Green Buildings:

Exploring Policies, Tools, and Incentives for Reducing Embodied Emissions in New Construction

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Disclaimer

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Greenhouse gas emissions from the building sector are made up of both operational emissions (emissions released from energy use during the lifetime of the building) and embodied emissions (emissions released during the whole building life cycle, from the extraction of raw materials to disposal at the building's end of life).

Embodied emissions of the building sector account for approximately 10% of global greenhouse gas (GHG) emissions [1]. It is critical to significantly reduce embodied emissions from the building sector urgently because, on average, more than 70% of all embodied emissions occur before the building is occupied [2].

In British Columbia (BC), the BC Energy Step Code has been developed to improve the energy efficiency of new buildings. Although many communities in BC have leveraged it to reduce operational emissions of new buildings, embodied emissions have been largely overlooked. This research report aims to help develop policies that could reduce embodied emissions of new construction in the District of North Vancouver (DNV). The main purpose of this research was to identify potential challenges and opportunities for DNV to develop a policy to reduce embodied emissions in new construction. To help achieve this goal, best practices for policy and regulatory approaches for embodied emissions accounting in new construction in Canada, Europe, and the U.S. were researched and a number of experts in this field were interviewed. An analysis was performed to estimate the average annual embodied emissions associated with the DNV's building sector between 2011-2019. The average annual embodied emissions for the DNV is estimated to be approximately 30,000 tonnes CO_2e/m^2.

The following recommendations are outlined to achieve the DNV's goals of reducing embodied emissions in its building sector:

1. **Leverage existing tools and local data:** Make use of local data and relevant emerging tools, (e.g. the Building Emissions Accounting for Materials [BEAM] calculator) to quantify opportunities for reducing embodied emissions of buildings in the District.

2. **Work towards a standard framework:** Work with other municipalities, industry, and the Province towards developing a standard framework such as the BC Energy Step Code to encourage lower embodied emissions for consistency among municipalities.
3. **Use consistent methods:** Use the Baseline method (project defined baseline) to measure and reduce embodied emissions related to new construction and for consistency with the City of Vancouver and common green building rating systems such as Leadership in Energy and Environmental Design (LEED).
4. **Start with reporting:** Incentivize completion of Whole Building LCA (WBLCA) reports for new construction and develop strategies for reducing embodied emissions by 10-40%, providing clear guidance for applicants to reduce variability.
5. **Acknowledge different building types:** Ensure policies address different types of buildings and their unique regulatory context. This could include a rezoning policy for larger, more complex (Part 3) buildings that incentivizes applicants to report on embodied emissions, as well as a program that offers incentives to build small ground-oriented (Part 9) buildings with lower embodied emissions.
6. **Develop incentives:** Explore incentives such as reduced building permit fees, density bonuses, recognition of embodied emissions leadership, capacity building, expedited development and building permits, and property tax rebates in exchange for reducing embodied emissions.
7. **Engage with industry:** Engage with industry and product manufacturers to learn what incentives would be most attractive to encourage a shift from concrete buildings to wood buildings. Inform the designers and builders of the preferred incentives and new policies through online webinars and in-person meetings.
8. **Prioritize actions:** Review the policy measures in Appendix C to prioritize actions for policy-making in the District.

1. Introduction

As seen in Figure 1, 38% of the total global CO_2 emissions in 2019 was associated with the building sector, 28% of which were operational emissions from buildings and the remaining 10% from the buildings construction industry, or more commonly referred to as 'embodied emissions' [1]. In recent years as policies and regulations are put in place to reduce operational emissions, embodied emissions associated with building construction have attracted a lot of attention and policymakers around the world have started to develop policies to reduce their impact.

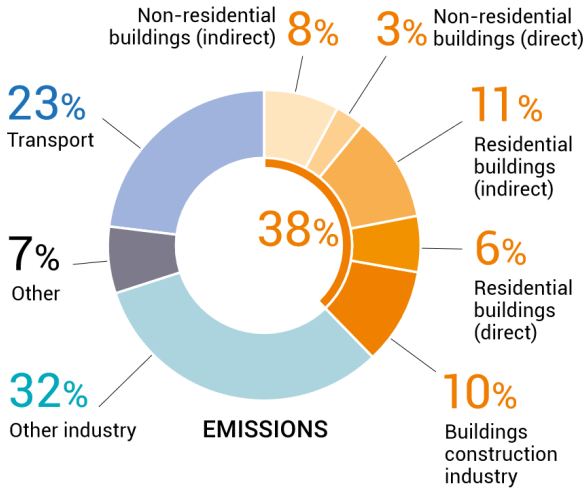

Figure 1. Global share of emissions related to the building sector, 2019 [1]

Note: The buildings industry is the portion (estimated) of the overall industry devoted to manufacturing building construction materials such as steel, cement, and glass. Indirect emissions are emissions from power generation for electricity and commercial heat. Sources: (IEA 2020d; IEA 2020b). All rights reserved. Adapted from "IEA World Energy Statistics and Balances" and "Energy Technology Perspectives". [1]

1.1. Research Objectives

The District of North Vancouver (DNV) intends to build from emerging research and innovative approaches to help develop policies and tools that could support low carbon new buildings that are energy efficient and low in both operational and embodied emissions. Key objectives for this project are as follows:

- Researching best practices for policy and regulatory approaches for embodied emissions accounting in new construction and how these best practices may relate to or be incorporated into the BC Energy Step Code.
- Identifying potential challenges and opportunities for both local government and industry to reduce embodied emissions in new construction.

1.2. Scope and Limitations

The policies and recommendations included in this report are limited to new construction only. It is noteworthy to mention that avoiding construction of new buildings by getting more out of existing buildings as well as renovating and retrofitting existing buildings rather than constructing new buildings are viable alternatives that have considerably higher impacts in reducing embodied emissions, as seen in Figure 2. [3] For example, reducing parking requirements would reduce the amount of concrete required and thus reduce embodied carbon associated with new construction.

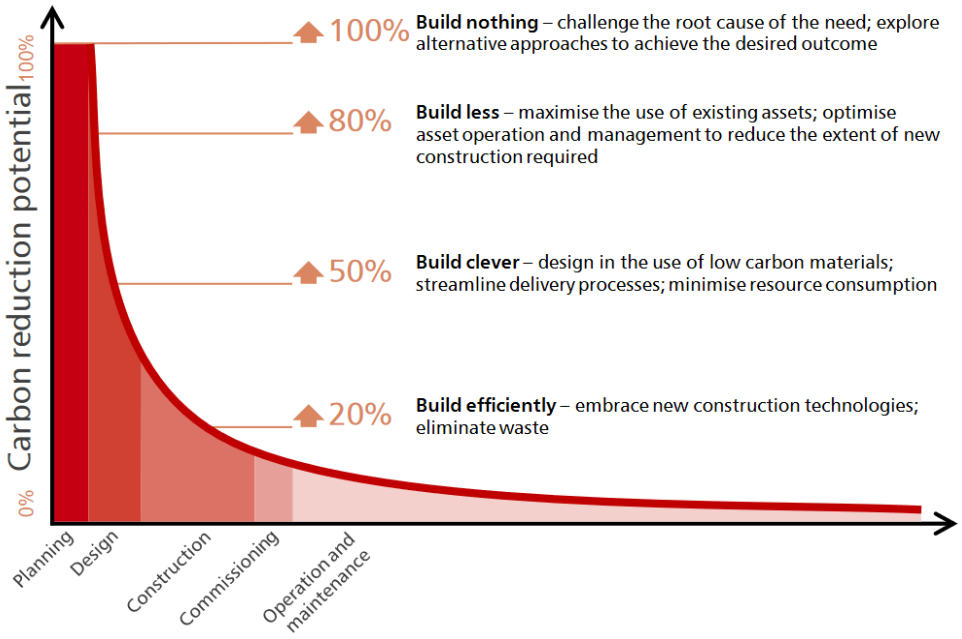

Figure 2. Carbon reduction potential associated with different building policies [3]

2. Background

2.1. Significance of Embodied Emissions

While operational emissions are greenhouse gas (GHG) emissions that are released from energy used (e.g. through cooling, heating, ventilation, etc) during the lifetime of the building, embodied emissions are, for the purposes of this report, those GHG emissions that are released during the whole building life cycle, from the extraction of raw materials in the production phase to the disposal at the building's end of life (Figure 3). As operational emissions are reduced, the remaining embodied emissions become proportionally more significant. Unlike operational emissions that are spread out through the lifetime of the buildings, the vast majority of embodied emissions occur before the building is occupied and are therefore a key source of carbon emissions in new buildings.

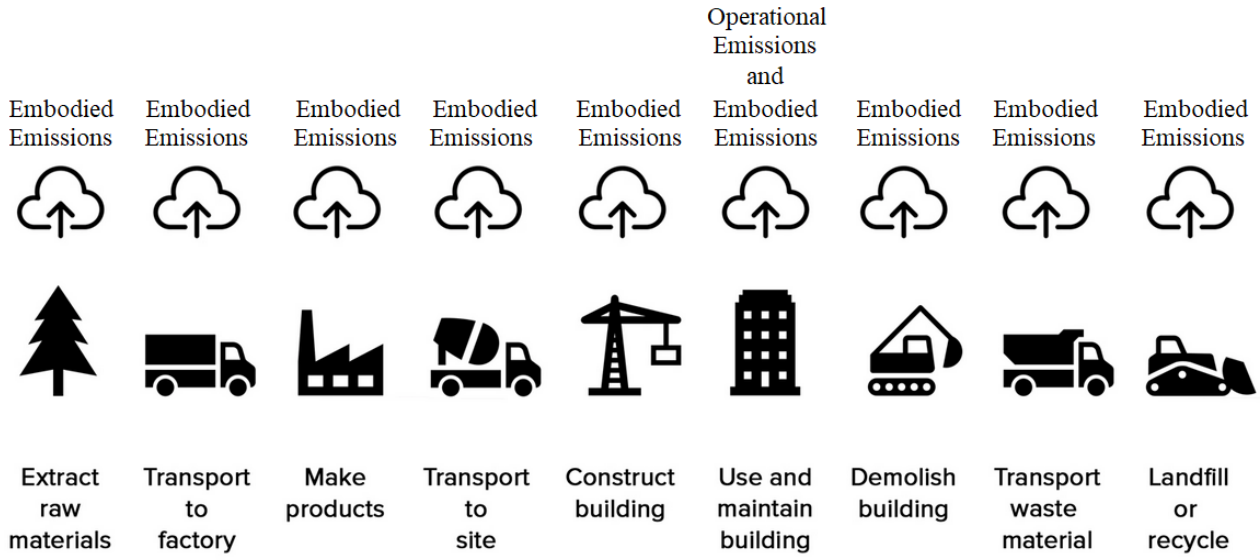

Figure 3. Adapted from the source: GHG emissions of a building during its lifetime [4]

2.2. BC Energy Step Code Implementation by the District of North Vancouver

In early 2017, BC Energy Step Code [5] was adopted as a regulation by the Province of BC. This is an optional compliance path in the BC Building Code that local governments may use, if they wish, to incentivize or require a level of energy efficiency in new construction that goes above and beyond the requirements of the BC Building Code. Builders may also voluntarily

use the BC Energy Step Code as a new compliance path for meeting the energy-efficiency requirements of the BC Building Code [5], thus providing a consistent approach. This was particularly designed to help government and industry build a pathway such that by 2032 all new construction within the province is “net-zero energy-ready”. Figure 4 shows steps levels for Part 9 and Part 3 buildings in the BC Energy Step Code.

