DECARBONIZING METROPOLISES: ANALYZING NEW YORK'S LL97 AND BOSTON'S BERDO NET ZERO POLICIES

by

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Submitted to the Center of Real Estate and Department of Urban Studies and Planning in partial fulfillment of the requirements for the degree of

Master of Science in Real Estate Development
and Master of City Planning

at the

Massachusetts Institute of Technology

June 2023

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ABSTRACT

Carbon neutrality and net zero have emerged as critical goals in global climate governance, seeking to address human activities' environmental and social implications on Earth. This thesis explores the decarbonization of urban environments by critically analyzing New York's Local Law 97 (LL97) and Boston's Building Energy Reporting and Disclosure Ordinance (BERDO) through system thinking. The study evaluates the impact of these pioneering policies and renewable grid integration on office spaces.

The narrative unfolds by analyzing the challenges faced by pre-1985 office buildings in Manhattan. It employs system thinking to decipher developers' decision-making processes when choosing between renovation and demolition to pursue more sustainable buildings. The study further explores the potential of repurposing aging office spaces into residential units, considering the complex dynamics involved and utilizing Net Present Carbon to calculate the time value of carbon.

Shifting focus to Boston's BERDO, the research investigates developers' experiences using system thinking. The analysis illustrates BERDO's impact on older buildings at the neighborhood level, revealing the unintended consequences of a one-size-fits-all policy approach.

Examining the policies on a larger picture, the study examines federal and state-level policies across the United States, investigating their potential to bolster decarbonization efforts in New York and Boston. It unravels the economics of sustainable construction, contemplating ripple effects on housing prices and exploring pioneering practices of developers embracing circular building materials.

This thesis synthesizes the effectiveness of LL97 and BERDO policies in driving urban decarbonization while acknowledging their good intentions and the pressures they exert on big players. In doing so, it also highlights areas for refinement to address unintended consequences and better cater to diverse segments of the built environment. Through these means, the study contributes to understanding net zero policies as catalysts for a greener, more sustainable urban built environment.

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ACKNOWLEDGEMENTS

I sincerely thank my thesis advisors, Juan and Siqi, for their invaluable guidance, support, and mentorship throughout this research journey. In particular, I want to express my profound appreciation to Juan, whose insightful advice and steadfast encouragement have been instrumental in shaping this work.

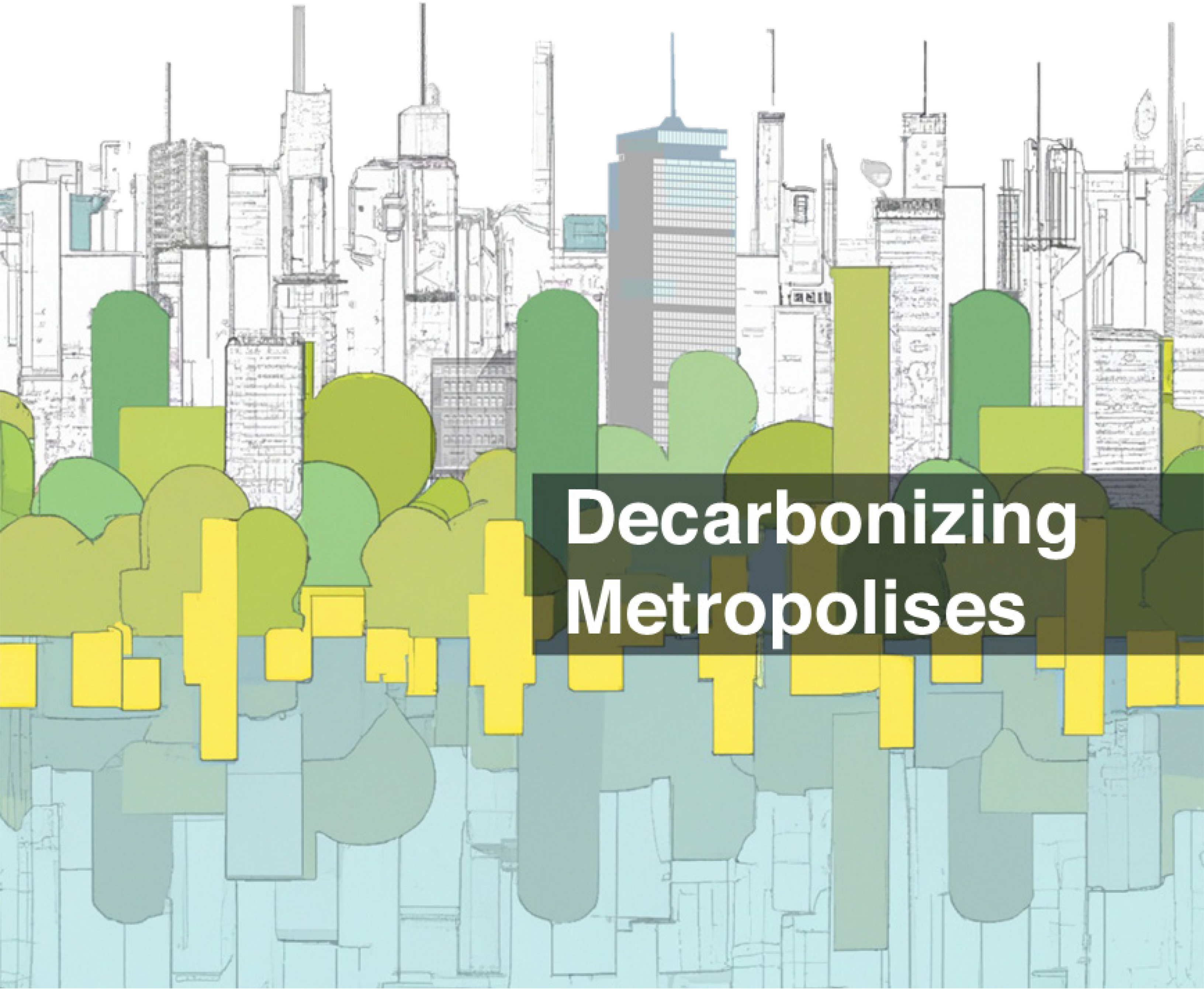
I am also immensely grateful to my friend Will and Professor Saiz for encouraging me to explore the time value of carbon. Their thought-provoking discussions have significantly enriched my understanding and perspective.

Alberto, we've sailed together through the MCP and MSRED journey. Your camaraderie was like the wind beneath my academic wings. To all my classmates, your shared experiences, diverse perspectives, and friendship have been an immense source of learning and inspiration. I'm grateful for the vibrant and supportive community we have built together.

I want to thank the entire CRE faculty and staff for their constant support and for fostering an environment conducive to learning and growth. Their commitment to nurturing curious minds has been a source of continual motivation.

Last but not least, a simple and earnest thanks to my roommate,Rohit. The late-night brainstorming sessions were the same with your steadfast companionship.

To everyone who's been part of this journey: thank you for all the footnotes you've added to the thesis of my academic life. You're all integral to this work; I am eternally grateful.



Decarbonizing Metropolises

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1. Introduction

Climate change has emerged as one of the most pressing challenges of our time, with far-reaching consequences for ecosystems, economies, and societies worldwide. As global temperatures continue to rise, the frequency and severity of extreme weather events increase, leading to devastating impacts on agriculture, infrastructure, and human health. Global GHG emissions in 2030, implied by nationally determined contributions (NDCs) announced by October 2021, make it likely that warming will exceed 1.5°C during the 21st century and make it harder to limit warming below 2°C by 2050 (IPCC, 2023). The urgency of addressing climate change is captured eloquently by the former United Nations Secretary-General Ban Ki-moon, who stated, “We are the first generation to be able to end poverty, and the last generation that can take steps to avoid the worst impacts of climate change” (United Nations, 2015).

The built environment, including residential and commercial buildings, contributes significantly to greenhouse gas emissions, accounting for nearly 40% of global CO_2 emissions (IEA, 2022). Developing and implementing effective policies and strategies to decarbonize this sector is imperative. New York and Boston have taken significant steps in this direction, implementing pioneering net-zero policies such as New York’s Local Law 97 (LL97) and Boston’s Building Energy Reporting and Disclosure Ordinance (BERDO).

This thesis critically evaluates the effectiveness of LL97 and BERDO policies in fostering urban decarbonization by analyzing their impacts on building emissions and the strategic responses of real estate investors and owners to meet emissions targets. Employing system thinking, the research delves into real estate decision-making processes, the decarbonization strategies of respective state electric grids, the implications on embodied carbon in buildings, and the larger US decarbonization landscape. By assessing the achievements and limitations of LL97 and BERDO, this study contributes to a more comprehensive understanding of net-zero policies' potential in driving sustainable development and combating climate change within urban environments.

1.1. **Setting the Stage:** A Global Imperative

Environmental sustainability has emerged as a critical global issue, demanding urgent action and cooperation from governments, businesses, and individuals. The consequences of neglecting sustainable practices are dire, with the potential to cause irreversible damage to the environment, economy, and society (Steffen, et al., 2015).

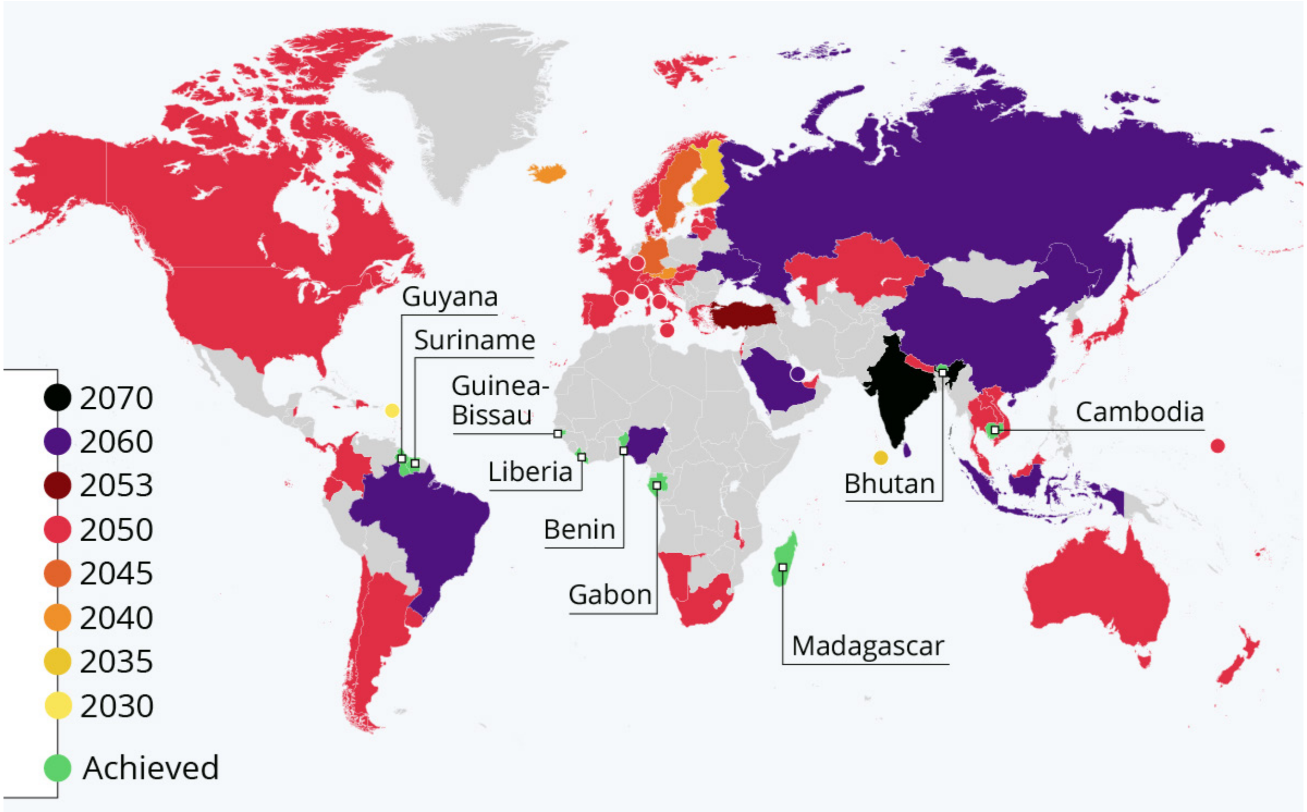
According to research by Hsiang and Kopp (2018), a 1 gigaton (1 billion metric ton) increase in CO_2 emissions in a year would result in a 0.0015°C increase in global mean surface temperature. This seemingly slight temperature increase can profoundly affect the Earth’s climate system, leading to more frequent and severe weather events, loss of biodiversity, and disruption of ecosystems.

The 2022 Buildings report by UN Environment Programme found that despite a substantial increase in investment and success at a global level in lowering the energy intensity of buildings, the buildings and construction sector is not on track to achieve decarbonization by 2050 and the gap between the actual climate performance of the sector and the decarbonization pathway is widening. CO_2 emissions from buildings operations alone have reached an all-time high of around 10 Gigaton CO_2 (United Nations Environment Programme, 2022).

Response to Counter Emissions

In response to the urgent need to reduce emissions, countries worldwide have committed to climate action under the Paris Agreement, with the goal of limiting global warming to well below 2°C. The United Nations' Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action), further emphasize the need for sustainable urban development and climate change mitigation. Various countries have established policies, regulations, and incentives to promote energy-efficient buildings, green certifications, and low-carbon construction materials. This has led to a surge in innovative building technologies, circular economy principles, and an increased focus on lifecycle assessments (United Nations Environment Programme, 2022).

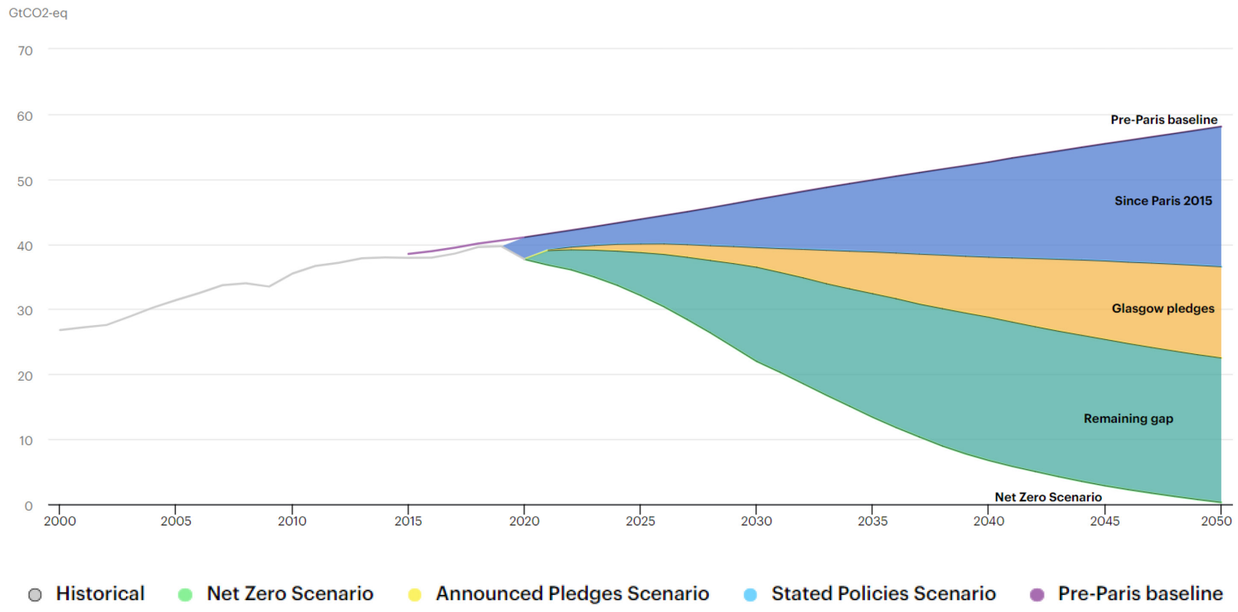
Figure 1 Net Zero targets



Source: Zandt, 2021

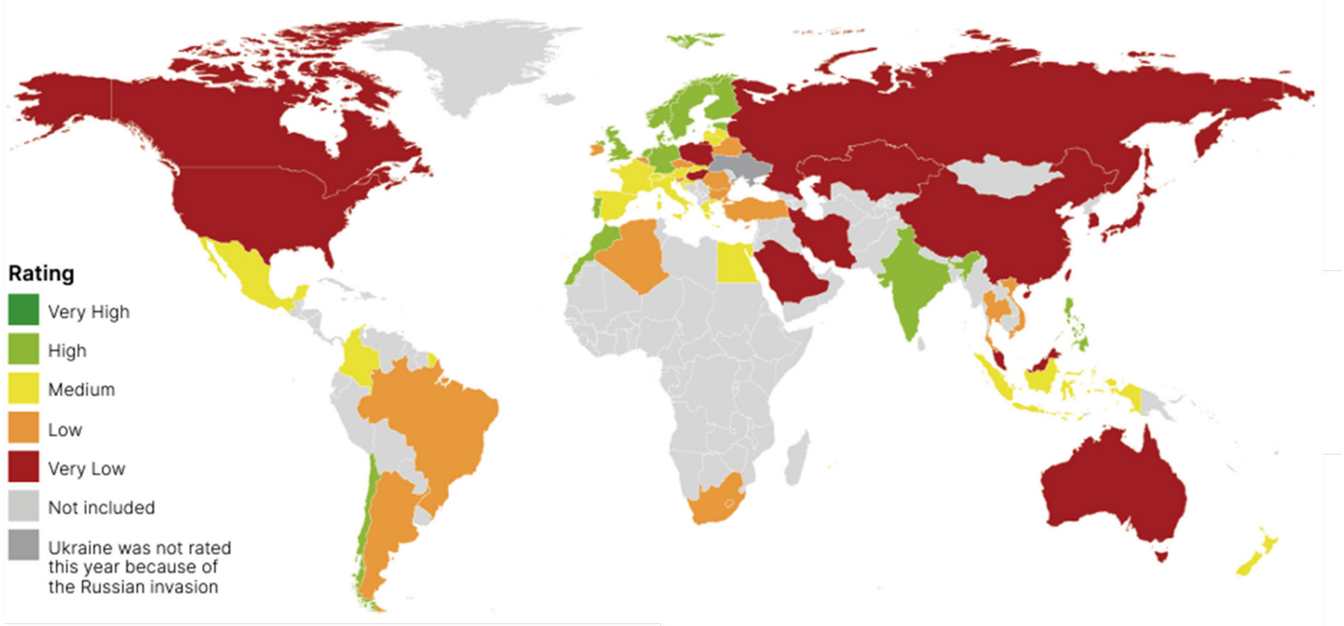
The Announced Pledges Scenario (APS) sees a doubling of clean energy investment and financing over the next decade. Still, this acceleration is not sufficient to overcome the inertia of today's energy system. Over the crucial period to 2030, the actions in this scenario fall well short of the emissions reductions required to keep the door open to a Net Zero Emissions by 2050 (NZE) trajectory. One of the critical reasons for this shortfall is that today's climate commitments, as reflected in Figure 2, reveal sharp divergences between countries in the pledged speeds of their energy transitions, as seen by the Climate Change Performance Index Map in Figure 3.

Figure 2 Global emissions by scenario, 2000-2050



Source: IEA, 2022
Figure 2 shows the pathways as per pledges taken by countries.
'Since Paris 201'5 & 'Glasgow pledges' line show where the world is heading if we are able to achive the goals shared in these pledges
Net Zero Scerio (Bottom-most line) is the pathway needed to limit temperateure rise to 1.5ºC. As the figure shows, a significant gap exists between the announced pledges and the goal.

Figure 3 Climate Change Performance Index 2023



Source: (CCPI, 2022)
Climate Change Performance Index (CCPI) is an annual ranking of countries' climate protection performance. It is calculated using four categories: GHG emissions (40% weight), renewable energy (20% weight), energy use (20% weight), and climate policy (20% weight). Each category is assessed using various indicators, which are then aggregated to determine the overall performance of a country. The CCPI aims to encourage nations to improve their climate policies and actions by comparing their efforts transparently.

The United States faces unique challenges compared to other countries due to its diverse climate zones, heterogeneous building stock, and historical reliance on fossil fuels. The federal government has re-committed to the Paris Agreement and is actively pursuing strategies to reduce emissions from the built environment. The US Environmental Protection Agency (EPA) has implemented policies and programs, such as the ENERGY STAR certification, to promote building energy efficiency. On a state level, progressive states like California and New York have set ambitious targets for emission reductions through legislation and building codes, including the California Title 24 Energy Efficiency Standards and the New York State Energy Plan. Cities such as New York and Boston have emerged as leaders in addressing these challenges by implementing net zero policies, like LL97 and BERDO, setting an example for the rest of the country.

However, significant disparities exist between states regarding emission reduction goals and policies, underscoring the need for a unified national approach. US ranks 52nd amongst 63 measured countries in the Climate Change Performance Index as experts criticize that some US policies lack a mandatory character and implementation will need to be quick enough (CCPI, 2022). To foster long-term, sustainable growth, it is crucial to integrate urban economics concepts, such as agglomeration benefits and accessibility, into building and infrastructure development, ultimately promoting sustainable material choices, local sourcing, and material reuse and recycling.

1.2. **Urban Intervention:** The Role of Cities

Cities play a pivotal role in addressing climate change as they are both significant sources of greenhouse gas emissions and hubs of innovation and policy experimentation. Urban areas account for around 70% of global energy-related CO2 emissions, with buildings and transportation being the primary contributors. More than 50% of the world’s population currently lives in cities, which is expected to increase to almost 70% by 2050. However, cities are also a global economic engine, responsible for 80% of global GDP, and represent a pivotal opportunity to accelerate progress toward ambitious climate goals. Taking action in cities could reduce emissions from urban buildings, materials, transport, and waste by nearly 90% by 2050, compared to the Pre-Paris baseline scenario shown in Figure 2 (IEA, 2021). As a result, city-level actions targeting the built environment can significantly impact global efforts to mitigate climate change.

