce the environmental damage and community health impacts from landfilling construction materials after demolition;
- Avoid environmental damage from new construction on greenfield (i.e., previously undeveloped) sites by encouraging preservation and increased density in historic portions of cities;
- Preserve cultural resources and heritage, providing economic and social co-benefits;[18]
- Reduce local noise and pollution from demolition activities (depending on the scope of adaptive reuse); and
- Provide an opportunity for energy retrofits of outdated, inefficient, and high-emission MEP systems.

2.3.2 Policy precedents

Relatively few precedents exist for policies that directly encourage adaptive reuse, outside of historic tax credits. While historic tax credits and other historic preservation policies do incentivize building reuse, additional types of policies could apply to a broader range of building reuse, such as preservation of only a building's primary structure, foundation, and/or envelope. Since these types of building reuse may not retain the historic portions of a structure, they may not qualify for a historic tax credit but would still avoid significant carbon emissions.

The Los Angeles Adaptive Reuse Ordinance provides development incentives—such as mezzanines, density bonuses, reduction in off-street parking requirements, and other regulatory exemptions—for adaptive reuse of eligible buildings in the specified downtown project area.[19] Another example is the City of Vancouver's (B.C.) Empty Homes Tax,[20] which encourages empty and under-utilized properties to get back on the rental market.

The adaptive reuse calculator developed for this proof-of-concept focuses exclusively on the carbon savings potential from reusing existing buildings, not on the carbon savings potential of deconstruction for material reuse. Deconstruction policies, such as the Portland Deconstruction of Buildings Law,[21] can also reduce embodied carbon significantly and could be addressed by future versions of the Embodied Carbon Policy Reduction Calculator.

18 Historic England. (2020). *Heritage and the Economy 2020*. https://historicengland.org.uk/content/heritage-counts/pub/2020/heritage-and-the-economy-2020/

19 Los Angeles Department of Building and Safety. (2001). *Adaptive Reuse Ordinance*. https://www.ladbs.org/docs/default-source/publications/ordinances/adaptive-reuse-ordinance---l-a-downtown-incentive-areas.pdf?sfvrsn=7

20 City of Vancouver. (2022). Empty Homes Tax. https://vancouver.ca/home-property-development/empty-homes-tax.aspx

21 City of Portland. (n.d.) *City Code Chapter 17.106 Deconstruction of Buildings Law.* https://www.portland.gov/code/17/106

2.3.3 Calculator functionality

To calculate a baseline scenario assuming 100% new construction, the calculator multiplies the projected area of growth for each typology by their corresponding BECI values. To calculate the reuse scenarios, the user selects a percentage of the total growth to be achieved through adaptive reuse, rather than new construction. The reuse area is then multiplied by reuse embodied carbon intensities while the remaining new construction area is multiplied by their corresponding BECI values. The impacts from both areas are then combined. See Appendix A Section A.5 for additional methodology details.

Similar to the BECI Reduction Policy and Low Carbon Concrete policy prototype calculators, the Adaptive Reuse Policy Calculator requires users to input building use, building size for that building use, and expected area of growth by 2050 (in m²) for building typologies being assessed. However, rather than selecting a percentage reduction requirement, users enter a percentage of projected growth to be met with adaptive reuse of existing buildings rather than new construction.

After entering this information, the calculator provides an estimate of projected embodied carbon by 2050 for a baseline scenario (e.g., new construction only) and the increased reuse scenario(s), and the total carbon savings potential by 2050. Figure 4 provides an illustrative example of the Adaptive Reuse Policy calculator inputs and resulting outputs.

Adaptive Reuse Policy Calculator

Step 1: Name Reduction Scenario: Scenario C, Multifamily/Commercial

Step 2: Enter Projected Growth Data

Step 3: Select % growth to be met with reuse

Building Use	Building Size	2050 Expected Area of Growth (million m²)	Percentage (%) Building Growth from Reuse
Multifamily	Low-rise (1-5)	3.9	20%
Multifamily	Mid-rise (6-10)	9.0	20%
Multifamily	High-rise (>10)	5.8	20%
Commercial	Low-rise (1-5)	2.1	10%
Commercial	Mid-rise (6-10)	4.8	10%
Commercial	High-rise (>10)	3.1	10%

CALCULATE

Results: Carbon Savings Potential by 2050

Baseline Scenario	16 million mtCO2e
Scenario C	14 million mtCO2e
Total Savings Potential	**2 million mtCO2e**

Key

Indicates user input

Indicates tool output

Figure 4. Examples of the Adaptive Reuse Policy Calculator inputs and outputs.

2.4 Evaluating the embodied carbon impact of housing policy

Calculator 4, or the "Housing Size Policy Calculator," was designed to answer the following question:

What is the **impact of housing typology and unit size on the carbon footprint of growth required to meet housing needs** based on a city's current 2050 housing growth goals?

Cities across the globe need to increase their available housing units rapidly to meet the growing and currently unmet needs for housing. Answering the question above would enable policymakers to include embodied carbon as a metric alongside other key metrics for evaluating the impact of land use and zoning decisions related to housing policy.