Figure 4. Definition of Lower and Upper Steps by building type (Part 9 and Part 3) [5]

The District has recognized the need to not only encourage energy efficiency in new construction but also to encourage low carbon buildings. This is currently achieved by incentivizing ‘low-carbon energy systems’ in new buildings such as heating systems that are powered by renewable hydropower instead of by fossil fuels. Table 1 illustrates the DNV’s current (2021) BC Energy Step Code requirements including providing options to industry to encourage energy efficiency and ‘low carbon energy systems in new construction [6]. The District has amended its Construction Bylaw to include a definition for a ‘low carbon energy system’ with a greenhouse gas intensity limit of 3 kg CO_2e/m^2/year.

Table 1. DNV's approach to encourage energy-efficient and low carbon buildings [6]

Building Type	Energy Step Code Requirement as of July 1, 2021	GHGI Requirement
Part 9 Residential (e.g. Single Family)	Step 5 or Step 3 + Low Carbon Energy System	<=3.0
Part 3 Residential (e.g. Multi-Family)	Step 4 or Step 3 + Low Carbon Energy System	<=3.0
Part 3 Commercial (e.g. Retail or Office)	Step 3 or Step 2 + Low Carbon Energy System	<=3.0
Part 3 Commercial (Major Renovation)	Step 1	N/A
Public Sector Buildings	Step 1	N/A

The District is currently providing options for industry, as outlined above, as municipalities do not currently have the authority to require carbon performance (e.g. GHG intensity) limits for new buildings outright. However, the Province of British Columbia indicated in November 2020 that they intend to expand the power of municipalities to regulate carbon performance.

2.3. Carbon Neutral Cities Alliance Policy Framework

The Carbon Neutral Cities Alliance (CNCA) is an alliance of leading cities aiming for carbon neutrality by 2050. The CNCA's 2020 Embodied Carbon Policy Framework was coordinated by a steering group composed of the cities of Vancouver, Portland, Copenhagen, Helsinki, Oslo, San Francisco, Seattle, London, New York, Boulder, and Tampere. The report includes 52 detailed policies and aims to guide cities and local governments towards developing a strategy, action plan and policies to dramatically reduce embodied carbon in the building sector [7]. All of these important policy levers have been addressed or contemplated in some way as part of the City of Vancouver's Embodied Carbon Strategy [8]. The CNCA report introduces innovative new policies that may be applicable for North American and European contexts. These policies are evaluated for their impact in terms of carbon reduction potential, cost-efficiency, implementability, and enforceability. This report classifies the embodied

emissions reduction measures into five categories identified in Table 2 and visualized in Figure 5.

Table 2. Embodied Carbon Reduction Policies, Carbon Neutral Cities Alliance [7]

Embodied Emissions Measure	Policy
REDEFINE the solution	● Meet the needs mainly by means other than construction (avoid new construction). ● Advantage: It has the highest impact. ● Disadvantage: It is the most difficult to implement.
REFURBISH existing assets	● Renovate existing buildings rather than constructing new buildings.
REDUCE AND REPLACE materials and structures	● Use lower carbon materials and structures ● Reduce the net use of materials
REUSE products and materials	● Reuse products and materials at end of life stage for extra uses for unused products from sites and for salvaged materials from renovations and demolitions.
REQUIRE low carbon products	● Use low-carbon materials and products. ● Advantage: It is the easiest measure to implement. ● Disadvantage: It has the lowest impact.

Reducing and replacing materials and structures have the earliest and most impact in lowering embodied emissions in “new” construction, as seen in Figure 5.

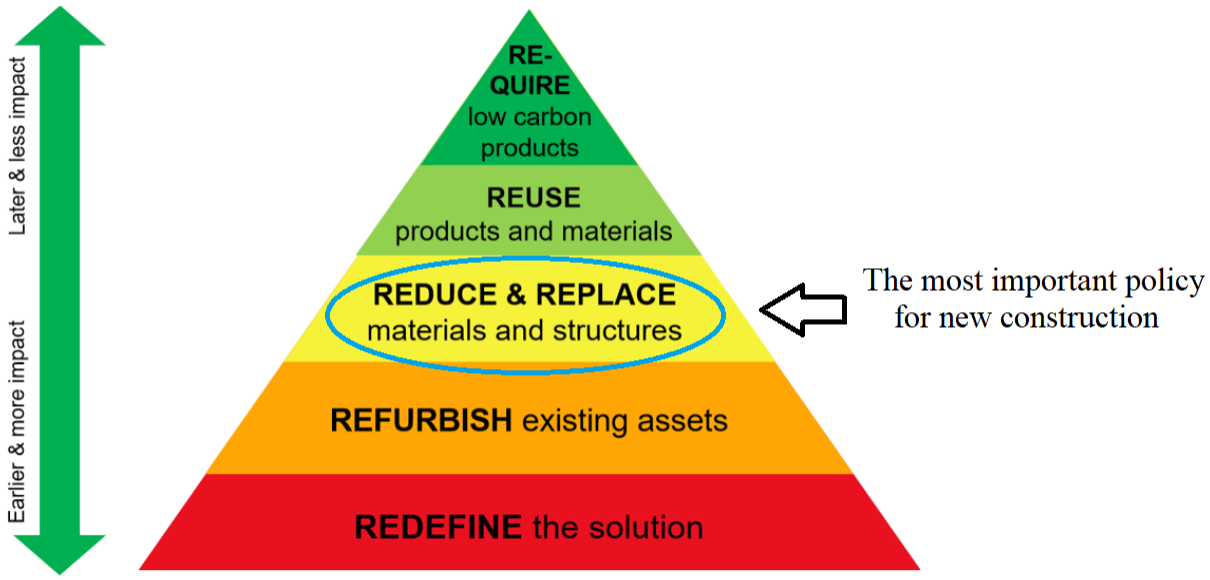

Figure 5. Modified from source: The Pyramid of Embodied Carbon Reduction Measures [7]

Examples for each of these measures are provided in Appendix C. The CNCA report has grouped the five aforementioned embodied carbon reduction measures into seven policy types, as shown in Table 3.

Table 3. Policy groups and their corresponding targets [7]

Policy Group	Targets
Zoning & land use	What and where the building can be constructed; Land sales / leases
Regulation	The private sector construction is affected by this policy group
Procurement	What and how materials, projects, and services should be purchased
Waste & circularity	Materials life-cycle; use of materials in their end of life
Infrastructure	Transport and utility networks and other civil works
Municipal buildings	Buildings owned and / or used by the city
Financial	Taxation, fees, incentives, commercial (dis)advantages

These policy groups affect one or more of the categories listed in Figure 6 below. The measures that are shown to have the highest potential for reducing embodied emissions in the construction sector are Zoning & land use and Regulation policies for private construction.

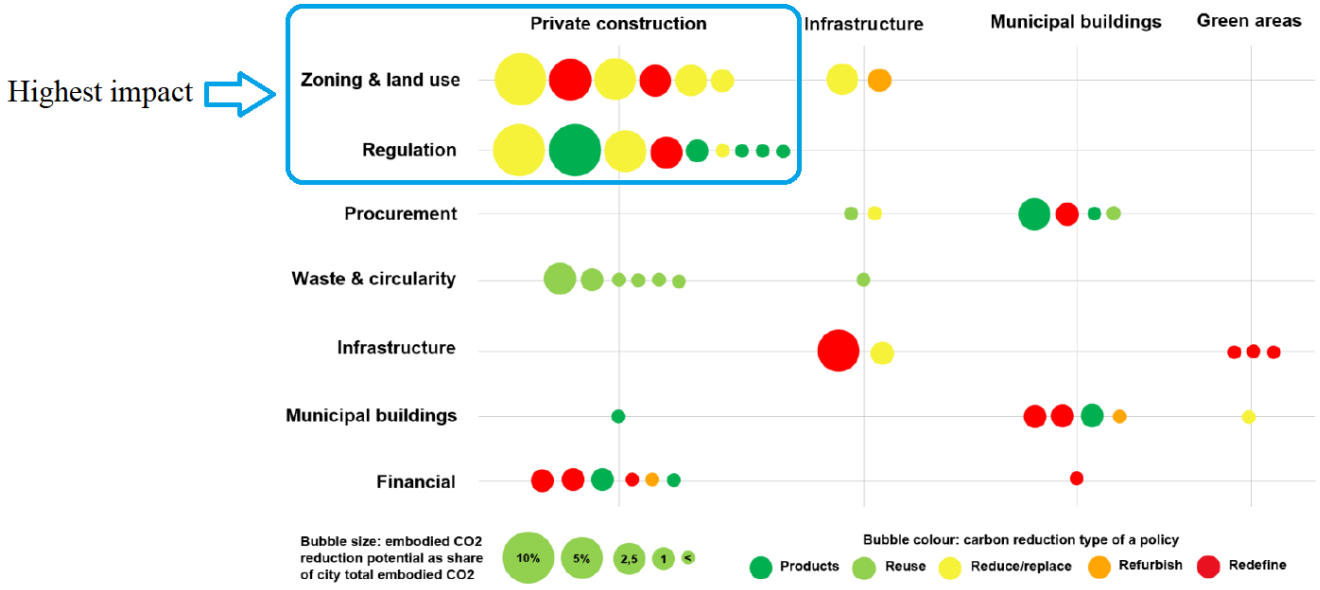

Figure 6. Modifies from source: embodied carbon policies visualized [7]

Four evaluation methods (carbon impact, cost-efficiency, implementability, and enforceability) have been used to score each of the 52 policies outlined in the CNCA report. (Appendix B). Of the 52 actions, those found to have the highest carbon impact include:

- **Embodied carbon targets for zoning process**: Zoning or rezoning can be implemented using carbon evaluation or early phase carbon intensity metrics to ensure zoning is resulting in a low carbon built environment. Decisions made in the zoning phase have a very high potential impact, starting from choosing the land to zone and to construct on, to determining constraints for massing, density, and height. Moreover, parking and transport infrastructure, and detailed requirements set for the builders are determined in zoning [7].
    - **Lifecycle carbon limits for new buildings**: Setting limits on the maximum life-cycle carbon for new buildings. This can be for whole life-cycle carbon including operational carbon or embodied carbon [7].
    - **Low carbon cement and concrete policy**

- **Set zoning requirements for bio-based materials**
- **Carbon-scored land sales competitions**, and
- **Material-efficient structural design requirement**.