The selection of New York and Boston as case studies for examining urban decarbonization policies is rooted in their leadership in climate action and the unique characteristics of their building stocks. New York City, the most populous city in the United States, has a diverse and dense built environment, with a significant number of older buildings that pose unique challenges for decarbonization (Rosenzweig, et al., 2011). New York accounted for 52.9 million ton of $C0_2$e emissions in 2021, of which 36 Million ton was from the Real estate sector, making New York the third-highest emitter city in the world and highest in the US (MOCEJ, 2023). Boston's strong focus on innovation and sustainability has led to the implementation of forward-thinking policies like BERDO. In 2019, Boston emitted 6.2 million metric tons of CO_2e from energy use in buildings and transportation (City of Boston, 2022).

Both cities have set ambitious climate goals and enacted comprehensive policies targeting building emissions reduction, making them ideal candidates for examining the effectiveness of urban decarbonization strategies. As the office market in these cities has gone into a deep and prolonged recession, the opportunity for substantial investment to improve the existing building stock has opened up.

Furthermore, the experiences of New York and Boston can provide valuable insights for other cities across the United States and worldwide. As both cities grapple with the challenges of retrofitting older buildings, repurposing office spaces, and integrating renewable energy sources, their successes and failures can inform the design and implementation of decarbonization policies in other urban centers. By analyzing the policies and outcomes in these two cities, this research aims to contribute to the broader understanding of the potential of urban interventions in promoting environmental sustainability and combating climate change.

2. Methodology: Uncovering the Impact of LL97 and BERDO

Assessing Building Carbon Emissions and Embodied Carbon

The first step in the methodology involves conducting a comprehensive literature review to identify critical studies and reports that discuss carbon emissions and embodied carbon in buildings. This review will encompass academic research and industry reports to provide a holistic understanding. For instance, Ramesh et al. (2010) thoroughly review life cycle energy analysis for buildings, while Pomponi and Moncaster (2018) systematically analyze embodied carbon mitigation strategies. I will explore the role of embodied carbon, which has been increasingly recognized as a crucial factor in the building sector's contribution to global emissions (Cabeza, et al., 2014).

This analysis will provide a solid foundation for understanding the environmental impact of buildings and help contextualize the significance of policy interventions like LL97 and BERDO. By identifying the key drivers of building emissions and evaluating the effectiveness of different strategies to address them, we can assess the potential impact of these policies on the built environment.

Establishing a Net Present Carbon: Time Value of Emissions

To determine the impact of policy interventions on building emissions, it is crucial to establish a Net Present Carbon (NPC) that accounts for both embodied and operational carbon emissions. Unlike Net Present Value (NPV), which typically monetizes the time value of cash flows, NPC focuses on quantifying the time value of embodied and operational carbon emissions throughout a building's lifecycle without converting them into financial terms.

In this context, the purpose of utilizing NPV is to provide a financial perspective that complements the non-monetized carbon-focused NPC, enabling stakeholders to evaluate better and compare different policy approaches and interventions. By considering both NPC and NPV, decision-makers can holistically assess the environmental and financial implications of various building strategies and policy options. This combined analysis helps ensure that sustainable building practices are not only environmentally sound but also economically viable, thus encouraging their widespread adoption in the pursuit of decarbonization.

Several studies have focused on calculating the total carbon emissions in various contexts. Cabeza et al. (2014), in their review of existing studies, found that they are focused on "exemplary buildings," that is, buildings that have been designed and constructed as low-energy buildings, but there are very few studies on "traditional buildings," that is, buildings such as those primarily found in our cities. These studies also are carried out only on new buildings and do not account for the time impact of emissions. The gaps in the literature exist mainly in the context of existing buildings and the time value of carbon emissions. A review of existing methodologies will be conducted to address this, and a tailored approach for calculating the Net Present Carbon (NPC) for buildings will be developed that help account for the present time value of carbon in these buildings (Including but not limited to existing embodied carbon and emissions over the lifecycle of these buildings). This approach will help create an assessment tool to evaluate the time value of carbon associated with the construction, operation, and end-of-life stages of a building for existing and new buildings. Additionally, discount rates will be applied to account for the time value of carbon and uncertainties in future emissions projections. By establishing a robust Net Present Carbon (NPC) methodology, this research will provide valuable insights into the effectiveness of LL97 and BERDO policies in promoting sustainable building practices and reducing carbon emissions in the built environment.

Developing a System Dynamics Model to simulate a Real Estate Developer's decision making

System dynamics modeling has been widely used to understand and simulate complex decision-making processes in various sectors, including real estate (Eskinasi, 2012). In this study, we will design a system dynamics model that captures real estate developers' decision-making processes, focusing on the net present value. This model will help us understand the potential impact of LL97 and BERDO on real estate developers' actions and investment choices.

The model will incorporate key factors influencing developers' decisions, such as city-level carbon emission targets, construction, and operational costs. The model will also account for elements not explicitly considered in policy frameworks, like embodied carbon, allowing for a more comprehensive understanding of how these policies might affect the total carbon footprint and exploring unintended consequences of policies.

Analyzing Building Emissions Data

This study will analyze the building emissions database for New York City, focusing on Manhattan's building stock and emissions profile, and for Boston, considering the entire city. The analysis will draw upon various data sources, including the New York City Mayor's Office of Sustainability (MOCEJ, 2023) and the City of Boston's Environment Department (City of Boston, 2022), which provide detailed information on building energy use and emissions.

The rationale for selecting Manhattan as the primary borough for analysis in New York is based on its high concentration of large commercial and residential buildings subject to LL97 regulations. Manhattan's built environment also represents dense urban centers' challenges in reducing carbon emissions.

For Boston, the entire city is chosen for analysis because, unlike New York City, Boston has a more evenly distributed building stock, with commercial and residential properties spread across the city. Moreover, the city's smaller size and unique urban landscape provide an opportunity to examine the impact of BERDO on a diverse range of buildings based on age and size.

Evaluating the Impact of Decarbonization of the Electricity Grid

Understanding the broader context of decarbonization plans at the state level is crucial for assessing the effectiveness of city-level policies such as LL97 and BERDO. This study will examine the impact of New York State's and Massachusetts' electricity grid decarbonization plans on the respective city policies.

The evaluation will consider how state-level grid decarbonization plans affect the emissions profiles of buildings subject to LL97 and BERDO. This will include examining the extent to which state-level plans complement or potentially conflict with city-level policies and analyzing the implications of these interactions for achieving decarbonization goals.

Most electrification studies focus on decarbonizing the grid on either the single building level or the city/region building stock level. Hong et al. (2023) studied how energy efficiency retrofits can help mitigate increased peak electric demand and quantify impacts on energy use and carbon emissions in San Francisco. This study, however, assumes that the state grid decarbonization plan will be effectively implemented and analyses the impact on the developer's willingness to retrofit.

3. The Carbon Conundrum: Unraveling Buildings

Real estate plays a substantial role in global carbon emissions, one of the largest end-use sectors worldwide. In 2021, the industry was responsible for nearly 37% of global energy-related CO2 emissions, with 28% originating from the operational energy use of buildings and around 9% from embodied carbon in building materials and construction processes. (United Nations Environment Programme, 2022)
Buildings contribute to emissions through both direct and indirect means. Direct emissions result from the on-site combustion of fossil fuels, such as natural gas for heating, while indirect emissions stem from off-site energy generation, like electricity consumed for cooling and lighting. Additionally, buildings generate emissions through the materials and processes used in construction and maintenance.

Direct emissions include burning natural gas, propane, or fuel oil for space and water heating. Indirect emissions can come from electricity used for lighting, cooling, and operating appliances, which generate emissions at power plants.

Embodied carbon emissions are associated with the extraction, processing, transportation, and assembly of building materials and the disposal or recycling of materials at the end of a building's life. Operational carbon emissions, on the other hand, are those produced during a building's use, including both direct and indirect emissions from energy consumption for heating, cooling, and lighting, among other activities.

The significance of building carbon emissions lies in their sheer volume and the long lifespan of buildings, which can lock in emissions for decades. As a result, decarbonizing the real estate sector is essential to achieving global climate goals and ensuring a sustainable future.

Figure 4 Real Estate Emissions

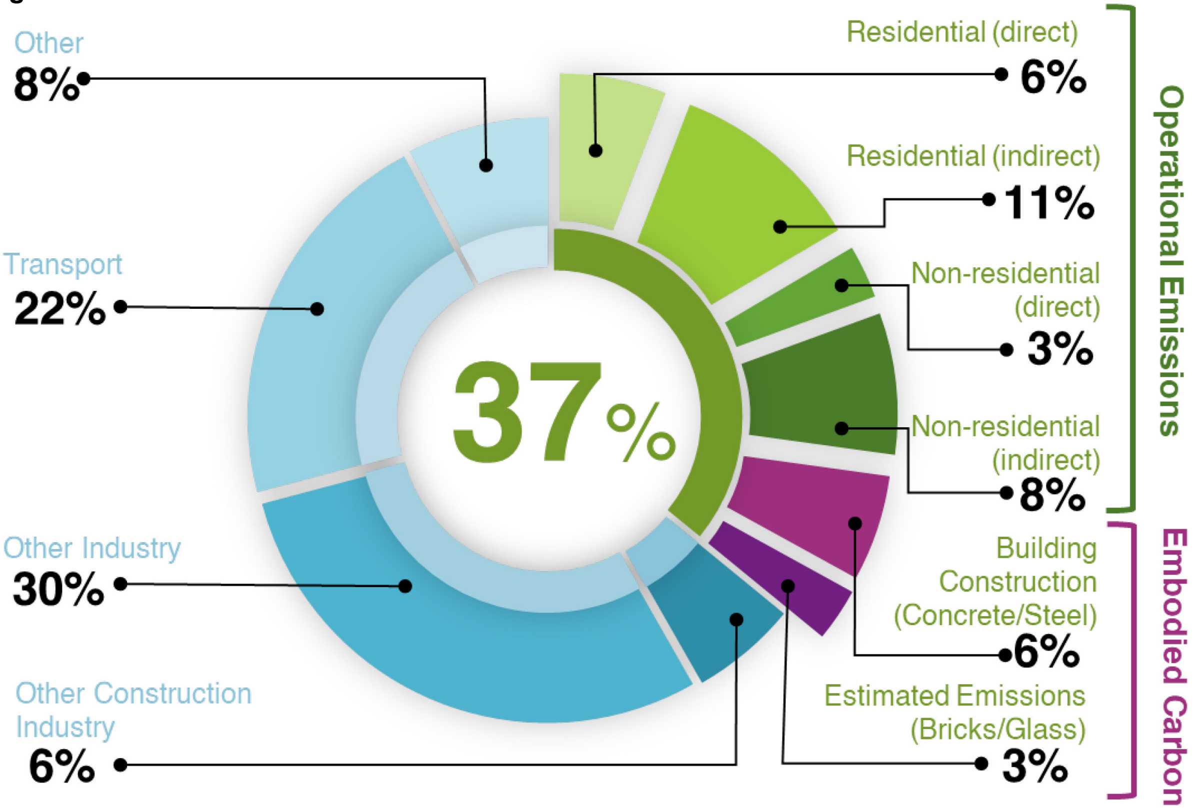


Illustration Recreated using Data Source: IEA, 2022

Embodied vs. Operational Carbon

Traditionally, regulation has focused on operational carbon emissions from buildings, which arise from energy consumption for heating, cooling, lighting, and other end uses. These emissions are heavily influenced by the building's energy efficiency, the local climate, and the carbon intensity of the energy supply (Ürge-Vorsatz & Akbari, 2014). As urbanization and population growth continue to drive demand for new buildings, it is crucial to prioritize energy efficiency improvements and use low-carbon energy sources to minimize operational emissions.

Significant efforts from policymakers, academics, and industry professionals have been dedicated to enhancing the energy efficiency of buildings. Until recently, the primary focus has been on the operational phase of buildings, as demonstrated by the European Union's final deadline for nearly Zero Energy Buildings (nZEB) starting in 2020 (EU, 2010). The rationale for this emphasis is that operational energy (and carbon) constitutes the most significant portion of a building's life cycle energy (and carbon) emissions.

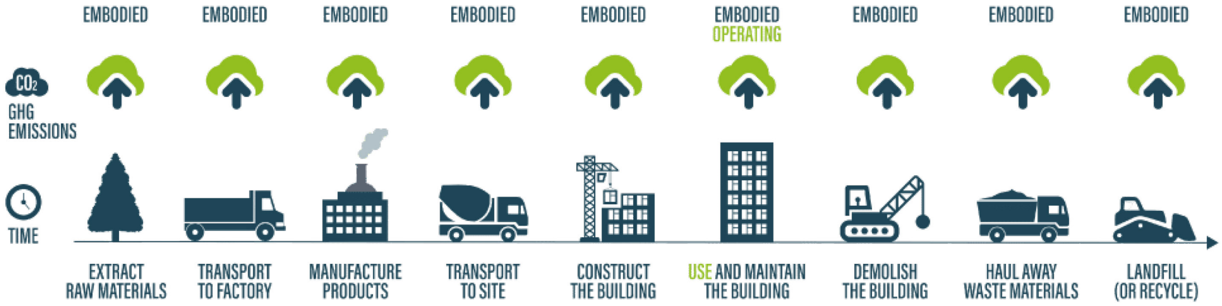
However, CO_2 emissions continue to rise, with the International Energy Agency (IEA) suggesting that emissions will not be met by 2050 (IEA, 2022). One contributing factor is the rebound effects of higher energy efficiency, resulting in increased energy demand due to expanded heated spaces, elevated temperatures, and extended durations (Rovers, 2014).

A less extensively studied reason relates to the unnecessary separation between operational and embodied impacts, leading to unintended consequences that overlook the ramifications of increased construction and, in some instances, transfer environmental burdens from one life cycle stage (occupancy) to others (Pomponi & Moncaster, 2018). To accommodate the largest wave of urban growth in human history, we expect to add 2.4 trillion ft^2 (230 billion m^2) of new floor area to the global building stock, the equivalent of adding an entire New York City to the world every month for 40 years.

Real Estate's reliance on high-carbon (construction) materials and processes involved in the construction of buildings create substantial embodied carbon emissions that tend to be overlooked. Embodied carbon emissions are associated with building materials production, transportation, disposal, and construction and maintenance processes. Critical contributors to embodied carbon emissions include materials such as cement, steel, and aluminum, which are energy-intensive to produce and emit significant quantities of CO_2.

Neglecting to address embodied carbon emissions in policy development and implementation may have negative consequences, hindering overall decarbonization efforts. Embodied emissions from the vast construction industry are as crucial as operational emissions and, in many ways, more challenging to arrest (United Nations Environment Programme, 2022). There is now robust evidence that the embodied impacts of buildings are a significant contributor to global emissions and that as a percentage of whole-life impacts of buildings, they can account for more than 50% (Crawford, 2011), with 70% calculated for some cases in the UK (Ibn-Mohammed et al., 2013). Ramesh et al. (2010) study using Life Cycle Energy Analysis (LCEA) of 73 cases in 13 countries shows that operating (80–90%) and embodied (10–20%) phases of energy use are significant contributors to a building's life cycle energy demand.

Figure 5 Embodied Carbon Lifecycle



Source: Sadler, 2020

As we transition towards a more sustainable built environment, energy-efficient designs and renewable energy sources have helped reduce operational carbon emissions considerably, and embodied carbon will become the dominant source of carbon emissions associated with buildings (Architecture 2030, 2018). When we look at all the new construction finished in 2020-2022 in Figure 6, we see embodied carbon’s critical role. Embodied carbon emissions, unlike operational carbon emissions, are set in stone once a building is constructed.

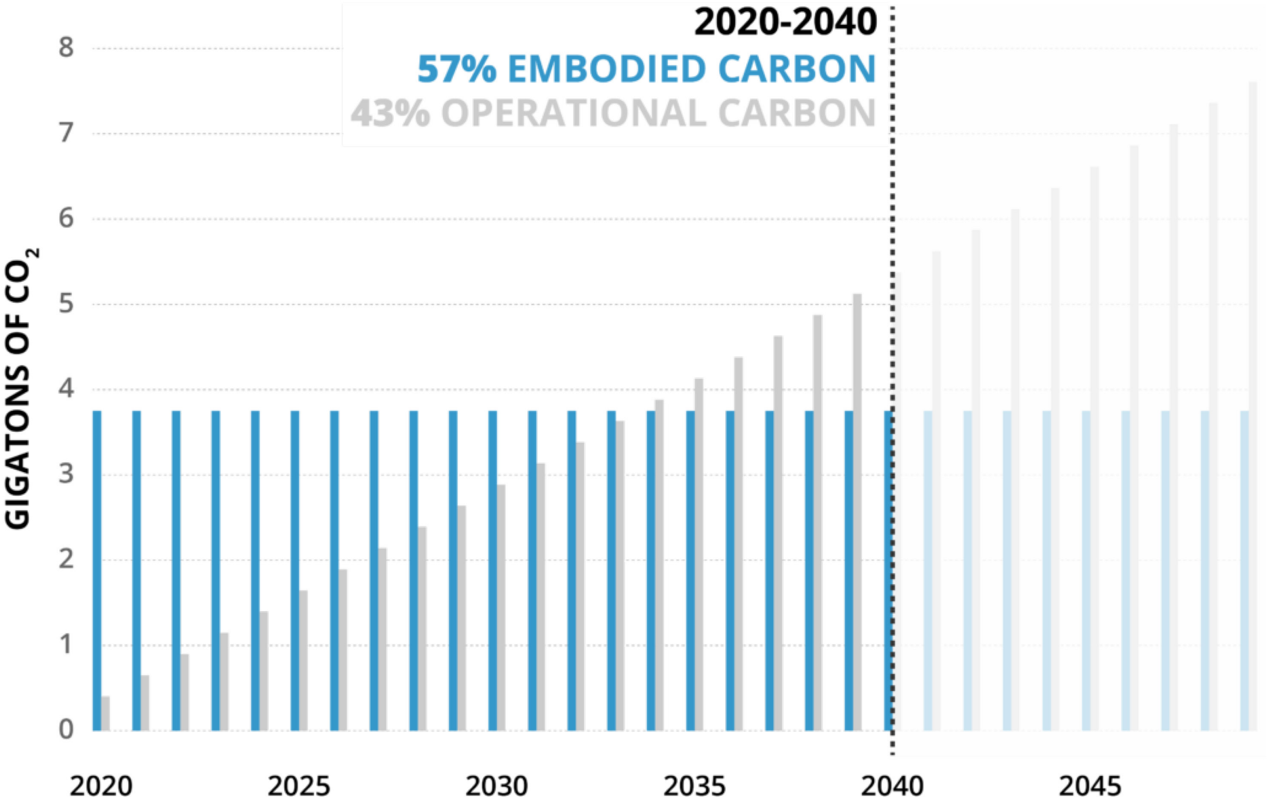
To achieve zero emissions by 2050, we must address embodied carbon now. Embodied carbon can be addressed through various practices and technologies that focus on reducing the carbon footprint of building materials and construction processes. On the other hand, operational carbon emissions can be reduced over time through building energy upgrades and using renewable energy sources.

Some strategies to address embodied carbon include:

- Material selection: Opt for low-carbon building materials, such as sustainably sourced timber, recycled steel, or alternative cementitious materials with a lower carbon footprint than traditional construction materials.
- Design for deconstruction: Create building designs that allow for easy disassembly and reuse of materials, thereby reducing the need for new materials and minimizing waste generated at the end of a building's life.
- Life cycle assessment: Conduct a comprehensive life cycle assessment (LCA) to identify and quantify the carbon emissions associated with all stages of a building's life, from material extraction to end-of-life disposal. This information can help guide decisions on material selection and design strategies.
- Carbon sequestration: Use materials that can store carbon, such as bio-based materials or carbon-storing concrete, which can help offset the embodied carbon emissions in a building.
- Material efficiency: Optimize building design to reduce the materials needed, such as through modular construction or by minimizing structural redundancies, which can lead to a lower embodied carbon footprint.
- Circular economy principles: Promote the reuse and recycling of building materials, which can help reduce the demand for new materials and lower embodied carbon emissions.

By incorporating these practices and technologies into building design, construction, and maintenance, we can effectively address embodied carbon and contribute to the global goal of achieving zero emissions by 2050.

Figure 6 Total Emissions with no interventions



Source: IPCC, 2023

Addressing embodied carbon is essential because:

- It immediately impacts the environment, releasing emissions before a building is occupied.
- Reducing embodied carbon can help mitigate the demand for carbon-intensive materials, fostering the adoption of low-carbon alternatives and promoting circular economy principles.

Despite its growing importance, addressing embodied carbon emissions remains a complex task due to several reasons:

- Limited awareness: The focus on operational carbon emissions often overshadows the need for material selection and construction processes that minimize embodied carbon.
- Data scarcity: Comprehensive data on embodied carbon of various building materials is limited, making comparing and optimizing material choices challenging (Hammond & Jones, 2011).
- Supply chain intricacies: The global nature of the building industry complicates the tracing and accounting of embodied carbon, as materials are sourced from multiple locations.