However, due to the lack of available data on the embodied carbon of specific housing typologies (3-6 story, 6-10 story, etc.) the policy calculator developed for this study currently focuses on housing unit size only. While unit size is a critical factor in understanding the impact on embodied carbon of housing, it is not sufficient for making comparisons at the scales of urban development or zoning. Furthermore, the calculator does not currently take into account infrastructure and parking needs which are also critical for capturing a more holistic scope of housing development.

For these reasons, the housing policy calculator requires the most development and filling of data gaps before it can be usefully deployed at scale (see Appendix B for more information).

2.4.1 Policy advantages and co-benefits

Housing will comprise a large portion of the global construction growth between now and 2050. For example, for New York City and Portland, projected housing growth made up nearly 50% of total citywide growth and accounted for nearly twice the amount of any other building typology. Addressing the embodied carbon associated with housing is therefore critical for making meaningful embodied carbon reductions.

Reducing the size of individual units reduces total embodied carbon by allowing more housing units to be built with the same amount of new materials. Policies dealing with the efficiency of housing units have the following advantages and co-benefits:

- Directly reduces the embodied carbon and other environmental impacts associated with manufacturing new materials for more floor area;
- Increased quantity of affordable housing, as smaller units are typically the lowest-cost option in expensive urban areas;
- Targets the largest growth typology for most cities;
- Avoids environmental damage from construction on greenfield (i.e., previously undeveloped) sites by allowing for more efficient use of land resources in developed urban areas; and
- Can increase access to transit and city services through increased density, resulting in a wide range of environmental and public health benefits from less driving for commuting and other travel.[22]

22 C40 Cities Climate Leadership Group and C40 Knowledge Hub. (2021). *Why every city can benefit from a '15-minute city' vision*. https://www.c40knowledgehub.org/s/article/Why-every-city-can-benefit-from-a-15-minute-city-vision

2.4.2 Policy precedents

Restrictions on which housing typologies can be constructed in a particular urban area are typically set by zoning. Therefore, if a particular housing typology was identified as optimized for embodied carbon, no policy precedent would be required aside from zoning. However, there is not currently enough data to determine the relative embodied carbon associated with different housing typologies and building heights to the level of accuracy required to associate different zoning types with relative embodied carbon impacts.

The most relevant policy precedents for the current scope of the housing size policy calculator are those that directly target unit size by removing size minimums or encouraging development of micro units. For example, New York City removed minimum apartment sizes in 2016 to allow for micro units developed under Quality Housing Regulations. Minimum unit sizes still apply for affordable housing, affordable senior housing, and certain zoning districts. This has allowed for the development of projects like Carmel Place, an income-targeted modular development with a high percentage of micro units.[23]

While micro units are seen as a promising opportunity for increasing the quantity of affordable housing units, particularly for first-time renters or to provide housing access in more expensive urban areas, they are not politically feasible in certain cities.

2.4.3 Calculator functionality

Whereas all other prototype calculators assume a fixed area of growth as provided by each city, this reduction scenario instead assumes a fixed number of housing units. For the reduction scenarios run in this report, all numbers of units remained the same between baseline and reduction scenarios.

The Housing Policy EC Calculator requires inputs for building use and size, number of units required by 2050, and baseline average unit size. To calculate the baseline scenario, the calculator multiplies the baseline number of units by the typical unit size and estimated BECI value for each building typology. To calculate the reduction scenario, the calculator does a similar calculation with the custom unit size. Unit size was the only variable used. See Appendix A Section A.6 for additional methodology details.

The calculator provides similar projections to the other prototype calculators (i.e., projected embodied carbon by 2050 for a baseline and reduction scenario(s) and the total carbon savings potential). Figure 5 provides an illustrative example of the Housing Size Policy Calculator inputs and resulting outputs.

23 Healthy Materials Lab Parsons School of Design. (2019). *Carmel Place: Innovative Practices for Healthier Homes*. https://prod-hml.s3.amazonaws.com/news/150219_Carmel-Place-Case-Study-Report.pdf

Housing Size Policy Calculator

Step 1: Name Reduction Scenario: Scenario 4, 20% Residential

Step 2: Enter projected growth data and typical unit size

Step 3: Enter New Unit Size

Building Use	Building Size	(New) Housing Units by 2050 (#)	Average Unit Size (ft^2/unit)	Typical Average Unit Size (ft^2/unit)
Single Family	Low-rise	20,000	1900	1600
Multifamily	Low-rise	150,000	800	650
Multifamily	Mid-rise	60,000	800	650
Multifamily	Very Large	15,000	800	650

CALCULATE

Results: Carbon Savings Potential by 2050

Baseline Scenario	9.6 million mtCO2e
Scenario D4	7.6 million mtCO2e
Total Savings Potential	**2 million mtCO2e**

Key
- *Indicates user input*
- *Indicates tool output*

Figure 5. Example of the Housing Size Policy Calculator inputs and outputs.