3. Tools and Methods for Estimating Embodied Carbon

3.1. Life Cycle Assessment (LCA) Tools

The following software tools are available to estimate the embodied emissions in larger, more complex (Part 3) buildings:

- **Athena Impact Estimator for Buildings** [9] estimates Global Warming Potential and six other environmental impacts. Athena is a free software tool that evaluates whole buildings and enables designers to compare the environmental impact of industrial, institutional, commercial, and residential designs. Athena has built its own database and does not depend on Environmental Product Declarations (EPDs). Athena Impact Estimator for Buildings complies with LCA methodology standards developed by the International Organization for Standardization (ISO) 14040 and 14044 series. The user enters basic information about building geography, size, and height, and then a building model is developed by creating a series of assemblies, such as walls, floors, and roofs. Materials in these assemblies can be altered to determine their relative impact on the building. Typically used in the conceptual stage of a project, it can model 95% of North American building stock and assess cradle-to-grave impacts related to embodied carbon [10].
- **Embodied Carbon in Construction Calculator (EC3)** is a free and open-access tool that offers building owners, engineers, and contractors benchmarking and assessment capabilities for the reduction of embodied carbon for construction materials. It will speed up the review of product EPDs within the same material categories. The EC3 is based on a database of US and Canadian EPDs. EC3 relies on building material quantities from construction estimates and/or BIM models, as well as digital, third-party verified EPDs. As a primarily supply management tool, it can be used in the design and procurement phase of projects, allowing users to access material carbon emissions data to encourage the selection of low carbon materials [10].
- **Tally LCA App — Revit® Plug-In** [11] is a building information modelling (BIMM) software tool for architects, landscape architects, structural engineers, mechanical, electrical, and plumbing (MEP) engineers, designers, and contractors. Tally is able to calculate the environmental impacts of building materials. Project teams can use Tally

to conduct whole building LCAs or use LCA data to run comparative analyses of various design options and their environmental impacts [10].

- **One Click LCA** [12] is a costing software tool that relies on published EPDs, which some experts warn may be not well suited for whole building LCAs due to inconsistencies across product categories. It can be used in all stages of a project from early design to commissioning of a building. One Click LCA delivers WBLCA for LEED v4 and v4.1, and supports 40+ other rating systems and standards, while also integrating with Autodesk Revit, IES-VE, and other software and data formats [10].
- **Woodworks' Carbon Calculator for Wood Buildings** [13] focuses on the volume of structural wood in a building, then estimates how much carbon is stored in the wood, the GHG emissions avoided by not using steel or concrete, and the amount of time it takes North American forests to grow that volume of wood. Knowing the volume of wood products including lumber, panels, engineered wood, decking, siding, and roofing, the carbon calculator is able to provide a detailed estimate for that specific building. If volume information is unknown, users can select from a list of building types and receive an estimate based on the typical use of wood [10].

The software tool described below can be used to estimate embodied emissions in smaller, low-rise (Part 9) buildings, including single-detached homes.

- **Builders for Climate Action' Building Emissions Accounting for Materials (BEAM)** [14] is a calculator that enables designers and builders to estimate the GHG emissions from their building materials and to make choices that will reduce the emissions to zero. Building dimensions are input, and the output will be the carbon footprint of all the material options for the building.

3.2. Baseline and Benchmark Methods

The two key methods that could be used in developing an embodied emissions policy are discussed below:

- **The Baseline Method (project defined baseline):** Applications for new construction include building designs that show how embodied emissions are reduced from a unique baseline that is created by the applicant for the proposed project.
- **The Benchmark Method (predetermined limit or fixed cap):** Applications for new construction include building designs that show how embodied emissions are reduced from a predefined limit, or 'fixed cap' set by the District (e.g. no more than 300 $kgCO_2/m^2$ for a certain building type).

Either of the aforementioned methods could be used in a similar way as the BC Energy Step Code by defining a number of "steps" with different percentage reduction values relative to the baseline or the fixed cap. The required percentage reductions could be increased incrementally such that achieving higher steps entails reducing higher amounts of embodied emissions. The two methods are discussed further in this report, including examples of how they could be implemented in the District.

3.2.1. The Baseline Method

In the Baseline method, each application for new construction establishes its own baseline building. For example, the proposed design for a 5-storey residential building would have a 5-storey baseline building with identical features such as the same gross floor area, function, orientation, location, and energy performance. An embodied emissions reduction policy that employs the Baseline method should ensure that applicants are provided with clear guidance on how to create the baseline building. After a baseline building is created, the proposed building designs are compared against the baseline building to identify how embodied emissions can be reduced, for example, by selecting less carbon-intensive building materials instead of concrete. The final building design must have lower embodied emissions than that of the baseline building. Applications for new construction could also respond to percentage reductions defined by the District, for example, a 20% reduction in embodied emissions relative to the baseline building.

The Baseline method is used by several existing green building certifications including Leadership in Energy and Environmental Design (LEED), Green Star, and the International Living Future Initiative (ILFI). LEED is a point-based system that requires that the proposed design and the baseline building against which it is compared must share the same features (e.g. floor area, location, and energy performance). LEED strategies for creating a baseline in One Click LCA can be found under “LEED Baseline Strategies” in the references section of this report [15]. To encourage conducting a whole-building LCA and reducing building life-cycle impacts in new construction, LEED provides four optional paths which award 1-4 points depending on which path is achieved. For example, Path 1 grants 1 point for conducting an LCA of the project’s structure and enclosure (without requiring percentage reductions in embodied emissions), and Path 2 grants 2 points for a project that conducts an LCA of the project’s structure and enclosure that demonstrates a minimum of 5% reduction, compared with a baseline building in at least three of the six impact categories, one of which must be global warming potential [16].

The City of Vancouver is currently considering employing the Baseline method and this approach has been implemented through the LEED certification process [17]. Vancouver provides guidance for how applicants can create a baseline building and estimate embodied emissions, including figures and assumptions for a variety of different building materials (e.g. for walls, roofing, glazing) that could be considered for use by the District. Some advantages and disadvantages of the Baseline Method are summarized in Table 4 below:

Table 4: Summary of advantages and disadvantages of the baseline method for reducing embodied emissions in new construction

The Baseline Method	
Advantages	**Disadvantages**
• The most cost-effective method [18] • Higher potential to ensure the building baseline and proposed building design have equivalent assumptions (e.g. same floor area, location, energy performance) [15]. • The industry is already familiar with this method as it is supported by the LEED certification program.	• Comparison may not necessarily lead to the best option being built. This may become a formality in some projects [18]. • Defining a self-declared baseline can be subjective [19]. • Some possibility of 'gaming' the rules (which can be minimized by determining specific attributes for projects to apply to their baseline) [20].

There are a number of approaches that are often cited for using the Baseline Method [2,3]. Of these approaches, using "The Proposed Building Analysis" is seen as the most efficient baseline strategy for the majority of the projects [15]. The proposed building design is modelled, then variants of that are created with one of them being the baseline building. This approach ensures that the scenarios, including baseline and proposed, are as functionally equivalent as possible. The baseline would use materials and assemblies that are typically used locally for the same building archetype.

3.2.2. The Benchmark Method

In this approach, all buildings are grouped into several archetypes and each archetype is assigned an embodied emissions limit (in $kgCO_2e/m^2$). This limit (fixed cap) is based on the typical amount of emissions of a sample of similar building archetypes. For example, the embodied emissions cap defined for Part 3 wood residential buildings could be an average or 'benchmark' of emissions of several existing Part 3 residential buildings. In the Benchmark method, the final building design submitted to the District would have to have lower embodied emissions than the fixed cap defined for the benchmark building (e.g. < 234 $kgCO_2e/m^2$ for Part 3 wood residential buildings). Similar to the Baseline method, applications for new

construction could be required to achieve a certain percentage reduction from this emissions cap (e.g. 20% reduction). Table 5 shows an example of this approach.

Table 5. Example of Potential Percentage Reductions for Part 3 Residential Buildings Using the Benchmark Method

Fixed Cap for Part 3 Residential (e.g. 234 $kgCO_2e/m^2$)	
Steps	**Example percentage reductions relative to the benchmark building**
Step 1	0% reduction
Step 2	10% reduction
Step 3	20% reduction
Step 4	40% reduction

In the Benchmark method, the roadmap could include incrementally increasing embodied emissions percentage reductions relative to the fixed cap(s) through several ‘steps’, similar to the method and tables that were suggested for the Baseline Method. The carbon reduction potential of the Benchmark method depends on how ambitious the fixed caps are defined [18]. Fren Énergie Carbone and Dutch MPG are two certification programs in Europe that use the Benchmark method to reduce emissions. Table 6 summarizes some advantages and disadvantages of the Benchmark method.

Table 6: Summary of advantages and disadvantages of the benchmark method

The Benchmark Method	
Advantages	**Disadvantages**
● It is a simple approach. ● It can be more effective than the Baseline method in reducing embodied emissions depending on how the fixed caps for embodied emissions are defined [18].	● It is difficult to set a cap to a level where it is effective in carbon reduction and yet cost-effective [18]. ● There would be a limited number of building archetypes compared to the baseline method. Therefore, some buildings may not fit into the reference building archetypes. Also, building archetypes change over time. ● It is not well suited to infrastructure projects [18]. ● Data variability: There are a lot of things that influence benchmarks (e.g. different LCA software tools, different types of buildings, the existence of an underground parkade, etc.). Different LCA software tools use different underlying data and assumptions resulting in different absolute numbers [19]. ● The progressive update of the data in the future may make it necessary to change the fixed caps over time. ● The industry is not familiar with this method.

4. Canadian Best Practices

The Government of Canada has implemented the Pan-Canadian Framework on Clean Growth and Climate Change [21] with the goal of reducing the nation's greenhouse gas emissions by 30% below 2005 levels by 2030. These carbon reduction targets will be achieved in part through the Low-Carbon Assets Through Life Cycle Assessment (LCA^2) initiative. This initiative, a collaboration between the National Research Council and other federal government departments, academia, non-government organizations, industry partners, and low-carbon asset experts from across Canada, will create infrastructure-specific LCA guidelines/tools and related procurement specifications, low-carbon benchmarks and a Canadian LCI database. This will support low-carbon procurement of materials and designs while maintaining lowered costs. The focus will be mainly on buildings [21,10].