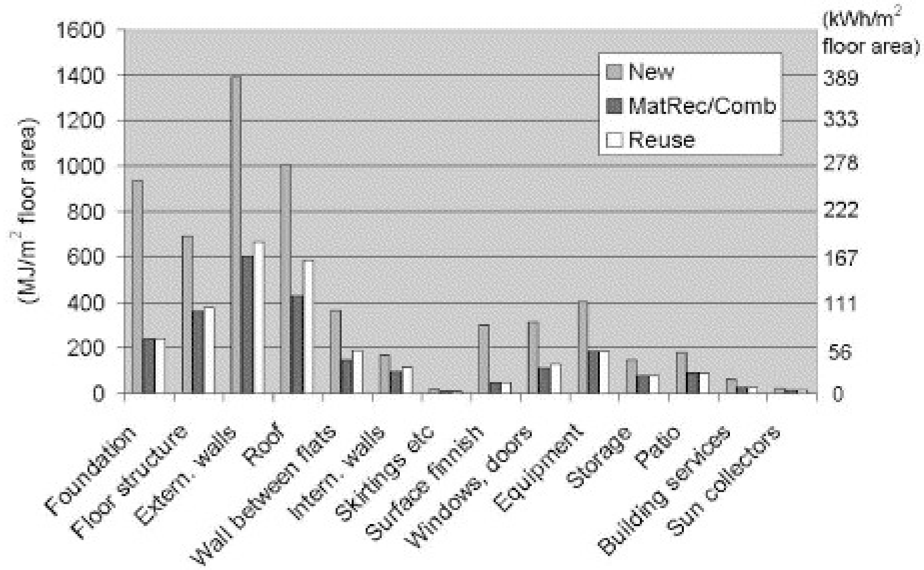
3.1. Build New or Renovate?

When considering the environmental impact of buildings, it is essential to compare the embodied carbon emissions associated with constructing new buildings versus renovating existing structures. Embodied carbon emissions are generated during the extraction, production, transportation, and construction of building materials and end-of-life emissions from deconstruction and disposal.

A study by Ortiz, Castells, and Sonnemann (2009) investigated the embodied carbon emissions of various building renovation scenarios compared to constructing new buildings. The authors found that renovating existing buildings could reduce embodied carbon emissions by 35-50% compared to constructing new buildings. They employed a Life Cycle Assessment (LCA) methodology to evaluate the environmental impact of different renovation scenarios and materials over the buildings' life cycle.

Another study by Thormark (2002) compared the life cycle environmental impact of constructing new buildings with recycled materials and renovating existing buildings in Sweden. The author found that about 37–42% of the embodied energy can be recovered through recycling. The recycling potential was about 15% of the total energy use during an assumed lifetime of 50 years. Optimizing material recycling and combustion can yield approximately 90% of the maximum energy recovery. The most crucial step to facilitate future recycling is using recyclable materials and avoiding constructions that are challenging to disassemble or cause material contamination. The study also found that prolonging the lifetime of components/choosing materials with less embodied energy can reduce maintenance. Considering the embodied energy in materials/components with relatively short maintenance intervals and their recycling potential is essential. This study's maintenance accounted for about 12% of the total embodied energy. Thormark used a process-based Life Cycle Assessment (LCA) methodology to analyze the environmental impact of different building materials and construction methods.

Figure 7 Embodied energy for initial materials and materials for renovation



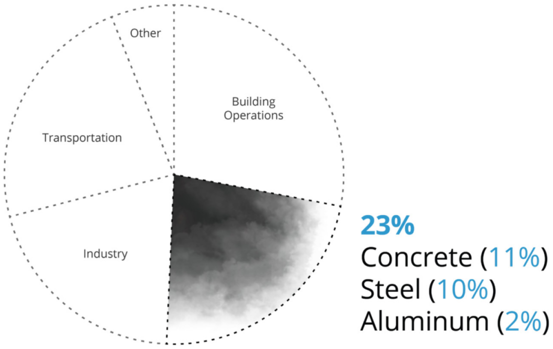
Source: Thormark, 2002

These studies demonstrate that renovating existing buildings or recycling building materials for construction can significantly reduce embodied carbon emissions compared to constructing entirely new structures. As a result, building renovation and material circularity should be considered vital strategies for mitigating the environmental impact of the built environment and achieving sustainability goals in the Real Estate industry.

3.2. Hidden Carbon Impact of Material Choices

The high difference in embodied carbon can be correlated to a limited highly used construction material: Concrete, steel, and aluminum. These three materials are responsible for 23% of total global emissions and the most embodied carbon in buildings (Architecture 2030, 2022).

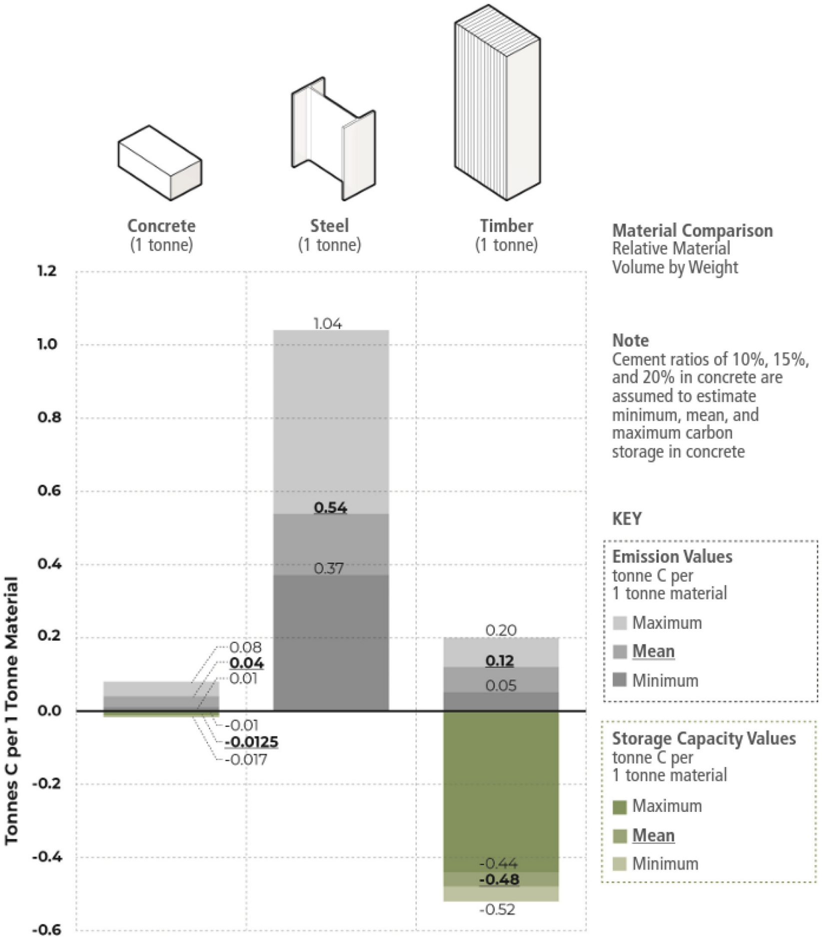
Figure 8 Annual Global CO2 Emissions



Source: IEA, 2022

Concrete and steel have substantial embodied carbon emissions with minimal carbon storage capacities, while timber stores a considerable quantity of carbon with a relatively small ratio of carbon emissions-to-material volume, as shown in Figure 9. The displayed carbon storage of concrete represents the theoretical maximum value, which might be reached after hundreds of years. Cement ratios of 10%, 15%, and 20% are assumed to estimate minimum, mean, and maximum carbon storage in concrete. Carbon storage of steel is not displayed as it is negligible (0.004 ton CO_2 per ton of steel).

Figure 9 Emissions of Concrete, Steel & Wood



Source: IPCC, 2023

For the carbon embodied in supply chains to become net-zero, all critical infrastructure and provisioning systems must be decarbonized, including electricity, mobility, food, water supply, and construction (Seto, et al., 2021). The growth of global urban populations anticipated over the next several decades will create significant demand for buildings and infrastructure. As cities expand in size and density, there is an increase in the production of mineral-based structural materials and enclosure systems that are conventionally associated with mid and high-rise urban construction morphologies, including concrete, steel, aluminum, and glass. This will create a significant spike in GHG emissions and discharge of CO2 at the beginning of each building lifecycle, necessitating alternatives (Churkina, et al., 2020)

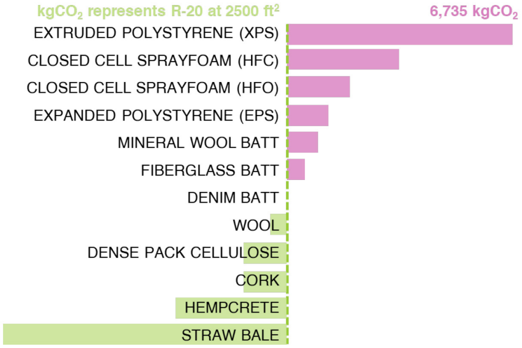
Among the category of primary structural materials, it is estimated that the final energy demand for steel production can be reduced by nearly 30% compared to 2010 levels, with a 12% efficiency improvement for cement (Lechtenböhmer, et al., 2016). Even when industries are decarbonized, residual CO2 emissions will remain from associated chemical reactions in calcination and coke from coking coal to reduce iron oxide (Davis et al. 2018). Additionally, carbon sequestration by cement occurs throughout the building lifecycle in quantities that would offset only a fraction of their production stage carbon spike (Xi, et al., 2016). Moreover, there are collateral effects related to modern construction and associated resource extraction on the carbon cycle. The production of cement, asphalt, and glass requires large amounts of sand extracted from beaches, rivers, and seafloors, disturbing aquatic ecosystems and reducing their capacity to absorb atmospheric carbon. Ore mining can lead to extensive local deforestation and soil degradation (Sonter, et al., 2017). Deforestation significantly weakens the converted land as a carbon sink and, in severe cases, may even create a net emissions source.

Embodied carbon in energy-efficient buildings

Even in sustainable buildings, the initial carbon debt incurred in the production stage can take decades to offset through operational energy efficiencies alone. Reducing energy demands and GHG emissions associated with manufacturing mineral-based construction materials will be challenging, as these industries have already optimized their production processes. A deeper understanding of material choices can help highlight the importance of considering embodied carbon. For instance, comparing the embodied carbon of single-glazed glass (approximately 6.8 kg CO2e/m2) and triple-glazed glass (around 14.6 kg CO2e/m2) reveals that the more energy-efficient option may have higher embodied carbon emissions due to the additional glass panes and the gas-filled layers between them (Glazing Vision Europe, 2016).

Insulation materials provide another example of the need to consider embodied carbon. Traditional insulation materials, such as expanded polystyrene (EPS) or extruded polystyrene (XPS), are petroleum-based plastics contributing to high embodied carbon emissions. In contrast, more sustainable insulation options, like cellulose or sheep's wool, have lower embodied carbon emissions due to their natural and renewable sources. By considering the embodied carbon of various materials, designers, and builders can make more informed choices that contribute to a more sustainable built environment. (Ebrahimi, 2020)

Figure 10 Insulations Emissions



Source: 2030 Palette, 2023)

Tackling embodied carbon emissions requires adopting circular economy principles, such as designing for deconstruction, using low-impact building materials, and recycling construction waste. Incorporating embodied carbon considerations into building policies and regulations will help ensure a more comprehensive approach to decarbonizing the Real Estate sector.

3.3. Calculating Total Carbon

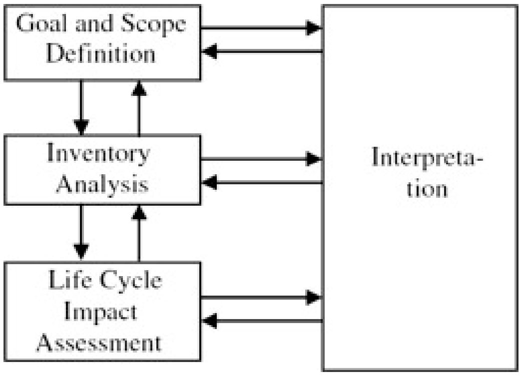
Life Cycle Assessment (LCA) and Life Cycle Energy Analysis (LCEA) are two of the most widely used research methodologies for the environmental evaluation of buildings and building-related industries and sectors.

Life Cycle Assessment (LCA)

They serve as a tool for systematically analyzing the total carbon performance (embodied and emissions) of products or processes throughout their life cycle, encompassing raw material extraction, manufacturing, usage, and end-of-life (EOL) disposal and recycling. Hence, LCA is often considered a "cradle to grave" approach to evaluating environmental impacts (Ciambrone, 1997).

Since 1990, the building sector has employed life cycle assessment, and it has been utilized for many years to evaluate product development processes from the cradle to the grave. With the current push toward sustainable construction, LCA has gained importance as an objective method to evaluate the environmental impact of construction practices (Cabeza, et al., 2014).

Figure 11 LCA framework

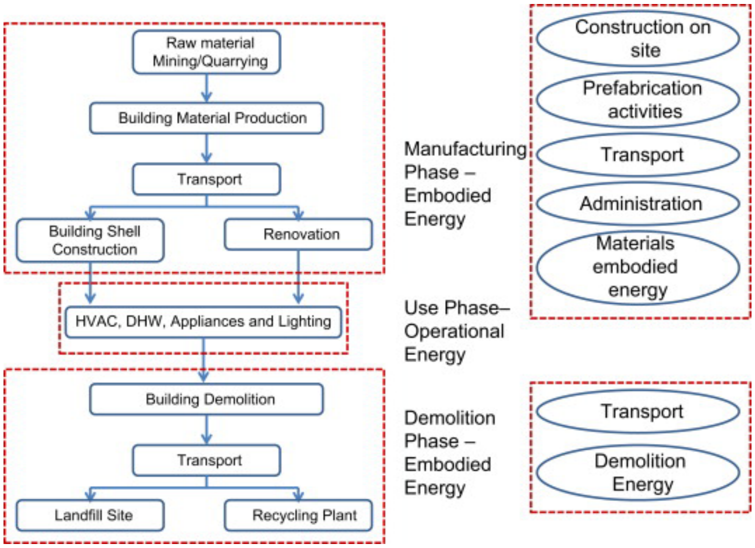


Source: Cabeza, et al., 2014

Life cycle energy analysis (LCEA)

This method considers all energy inputs throughout a building's life cycle. The system boundaries of this analysis (**Error! Reference source not found.**) include the energy use of the following phases: Manufacture, use, and demolition. The manufacturing phase includes manufacturing and transporting building materials and technical installations used in the erection and renovation of the buildings. The operation phase encompasses all activities related to using the buildings over their life span. These activities encompass maintaining comfortable conditions within buildings, water usage, and powering appliances. Finally, demolition includes destroying the building and transporting dismantled materials to landfill sites and recycling plants. (Ramesh, et al., 2010)

Figure 12 Life cycle energy of a building



Source: Cabeza, et al., 2014

Calculating LCEA (Ramesh, et al., 2010)**:**

Embodied energy
Embodied energy is the energy utilized during the manufacturing phase of the building. It is the energy content of all the materials used in the building, technical installations, and energy incurred during erection/construction and renovation. The energy content of materials refers to the energy used to acquire raw materials (excavation), manufacture, and transport to the building site. Embodied energy is divided into two parts: initial embodied energy and recurring embodied energy.

Initial embodied energy
The initial embodied energy of a building is the energy incurred for the initial construction of the building. It is expressed as:

$$EE_i = \Sigma\, m_i M_i + E_c$$

Where, EE_i = initial embodied energy of the building; m_i = quantity of building material (i); M_i = energy content of material (i) per unit quantity; E_c = energy used at the site for erection/construction of the building.

Recurring embodied energy
The energy incurred for repair and replacement (rehabilitation) is accounted for during the entire life of the buildings and can be expressed as:

$$EE_r = \Sigma\, m_i M_i\, [(L_b / L_{mi}) - 1]$$

Where, EE_r = recurring embodied energy of the building; L_b = life span of the building; L_{mi} = life span of the material (i).

Embodied energy largely depends on the type of materials used, primary energy sources, and efficiency of conversion processes in making building materials and products.

Operating energy
It is the energy required for maintaining comfort conditions and day-to-day maintenance of the buildings. It is the energy for HVAC (heating, ventilation, and air conditioning), domestic hot water, lighting, and running appliances. Operational energy largely depends on the comfort level required, climatic conditions, and operating schedules. Operating energy in the life span of the building is expressed as:

$$OE = E_{OA} L_b$$

Where, OE = operating energy in the life span of the building; E_{OA} = annual operating energy; L_b = life span of the building.

Demolition energy
At the end of the building's service life, energy is required to demolish the building and transport the waste material to landfill sites and/or recycling plants. This energy is termed demolition energy and expressed as:

$$DE = E_D + E_T$$

Where, DE = demolition energy; E_D = energy incurred for the destruction of the building; E_T = energy used for transporting the waste materials.

Life cycle energy (LCE)
The life cycle energy of the building is the sum of all the energies incurred in its life cycle.

$$LCE = EE_i + EE_r + OE + DE$$

Energy savings from recycling or reusing demolished building materials are not considered in the life cycle energy estimation of the buildings. This is primarily because no standard agreement over attributing this saved energy to the demolished building exists. However, it would be more appropriate to incorporate this energy from recycling or reusing into the life cycle energy estimation overall. (Ramesh, et al., 2010)

Life Cycle Assessment (LCA) and Life Cycle Energy Analysis (LCEA) are essential tools for evaluating the environmental impact of products and processes. However, they have some drawbacks that may limit their accuracy or usefulness.

Data availability and quality: LCA and LCEA require detailed and accurate data on materials, energy consumption, and emissions at various stages of a product's life cycle. However, data availability and quality can be limited, leading to uncertainties in the results (Wiedmann & Minx, 2008).

Allocation issues: When multiple products or outputs are generated from a single process, allocating environmental impacts in a just manner can be challenging. Allocation issues can result in the overestimation or underestimation of the environmental impact of a product (Suh, et al., 2004).

Temporal and spatial variability: LCA and LCEA results can be affected by temporal and spatial variability in resource use, emissions, and impacts, which may not be adequately captured in the analyses (Azapagic & Clift, 1999).

Subjectivity in selecting system boundaries and functional units: LCA and LCEA results can be influenced by the choice of system boundaries and functional units, which may introduce subjectivity and affect the comparability of results (Rebitzer, et al., 2004).

Simplifications and assumptions: LCA and LCEA often involve simplifications and assumptions to make the analysis manageable. These simplifications can lead to uncertainties and inaccuracies in the results (Curran, 2013).

Exemplary Buildings: Cabeza et al. (2014) review of research papers using these two methodologies showed that most of these studies are carried out in what is shown as "exemplary buildings," that is, buildings that have been designed and constructed as low-energy buildings, but there are very few studies on "traditional buildings," that is, buildings such as those primarily found in our cities. Similarly, most studies are conducted in urban areas, while rural areas are not well represented in the literature. Finally, studies are not equally distributed around the world.

Time value of carbon: The time value of carbon is a crucial factor in LCA, as the environmental impact of emissions depends on when they occur. However, traditional LCA methods often need to account for this time value, leading to inaccuracies in estimating the environmental impact of a product (Levasseur, et al., 2010).

Despite these drawbacks, LCA and LCEA remain valuable tools for assessing the environmental impact of products and processes over their entire life cycles. They provide essential insights into the environmental performance of various options, enabling informed decision-making for sustainable development. By addressing the limitations and continuously improving methodologies, LCA and LCEA can contribute significantly to developing more environmentally friendly products, processes, and policies.

3.4. **Net Present Carbon (NPC):** Time Value of Real Estate Carbon Footprint

“When you save matters, what you build matters, what you don’t build matters more” – Larry Strain (2017)

There is a greater benefit from reducing carbon dioxide (or other greenhouse gas) emissions immediately than reducing the same amount of emissions (or rate of emissions) in the future (Richards, 1997). We need to think about carbon stocks and flows because carbon dioxide (CO_2) continues to warm the planet for many decades after it is released (Generation, 2021). Globally, we emitted around 40 billion tons of CO_2 in 2020 despite the economic impact of the pandemic (IEA, 2021). At this rate, we will exceed the carbon budget for 1.5 degrees of warming by 2030.

The currently available methodologies did not incorporate the time impact of Carbon emissions specifically for the Real Estate sector. To fill the gap, this thesis proposes a concept analogous to the financial analysis metric Net Present Value (NPV): Net Present Carbon (NPC).

While there is no extensive body of literature specifically on Net Present Carbon, various related concepts and methodologies address the quantification of carbon emissions in present value terms and building sustainability and life cycle assessment (LCA). Some key publications include:

- Embodied energy and carbon in construction materials (Jones & Hammond, 2008)
- Sustainability in the construction industry: A review of recent developments based on LCA ((Ortiz, et al., 2009)

These sources provide valuable insights into quantifying embodied and operational carbon emissions, setting the foundation for developing a Net Present Carbon methodology.

This chapter explains the relevance of Net Present Value and proposes a methodology for calculating Net Present Carbon to evaluate buildings’ total carbon footprint impact and support better decision-making.

Net Present Value and its Relevance to Carbon Impact Assessment

Net Present Value (NPV) is a financial metric used to evaluate the profitability of a Real Estate investment by calculating the present value of all cash flows, both incoming and outgoing, discounted to the present time (Geltner, et al., 2014). Similarly, Net Present Carbon (NPC) can be employed to quantify the total carbon footprint impact of a building, considering both embodied and operational carbon emissions over its lifetime while discounting future emissions using a discount rate.

NPV is solved using Discounted Cash Flows (DCF):

$$NPV = CF_0 + \frac{CF_1}{(1+IRR)} + \frac{CF_2}{(1+IRR)^2} + \cdots + \frac{CF_T}{(1+IRR)^T}$$

Where T is the number of future periods encompassed in the analysis (beyond the present), IRR is Internal rates of return or discount rate, and CF is Cash Flow (net cash flow amounts labeled CF0, CF1, CF2, etc., occurring in time periods labeled 0, 1, 2, and so on, where period 0 is the present period).

As per NPV Investment Decision Rule, a Real Estate investor should (Geltner, et al., 2014):

- Maximize the NPV across all mutually exclusive alternatives.
- Never choose an alternative that has: NPV < 0.