The Government of Canada's Greening Government Strategy: A Government of Canada Directive [22] intends to reduce the environmental impact of structural construction materials used in federal government operations by:

- Disclosing the amount of embodied carbon in the structural materials of major construction projects by 2022, based on material carbon intensity or a life-cycle analysis.
- Reducing the embodied carbon of the structural materials of major construction projects by 30%, starting in 2025, using recycled and lower-carbon materials, material efficiency, and performance-based design standards.
- Conducting whole building (or asset) life-cycle assessments by 2025 for major buildings and infrastructure projects.

Projects will also minimize the use of harmful materials in construction and renovation, including using low volatile organic compound (VOC) materials in building interiors [22].

City of Vancouver's Climate Emergency Action Plan (CEAP) [23], declared in 2019, comprises 6 Big Moves. Big Move 5 (Low Carbon Materials and Construction Practices) sets a goal of reducing the embodied emissions in new buildings and construction projects by 40%

by 2030 compared to a 2018 baseline, and a reduction in operational emissions from new buildings by 90% by 2025, with the target of being carbon neutral by 2050 [10,23].

The City has developed 7 principles that are used to inform and guide as to which actions to take and/or prioritize as well as how to implement them as all the actions should be consistent with these principles. The 7 principles are as follows [23]:

1. **Urgency**: Reducing the embodied emissions should be as quickly as possible.
2. **Neutrality of materials**: No material should be singled out as the only problem or the only solution. The right materials for the right applications should be used.
3. **Healthy materials and buildings**: shifting to safe, natural, non-toxic, simple and reusable materials, assemblies, and finishes should be promoted.
4. **Circularity**: Preventing/reducing the construction and demolition waste by reducing, reusing, and recycling building materials through a circular construction and demolition economy.
5. **Equity and responsibility**: The benefits of construction should be distributed equitably to those communities which are impacted by the construction in their land.
6. **Affordability**: The actions should not add costs to the residents and businesses who can barely afford it, or reduce our capability to construct the required housing and infrastructure.
7. **Shared knowledge and vision**: Work together and educate each other about embodied emissions and make a shared vision that addresses all parts of embodied emissions enabling us to work together to tackle the issue.

The City of Vancouver's strategy contains four actions, outlined below:

1. **Change the Rules (Policy and Regulations)**: Only low-carbon buildings are permitted to be constructed. This is applied to both private and public developments. Developers are required to conduct a WBLCA and show that their materials and construction practices have reduced the emissions. This action has four components:
    - Establish standardized 2018 baselines to measure reductions for developments and the city.

- Require rezoning reduction targets through updates to the Green Buildings Policy for Rezonings.
- Require Building By-law reduction targets and low-carbon code requirements, following the steps in the Green Buildings Policy for Rezonings: Update the Building By-law.
- Target deep reduction in embodied emissions for City-owned buildings and infrastructure, as part of the City's Green Operations Plan: Leading targets for City-owned buildings.

2. **Change the Market**: Remove barriers and provide incentives. here existing construction rules hamper the progress towards using low-carbon construction materials and practices, the barriers should be identified and removed. New incentives should be developed to arouse interest in developers to build with low-carbon materials. This action has two components:
    - Remove barriers in planning and building by-laws, policies, guidelines, and bulletins to low-carbon construction.
    - Incentivize deep embodied carbon reductions in building design and construction.
    - Expand the City's Zero Emissions Building Catalyst Policy which allows up to 5% increased floor area for multi-family projects to build to zero-emissions standards.
3. **Change the Culture**: Capacity Building and Industry Transformation. This action has two components:
    - Coordinate, support, advocate, and share knowledge with external organizations and other governments
    - Support databases, tools, practice guides, training, and knowledge-sharing networks
4. **Change the Context**: Complementary Strategies and Actions. This action has six components:
    - Plan for low-carbon neighbourhoods, Optimize parking requirements, Support zero emissions construction sites, Support zero waste and

deconstruction, Support seismic resilience, Support the green building economy.

Vancouver's timeline of the aforementioned actions is summarized in Table 7.

Table 7. Vancouver's timeline of actions to reduce embodied emissions [23]

YEAR	ACTION
2020	• Embodied Carbon Strategy approved by City Council.
2021	• City staff begin work to update policies and regulations, provide incentives, build industry capacity, and integrate embodied carbon efforts with other City strategies.
2021	• Introduce our first reduction target(s) in updated rezoning policy, to begin reducing embodied emissions in new construction.
2021/22	• Rezoning updates come into effect for new rezoning applications.
2022–2025	• City staff seek approvals of various actions to support transition to low embodied carbon construction and begin implementation of approved changes.
2023	• Possible first changes to the Building By-law to include embodied carbon come into effect, such as material-specific requirements or changes for single-detached homes.
2025	• Review and update of Embodied Carbon Strategy for Council. • Adopt the targets and other requirements from the 2021/22 rezoning policy, and possibly those from incentive programs, into the code. • Increase reduction targets in the rezoning policy to be consistent with the 40% reduction target set by Council.
2025/26	• Updated embodied carbon reduction requirements come into effect for new rezoning applications and building permit applications.
2026–2030	• City staff seek approvals of further actions to support transition to low embodied carbon construction, and begin implementation of approved changes
2030	• Adopt the targets and other requirements from the 2025/26 rezoning policy into the code, consistent with the 40% reduction target set by Council. • Introduce new targets in the rezoning policy that go beyond 40%, taking a step toward net zero carbon construction.

In order to estimate the City-wide embodied emissions and create a policy baseline, the City of Vancouver estimated the built floor area for different building categories. This included an

estimate of new buildings that are likely to be built by 2030 divided by 10 years to have an average amount of built floor area per year between 2021 to 2030 [20]. Also, Vancouver estimated the embodied emissions intensity for eight building types, as seen in Table 8 [20], based on benchmark data from Athena Sustainable Materials Institute and a benchmarking study from the University of Washington [24,25]. Vancouver's city-wide baseline was estimated to be 178,000 tons of embodied emissions per year. DNV's district-wide embodied emissions were estimated to be approximately 30,000 tonnes in 2019.

Table 8. Vancouver's estimated embodied emissions for different building archetypes [20]

	VBBL Requirements							
	Single Family	Residential < 7 storey wood	Residential 7-12 storey wood	Residential < 7 storey concrete	Residential ≥ 7 storey concrete	Office	Commercial	Industrial
BAU (kgCO2e/m2)	132	234	234	376	388	470	470	470
Reduction relative to BAU (2022-2025)	0%	0%	0%	0%	0%	0%	0%	0%
Reduction relative to BAU (2026-2029)	20%	20%	20%	20%	10%	10%	10%	10%
Reduction relative to BAU (2030+)	40%	40%	40%	40%	20%	20%	20%	20%

Figure 7 depicts Vancouver's city-wide embodied emissions reduction pathway over the next 10 years. The City of Vancouver has estimated the average city-wide annual emissions associated with embodied carbon between 2021-2050 to be approximately 178,000 tonnes CO_2e/m^2. The top of the yellow band represents a moderate regulatory pathway resulting in a reduction close to the target (40% reduction; the green line), and the yellow band represents the range of voluntary adoption of wood and mass timber construction and low carbon materials and incentives and transforming the way industry works [20]. Therefore, it is theoretically possible to exceed the 40% reduction target and potentially achieve a 50% reduction by 2030.

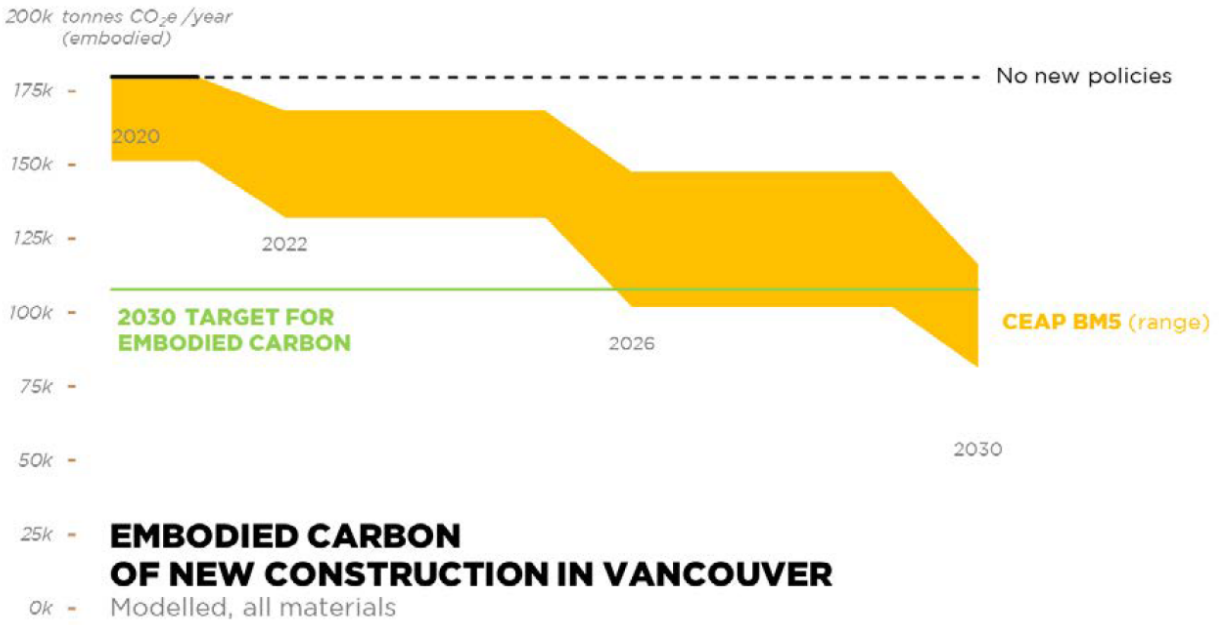

Figure 7. Modelled embodied carbon reductions under varying scenarios [8]

A similar pathway could be developed for DNV, with the top of the yellow band representing the rezoning policy, and the yellow band representing the range of voluntary adoption of wood and mass timber construction and low carbon materials and incentives and transforming the way industry works. The DNV's district-wide annual embodied emissions between 2011-2019 were estimated to be approximately 30,000 tonnes CO_2e/m^2 and it was assumed that this number would not change in the time period between 2021-2030. This number could be re-estimated as an embodied emissions program is implemented in order to evaluate the appropriateness of the targets and the employed method, and update/revise them if necessary.

The City of Vancouver has identified low carbon materials and construction practices as one of its six Big move targets [23]. In 2021/22, Vancouver is considering a rezoning policy update to require a percentage reduction in embodied emissions for new development applications [20]. Key components of Vancouver's current thinking are outlined below [17]:

- Employ the baseline method consistent with the LEED approach (This approach for new construction has been explained in Appendix D)
- Set percentage reduction requirements through rezoning policy update

- Create rules and guidelines for projects, material and resourcing requirements (e.g. low-carbon concrete) as well as minimizing “gaming”, for example, by providing specific figures and support for how applicants can establish a building baseline. An example of the material assumptions for a baseline building is shown in Table 9, based on current thinking from the City of Vancouver.