3.4.1. Net Present Carbon Calculation

Substituting Cash Flows in NPV with Carbon Emission to calculate NPC, the following variables are needed:

EC: Embodied carbon (in tons of CO_2-equivalent)
OC_t: Operational carbon emissions in year t (in tons of CO_2-equivalent per year)
r: Discount rate (a value between 0 and 1)
n: Lifetime of the building (in years)

The formula for Net Present Carbon can be expressed as follows:

$$\mathbf{NPC = EC + \Sigma[(OC_t) / (1 + r)\text{\textasciicircum}t]}$$

Where the summation (Σ) runs from t = 1 to t = n (the building's lifetime).

The above formula is a simplified version similar to the NPV calculation representing the total carbon footprint of a new building that would not undergo any renovations and repairs.

To evaluate the decision to demolish or renovate a building, the formula can be modified as follows:

$$\mathbf{NPC = EC_d + EC_n + EC_r + \Sigma[(OC_t) / (1 + r)\text{\textasciicircum}t] + \Sigma[(EC_{re\ t}) / (1 + r)\text{\textasciicircum}t] + \Sigma[(OC_{re\ t}) / (1 + r)\text{\textasciicircum}t] + [EC_{demo} / (1 + r)\text{\textasciicircum}n] + [OC_{demo} / (1 + r)\text{\textasciicircum}n]}$$

Where,
EC_d: Embodied carbon of building (part or whole) being demolished (in tons of CO_2-equivalent)
EC_n: Embodied carbon of new building constructed (in tons of CO_2-equivalent)
EC_r: Embodied carbon of renovated parts (in tons of CO_2-equivalent)
$EC_{re\ t}$: Embodied carbon of recurring repairs/capital investment in year t (in tons of CO_2-equivalent)
EC_{demo}: Embodied carbon of demolition at the end-of-life cycle (in tons of CO2-equivalent)
OC_t: Operational carbon emissions in year t (in tons of CO2-equivalent per year)
$OC_{re\ t}$: Operational carbon of installing/implementing repairs/capital investment in year t (in tons of CO_2-equivalent)
OC_{demo}: Operational carbon emissions of demolitions (in tons of CO2-equivalent per year)

r: Discount rate (a value between 0 and 1)
n: Lifetime of the building (in years)

The above formula captures scenarios of new build, renovation, demolition & construction, partial demolition of a historical building to preserve the façade (and other historical elements) & building new construction, partial renovation, and reuse of construction material at the end of the life cycle of the building.

The formula can also be modified to subtract Embodied carbon from existing left-alone parts of the building to incentivize developers to adopt and reuse by the city:

$$\mathbf{NPC = EC_d + EC_n + EC_r + \Sigma[(OC_t) / (1 + r)\text{\textasciicircum}t] + \Sigma[(EC_{re\ t}) / (1 + r)\text{\textasciicircum}t] + \Sigma[(OC_{re\ t}) / (1 + r)\text{\textasciicircum}t] + [EC_{demo} / (1 + r)\text{\textasciicircum}n] + [OC_{demo} / (1 + r)\text{\textasciicircum}n] - EC_{exist}}$$

Where, EC_{exist}: Embodied carbon of existing building (part or whole) (in tons of CO_2-equivalent)

In calculating the Time Value of Carbon, the NPC rule would be the complete opposite of the NPV rule:

- Minimize the NPC across all mutually exclusive alternatives.
- Choose an alternative with NPC < 0 or closer to 0.

3.4.2. Calculating Variables

a. Embodied Carbon (EC)

Embodied carbon represents the total greenhouse gas emissions associated with the extraction, processing, manufacturing, transportation, construction, and disposal of building materials. To calculate embodied carbon, consider the following steps based on existing literature:

- **Inventory of materials:** Create a detailed inventory of all the materials used in the building, including quantities and types. Include everything from structural elements to insulation and finishes.
- **Data sources for embodied carbon:** Use Life Cycle Assessment (LCA) databases, such as the Inventory of Carbon and Energy (ICE) by Hammond and Jones (2008) or Environmental Product Declarations (EPDs), to obtain the embodied carbon values for each material. These sources provide carbon emissions data in units of CO_2-equivalent per unit of material (e.g., kg CO_2e per kg of material).
- **Material carbon calculations:** Multiply the quantity of each material by its respective embodied carbon value obtained from the data sources. Sum the resulting values to obtain the total embodied carbon for the building.

b. Operational Carbon Emissions (OC)

Operational carbon emissions are the greenhouse gas emissions from a building's energy consumption during its use phase. These emissions include heating, cooling, lighting, and other energy-consuming activities. To estimate operational carbon emissions, consider the following steps based on existing literature:

- **Energy modeling:** Use energy modeling tools, such as EnergyPlus, eQUEST, or IES-VE, to estimate the annual energy consumption of the building. These tools consider factors like building design, materials, systems, and local climate to estimate energy use comprehensively.
- **Energy consumption data:** If energy modeling is not feasible, one can use historical energy consumption data for similar buildings in the same region or with similar uses. Adjust the data for any differences in building size, occupancy, or other energy consumption factors.
- **Emissions factors:** Obtain local emissions factors for different energy sources (e.g., electricity, natural gas, etc.) to convert energy consumption data into carbon emissions. Emissions factors are typically expressed in units of CO_2-equivalent per unit of energy consumed (e.g., kg CO_2e per kWh). National or regional environmental agencies often provide these factors.
- **Future changes:** Consider future changes in energy consumption patterns and the potential for energy efficiency improvements over the building's lifetime. Account for factors like technological advancements, changes in energy sources, and energy efficiency policies when estimating operational carbon emissions in future years.
- **Annual operational carbon calculations:** Multiply the annual energy consumption for each energy source by its respective emissions factor to obtain the annual carbon emissions for each year of the building's lifetime.

c. Discount Rate (r)

The discount rate in the context of Net Present Carbon reflects the time preference for addressing carbon emissions. In other words, it expresses the relative importance placed on future carbon emissions compared to present emissions. Selecting an appropriate discount rate can significantly impact the results of the NPC calculation.

To select a suitable discount rate, consider the following:

- **Review existing literature:** Examine academic research, industry reports, and policy recommendations for carbon emissions, climate change, and environmental economics. Influential publications such as the Stern Review's average discount rate for climate change damages at approximately 1.4% (Stern, 2007)and the work of Nordhaus (2008) provide valuable insights into the use of discount rates in climate change.
- **Social cost of carbon:** The social cost of carbon (SCC) estimates the economic damage caused by emitting one additional ton of CO2-equivalent. SCC calculations typically use a range of discount rates, such as 2.5%, 3%, and 5% (Interagency Working Group, 2022). These discount rates can be a reference when selecting a discount rate for NPC.
- **Stakeholder consultation:** When working on a project for a specific organization, consult with relevant stakeholders, such as management, investors, or policymakers, to understand their preferences and risk tolerance. This information can help choose an appropriate discount rate that aligns with the organization's goals and priorities.
- **Sensitivity analysis:** Conduct a sensitivity analysis using various discount rates to understand how different discount rates affect the Net Present Carbon. This approach can inform decisions on the most appropriate rate to use.

d. Building Lifetime (n)

Estimating the lifetime of a building is crucial for accurately calculating the Net Present Carbon. Factors such as the building's design, materials, quality of construction, maintenance practices, and adaptability can impact its lifetime. To estimate the building's lifetime, consider the following:

- **Building codes and industry standards:** Refer to local building codes and industry standards, which often provide guidelines or requirements for the expected lifespan of different types of buildings and their components.
- **Material lifespans:** Assess the lifespans of the materials used in the building's construction. (Jones & Hammond, 2008)
- **Historical data:** Examine historical data on the lifespans of similar buildings in the same region or with similar construction techniques.
- **Maintenance and renovation practices:** The quality and frequency of maintenance and any planned or potential renovations can affect the building's lifetime.
- **Adaptability and flexibility:** Buildings designed for adaptability and flexibility, enabling them to accommodate changing uses or technologies over time, may have longer lifetimes than buildings with rigid designs. (Brand, 1995)

Net Present Carbon provides a helpful methodology for this thesis to evaluate the total carbon footprint impact of the existing building stock in the context of LL97 and BERDO.

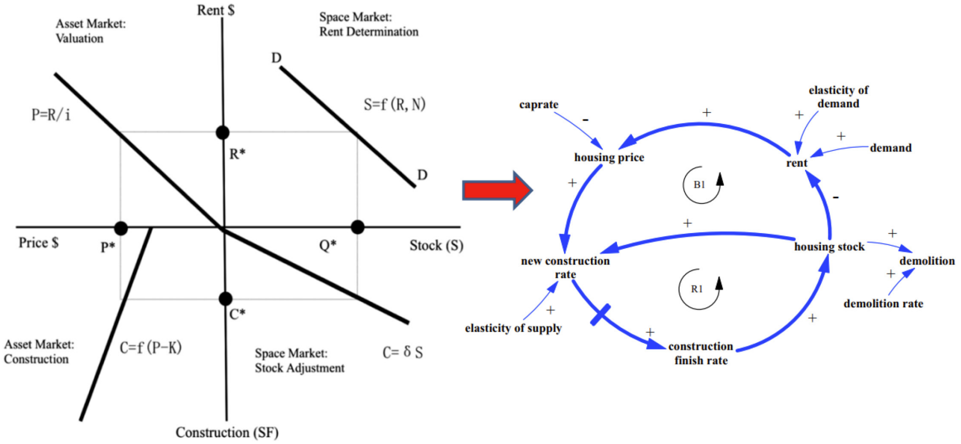
4. System Dynamics: Simulating Decision-Making

System Dynamics (SD) is a simulation-based approach to modeling complex systems and analyzing their behavior over time. Jay W. Forrester initially developed it in the late 1950s, and it has since been widely applied in various fields, including business, economics, and environmental studies (Forrester, 1961). The SD methodology uses causal loop diagrams and stock-and-flow diagrams to represent the structure of the system and its feedback mechanisms, which allows for a better understanding of the dynamic relationships among the system's components (Sterman, 2002).

4.1. System Dynamics in Real Estate

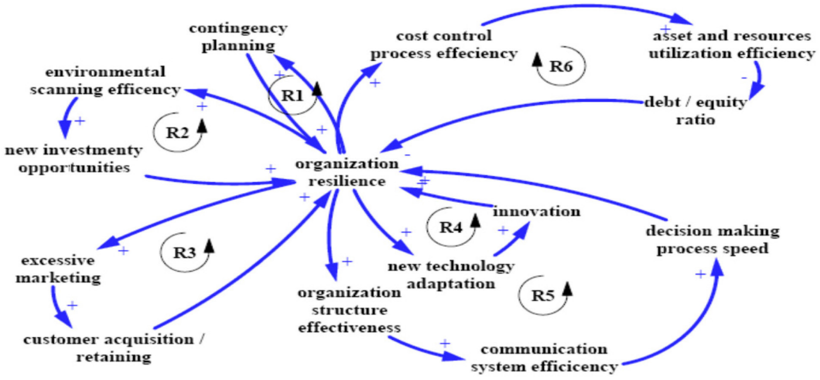
System dynamics unmistakably has perfect innate capabilities for helping responsible decision-making in an increasingly complex world. A paper by Ekinasi (2012) demonstrated that a typical real estate model is easily translated to system dynamics as a helpful template. Most notably, it presented Di Pasquale and Wheaton's (1996) implicit system dynamics model connecting the main three real estate markets: the consumer market, e.g., office or housing space, the asset market for real estate property and the construction market and suggested it to be a standard student assignment to replicate this model in system dynamics software. Similarly, Zhang, Geltner, and de Neufville (2018), in their paper on Chinese housing markets for pedagogical and policy analysis, use the Four Quadrant Model (4QM) as a basic starting-point platform for building an SD model of a real estate market. Another paper used the SD model to simulate decision-making in managing crises in Real Estate development (Abdel-Latif, et al., 2019).

Figure 13 Causal loop diagram of the DiPasquale-Wheaton model



Source: Zhang, et al., 2018

Figure 14 Real Estate Resilience Decision Making



Source: Abdel-Latif, et al., 2019

4.2. Creating an SD Model for Developer Decision-Making

In this study, we aim to develop a system dynamics model to simulate real estate developers' decision-making processes, specifically focusing on the implications of LL97 and BERDO emission penalties.

The model will incorporate various inputs, including building footprint, rent rate, green certification, other operation costs related to footprint, rent rate and annual rent escalation, vacancy, operating cost (OPEX), and capital expenditure (CAPEX). The OPEX will include steam, electricity, gas, and associated carbon emissions costs. The model will also consider the yearly penalties resulting from LL97 and BERDO, which directly impact the net cash flow for developers. This, in turn, will affect the net present value (NPV) of a building based on the cost of capital.

The NPV will influence the developer's decisions on green certification, energy retrofit, and other capital expenditures. These decisions will affect both CAPEX and the total emissions of the building. Additionally, the energy retrofit will impact the retrofit embodied carbon, which will contribute to the total embodied carbon. The NPV will also play a role in the "decision to rebuild" a building. If the developer opts to rebuild, this will result in a new embodied carbon for the new building, which will be added to the total embodied carbon.

Stocks:

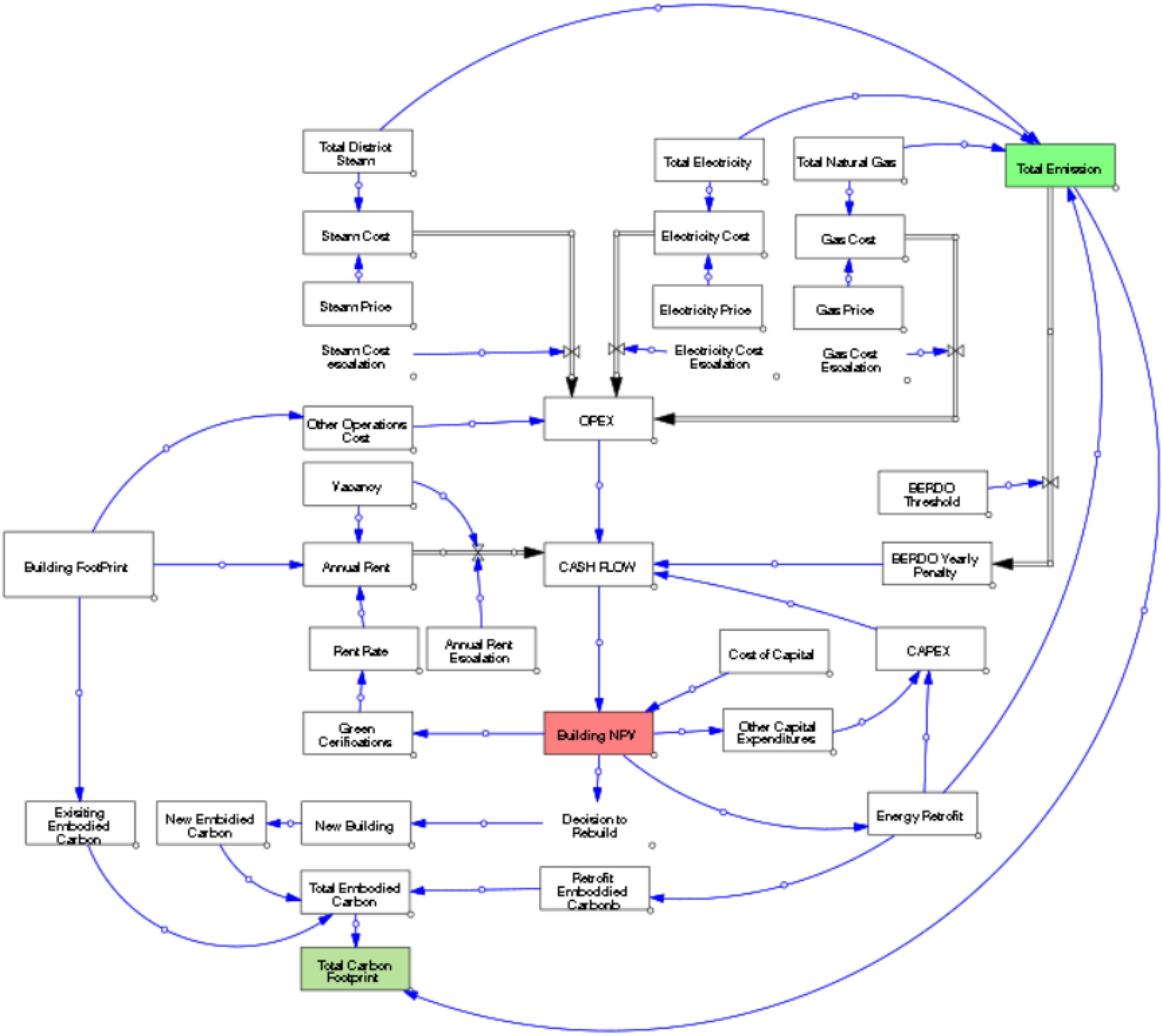
- Building Net Present Value (NPV) - This represents the present value of the building's expected cash inflows and outflows over its lifetime. The NPV is a crucial decision-making tool for developers to evaluate potential investments.
- Total Emissions - Represents the sum of carbon emissions from the building, including operational emissions (e.g., energy consumption) and embodied emissions (e.g., materials and construction). This stock reflects the environmental impact of the building and is affected by the implementation of LL97 and BERDO policies.
- Total Embodied Carbon - Represents the carbon emissions associated with the building's construction, renovation, or demolition processes. This stock is influenced by the developer's decision to retrofit or rebuild a building.
- Capital Expenditure (CAPEX) - This represents the total investment in the building for construction, renovation, or retrofitting. This stock is influenced by the developer's decision-making, such as the choice of green certification and energy retrofit measures.

Flows:

- Cash Inflows - Represent the revenue generated from the building, primarily through rent collections. This flow is affected by rent rates, annual rent escalation, and vacancy rates.
- Cash Outflows - Represents the building's operating expenses (OPEX), including costs of steam, electricity, gas, and other operational costs related to the building's footprint. The OPEX is also influenced by the carbon emissions penalties imposed by LL97 and BERDO policies.
- Yearly Penalties - Represent the financial penalties imposed on the building due to non-compliance with LL97 and BERDO emission targets. This flow affects the net cash flow and, consequently, the NPV of the building.
- Decision Flows - This represents the developer's decision-making processes based on the NPV of the building, which influences CAPEX, energy retrofit measures, and the decision to rebuild a building. These flows will directly impact the building's emissions and embodied carbon stocks.

By understanding these stocks and flows, we can simulate the interactions and dynamics within the system, enabling a comprehensive analysis of how LL97 and BERDO policies impact developer decision-making and the overall real estate market.

Figure 15 SD Model for Developer Decision-Making



Created using Venism PLE

5. New York’s Local Law 97: A Green Urban Revolution

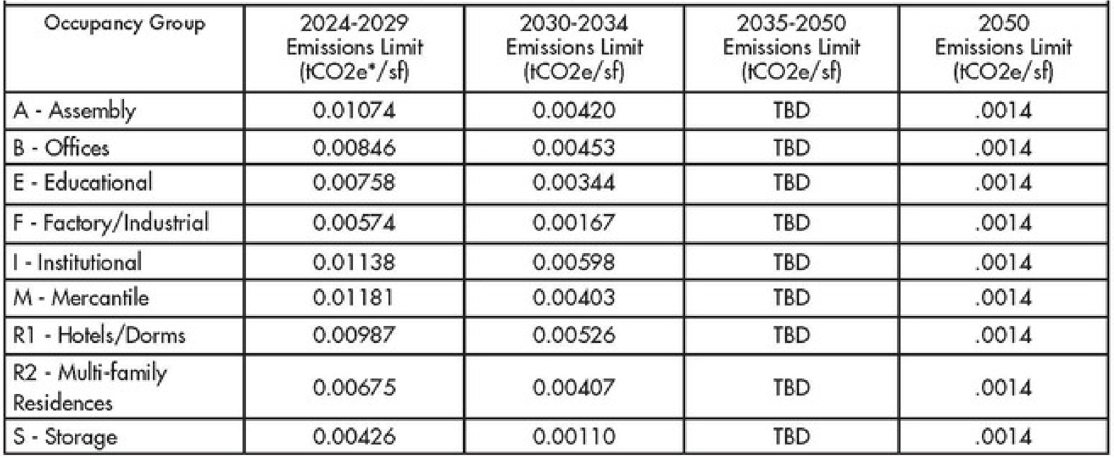
New York City has taken bold steps toward a greener future by introducing Local Law 97 (LL97), a groundbreaking policy to reduce carbon emissions from the city’s large buildings. This chapter delves into the details of LL97, exploring its scope, targets, and the affected buildings. It also examines the challenges faced by legacy office buildings constructed before 1985 and discusses the decision-making process for property owners and developers as they choose between renovation and demolition.

5.1. **The Unveiling LL97:** Scope, Targets, and Affected Buildings

LL97, enacted in 2019 as part of the Climate Mobilization Act, requires large buildings (over 25,000 square feet) to meet strict carbon emissions limits starting in 2024, with further reductions mandated in 2030 and beyond. The policy aims to reduce greenhouse gas emissions by 40% by 2030 and 80% by 2050, compared to a 2005 baseline (City of New York, 2019). Approximately 50,000 buildings are affected by LL97, accounting for nearly 60% of New York City’s built square footage (Urban Green Council, 2019).

It sets specific carbon emission caps for each building category based on the building’s occupancy group and its square footage. The caps vary across building types are as follows:

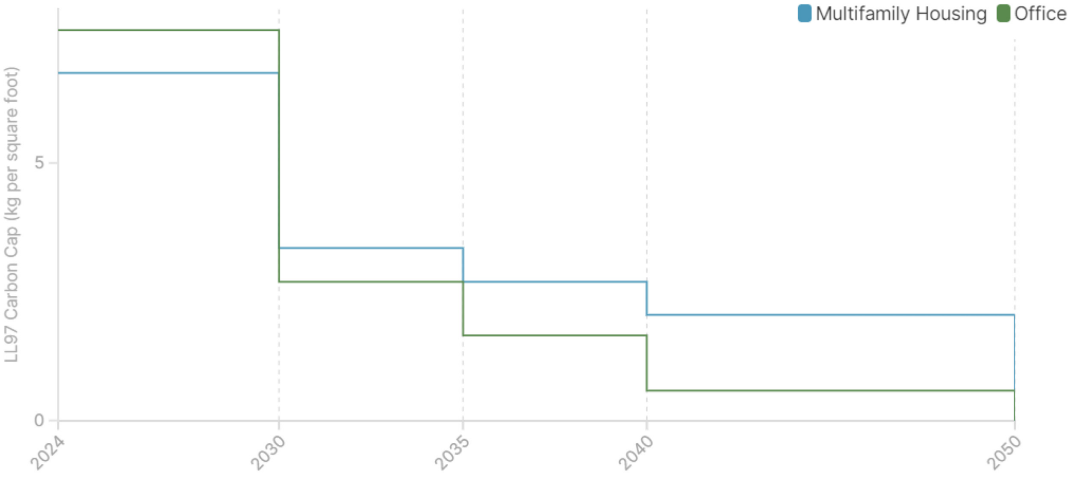
Figure 16 LL97 Emission Limits by Occupancy Group



Occupancy Group	2024-2029 Emissions Limit (tCO2e*/sf)	2030-2034 Emissions Limit (tCO2e/sf)	2035-2050 Emissions Limit (tCO2e/sf)	2050 Emissions Limit (tCO2e/sf)
A - Assembly	0.01074	0.00420	TBD	.0014
B - Offices	0.00846	0.00453	TBD	.0014
E - Educational	0.00758	0.00344	TBD	.0014
F - Factory/Industrial	0.00574	0.00167	TBD	.0014
I - Institutional	0.01138	0.00598	TBD	.0014
M - Mercantile	0.01181	0.00403	TBD	.0014
R1 - Hotels/Dorms	0.00987	0.00526	TBD	.0014
R2 - Multi-family Residences	0.00675	0.00407	TBD	.0014
S - Storage	0.00426	0.00110	TBD	.0014

Source: RAND, DPC, 2019

Figure 17 LL97 Office & Residential Emissions Limits Over Time



Source: Urban Green Council, 2019

It is important to note that emission caps referenced in Figure 16 LL97 Emission Limits by Occupancy Group are subject to change in future compliance periods, as the law is designed to progressively tighten the emission limits to achieve the overarching goal of reducing greenhouse gas emissions by 40% by 2030 and 80% by 2050, compared to a 2005 baseline.

Penalties for Non- Compliance:

Buildings that fail to comply with the emissions limits may face substantial fines. Penalties are calculated based on the building's excess emissions, determined by multiplying the difference between the building's annual emissions and the applicable emissions limit by the building's gross floor area. The penalty rate is $268 per metric ton of excess emissions (City of New York, 2019). For example, if a building exceeds its emission cap by 100 metric tons, the penalty will amount to $26,800 for that year. Additional penalties for non-compliance with reporting requirements or failure to submit an emissions intensity reduction plan may apply.

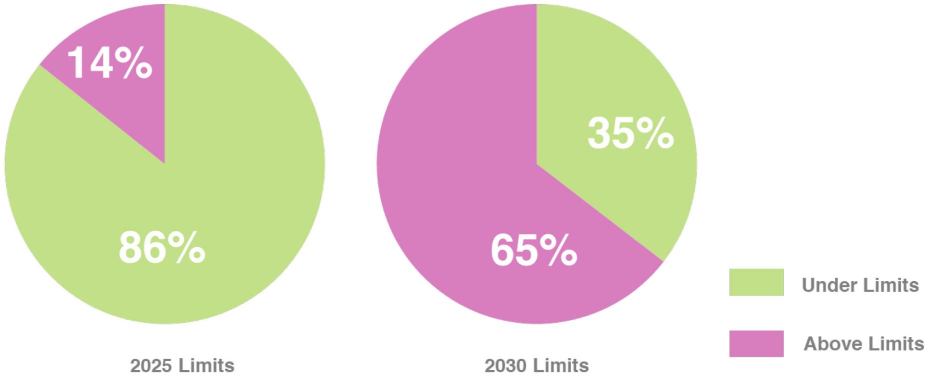
The fines for non-compliance are steep and purposely designed to incentivize owners to comply (City of New York, 2019):

- For owners of buildings that exceed their annual emissions limit, the law establishes a potential civil penalty based on the difference between the reported emissions and the annual emissions limit in metric tons, multiplied by $268.
- Failure to file the required annual report within 60 days of the deadline could result in a violation with a penalty of $0.50 per square foot of the gross floor area of the building per month, for a minimum penalty of $12,500 per month for a property with a gross floor area of 25,000 square feet.
- Making a false statement on a report is a misdemeanor and carries a penalty of $500,000 and/or imprisonment.

Properties that must comply are:

- Buildings over 25,000 square feet
- Two or more buildings on the same tax lot that together exceed 50,000 square feet
- Two or more condominium buildings governed by the same board of managers that together exceed 50,000 square feet

Figure 18 Buildings Above or Below LL97 Limits



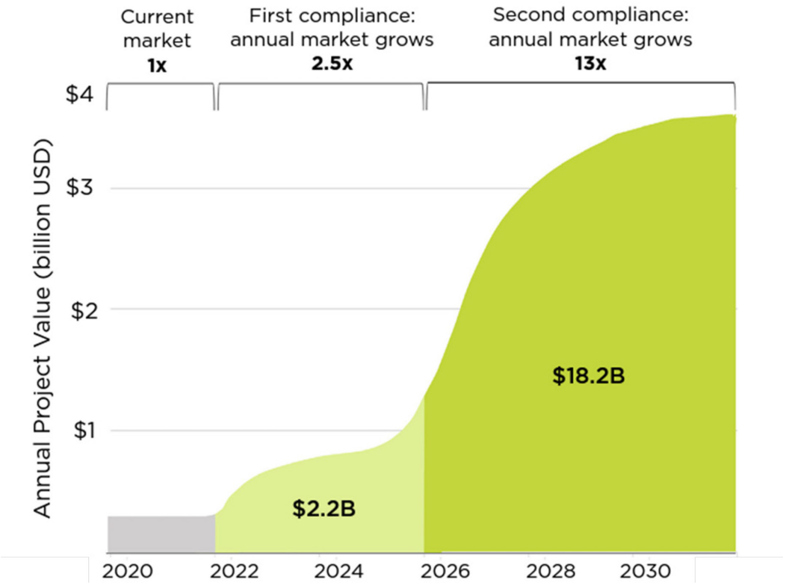
Own calculations using Data Source: NYC OpenData, 2021

The comprehensive approach of LL97, encompassing a diverse range of buildings and setting specific emission caps, is designed to drive significant carbon reductions in New York City's built environment. The policy provides a strong financial incentive for property owners and developers to invest in energy efficiency improvements and adopt greener building practices, ultimately contributing to a more sustainable urban landscape.

5.1.1. Retrofit Market:

LL97 is arguably the largest disruption of the NYC real estate industry. In order to meet the challenges ahead, new technologies and business models will be needed, and labor and professional services must significantly ramp up. There is an enormous opportunity for market growth if all buildings choose efficiently to meet the carbon caps; the 2030 forecast shows a $16.6B to $24.3B energy retrofit market opportunity in New York City. In 2018, just $235M was spent building improvements to save energy. The new law could trigger a 13-fold increase over the 2021 annual market, depending on how soon owners begin investing in their properties. (Urban Green Council, 2019).

Figure 19 Market Growth



Source: Urban Green Council, 2019

As per a study done by Urban Green Council in 2019, the costs of cost per square foot of various levels of energy efficiency retrofits as the below table. Each sector has a low and high retrofit cost estimate due to the city's wide range of building types, vintages, and systems. For analysis of buildings older than 1985, the High value is taken for energy retrofits.

Figure 20 Retrofit Cost Ranges

	Residential		Commercial	
Retrofit Size	**Low** (USD/SF)	**High** (USD/SF)	**Low** (USD/SF)	**High** (USD/SF)
Operational (<5% saved)	$0.20	$0.20	$0.50	$0.50
Light (5%-15% saved)	$1.00	$2.25	$1.50	$4.00
Medium (15%-25% saved)	$2.50	$3.75	$4.50	$8.50
Heavy (25%-35% saved)	$4.00	$6.00	$10.00	$13.00
Deep (>35% saved)	$7.00	$12.00	$15.00	$18.00

Source: Urban Green Council, 2019

5.2. NYC Uncharted Emission Territory

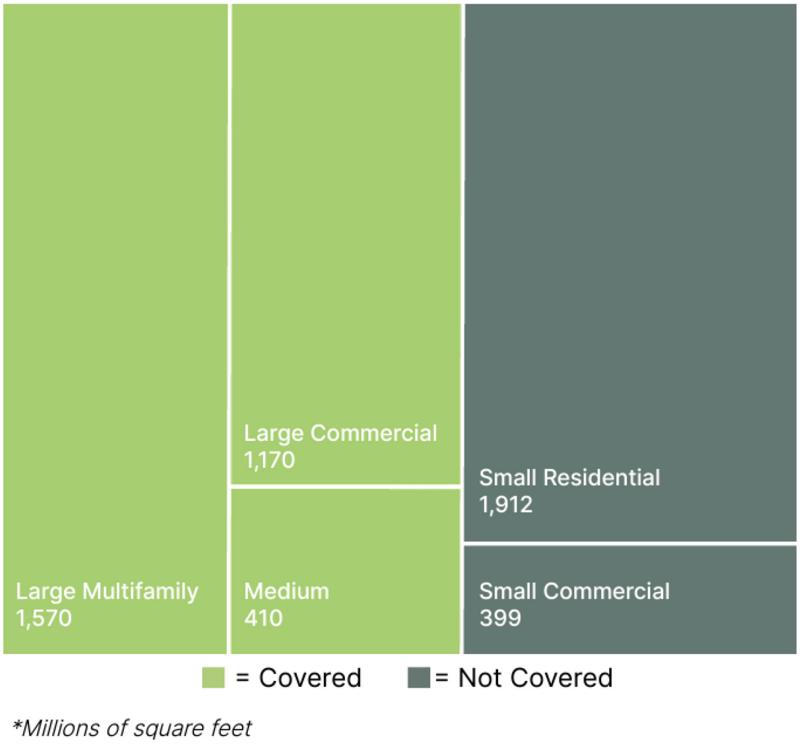
According to the New York City Mayor's Office of Sustainability, buildings in NYC contribute to nearly 70% of the city's total greenhouse gas (GHG) emissions (New York City, 2014). In 2019, the city's total emissions were approximately 52 million metric tons of carbon dioxide equivalent (CO2e) (MOCEJ, 2023). The NYC Department of City Planning estimates the city's total building area to be around 5.8 billion square feet (PLUTO, 2022).

LL97 targets medium and large buildings with a gross floor area of 25,000 square feet or more. It is estimated that this law covers around 50,000 buildings, representing approximately 60% of the city's total building area (Urban Green Council, 2022). Consequently, the emissions covered by LL97 account for nearly 40% of NYC's total emissions, or about 20.8 million metric tons of CO2e (Urban Green Council, 2019).

Building Area and Emissions Not Covered by LL97

The remaining 40% of the building area in NYC, approximately 2.3 billion square feet, is not covered by LL97. Smaller than 25,000 square feet, these buildings contribute to an estimated 60% of the city's total emissions, or roughly 31.2 million metric tons of CO2e (Urban Green Council, 2019).

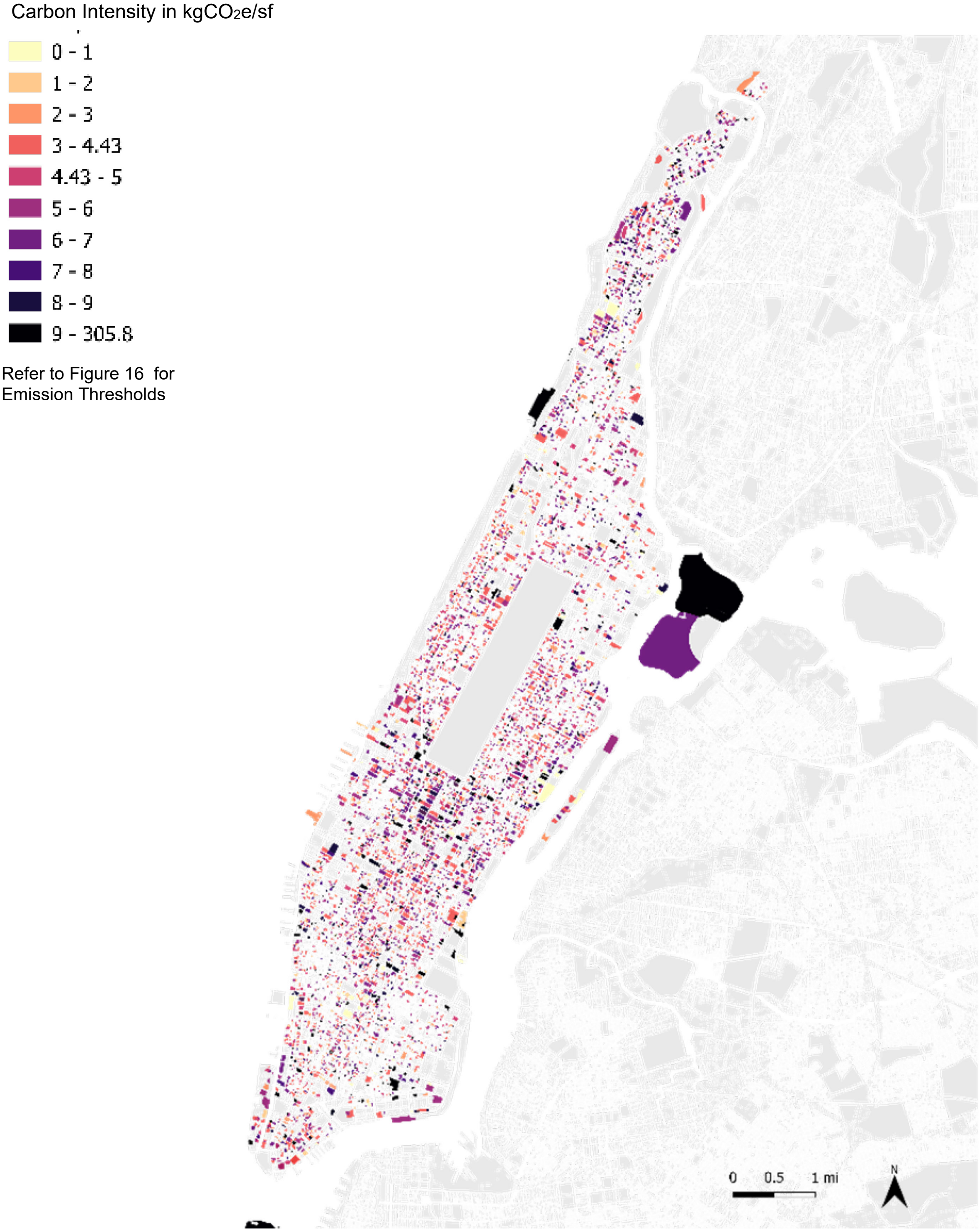
Figure 21 Citywide Building Area



Source: Urban Green Council, 2019

While LL97 addresses a significant portion of NYC's building area and associated emissions, a substantial amount of emissions remain outside the scope of the law. To achieve the city's ambitious climate goals, it is crucial to consider additional policies and measures targeting smaller buildings and further reducing emissions across the entire building sector.

Figure 22 Manhattan Emissions



Refer to Figure 16 for Emission Thresholds

Created using Data Source: NYC OpenData, 2021

Figure 22 shows Manhattan's emissions as the primary borough for analysis in New York based on its high concentration of large commercial and residential buildings subject to LL97 regulations. Manhattan's built environment also represents dense urban centers' challenges in reducing carbon emissions.

5.3. NYC Grid Decarbonization

As New York State endeavors to achieve net-zero emissions from the electricity grid, renewable energy emerges as a potent ally in pursuing carbon neutrality. This section explores the potential benefits of integrating renewable energy into the urban landscape and the state's efforts to promote clean energy solutions in the context of New York City's LL97 objectives.

New York State's ambitious Climate Leadership and Community Protection Act (CLCPA) targets achieving a 70% renewable energy supply by 2030 and a zero-emission electricity grid by 2040 (NYSERDA, 2021). The state's commitment to clean energy has the potential to significantly bolster New York City's efforts to reduce greenhouse gas emissions from buildings, as mandated by LL97.

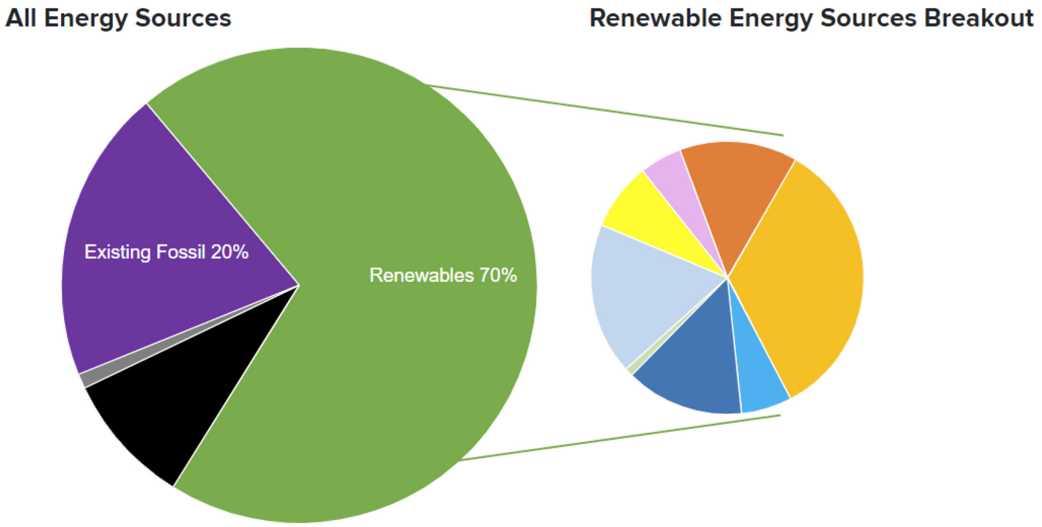
The city can benefit by incorporating renewable energy sources such as solar, wind, and geothermal into new and retrofitted buildings. These clean energy solutions reduce dependence on fossil fuels, lower greenhouse gas emissions, improve local air quality, and foster energy resilience (US Department of Energy, 2019).

The state's support for renewable energy initiatives allows property owners and developers to access various incentives and programs. For instance, the New York State Energy Research and Development Authority (NYSERDA) offers incentives for solar installations, wind energy projects, and energy efficiency improvements (NYSERDA, 2021).

Furthermore, the state's commitment to a clean energy grid can stimulate innovation and job creation in the renewable energy sector, fostering economic growth while addressing climate change. By aligning their building renovation and retrofit strategies with the state's clean energy goals, property owners and developers in New York City can contribute to a sustainable and resilient urban environment.

This plan, when successfully implemented, can significantly help buildings in New York City (NYC) avoid penalties under Local Law 97 (LL97), which mandates stringent emission reduction targets for the city's building sector. This chapter explores the synergies between New York State's renewable energy plan and NYC's LL97, focusing on the benefits and challenges of this interconnected approach.