Table 9. Example material assumptions for establishing a baseline building (City of Vancouver's Draft) [26]

High-rise (7+ stories) residential and all other buildings	
Assembly	**Assumption**
Below-grade structure	Concrete
Columns & Beams	Concrete
Floors	35 MPa Concrete - Industry Average Benchmark Mix 10% SCM (CRMCA 2017) (*consider using GU or GUL, 0-14% FA/SC or 15-29% FA/SC)
Interior Walls	Elevator cores: concrete; Interior walls: steel-stud wall assemblies.
Exterior Walls	Window wall construction; Mineral wool batt insulation; Glass cladding
Roof	35 MPa Concrete, using CRMCA 2017 Industry-Wide EPD, mix (*consider using GU or GUL, 0-14% FA/SC or 15-29% FA/SC) Polyiso insulation; Modified bitumen roofing.
Glazing	Double-pane aluminum frame window wall; Same glazing ratio as proposed.

- Create incentives for Part 9 homes
- Encourage the use of the Builders for Climate Action carbon calculator to estimate embodied emissions
- Optimize parking requirements to reduce embodied emissions
- Establish leading targets for city-owned buildings that have low embodied emissions
- Consult with LCA experts and industry stakeholders
- Coordinate with emerging national standards, databases, and tools
- Iterate and compare with city-wide modelling.
- Starting in 2025/2026, Vancouver intends to start requiring reductions in embodied emissions from new building permit applications, not only applications received through rezoning. Table 6, shown previously, includes a summary of CoV's timeline of actions.

The regulatory authority of almost all local governments in B.C. is defined by provincial legislation including the *Community Charte*r and the *Local Government Act*. The exception is the City of Vancouver which is served by its own legislation, the *Vancouver Charter*. For this reason, the District is in a different regulatory context that must be considered.

The City of Vancouver's Green Building Policy for Rezonings [27] is a compliance path that requires reporting of embodied emissions, as calculated by a whole-building LCA. Projects applying for rezoning are required to either be designed to and apply for an emissions building standard or meet numerous low-emissions green building requirements, including being designed to and registering for LEED Gold. Applicants must submit embodied carbon calculations during multiple phases of the development for low emissions green buildings, including for the rezoning application, building permit, and occupancy permits [10,27].

The Township of Douro-Dummer, Ontario's Sustainable Development Guidelines 2020 [28] provides 50 first applications after March 1st, 2020 the opportunity to apply for a block grant for projects whose carbon emissions are below the fixed target. The planned program outline is to reward builders for meeting a fixed threshold with a grant of $10,000 per house that meets the requirements. As the grant application is not open yet, the final threshold values are not set. The construction will be measured in accordance with defined criteria and using the Building Emissions Accounting for Materials (BEAM) tool. The up-front carbon emissions of the buildings are divided by eligible floor area. The cap is anticipated to be 75 $kgCO_2e/m^2$. There are additional requirements for building operational performance as well [7]. Designers must use the Builders for Climate Action tool to calculate the embodied impact of building materials. The tool will require the applicant to enter the overall dimensions of the building and to choose from a list of potential materials for each assembly component. The applicant can adjust the material selections and refine choices until the program target is achieved. The applicant will provide verification documents to the program provider to ensure that material selections were used during construction. The program provider will then notify the municipality that all requirements for the rebate were met.

The City of Nelson's Nelson Next [29] is an action plan and roadmap aimed at reducing greenhouse gas (GHG) emissions and vulnerability to climate change impacts. The City

examined a sample of three homes in Nelson, constructed to high BC Energy Step Code targets between 2019 and 2021, to figure out how both low embodied carbon and high-efficiency materials could assist in reducing the total emissions of the building sector. Their preliminary findings suggested that limiting concrete use, choosing natural products (e.g. timber, wood fiberboard, etc), and avoiding foam products have the highest impact on reducing the upfront embodied emissions.

Quebec's Wood Charter [30] is an initiative that aims to ramp up the use of wood in construction to increase employment, reduce GHGs and enrich the province as a whole. For provincially funded projects, project managers must consider the possibility of wood before the project begins and complete a comparative analysis of GHG emissions for structural materials using the Gestimat tool [10,30]. The emissions data, derived from Quebec's life cycle inventory database, will be required at the funding application stage, not the building permit stage. Funding is dependent on the analysis being conducted and not on the project manager ultimately choosing lower carbon materials [10]. In 2019, the Quebec government released Gestimat. It calculates the GHG reductions resulting in the selection of wood in construction and the reductions related to concrete or steel structures. The Minister of Forests, Wildlife and Parks for Quebec mandated the Centre d'expertise sur la construction commerciale en bois (Cecobois) to develop the tool. Cecobois supports and advances the reliance on wood in multi-family and non-residential construction in Quebec by offering technical services and training to building industry professionals. Going forward, Quebec's intention is to support fellow Canadian provinces and territories who wish to adapt Gestimat for their use [10].

Best Practices for Policies in Europe and the U.S are found in Appendix A.

5. An example approach for the District of North Vancouver

The District could encourage construction that is low in embodied emissions through new policy, incentives, and supportive tools. A new rezoning policy could request embodied emissions reporting from applicants (e.g. Whole-Building Life Cycle Assessment) and encourage that applicants meet embodied emissions reduction targets. More broadly, the DNV could develop a potential timeline and roadmap for reducing embodied emissions from new construction.

The District could work with other municipalities and the Province towards developing a standard framework such as the BC Energy Step Code for encouraging lower embodied emissions for consistency among municipalities.

An example approach could include the following items:

1. Embodied Emissions Reporting
2. Embodied Emissions Reductions
3. Incentives and Training
4. Timeline
5. Roadmap

Explanations and examples for each of the above items are provided below.

1. **Embodied Emissions Reporting:** The District could explore incentivizing whole building LCA reports for new construction as part of the rezoning application process. This could be the first step (or Step 1 in the Embodied Emissions Policy) in addressing embodied emissions and provide a policy signal for the construction industry.

2. **Embodied Emissions Reductions**: The District could incentivize reductions in embodied emissions: for example, a 10-40% reduction relative to a baseline

building. A rezoning policy could be updated and could include embodied emissions requirements.

3. **Incentives and Training:** The District could develop incentives and supportive programs in consultation with building industry stakeholders to encourage low carbon new construction. The incentives could be tailored to different building types (Part 9 vs. Part 3) and be provided at different levels (e.g. initial incentives for achieving a lower embodied emissions reduction and better incentives for greater reductions). For Part 9 buildings, incentives could include reduced building permit fees, whereas for Part 3 buildings incentives could provide density bonuses or expedited timelines for development and building permits. Incentives would need to be coordinated and balanced with existing incentives for other social and environmental objectives (e.g. affordable housing), and with input from building industry stakeholders. Training and incentives could be promoted through online webinars and in-person meetings. Vancouver is creating an embodied emissions incentive program for Part 9 buildings in 2021, which could be useful to consider. Potential incentive types to consider are:
    a. **Density bonusing:** This incentive should be offered in a way that does not compete with similar incentives for other community amenities, such as affordable housing, or cycling infrastructure.
    b. **Rebates on permit fees:** Different rebates could be offered for different levels of embodied carbon reduction.
    c. **Recognition of embodied emissions leadership:** Rewarding projects that demonstrate leadership in achieving deep reductions in embodied emissions through, for example, an annual challenge and dedicated award.
    d. **Capacity building:** Dedicated training programs could be offered to local builders, designers, and developers with information on embodied emissions, incentives available, and strategies for achieving deep reductions.
    e. **Property tax rebates.** Annual property tax rebates for a number of years (e.g. 5 years) could be offered to property owners whose buildings meet the predefined embodied emissions criteria, or owners who decide to renovate or reuse,

instead of new construction.

f. **Expedited development and building permits.** Developments and building permits could be accelerated for those buildings that meet the predefined embodied emissions criteria.

4. **Timeline:** The District could develop a timeline with options for encouraging low carbon new construction through policies, guidance, and incentives (See example from Vancouver in Table 7). Incentives could be offered to stimulate the industry and in advance of future regulations. For example, incentives could provide an incremental building permit fee rebate, or an annual award could be provided for applicants that demonstrate leadership in reducing embodied emissions. A rezoning policy could start by requiring whole building LCA reports for new construction and incentivizing reduced embodied emissions at higher steps. The incentivized steps could gradually turn into mandatory steps in subsequent years.

5. **Roadmap:** Table 10 shows an example 'roadmap' with associated actions to reduce embodied emissions through rezoning for DNV.

Table 10. An Example Roadmap for the District

Stage	Action	Details
1	Analyze building stock to identify lower carbon construction materials.	• Conduct analysis of building stock to identify low embodied carbon materials available in BC as alternatives to the current high embodied emission materials. (E.g. hempcrete and straw bale insulation can replace XPS foam, and is available in BC) • Conduct a cost-benefit analysis to estimate the potential of reducing embodied emissions in District buildings. Engage with industry stakeholders for input.
2	Identify preferred incentives	• Identify preferred incentives that could be offered by the District. • Incorporate stakeholders' feedback on potential incentives

3	Determine the preferred method for managing embodied emissions	● The Baseline method is recommended (project-specific baseline) for consistency with the City of Vancouver approach and existing tools already familiar to the industry (e.g. LEED).
4	Establish embodied emission reduction targets	● Establish incremental percentage reduction targets. ● Require and/or incentivize embodied emissions reporting and reductions for rezoning and non-rezoning applications and work towards a consistent regulatory framework similar to the Energy Step Code (e.g. Step 1: Only reporting, Step 2: 10% reduction, Step 3, 20% reduction, etc.).
5	Offer preferred incentives	● Offer preferred incentives.
6	Identify a preferred embodied emissions reporting tool and provide guidance for industry	● Identify a preferred embodied emissions reporting tool (e.g. BEAM calculator for Part 9 and Athena Impact Estimator for Part 3) ● Consider the fees associated with using the tool and collect input from industry stakeholders. ● Develop guidelines for the selected tool to support the industry.
7	Create an overall policy to encourage low embodied emissions in new construction	● Integrate actions above into an overall policy, for example, a rezoning policy for Part 3 buildings, an incentive program for Part 9 buildings, and a policy for new municipal buildings and infrastructure. ● Coordinate with other municipalities (e.g. an Embodied Emissions Working Group) and the Step Code Council to explore and improve emerging tools and policies, and to work towards a coordinated, consistent framework such as the BC Energy Step Code.
8	Support local suppliers of low embodied carbon materials	● Explore non-financial means to support local suppliers of low embodied carbon products (e.g. identify barriers, provide information, etc.).
9	Engage with stakeholders and support educational and training programs	● Engage with stakeholders throughout various stages as needed, for example, through surveys and workshops to improve programming. Support educational programs on embodied emissions (whole building LCA) reporting, local low-carbon materials and suppliers in BC, and available incentives.