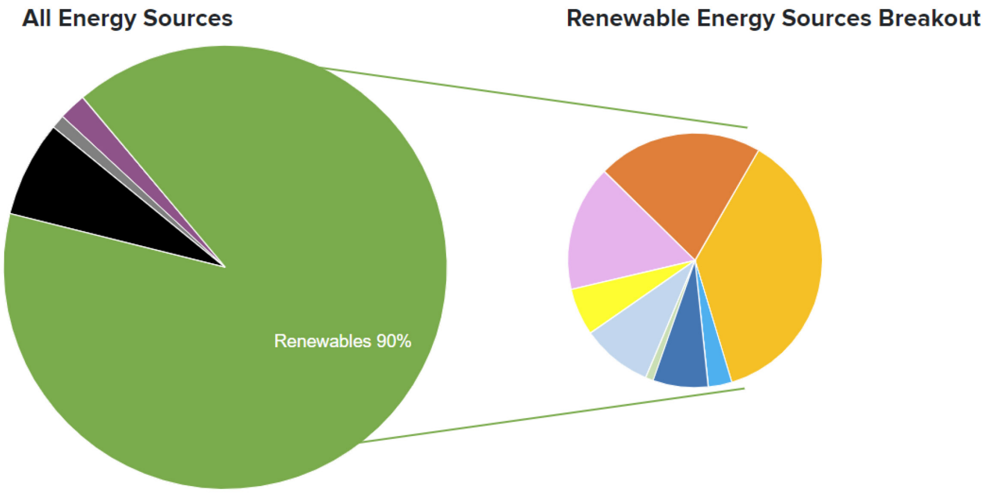
Figure 23 Downstate (Zones F-K - contains New York City) Generation 2030



Source: NYSERDA, 2022

- 80% of the downstate load will be met with zero emissions resources in 2030. 70% of this electricity comes from renewable resources (26% from existing New York and Quebec hydroelectric generation and an illustrative Tier 4 renewable energy project, 24% from offshore wind generation, 20% from solar, land-based wind, and other renewables). The other 10% comes from zero-emission resources that, include nuclear generations.
- 2030 CO2e downstate: 0.1 metric tonne/MWh
-

Figure 24 Downstate (Zones F-K - contains New York City) Generation 2040



Source: NYSERDA, 2022

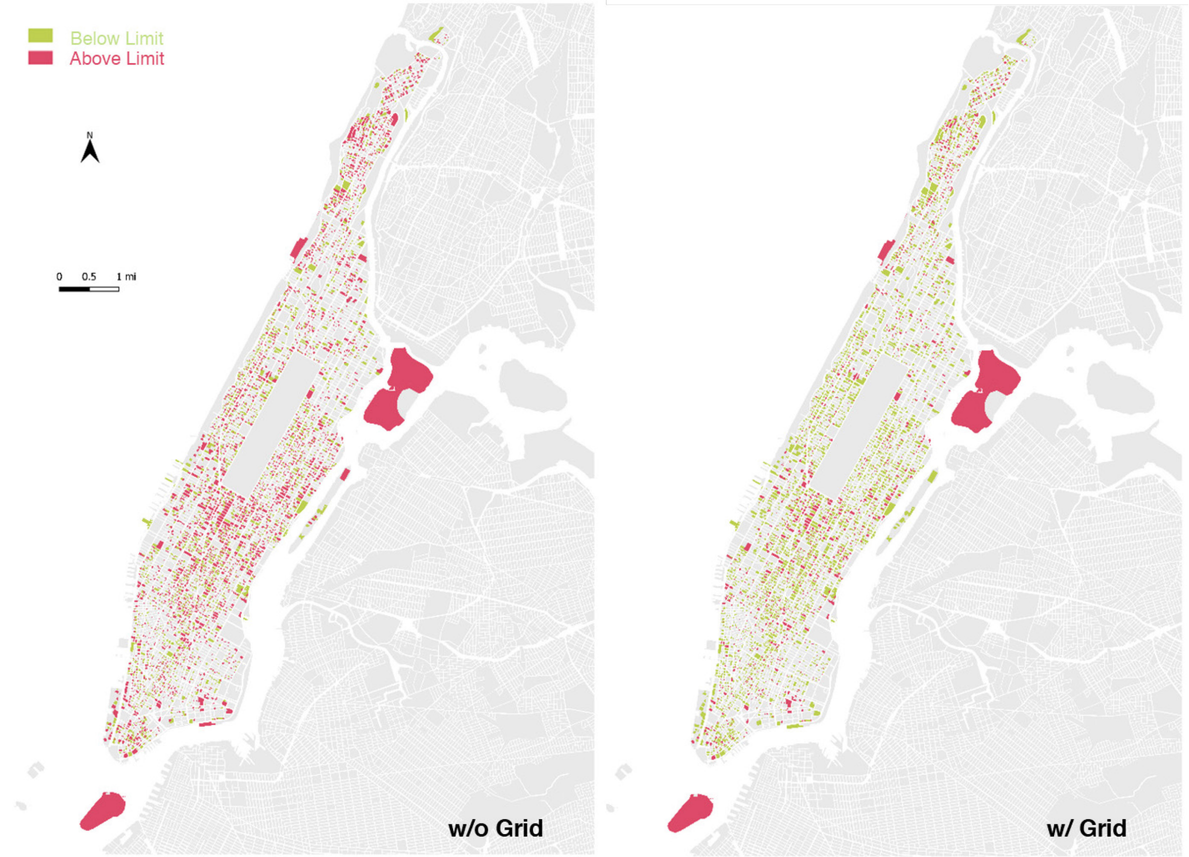
Downstate load is completely met with zero emissions generation in 2040. 90% of this electricity comes from renewable resources, while the other 10% comes from zero-emission resources, including nuclear generation and Renewable Natural Gas.

5.3.1. **The Synergistic Effect:** Green Electricity Plan and LL97 Penalties

The successful implementation of New York State's green electricity plan can substantially alleviate the pressure on NYC building owners to comply with LL97. As the grid becomes greener, the operational carbon emissions of buildings connected to it will decrease, making it easier for building owners to meet LL97's stringent emission limits without incurring penalties.

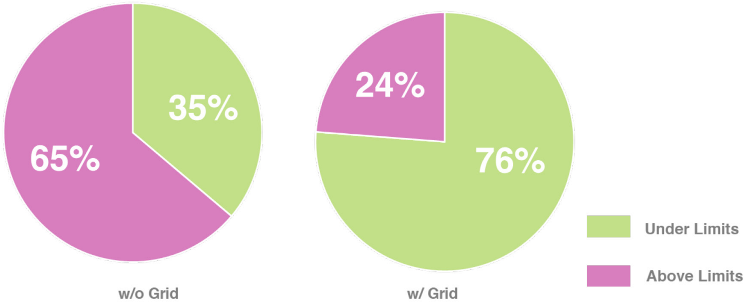
Moreover, a greener grid can support the electrification of building systems, such as heating and cooling, which rely heavily on fossil fuels (natural gas). The transition to electricity-based systems powered by renewable sources can help reduce buildings' overall carbon emissions, contributing to LL97 compliance.

Figure 25 Carbon Intensity in 2030 limits w/o and w/ green electricity plan



Created using Data Source: NYC OpenData, 2021
w/o Grid shows the buildings that are above the 2030 limit without Grid achiving 70% Nonrenewables target
w/ Grid shows the buildings that are above the 2030 limit after the Grid achieves 70% Nonrenewables target

Figure 26 Buildings Above or Below 2030 LL97 Limits



Created using Data Source: NYC OpenData, 2021

Challenges and Considerations

While the green electricity plan offers potential benefits for NYC building owners, challenges remain. Ensuring the timely development and integration of renewable energy projects into the grid is critical for achieving the state's clean energy targets. Additionally, building owners must navigate the complexities of retrofitting and upgrading building systems to take full advantage of the greener grid.

Furthermore, as the green electricity plan primarily addresses operational carbon emissions, it is essential not to overlook the importance of embodied carbon emissions in the built environment. Building owners and developers must adopt a holistic approach, considering operational and embodied carbon emissions to achieve a sustainable, low-carbon built environment.

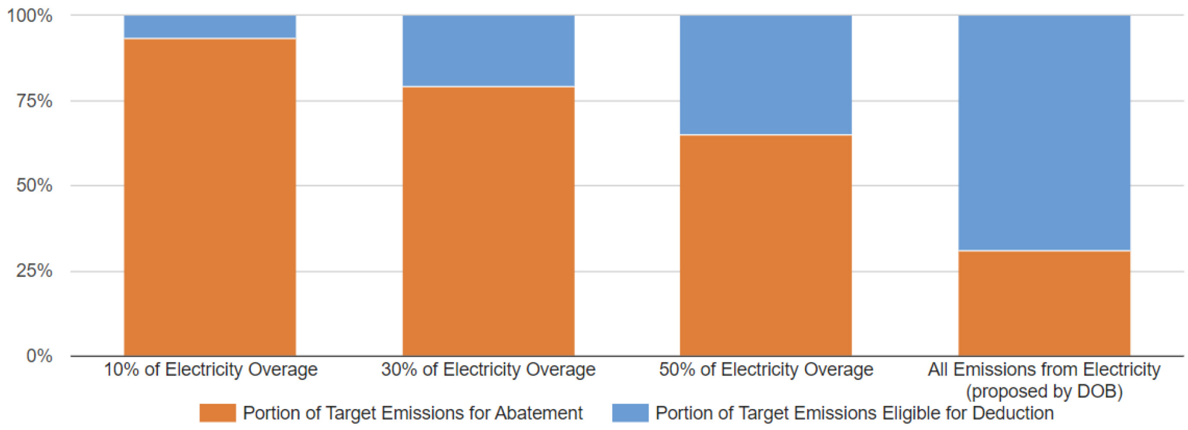
5.3.2. Renewable Energy Credits

LL97 rules permit property owners to purchase Renewable Energy Credits (RECs) and deduct the equivalent value from their emissions overage. RECs used for LL97 compliance must be derived from renewable energy projects in the New York City region or projects that deliver power to the New York City electrical grid. The sale of RECs represents a critical revenue stream for renewable energy developers, allowing purchasers to subsidize the decarbonization of the grid (NYC Comptroller, 2022).

However, LL97 allowed for RECs based on the assumption of supply constraints. As noted in 5.1, in 2021, the New York State Public Service Commission and NYSERDA approved two large renewable energy projects – the Clean Path NY project (CPNY) and the Champlain Hudson Power Express project (CHPE) – to deliver renewable power to New York City to have the grid on 70% renewables by 2030. The now-abundant supply of RECs that will be available means that the City must reconsider limits on the use of RECs for LL97 compliance (NYC Comptroller, 2022).

Allowing RECs to be used for a building's total electricity overage, as DOB proposes, would significantly reduce the impact of the law. One option for addressing this problem is to limit the percentage of a building's electricity overage that RECs can offset.

Figure 27 Impact of REC Limits on Emission Reduction



Source: NYC OpenData, 2021

5.4. **Legacy Offices:** The Pre-1985 Dilemma

New York City's office buildings constructed before 1985 face particular challenges in meeting the stringent emission standards set by LL97. These legacy buildings often feature outdated systems and materials, contributing to higher energy consumption and carbon emissions (Building Energy Exchange, 2020). The study includes 172 offices constructed before 1985 and not renovated since then. These buildings are also above 2030 limits if the green grid is implemented. RECs are not considered as no data is available regarding costs and eligibility. This section examines the additional costs associated with renovating these buildings and explores the potential impact of changes in fire safety regulations on renovation costs.

Figure 28 Key Facts: Pre-1985 Offices

$268 Fines Per ton of exceeding C02e

LL97 Buildings over 25,000 ft² to meet greenhouse gas emissions limits by 2024, with stricter limits in 2030

172 offices

43M ft²

40% Avg. Vacancy (2023)

Source: CoStar

300K+

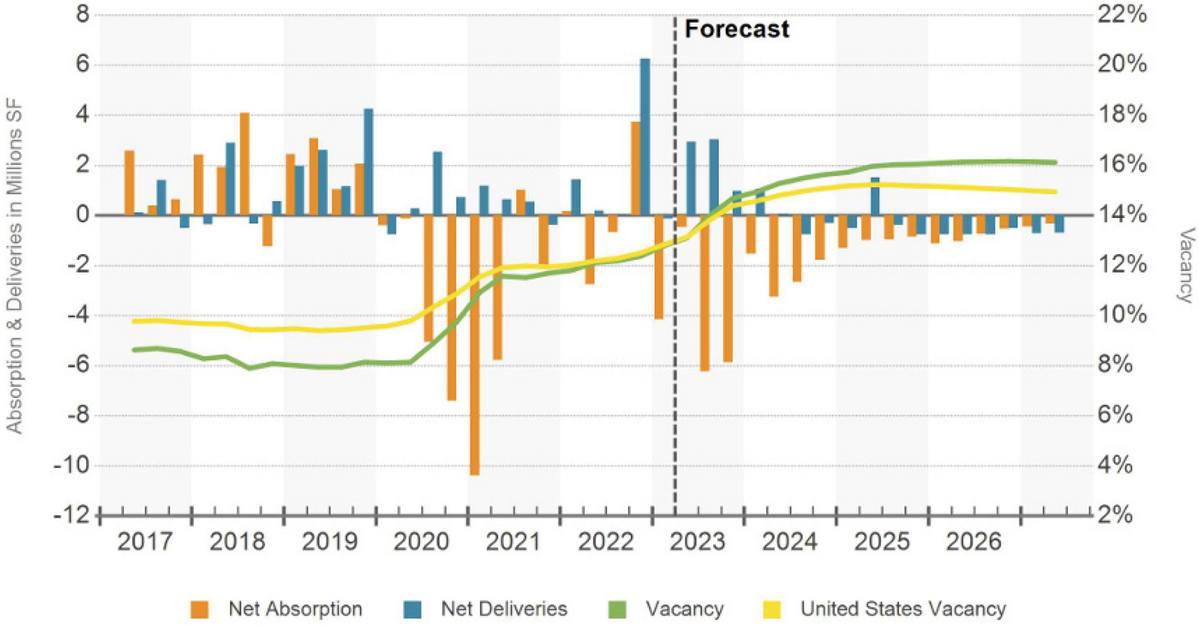
Metric Tons CO2e Carbon Emissions per year (2022)

$162 K

Estimated Total Annual Penalty starting 2030

Source: data.cityofnewyork.us/Environment

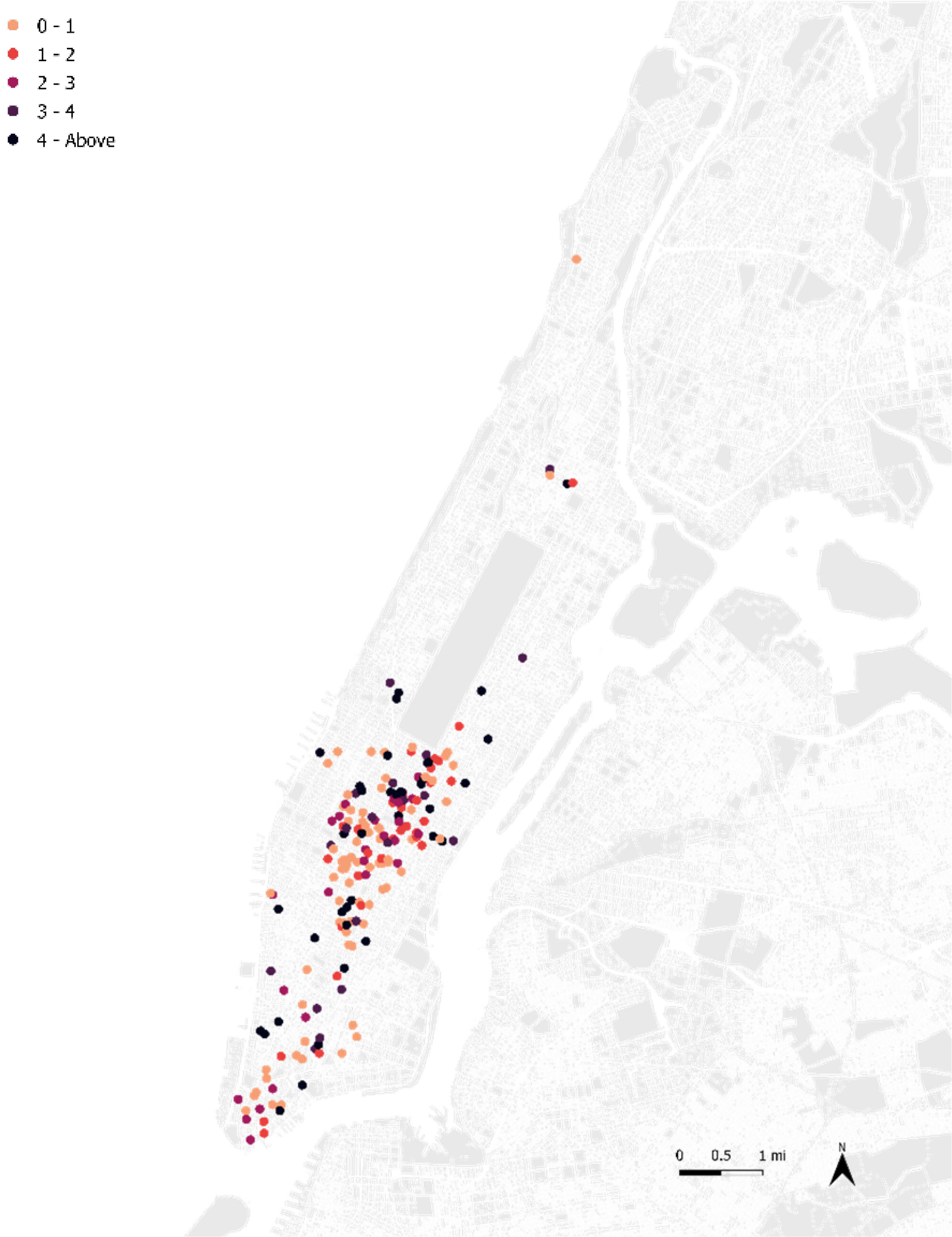
Figure 29 NYC Office Market



Source: CoStar, 2023-1

Figure 30 Office built before 1985

Carbon Intensity above 2030 limits (kgCO2e/sf)



Created using Data Source: NYC OpenData, 2021

5.4.1. **Weighing the Options:** Renovate or Rebuild?

Property owners and developers must make critical decisions regarding the future of these pre-1985 office buildings. Two primary options are renovating the building to improve its energy performance or demolishing it and constructing a new, more energy-efficient building (Urban Green Council, 2019).

Renovations may involve a range of measures, such as upgrading the building's envelope, replacing outdated HVAC systems, installing energy-efficient lighting, and optimizing building operations (Building Energy Exchange, 2020). While these retrofits can significantly improve the building's energy performance, they may be costly and disruptive, particularly for buildings with extensive renovation needs (Urban Green Building Council, 2019). A study by the Building Energy Exchange (2020) estimated that comprehensive retrofits to achieve the 2030 emission targets for large office buildings would cost between $20 and $65 per square foot, depending on the building's existing condition and the extent of required upgrades. The cost of retrofitting older buildings tends to be higher due to the need to replace aging systems and infrastructure.

Impact of Renovation: Triggering other regulations

In addition to the costs associated with energy efficiency upgrades, property owners and developers must consider the potential impact of regulation changes since the building was last renovated. In the years following the construction of these pre-1985 buildings, fire safety codes have evolved to enhance the safety and resilience of buildings (National Fire Protection Association, n.d.). Consequently, renovations to comply with LL97 may also need to address fire safety upgrades, increasing renovation costs.

For instance, the Local Law 26 of 2004 required the installation of automatic sprinkler systems in existing office buildings over 100 feet in height by July 1, 2019 (City of New York, 2004). Buildings undergoing renovations to meet LL97 requirements may need to comply with this and other fire safety regulations, which could add to the overall cost of the renovation project.

To bring pre-1985 buildings up to current fire safety standards, building owners must comply with the NYC Fire Code, Local Law 26, and Local Law 10, which mandate the following upgrades:

- Installation of automatic sprinkler systems throughout the building, including common areas, hallways, and individual units (NYC Fire Code).
- Photoluminescent exit path markings and emergency lighting systems guide occupants to exits in case of a fire or power outage (Local Law 26).
- Installation of fire-resistant materials and fireproofing for structural elements (Local Law 10).

Other Laws & codes affecting Office buildings:

- Local Law 58 of 1987 (Accessibility)
  This law requires that office buildings be accessible to people with disabilities, including wheelchair ramps, accessible restrooms, and other accommodations.

- New York City Building Code (2008 and subsequent revisions)
  Some notable changes from the previous code that significantly affect commercial office buildings:

    - Structural Design: Changes included updated seismic design requirements, wind design provisions, and material standards.
    - Fire Protection and Life Safety: Included improved compartmentation, increased fire-resistance ratings for certain building elements, and additional requirements for fire-resistant joint systems, introduced new requirements for fire sprinkler systems, fire alarm systems, and emergency voice communication systems in high-rise office buildings.
    - Mechanical and Plumbing Systems: New requirements for HVAC equipment efficiency, plumbing fixtures, and pipe materials were included.

The costs associated with these upgrades depend on the building's size, complexity, and existing infrastructure. For example, installing an automatic sprinkler system may cost between $2 to $7 per square foot (Fire Protection Group, Inc.), while photoluminescent exit path markings can range from $1,000 to $3,000 for a small building (Safe-T-Nose).

In addition to the costs associated with fire safety system upgrades, owners of pre-1985 buildings in New York City (NYC) must also consider the potential structural costs of retrofitting projects. Ensuring adequate fire escapes and egress routes is critical to building safety.

- Replacement or repair of existing fire escapes: Many pre-1985 buildings in NYC feature external fire escapes, which may have deteriorated over time or no longer comply with current safety standards. Building owners may need to invest in repairing, replacing, or upgrading these fire escapes to meet the NYC Building Code and Fire Code requirements. The cost of fire escape replacement can range from $15,000 to $100,000, depending on factors such as the building's height, the number of fire escapes, and access to the installation site.

- Egress route modifications: Modern safety standards may necessitate modifications to the building's internal egress routes, such as widening corridors or stairwells, improving lighting, and installing fire doors. These modifications can be costly and require significant structural alterations, such as relocating walls or reinforcing structural elements to accommodate the changes.

- Addition of secondary means of egress: Owners may need additional staircases or exit doors if a building does not have adequate exits or secondary means of egress. This can be a complex and expensive endeavor, particularly for buildings with limited space or those requiring extensive structural modifications to accommodate new exits.

On the other hand, demolishing the building and constructing a new, energy-efficient structure may offer long-term benefits regarding energy savings and compliance with LL97. However, demolition and new construction also entail significant upfront costs and the environmental impacts associated with construction materials and processes (Building Energy Exchange, 2020).

Ultimately, the decision between renovating or demolishing a legacy office building will depend on factors such as the building's current condition, the extent of required retrofits, the availability of financing, and the long-term goals of the property owner or developer (Urban Green Building Council, 2019).

5.4.2. **Repurposing Spaces:** Transforming Offices into Homes

The prospect of transforming outdated office buildings into residential spaces has gained traction as a viable solution for reducing emissions and addressing housing shortages in New York City. This section explores the potential benefits and challenges of converting commercial spaces into homes and the implications for housing dynamics in the city.