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7. Appendices

Appendix A - Best Practices for Policies in Europe and the U.S.

Netherlands' 2013 version of the Building Act required all new residential and office buildings with a surface of 100m^2 or above to account for their embodied impacts at the building permit application stage in the form of an LCA using the national assessment method and associated database. The method is based on EN 15804 and EN 15978 with national adaptations, including health impact accounting. The assessment method converts the 11 LCA environmental impact categories, such as Global warming, to a price expressed in EUR. For example, for the Global warming category, 1 kgCO_2e = 0.05 EUR. All impacts are transformed into a single monetary value, which is divided by the building gross floor area and assessment period length. The assessment period is 50 years for offices and 75 years for residential buildings. The regulation was revised in 2018 to set a mandatory environmental impact cap for buildings at 1.00 EUR per square meter and year. It is the first national regulation of this type in the world [18]. This regulation applies only to new construction. Applying the method to a project requires the use of software tools that have been previously verified and approved.

Austria consists of nine states, with each state setting their own requirements and incentive policies. There is no formal government-set methodology. However, IBO (Österreichisches Institut für Baubiologie und -ökologie) has published a performance-based methodology, named Ökoindex 3) which is a weighted score of global warming potential (carbon footprint), primary energy depletion, and acidification, expressed as an A to E rating [18]. The scale of performance has been fixed by IBO. Baubook, which is a limited company owned by a regional energy association and IBO, provides the calculation data applied for these analyses. There are demands to revise this methodology to be in line with EN 15804 as well as to make public the method which has been used to establish the performance scales. Austria has a governmental environmental rating system called Klimaaktiv, which applies the Ökoindex 3 as the methodology for the building materials environmental impact assessment. Materials assessment is a mandatory part of the certification. Residential buildings are eligible for an additional environment-related subsidy if they have good performance in this certification [18]. By 2018, this certification had been applied to over 500 buildings. Six of the nine Austrian states have applied Ökoindex 3 to their housing subsidy mechanisms alongside

energy-related performance and features. Since the regulations are defined and managed at the level of the individual states, they vary greatly. For example, in the state of Tirol the embodied impact performance improvement is translated into cash using a scoring scheme, whereas, in the state of Vorarlberg, performance improvements release a 35-year low-interest loan. The funding scheme in Vorarlberg is for constructing new houses for low-income households; and consists of a 35-year loan with a fixed 1.75% interest rate [18]. The loan has a fixed basic value, incremented by the number of children, and an additional bonus for low-income families. There is an income limit for eligibility, and the maximum area covered by the scheme is 110 m^2. Voralberg energy and environmental bonuses for housing subsidies include, for example:

- Wooden façade: 20 EUR / m^2
- Renewable insulation: 30 EUR / m^2
- The improvement compared to reference heating: up to 180 EUR / m^2
- Improvement of energy use carbon impacts: up to 180 EUR / m^2
- The improvement compared to ÖköIndex 3 reference: up to 150 EUR / m^2

As seen, this policy consists of both characteristic-based (type of material) and performance-based criteria [18].

France' Energy Transition Law (Transition Energétique pour la Croissance Verte, or TECV) encourages new construction to be low carbon and low energy. To meet the goals of the Paris Agreement, the French government collaborated with the building industry to launch an experiment to produce positive energy and lower carbon footprint in the built environment, which would inform future regulations. The program that is called "Energie Positive et Réduction Carbone" aims to generate positive energy from buildings and lower the carbon emissions of buildings throughout their life cycle, from design to demolition. "Energie Positive et Réduction Carbone" outlined three main components:[10,31]

1. **Experimentation:** 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. This will help the French government test the technical and financial feasibility of low carbon and energy-efficient building construction. The government offers various incentives to motivate builders and developers to meet energy and carbon-performance

benchmarks. For example, new buildings that opt into 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 [10].

2. **Consultation:** The success of the program relies heavily upon industry participation and buy-in. Builders, developers, contractors, energy companies, NGOs, and associations are given a year of consultation for achieving the below labels [10].

3. **Labeling:** Builders and developers can receive a national building label, “Energie Carbone (E+C-) which indicates various performance levels based on energy efficiency and low embodied carbon. They may also receive financial assistance to support LCA studies. The program relies on the national EPD database. Manufacturers wishing to make environmental marketing claims must submit an EPD to the database. As of February 2020, President Emanuel Macron announced that all new public buildings should use 50% timber or another bio-sourced material after 2022. According to Julien Denormandie, the French minister for cities and housing, this move was inspired by Paris’ mandate to use timber in structures eight stories or higher for the 2024 Olympic games to achieve lower carbon footprints. The Olympic Village will come to life through mid-rise developments including 2,400 units of housing, offices, shops, restaurants, and activity centers constructed with wood or other sustainable materials [10,32]. These moves follow President Macron’s 2019 proposal to achieve carbon neutrality for France by 2050, through initiatives such as urban farm development and planting trees near architectural landmarks [10,33].

Switzerland’s Minergie is the most widely used Swiss national green building rating system, with many versions of the standard. Minergie-Eco requires WBLCA for all new government buildings in several municipalities, including Zurich, with an embodied carbon performance target for some building types. The City of Zurich requires all new government buildings to obtain Minergie-Eco certification. Moreover, some private and public organizations have made it a requirement for new buildings [10]. 2000 Watt Society, created by the Swiss Federal Institute of Technology, is an environmental call-to-action that aims to reduce per-capita energy usage to 2,000 watts per day. It has been voluntarily adopted by over 100 cities, towns, and cantons across Switzerland and Germany, and recognizes embodied carbon as

being an important element to understanding personal energy consumption. The City of Zurich has incorporated this in their municipal code and set a 2050 target for life cycle embodied carbon in residential buildings [10,34,35].

The United Kingdom's Royal Institution of Chartered Surveyors (RICS) published guidance on embodied carbon to ensure consistency in carbon reporting, *Whole Life Carbon Assessment for the Built Environment Professional Statement* in 2017 [10,36]. It was built around a whole life carbon approach, suggesting that it is necessary to understand not only embodied and operational emissions independently, but also the interaction between them. It provides a recommended methodology for calculating embodied and operational emissions over a building's life cycle. It can be used for new and existing buildings, infrastructure, and structural elements. This methodology relies on LCAs to EPD data for embodied carbon in materials and systems, in accordance with BS EN 15978:2011, which outlines the principles of embodied and whole life carbon measurement in the built environment. The RICS guidance also recognizes the importance of the development of mass timber products and incorporates a methodology for assessing carbon sequestered in timber structures and other products, as well as the impact of emissions associated with the end of life [10,37]. The UK Green Building Council offers guidance to help professionals measure embodied carbon. In 2012, they established the Green Construction Board, a joint industry-government board focused on green construction. This board created The Low Carbon Routemap for the Built Environment, a tool accounting for both operational and embodied emissions that outlines policies and actions to advance the government's goal of reducing GHG emissions by 80% by 2050 [10,38].

The City of Portland, Oregon has introduced requirements for concrete in municipal procurement which require product-specific and third-party verified EPD for products from January 2020. Below are the requirements:

Beginning January 1, 2020, all Portland Cement Concrete submitted to the City of Portland Materials Testing Lab for inclusion on the City's (Pre)Approved Concrete Mix Design List will need to have a product-specific Type III Environmental Product Declaration (EPD) that is third party verified and within its 5-year period of validity. As well, all Portland Cement Concrete not on the City's (Pre)Approved Concrete Mix Design List that is proposed for use over 50 yd^3 on

a City-owned or solicited construction project will need to have a product-specific Type III EPD that is 3rd party verified and within its 5-year period of validity. By April 1, 2021, the City of Portland Procurement Services will publish the maximum acceptable Global Warming Potentials (GWPs) for Portland Cement Concrete submitted to the City of Portland Materials Testing Lab for inclusion on the City's (Pre)Approved Concrete Mix Design List and project-specific Portland Cement Concrete proposed for use over 50 yd^3 on a City-owned or solicited construction project. The City will use EPD data collected in 2020, City concrete usage data, stakeholder feedback, the National Ready Mixed Concrete Association (NRMCA) Member National and Regional Life Cycle Assessment Benchmark (Industry Average) Report, and related applicable data to determine the GWP maximum values. The City will also use this information to evaluate how to effectively specify Portland Cement Concrete performance criteria within the context of lower GWP mixes [39].

The City of Bend, Oregon has a Community Climate Action Plan [40] that includes an incentive program based on concrete EPD calculations to encourage developers to use low carbon concrete [41]. As written in the "Waste and Materials" section in Appendix F of this action plan, the city plans to use 30% low carbon material in 50% of municipal projects.

Marin County, California has implemented a Low Carbon Concrete Code [42] which provides a Cement limit and an Embodied Carbon limit pathway. For each specified compressive strength, a maximum amount of ordinary Portland cement and a maximum embodied carbon are defined, as seen in Table 12. Embodied carbon is shown by an Environmental Product Declaration in line with ISO 14025, and EN 15804 or ISO 21930 [42].

Table 12. Cement and Embodied Carbon Limit Pathways [42]

	Cement limits for use with any compliance method 19.07.050.2 through 19.07.050.5	**Embodied Carbon limits** for use with any compliance method 19.07.050.2 through 19.07.050.5
Minimum specified compressive strength f'_c, psi (1)	Maximum ordinary Portland cement content, lbs/yd^3 (2)	Maximum embodied carbon kg CO_2e/m^3, per EPD
up to 2500	362	260
3000	410	289
4000	456	313
5000	503	338
6000	531	356
7000	594	394
7001 and higher	657	433
up to 3000 light weight	512	578
4000 light weight	571	626
5000 light weight	629	675

Notes
(1) For concrete strengths between the stated values, use linear interpolation to determine cement and/or embodied carbon limits.
(2) Portland cement of any type per ASTM C150.

The State of California's Buy Clean California Act seeks to reduce its own emissions and emissions embodied in products that it imports [10,43]. This legislation mandates that state agencies consider embodied carbon of the full supply chain for new construction or infrastructure projects, in turn, rewarding manufacturers that produce materials with lower embodied carbon levels. The legislation requires the assessment of embodied carbon within material categories, driving improvement after the design phase when materials have already been chosen [10].

The Department of General Services (DGS) is required to establish and publish the maximum acceptable Global Warming Potential (GWP) limit for select construction materials. The Buy Clean California Act targets carbon emissions associated with the production of structural steel (hot-rolled sections, hollow structural sections, and plate), concrete reinforcing steel, flat glass, and mineral wool board insulation. These materials must have a GWP that does not exceed the limit set by DGS [44]. State agencies consider environmental impacts in planning and investment decision-making by using full LCAs to evaluate and compare infrastructure investments and alternatives. As well, companies bidding on projects with the state submit full LCAs of materials used in a project [10].