Housing Dynamics in the Big Apple

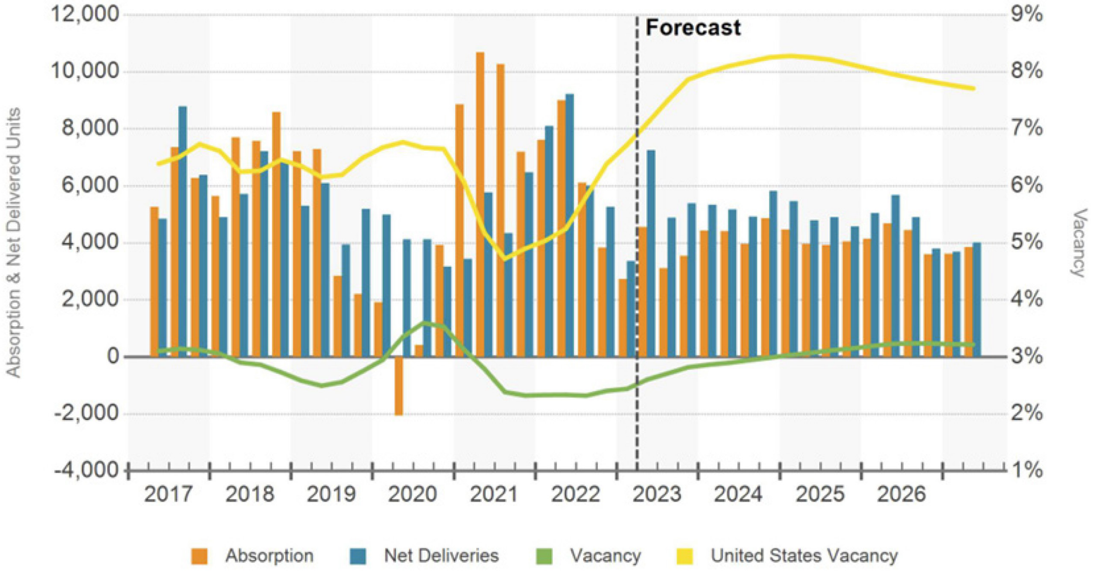
New York City's housing market has long been characterized by a high demand for housing and limited supply, resulting in escalating rents and housing prices. With the growing popularity of remote work and an increasing number of vacant office spaces, converting commercial properties into residential units presents an opportunity to address these housing challenges.

Converting offices into residential spaces can help increase the city's housing stock, potentially easing the pressure on housing prices and making it more accessible for a broader range of income levels. Additionally, these conversions could contribute to the revitalization of urban neighborhoods by repurposing underutilized commercial properties and fostering mixed-use development (Furman Center, 2020).

However, transforming office spaces into homes also comes with particular challenges. The process requires significant investment to modify the building's infrastructure, including adapting the layout to accommodate residential units, upgrading systems to meet energy efficiency standards, and ensuring compliance with building and fire safety codes. Furthermore, navigating zoning regulations and obtaining necessary permits can be time-consuming and costly.

Despite these challenges, repurposing office spaces into residential units holds promise to address the city's housing demands and the emissions reduction goals of LL97. The successful implementation of such conversions hinges on carefully assessing the costs and benefits and developing supportive policies and incentives to facilitate the transformation of these legacy office buildings.

Figure 31 NYC Multi-Family Market



Source: CoStar, 2023-2

4.2.2.1. New Office vs. Residential Conversion:

Developers face complex decision-making processes when dealing with aging commercial office buildings. This chapter explores the choice between demolishing and constructing a new office building versus converting the old office building into residential units. The system dynamics model developed in 4.2 (Creating an SD Model for Developer Decision-Making) is used as a simulation tool. The simulation considers the 172 office buildings constructed before 1985 and not renovated since then. We consider 3 Scenarios: Renovate, Build New and Conversion to Multi-Family. For comparing the scenarios, we have assumed that the buildings in all 3 scenarios will build/renaovated to achieve the same energy efficiency standard. The buildings will be achiving full electrification by 2040. In addition, the following assumptions are used:

- Existing Office Rating – 1 & 2 Star
- Existing Rent - $34.2 /sf (CoStar, 2023-3)
- 4 & 5 Star Rated Office Rent for New Building - $71.73 /sf (CoStar, 2023-1)
- Converted Multi-Family (4 & 5 Star rated) - $4022 /Unit (CoStar, 2023-2)
- Existing Office Vacancy – 40% (CoStar, 2023-3)
- New Office Building Vacancy – 16.30% (CoStar, 2023-1)
- Converted Multi-Family Vacancy – 2.5% (CoStar, 2023-2)
- Office Renovation Cost - $95 /SF (Urban Green Council, 2019)
- New Office Construction Cost - $740 /sf (RLB, 2023)
- Residential conversion Cost - $200 /sf (RLB, 2023)
- Average Residential Unit Size – 700sf (HPD, 2022)
- Office Caprate – 7% (CBRE, 2023)
- Residential Capate – 4.5% (CBRE, 2023)
- Discount Rate for NPV Analysis – 10% (Ori, 2019)
- Discount Rate for Net Present Carbon (NPC) Analysis – 2.5% (Interagency Working Group, 2022)

Base Scenario : Doing Nothing
In this scenario, a developer, facing the implications of LL97, opts for a seemingly counterintuitive strategy - doing nothing. Despite owning a portfolio of buildings that fail to meet the energy efficiency standards set by LL97, the developer decides not to undertake any renovation or retrofitting measures to reduce carbon emissions.The decision is driven by a cost-benefit analysis. The developer considers the financial implications of extensive renovations, including the direct costs of retrofitting, potential increase in vacancy rates during construction, loss of rental income, and opportunity costs associated with diverting resources towards renovation projects.
When weighed against the LL97 penalties, the developer concludes that the costs of renovation significantly outweigh the imposed fines. As a result, the developer decides to continue operations as usual and pay the LL97 penalties, perceiving them as a more cost-effective alternative. This decision, however, may not account for potential reputational risk, tenant preference for energy-efficient spaces, and future regulatory changes, which could make this "do nothing" strategy less viable in the long term. In this scenario we assume that the New York State electricity Grid is decarbonized by 2040

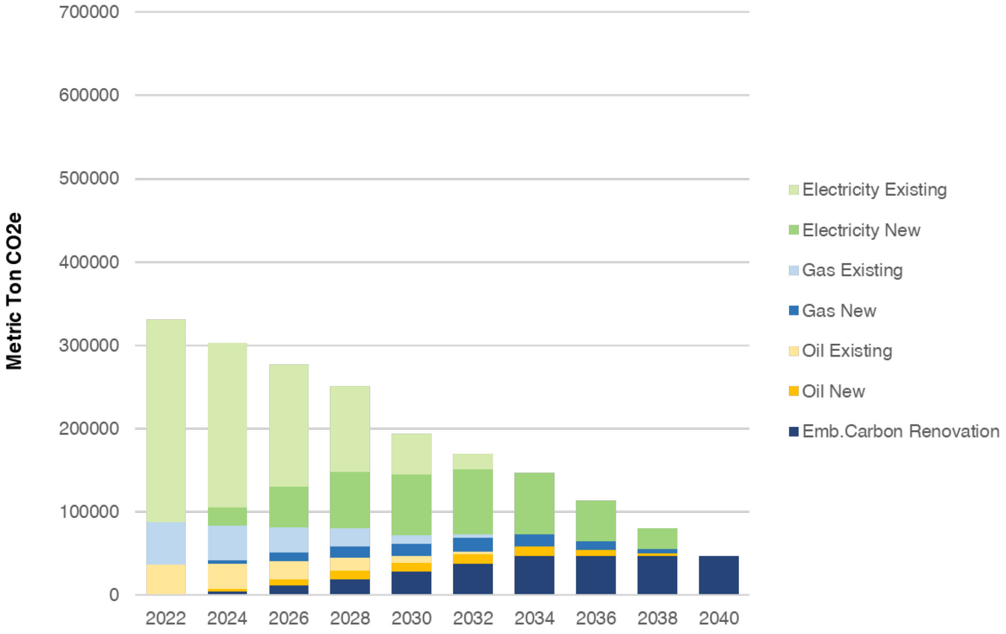
CO2e Operational Emissions calculated as per LL97: 4.55 M Metric Ton CO2e
Net Present Value: $2.18 M
Net Present Carbon (Time Value of Total CO2e) : 3.35 M Metric Ton CO2e

Scenario 1: Renovation the Old Office Building:
In this scenario, the developer decides to renovate the existing office building, retaining its commercial use. Factors that may influence this decision include:

- The structural condition of the existing building, making renovation more feasible and cost-effective than demolition or conversion
- Lower construction costs and shorter project timelines compared to new office construction or conversion projects
- The opportunity to retain existing tenants or attract new ones with upgraded facilities and amenities
- A supportive regulatory environment, including tax incentives, grants, or other financial assistance for building renovations

CO2e Operational Emissions calculated as per LL97: 2.91 M Metric Ton CO2e
Net Present Value: $13.22 M
Net Present Carbon (Time Value of Total CO2e) : 2.54 M Metric Ton CO2e

Figure 32 Scenario 1 Total CO2e

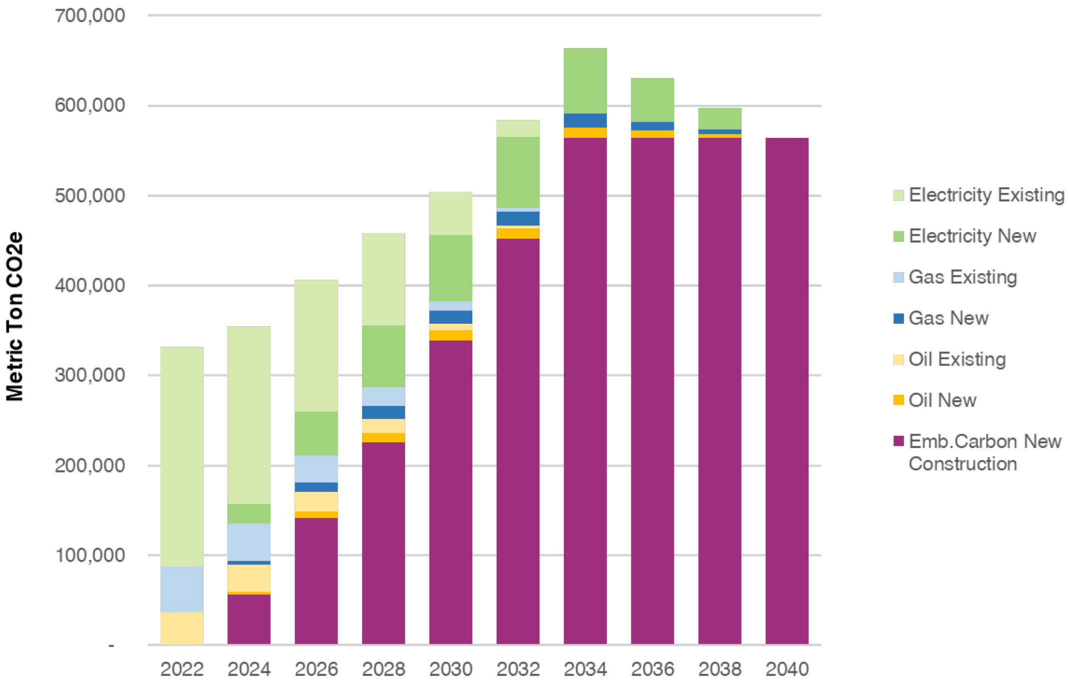


Scenario 2: Demolition and New Office Construction:
In this scenario, the developer decides to demolish the existing office building and construct a new one. Factors that may influence this decision include:

- High demand for modern office spaces
- The potential for higher rental rates and returns on investment
- Availability of financing for new construction projects
- The structural condition of the existing building, making renovation or conversion less feasible or cost-effective

CO2e Operational Emissions calculated as per LL97: 2.91 M Metric Ton CO2e
Net Present Value: $128.60 M
Net Present Carbon (Time Value of Total CO2e) : 3.65 M Metric Ton CO2e

Figure 33 Scenario 2 Total CO2e



Scenario 3: Conversion to Multi-Family:
In this scenario, the developer opts to convert the existing office building into residential units. Factors that may drive this decision include:

- Lower construction costs and shorter project timelines compared to new office construction
- The potential for higher returns on investment due to the residential market's performance
- The structural condition of the existing building makes it more suitable for conversion than demolition

CO2e Operational Emissions calculated as per LL97: 2.91 M Metric Ton CO2e
Net Present Value: $47.62 M
Net Present Carbon (Time Value of Total CO2e) : 2.67 M Metric Ton CO2e

Figure 34 Scenario 2 Total CO2e

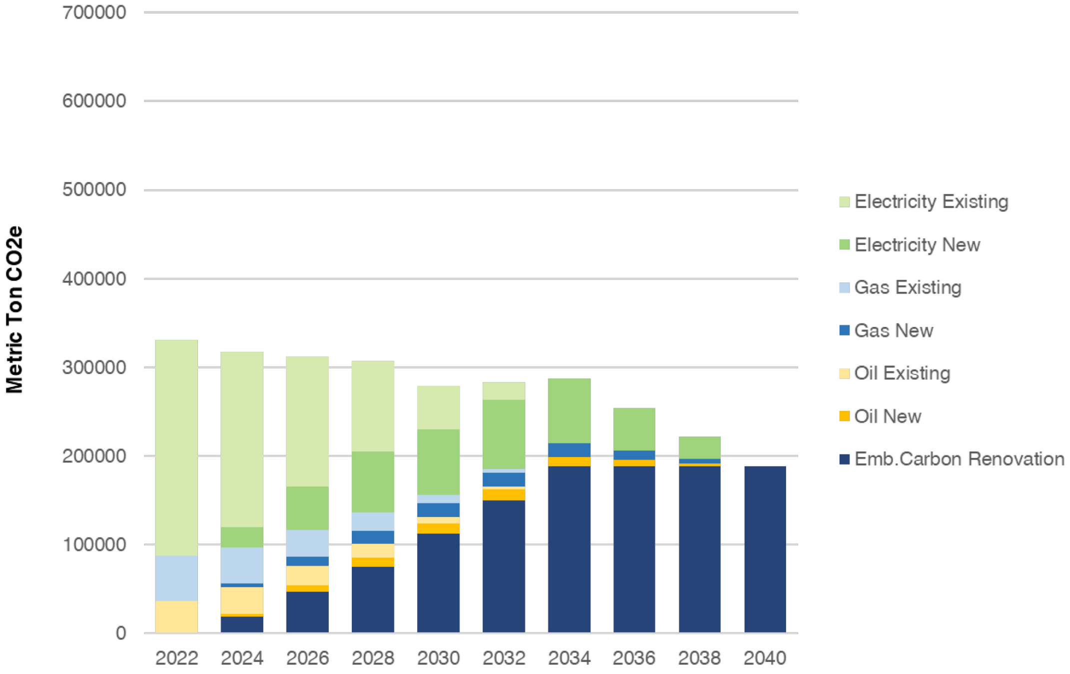
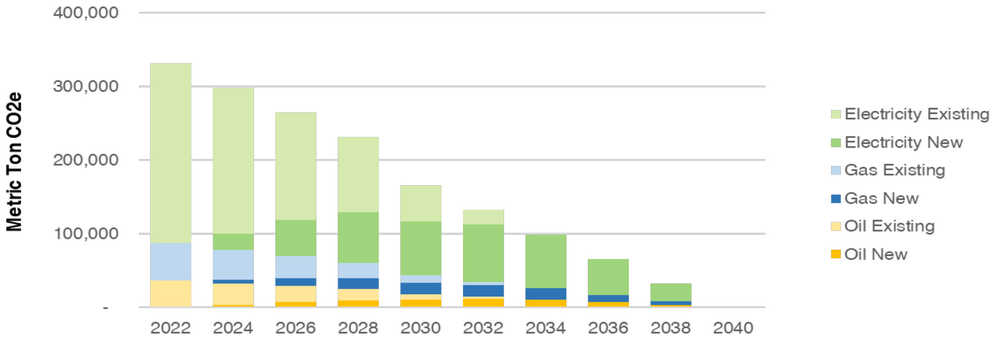
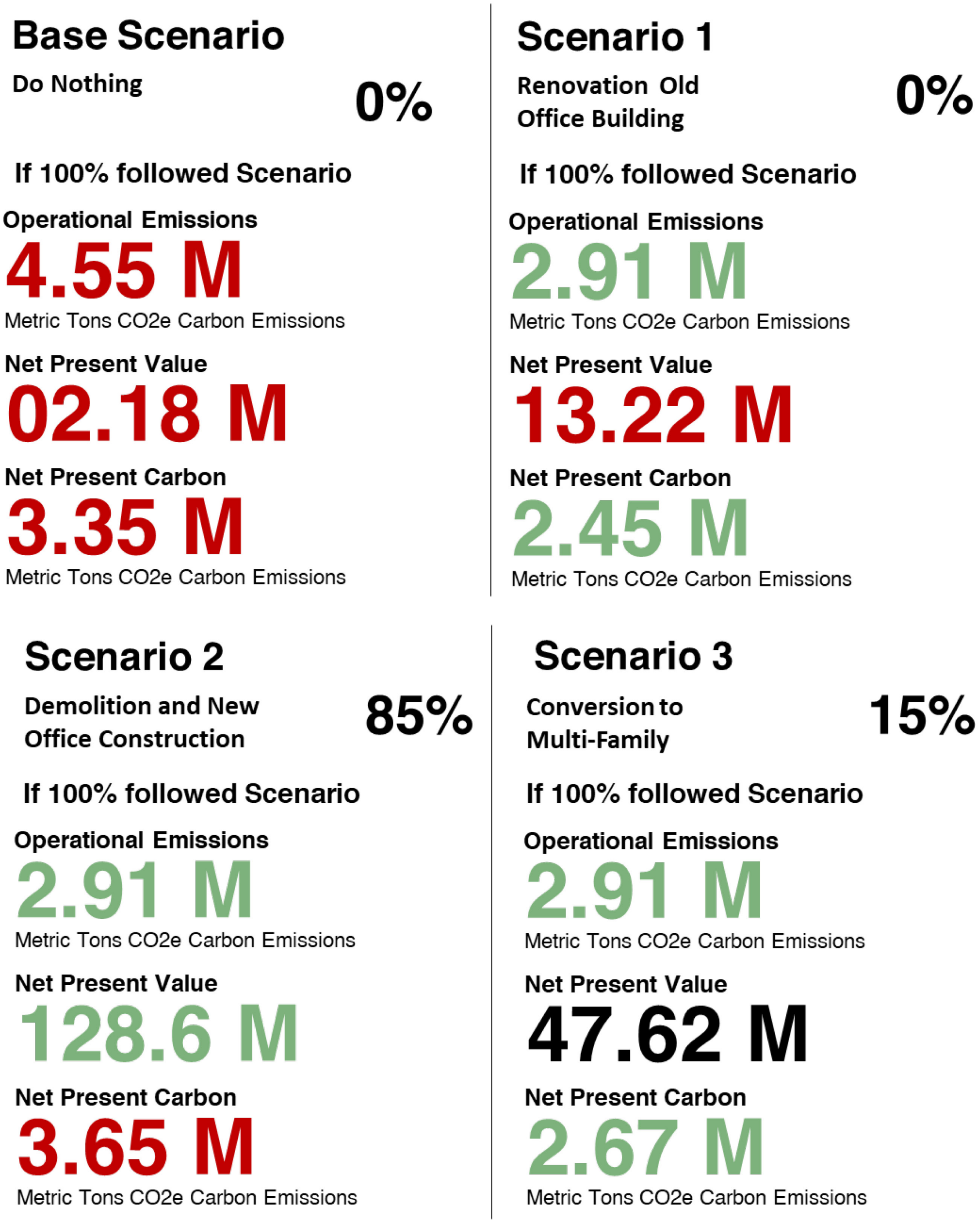


Figure 35 Scenario 1, 2 and 3: Operational CO2e (LL97)



The operational CO2e regulated by LL97 will find that all these three scenarios to be equal and below the emissions thresholds and also the base scenario. A developer only looking at the LL97 threshold and calculating the NPV analysis will prefer scenario 2 (Demolition and New Office Construction), while from the city's point of view all three scenarios have are helping it keep track of the emissions target set by LL97, but would prefer the Residential conversion option to aleviate the housing affordability crisis in the city. The city can reduce the marginal NPC between Scenario 1 and Scenario 2 through a more stringent emission standard(2.54 M CO2e against 2.67 CO2e), and provide subsidies/other monetary benefit to overcome the NPV difference between Scenario 2 and Scenario 3, so both incentivize developer as well mitigate CO2 emissions.



Base Scenario

Do Nothing **0%**

If 100% followed Scenario

Operational Emissions

4.55 M

Metric Tons CO2e Carbon Emissions

Net Present Value

02.18 M

Net Present Carbon

3.35 M

Metric Tons CO2e Carbon Emissions

Scenario 1

Renovation Old Office Building **0%**

If 100% followed Scenario

Operational Emissions

2.91 M

Metric Tons CO2e Carbon Emissions

Net Present Value

13.22 M

Net Present Carbon

2.45 M

Metric Tons CO2e Carbon Emissions

Scenario 2

Demolition and New Office Construction **85%**

If 100% followed Scenario

Operational Emissions

2.91 M

Metric Tons CO2e Carbon Emissions

Net Present Value

128.6 M

Net Present Carbon

3.65 M

Metric Tons CO2e Carbon Emissions

Scenario 3

Conversion to Multi-Family **15%**

If 100% followed Scenario

Operational Emissions

2.91 M

Metric Tons CO2e Carbon Emissions

Net Present Value

47.62 M

Net Present Carbon

2.67 M

Metric Tons CO2e Carbon Emissions

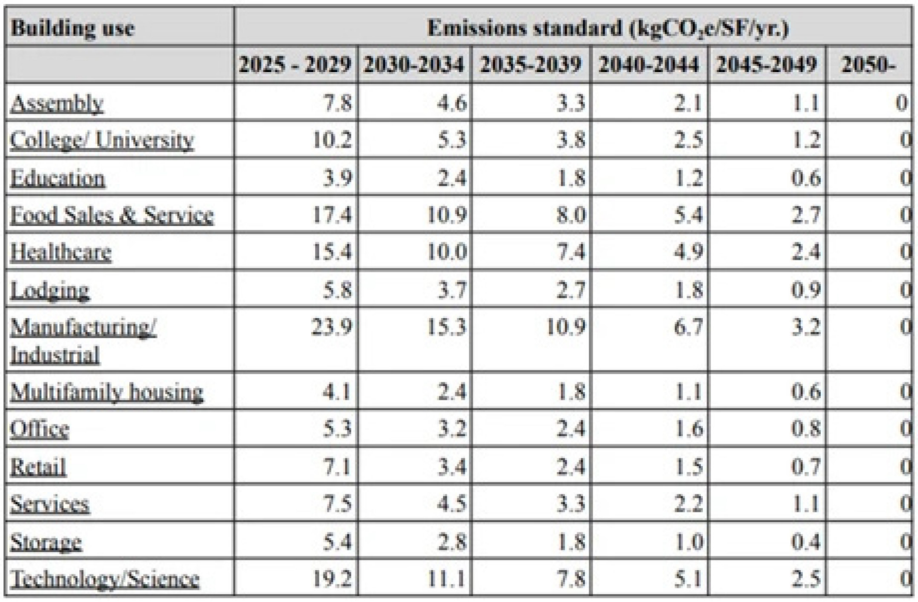
6. Boston’s BERDO: Path to a Sustainable Future

The Building Energy Reporting and Disclosure Ordinance (BERDO) was enacted in Boston to promote energy efficiency and reduce greenhouse gas emissions in the city’s building sector. This chapter overviews BERDO, its strategy and goals, and the range of buildings impacted by the ordinance.