The New York State (A2591/S542) **and The New Jersey** (A5223) Low Embodied Carbon Concrete Leadership Acts (LECCLA) is new legislation that would require all state agencies and departments to factor climate impact in their selection criteria for concrete procurement. The more sustainable a concrete provider's bid is for a state-funded project, the more competitive and likely it will be to win the State's business. As the single largest purchasers of concrete in their respective states, New York and New Jersey's collective buying power could kick-start a market transformation across the region's economies, creating significant demand for low carbon concrete while broadening its availability in the private sector. LECCLA also includes an allowance promoting the use of products that not only reduce CO_2 emissions but store them in the concrete itself. Today these technologies collect those greenhouse gases from industrial emissions sources like cement plants, but in the future, they could use CO_2 drawn directly from the air, cancelling out earlier emissions, a way to carbon negativity [45].

The State of Washington published State Efficiency and Environmental Performance which outlines emissions reduction initiatives in 2018. It states that for a growing number of facilities, the cost of constructing zero energy or zero energy-capable buildings is now comparable to that of a conventional building, promising decades of reduced energy costs. Therefore, Directors shall ensure that all newly constructed, state-owned (including lease-purchase) buildings shall be designed to be zero energy or zero energy-capable, and include consideration of net-embodied carbon. In unique situations where a cost-effective zero-energy building is not yet technically feasible, buildings shall be designed to exceed the current state building code for energy efficiency to the greatest extent possible [46].

The City of Los Angeles's Green New Deal - Sustainable City Plan requires all new municipally-owned buildings and major renovations to be all-electric, beginning in 2021 [47]. It also requires the implementation of GHG performance standards for material procurement for purchasing by City Departments, updating the City's Environmentally Preferred Products Purchasing Program to include additional construction materials and a GHG performance standard, such as the Buy Clean California Act, and further identification of embedded carbon emissions in the City's supply chain through Departmental participation in the Carbon Disclosure Project supply chain reporting program. Moreover, The Central City Association of Los Angeles (CCA) published a white paper in 2019 with the title of "Mass Timber, a Faster,

More Affordable, and More Sustainable Way to Build Housing" in which it recommends specific actions that the State of California, city government, and local developers and architects can take to catalyze the mass timber construction market and begin delivering jobs and mass timber housing. Among its recommendations, the following two may be used by the District:

- Project approval streamlining: At the local level, cities should adopt processes for mass timber projects that minimize delay and uncertainty from application to project approval. Many cities already have streamlined or expedited approvals for affordable developments, and similar processes should be extended to mass timber developments.
- Development incentives: State and local governments should explore development incentives such as density, floor-area ratio (FAR), and height bonuses for projects that utilize mass timber. Government officials should collaborate with stakeholders in the development community to determine the appropriate level of incentives needed to tilt the scales in favour of mass timber projects.

Minnesota's Buildings, Benchmarks and Beyond (B3) guidelines, enforce requirements for reducing the embodied environmental impact and toxicity in building materials in new buildings under The Materials Waste Section. It comprises four guidelines: M.1 Life Cycle Assessment of Materials, M.2 Environmentally Preferable Materials, M.3 Waste Reduction and Management, and M.4 Health. New buildings projects must demonstrate a reduction in GWP through three proposed compliance pathways and submit a WBLCA using either Tally, Athena Impact Estimator, or One Click LCA [48].

Appendix B - Carbon Neutral Cities Alliance Embodied Carbon Reduction Policy Summary

Redefine the solution

- Using a “school as a service” concept to make use of underused spaces and deliver education without requiring new buildings to be built.
- Identifying an alternative means to deliver a need (e.g. if a leisure time facility is underused, the problem may relate to public transport access as opposed to needing to rebuild or renovate the building).
- Developing alternative low carbon systems – e.g. natural or low-impact development for stormwater management, not concrete stormwater routes.
- Deliver summer shading with foliage from trees instead of structures or systems.

Refurbish existing assets

- Selling rights to convert a building to a different, more sought-after use.
- Extending existing buildings with modular, later moveable spaces.
- Renovations to increase usage efficiency in capacity, occupancy, or both.

Reduce and replace materials and structures

- Reducing materials demand by zoning only materials-efficient building shapes.
- Reducing materials demand by requiring the use of lighter or more efficient structures.
- Replacing materials with zoning provisions requiring the use of low-impact materials.

Reuse products and materials

- Reducing materials destruction by requiring design for disassembly.
- Requiring salvaging specified materials from deconstructed buildings for reuse.
- Requiring cutting off brick & mortar facades as blocks and using them in new buildings.

Require low carbon products

- Specifying that all buildings must only use low carbon concrete or biogenic material.
- Specifying the highest allowed emissions limits for selected materials using EPDs.

- Specifying low carbon products while limiting and/or substituting the use of high carbon materials for the lower-impact ones.

Appendix C - Tables from the Carbon Neutral Cities Alliance Embodied Carbon Policy Framework [7]

ZONING AND LAND USE POLICIES

POLICY CODE	POLICY NAME	CARBON IMPACT	COST-EFFICIENCY	IMPLEMEN-TABILITY	ENFORCE-ABILITY	SUM OF SCORES	EXAMPLES PROVIDED
Z1	EMBODIED CARBON TARGETS FOR ZONING PROCESS	●●●●●	●●●●○	●●●○○	●●●●○	16	-
Z2	SET ZONING REQUIREMENTS FOR BIO-BASED MATERIALS	●●●●○	●●●○○	●●●●○	●●●●○	15	Helsinki
Z3	CARBON-SCORED LAND SALES COMPETITIONS	●●●●○	●●●○○	●●●○○	●●●●○	14	Porvoo, Tampere
Z4	PARKING REQUIREMENT OPTIMIZATION	●●●○○	●●●●●	●●●●○	●●●●●	17	London, Portland, Helsinki
Z5	APARTMENT SIZE AND SPACE EFFICIENCY GUIDELINES	●●●○○	●●●●●	●●●●○	●●●●●	17	NYC
Z6	PREFABRICATED OR MODULAR CONSTRUCTION PRIORITY	●●●○○	●●●●○	●●●○○	●●●●○	14	-
Z7	INCREASING DENSITY USING EXISTING INFRASTRUCTURE	●●○○○	●●●●○	●●●●○	●●●●○	14	-
Z8	USE LOW CARBON BUILDING TYPOLOGIES IN ZONING	●●○○○	●●●○○	●●●●○	●●●●●	14	-

BUILDING REGULATION AND SUPERVISION

POLICY CODE	POLICY NAME	CARBON IMPACT	COST-EFFICIENCY	IMPLEMEN-TABILITY	ENFORCE-ABILITY	SUM OF SCORES	EXAMPLES PROVIDED
R1	LIFE-CYCLE CARBON LIMITS FOR NEW BUILDINGS	●●●●●	●●●○○	●●●○○	●●●○○	14	Vincent, Douro-Dummer, London
R2	LOW CARBON CEMENT AND CONCRETE POLICY	●●●●●	●●●○○	●●○○○	●●●○○	13	Singapore, Masdar City, Portland, Dubai
R3	MATERIAL-EFFICIENT STRUCTURAL DESIGN REQUIREMENT	●●●●○	●●●●●	●●●○○	●●●○○	15	Singapore, San Francisco, Los Angeles, Seattle
R4	DENSITY BONUS FOR CARBON EFFICIENCY	●●●○○	●●●●●	●●●●○	●●●●○	16	Seattle, Washington, other US cities, Singapore
R5	ZERO CARBON CONSTRUCTION SITES	●●○○○	●●○○○	●●●●○	●●●●○	12	Trondheim, Oslo, Malmö, Göteborg, Stockholm
R6	CONSTRUCTION MATERIALS EFFICIENCY DECLARATION	●○○○○	●●●●○	●●●●○	●●●●○	13	-
R7	EXPEDITED PERMITTING FOR LOW CARBON PROJECTS	●○○○○	●●●○○	●●●●○	●●●●●	13	San Diego, Seattle
R8	PROHIBITING EXTREMELY HIGH EMITTING MATERIALS	●○○○○	●●●○○	●●●○○	●●○○○	9	North Bend, Washington, Tuttle
R9	LIFE-CYCLE CARBON CALCULATION AND REPORTING	●○○○○	●●●○○	●●●●○	●●●●○	12	London

PROCUREMENT

POLICY CODE	POLICY NAME	CARBON IMPACT	COST-EFFICIENCY	IMPLEMEN-TABILITY	ENFORCE-ABILITY	SUM OF SCORES	EXAMPLES PROVIDED
P1	CARBON LIMITS FOR BUILDING MATERIALS PROCUREMENT	●●●○○	●●●○○	●●●●○	●●●●○	14	Trondheim
P2	GREEN PUBLIC PROCUREMENT FOR CITY BUILDINGS	●●○○○	●●●○○	●●●○○	●●●●○	12	Trondheim
P3	REQUIREMENT OF RECYCLED AGGREGATES	●○○○○	●●●●○	●●●●○	●●●●○	13	Copenhagen
P4	LOW-CARBON ASPHALT PROCUREMENT	●○○○○	●●●○○	●●●●○	●●●○○	11	-
P5	REQUIRE USE OF CERTIFIED WOOD PRODUCTS	●○○○○	●●●○○	●●●○○	●●●○○	10	-
P6	CIRCULAR MATERIALS PURCHASING STRATEGY	●○○○○	●●○○○	●●●○○	●●●○○	9	Rotterdam

WASTE AND CIRCULARITY

POLICY CODE	POLICY NAME	CARBON IMPACT	COST-EFFICIENCY	IMPLEMEN-TABILITY	ENFORCE-ABILITY	SUM OF SCORES	EXAMPLES PROVIDED
W1	DESIGN FOR DISASSEMBLY AND ADAPTABILITY CRITERIA	●●●○○	●●●●●	●●●○○	●●●○○	14	-
W2	MANDATORY PRE-DEMOLITION AUDITS AND DATA SHARING	●●○○○	●●●●●	●●●○○	●●●●○	14	-
W3	MANDATORY MATERIAL TAKEBACK PROGRAM	●○○○○	●●●●●	●●●●○	●●●●○	14	-
W4	SOIL COORDINATION FOR MASS STORAGE AND REUSE	●○○○○	●●●●●	●●●●○	●●●●○	14	Helsinki, Espoo
W5	INFORMATION ON ADAPTABILITY AND WASTE REDUCTION	●○○○○	●●●●○	●●●●●	●●●●●	15	-
W6	MATERIALS LONGEVITY POLICY	●○○○○	●●●●○	●●●○○	●●●●○	12	-
W7	ESTABLISH OR SUPPORT MATERIALS REUSE FACILITIES	●○○○○	●●●○○	●●●●●	●●●●●	14	Seattle, Washington
W8	CARBON REDUCTION OR SALVAGING REQUIREMENT FOR DEMOLITIONS	●○○○○	●●●○○	●●●○○	●●●○○	10	Vancouver, Portland, London (Camden)
W9	MANDATORY CONSTRUCTION AND DEMOLITION WASTE LANDFILL DIVERSION	●○○○○	●●●○○	●●●○○	●●○○○	9	San Francisco, Trondheim

INFRASTRUCTURE

POLICY CODE	POLICY NAME	CARBON IMPACT	COST-EFFICIENCY	IMPLEMEN-TABILITY	ENFORCE-ABILITY	SUM OF SCORES	EXAMPLES PROVIDED
I1	EARLY DESIGN CARBON TARGETS FOR INFRASTRUCTURE	●●●○○	●●●●○	●●●○○	●●●●○	14	Stockholm
I2	WOOD FOR LIGHT BRIDGES AND SMALLER STRUCTURES	●●○○○	●●●○○	●●●●○	●●●●●	14	-
I3	USE VEGETATION FOR WATER MANAGEMENT	●○○○○	●●●●○	●●●●○	●●●●○	13	Helsinki
I4	PARK MANAGEMENT FOR CARBON SEQUESTRATION	●○○○○	●●●○○	●●●●○	●●●●●	13	-
I5	PLANT TREES IN CITY SPACES AND UNBUILDABLE AREAS	●○○○○	●●○○○	●●●●○	●●●●●	12	-

MUNICIPAL BUILDINGS

POLICY CODE	POLICY NAME	CARBON IMPACT	COST-EFFICIENCY	IMPLEMEN-TABILITY	ENFORCE-ABILITY	SUM OF SCORES	EXAMPLES PROVIDED
M1	SPACE USE AND OCCUPANCY EFFICIENCY	●●○○○	●●●●●	●●●●○	●●●●○	15	-
M2	EMBODIED CARBON LIMITS FOR NEW & LEASED BUILDINGS	●●○○○	●●●○○	●●●●○	●●●●○	13	Trondheim, Tampere
M3	USE CARBON AS A CRITERION FOR DESIGN COMPETITIONS	●●○○○	●●●○○	●●●○○	●●●●○	12	Helsinki
M4	LOW CARBON SITES, SOIL STABILIZATION AND FOUNDATIONS	●○○○○	●●●●○	●●●○○	●●●●○	12	Helsinki
M5	PUBLICIZE BEST PRACTISES AND CASE STUDY PROJECTS	●○○○○	●●●○○	●●●●●	●●●●●	14	Oakland
M6	RENOVATION VS. KNOCK DOWN AND REBUILD COMPARISON	●○○○○	●●●○○	●●●●○	●●●●○	12	Lahti
M7	SALVAGED, REUSED OR RECYCLED MATERIAL MINIMUMS	●○○○○	●●●○○	●●●●○	●●●○○	11	-

FINANCIAL POLICIES

POLICY CODE	POLICY NAME	CARBON IMPACT	COST-EFFICIENCY	IMPLEMEN-TABILITY	ENFORCE-ABILITY	SUM OF SCORES	EXAMPLES PROVIDED
F1	TAX REBATES FOR LOW CARBON DEVELOPMENTS	●●○○○	●●●●●	●●●●○	●●●●○	15	Milford
F2	INCREASED PROPERTY TAX FOR UNOCCUPIED PROPERTIES	●●○○○	●●●●●	●●●○○	●●●●○	14	Vancouver
F3	LINK LAND USE FEES TO PROJECT LIFE-CYCLE CARBON	●●○○○	●●●●●	●●○○○	●●●○○	12	-
F4	CARBON PERFORMANCE GRANTS FOR PROJECTS	●●○○○	●●○○○	●●●●●	●●●●○	13	Douro-Dummer, Voralberg
F5	INCLUDE EMBODIED CARBON IN CLIMATE ACTION PLAN	●○○○○	●●●○○	●●●●●	●●●●●	14	San Francisco, Boston
F6	INCREASE DEMOLITION PERMITTING FEES	●○○○○	●●●○○	●●●●○	●●●●○	12	-
F7	INCENTIVES FOR MANUFACTURERS TO REDUCE CARBON	●○○○○	●●●○○	●●●●○	●●●●○	12	-
F8	LANDFILL TAX ON CONSTRUCTION AND DEMOLITION WASTE	●○○○○	●●●○○	●●●●○	●●●○○	11	-

IMPACT	CONDITIONS FOR THIS CARBON IMPACT RATING AND INDICATIVE IMPACT RANGE
●○○○○	This policy's direct impacts are below 1 % of city's overall embodied carbon. At the same time, the policy can be an important enabler for other policies. *Example policy: Green Lane for Permitting Low Carbon Projects. This must offer a credible time saving in the permitting process and be easy enough to implement to be attractive. It is not considered able to mobilize a significant number of projects.*
●●○○○	This policy's impacts are estimated between 1-2,5% of embodied carbon.
●●●○○	This policy's impacts are estimated between 2,5-5% of embodied carbon.
●●●●○	This policy could reduce overall embodied carbon by at least 5%. Example: affects one-third of city's overall embodied carbon and cuts 20%; or affects one-half and cuts 10%.
●●●●●	This policy could reduce overall embodied carbon by at least 10%. Example: affects half and cuts 20%; or affects one quarter and cuts 50%. *Example policy: Embodied carbon intensity targets for zoning. This will basically be able to enforce carbon limits for all newly zoned areas (but will not have an impact on areas with existing zoning)*

EFFICIENCY	CONDITIONS FOR THIS COST EFFICIENCY RATING
●○○○○	This policy has considerable direct additional costs of implementation.
●●○○○	This policy has direct additional costs of implementation. *Example policy: Plant trees in city spaces and poorly constructible areas. This action needs to be funded out of the budget and creates no direct savings for anyone (but may have longer-term gains).*
●●●○○	This policy can be considered cost-efficient. Depending on specific circumstances, the market could end up in cost parity with and without this policy. All carbon tax/fee and competition-based policies are in this category as those allow market players to optimize costs.
●●●●○	This policy may save costs or is highly cost-efficient.
●●●●●	This policy can save costs significantly. It may still require enforcement to happen as cost savings may not be captured by the party making choices. *Example policy: Density bonus for carbon efficiency. This policy allows developers to create more space at a lower cost, and is very lucrative. The city may lose on fee income, however.*

EASE	CONDITIONS FOR THIS EASE OF IMPLEMENTATION RATING
●○○○○	Very difficult. This policy requires significant new investments or development of new skills, practises or standards beyond those generally available today.
●●○○○	Difficult. This requires a change of well-established business practises in a way that can be expected to create noticeable resistance for the new policy. *Example policy: Low carbon cement and concrete policy. These policies (depending on implementation) can change several business practises. Such policies would create resistance to change.*
●●●○○	Average. This is expected to require effort and determination to implement. All policies where the municipality is the actor are at least at this level.
●●●●○	Easy. This policy is expected to be easy to implement, but may require time for legislative adoption. *Example policy: Parking requirement optimization. As a general rule, most cities have required building a specific number of parking spaces. This has created additional costs for developers and clients. Reducing these is easy.*
●●●●●	Very easy. This policy can be expected to be very easy to implement and be of interest to market players, and can be adopted immediately. All information policies are in this category.

ENFORC.	CONDITIONS FOR THIS ENFORCEABILITY RATING
●○○○○	Compliance is difficult to achieve and very hard to verify and/or monitor. It could be monitored via whistle-blowers for example.
●●○○○	Compliance with this policy is difficult to achieve and hard to verify and/or monitor. It could be monitored through testing or reviews. *Example policy: Prohibit extremely high emitting materials. Blowing agents are only feasible to monitor through materials tests, except on site blowing.*
●●●○○	Compliance with this policy can be achieved, verified and monitored through paper trail. Spot checks on site would reveal any deviations.
●●●●○	This policy is easy to achieve and enforce, and compliance is easy to verify. The policy can use market-based monitoring or third-party verifications. All policies where the municipality is the key actor are at least at this level. *Example policy: Increased property tax for unoccupied properties. This policy is feasible to enforce as part of standard tax declaration and collection.*
●●●●●	Implementing this policy does not require any enforcement. All information policies are in this category.

Appendix D - LEED approach for New Construction

Below is the LEED approach that uses the Baseline Method [49]:

For new construction (buildings or portions of buildings), conduct a cradle-to-grave life-cycle assessment of the project's structure and enclosure and select one or more of the following paths below to earn up to 4 points:

- Path 1: Conduct a life cycle assessment of the project's structure and enclosure (1 point).
- Path 2: Conduct a life cycle assessment of the project's structure and enclosure that demonstrates a minimum of 5% reduction, compared with a baseline building in at least three of the six impact categories listed below, one of which must be global warming potential (2 points).
- Path 3: Conduct a life cycle assessment of the project's structure and enclosure that demonstrates a minimum of 10% reduction, compared with a baseline building, in at least three of the six impact categories listed below, one of which must be global warming potential (3 points).
- Path 4: Meet requirements of Path 3 and incorporate reuse and/or salvage materials into the project's structure and enclosure for the proposed design. Demonstrate reductions compared with a baseline building of at least 20% reduction for global warming potential and demonstrate at least 10% reduction in two additional impact categories listed below (4 points).

For Paths 2, 3 and 4 listed above, no impact category assessed as part of the life-cycle assessment may increase by more than 5% compared with the baseline building. Include a narrative of how the life cycle assessment was conducted and if applicable for paths 2, 3 and 4 what changes were made to proposed buildings to achieve the related impact reductions.

The baseline and proposed buildings must be of comparable size, function, orientation, and operating energy performance as defined in EA Prerequisite Minimum Energy Performance. The service life of the baseline and proposed buildings must be the same and at least 60 years to fully account for maintenance and replacement. Baseline assumptions must be based on the standard design and material selection for the project location and building type. Use the same life-cycle assessment software tools and data sets to evaluate both the baseline building and the proposed building, and report all listed impact categories. Data sets must be compliant with ISO 14044.

Select at least three of the following impact categories for reduction:

- global warming potential (greenhouse gases), in kg CO_2e;
- depletion of the stratospheric ozone layer, in kg CFC-11e;
- acidification of land and water sources, in moles H+ or kg SO_2e;

- eutrophication, in kg nitrogen eq or kg phosphate eq;
- formation of tropospheric ozone, in kg NOx, kg O3 eq, or kg ethene; and
- depletion of nonrenewable energy resources, in MJ using CML / depletion of fossil fuels in TRACI.