6.1. **Decoding BERDO:** Scope, Targets, and Affected Buildings

BERDO 2.0, established in 2022, aims to reduce energy consumption and greenhouse gas emissions from Boston’s medium and large buildings by requiring property owners to report their energy and water usage annually and conduct annual audits every five years (City of Boston, 2022). The ordinance supports the city’s goal of reducing greenhouse gas emissions by 50% by 2030 and achieving carbon neutrality by 2050 (City of Boston, 2019).

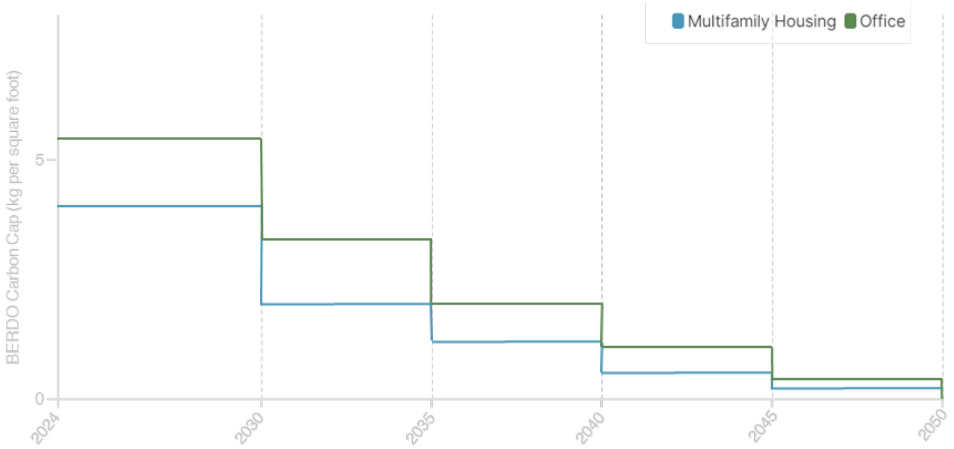
Figure 36 BERDO Emission Limits by Building Use



Building use	Emissions standard (kgCO$_2$e/SF/yr.)					
	2025 - 2029	2030-2034	2035-2039	2040-2044	2045-2049	2050-
Assembly	7.8	4.6	3.3	2.1	1.1	0
College/ University	10.2	5.3	3.8	2.5	1.2	0
Education	3.9	2.4	1.8	1.2	0.6	0
Food Sales & Service	17.4	10.9	8.0	5.4	2.7	0
Healthcare	15.4	10.0	7.4	4.9	2.4	0
Lodging	5.8	3.7	2.7	1.8	0.9	0
Manufacturing/ Industrial	23.9	15.3	10.9	6.7	3.2	0
Multifamily housing	4.1	2.4	1.8	1.1	0.6	0
Office	5.3	3.2	2.4	1.6	0.8	0
Retail	7.1	3.4	2.4	1.5	0.7	0
Services	7.5	4.5	3.3	2.2	1.1	0
Storage	5.4	2.8	1.8	1.0	0.4	0
Technology/Science	19.2	11.1	7.8	5.1	2.5	0

Source: City of Boston, 2023-1

Figure 37 Office & Resi Emissions Limits Over Time



Created using Source: City of Boston, 2023-1

Penalties for Non- Compliance:

Buildings that fail to comply with the emissions limits may face substantial fines. Currently, “Fines and Enforcement” are under review for Phase III of the BERDO 2.0 regulations development process launched on March 6, 2023 (City of Boston, 2023-1). The following is a detailed breakdown of the emissions and penalty structure under BERDO as adopted in 2021 (Boston City Council, 2021):

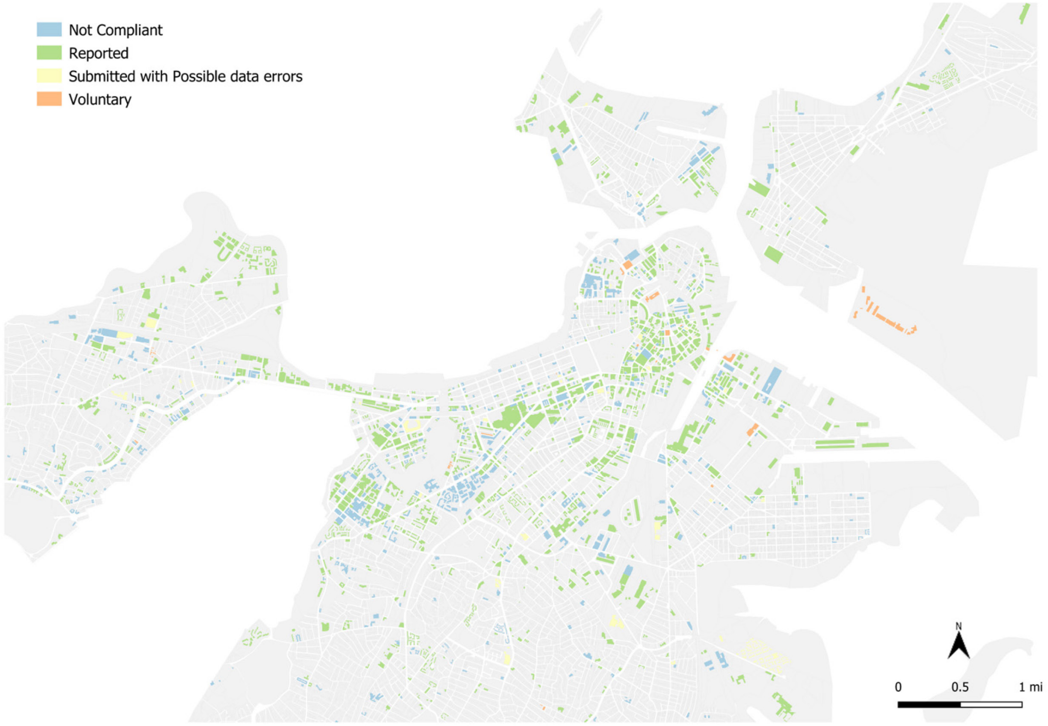
Failure to file Annual Benchmarking Data:	Failure to comply with Emission Standards:	Alternative Compliance Payments (ACP)
$300 per day 35,000+ SF (or Multi-family with 25+ units)	**$1,000 per day** 35,000+ SF (or Multi-family with 25+ units)	**$234 per metric ton of CO2e**
$150 per day 20,000 - 35,000 SF (or Multi-family with 15+ units)	**$300 per day** 20,000 - 35,000 SF (or Multi-family with 15+ units)	Buildings will also have the option to comply with the emissions standards by making Payments per ton of CO2e over the emissions standard**.**

Properties that must comply are:

- Non-residential buildings that are 20,000 square feet or larger.
- Residential buildings that have 15 or more units.
- Any parcel with multiple buildings totaling at least 20,000 square feet or 15 units.

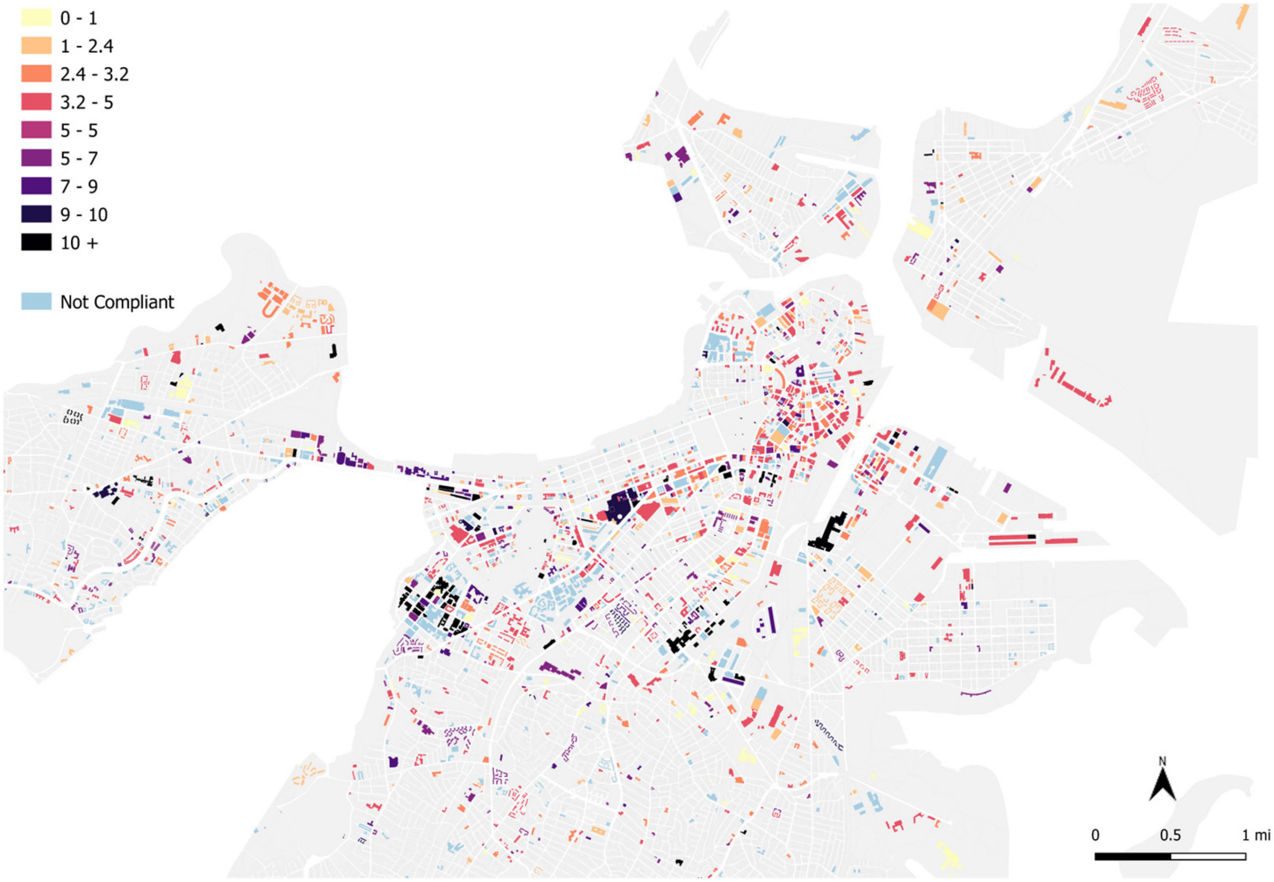
Buildings between 20,000 and 35,000 square feet or residential buildings with 15 to 35 units will need to begin reporting their energy in 2022 and going forward. They will not be subject to the emissions standards until 2031, reporting for 2030 emissions.

Figure 38 Boston – Building Report Status in 2021



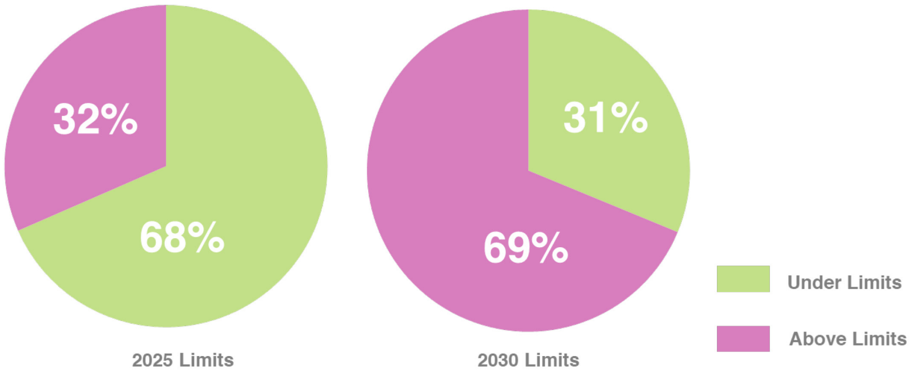
Created using Data Source: City of Boston, 2023-1

Figure 39 Boston - Self-Reported Carbon Intensity in 2021



Created using Data Source: City of Boston, 2023-1
For Emissions Threshold refer Figure 36

Figure 40 Buildings Above or Below BERDO Limits



Own calculations using Data Source: City of Boston, 2023-1

By enforcing mandatory energy reporting, disclosure, and energy audits, BERDO aims to raise awareness about energy efficiency, encourage building owners to invest in energy-saving measures, and facilitate the city's transition to a sustainable, low-carbon future. The ordinance represents a critical step in Boston's commitment to addressing climate change and promoting environmentally responsible development.

6.2. Boston Uncharted Emissions

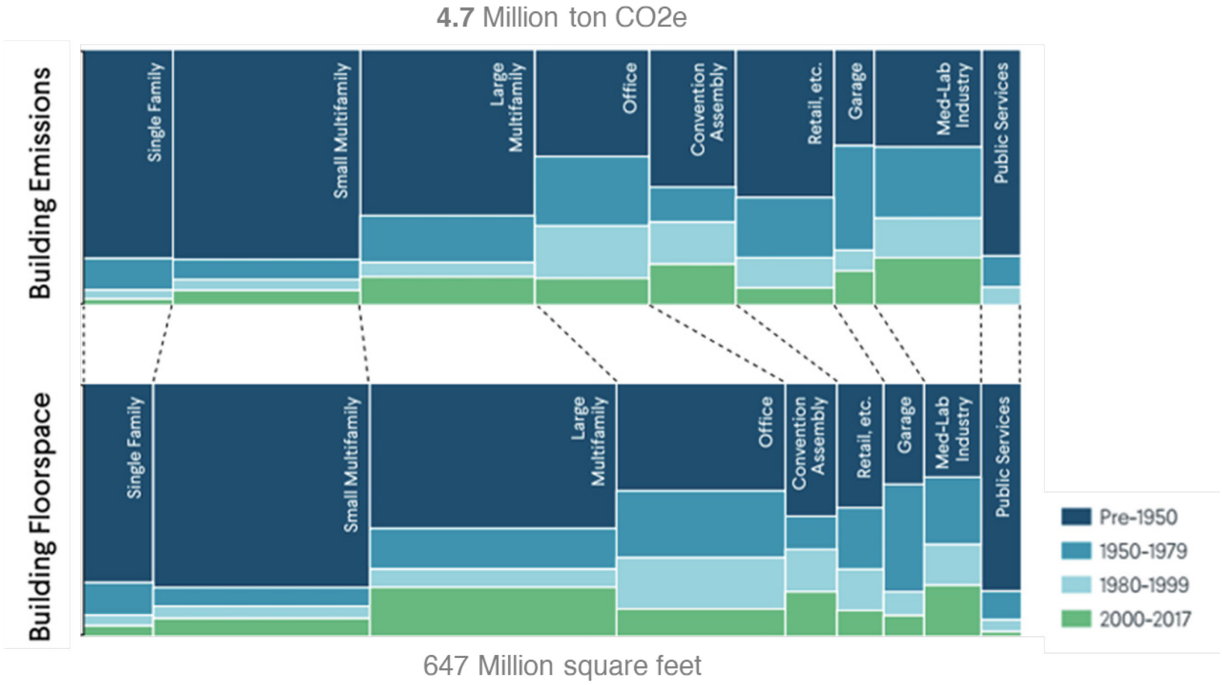
According to the Boston Mayor's Environment Department, buildings in Boston contribute to nearly 70% of the city's total greenhouse gas (GHG) emissions (Environment Department, 2021). Over 60 percent of Boston's floorspace and 84 percent of its buildings were built before 1950 when no energy codes existed. Boston's buildings stock predominantly comprises small residential buildings typically ranging from 1,000 to 5,000 square feet. Despite many small buildings, half of Boston's floor space is dominated by its largest 4,000 buildings (Hatchadorian, et al., 2019).

BERDO targets medium and large buildings with a gross floor area of 20,000 square feet or more. It is estimated that this law covers 4% (4,000) of the buildings, accounting for approximately 60% of the city's total building emissions (Environment Department, 2021) and almost 50% of total built-up floor area (Hatchadorian, et al., 2019).

Building Area and Emissions Not Covered by BERDO

The remaining 50% of the building area in Boston, approximately 96% of all buildings comprising mainly Single-family and small multifamily, is not covered by BERDO. Smaller than 20,000 square feet, these buildings contribute 40% of the city's total building emissions.

Figure 41 Boston's Building Emissions by building Type and Footprint



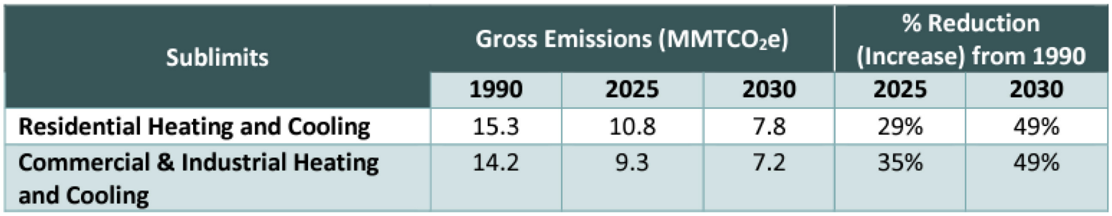
Source: (Hatchadorian, et al., 2019)

While BERDO addresses a significant portion of Boston's building area and associated emissions, a substantial amount of emissions remain outside the scope of the law. To achieve the city's ambitious climate goals, it is crucial to consider additional policies and measures targeting smaller buildings and further reducing emissions across the entire building sector.

6.3. Boston Grid decarbonization

Massachusetts has been actively pursuing clean energy initiatives to transition towards a low-carbon future, with the state's ambitious goal of achieving net-zero emissions by 2050 (Commonwealth of Massachusetts, 2020). The cleaner grid in Massachusetts directly impacts Boston's Building Energy Reporting and Disclosure Ordinance (BERDO), as buildings subject to the ordinance benefit from reduced greenhouse gas (GHG) emissions associated with electricity consumption. The roadmap outlines strategies and policy measures to reduce statewide GHG emissions by 45% below 1990 by 2030 while progressing towards the 2050 net-zero emissions target.

Figure 42 Economy-Wide GHG Emissions Limits and Sector-Specific Sublimit for 2025 and 2030



Sublimits	Gross Emissions ($MMTCO_2e$)			% Reduction (Increase) from 1990	
	1990	2025	2030	2025	2030
Residential Heating and Cooling	15.3	10.8	7.8	29%	49%
Commercial & Industrial Heating and Cooling	14.2	9.3	7.2	35%	49%

Source: (Commonwealth of Massachusetts, 2022)

As the state's electricity grid becomes cleaner, buildings in Boston subject to BERDO will see reduced GHG emissions associated with electricity consumption. The cleaner grid will lower the emissions intensity of electricity, which will subsequently reduce the overall carbon footprint of the building stock. Moreover, the cleaner grid will incentivize the electrification of building heating systems, as electric heating will produce fewer emissions than fossil fuel-based heating systems. This transition can help Boston reduce its building emissions and comply with BERDO requirements.

EMISSIONS FACTORS
(Cushman & Wakefield, 2022)

Energy Type	**kgCO2e/MMBtu**
Natural Gas	53.11
Fuel Oil	75.29
Diesel Oil	74.21
District Steam	66.40
District Hot Water	66.40
District Chilled Water – Electric Driven Chiller	52.70
District Chilled Water – using Natural Gas	49.31
Grid electricity	87.50

Without the Grid achieving Net Zero emission, the city of Boston will struggle to achieve emissions limits set by zero, as current BERDO estimation projects that the grid will have carbon emission of 20.84 kgCO2e/MMBtu (converted from lb/MWh) (Air Pollution Control Commission, 2023).

6.3.1. **Boston Community Choice Electricity:** A Clean Energy Initiative

Boston Community Choice Electricity (BCCE) is a municipal aggregation program designed to increase the use of renewable energy sources in Boston. Established in 2017, By using the City's collective buying power, the program aims to provide residents and businesses with an alternative to the primary service offered by their utility company, offering more stable electricity rates and a higher percentage of clean energy in the electricity mix (City of Boston, 2023-2).

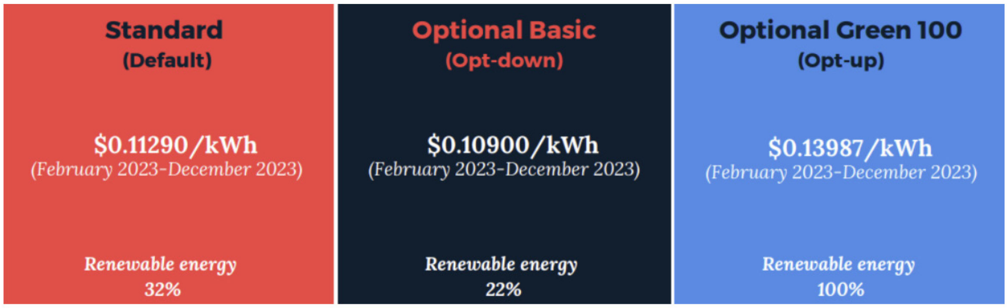
The primary objectives of the BCCE program are to:

- Increase the use of clean, renewable energy sources in the city's electricity supply
- Provide residents and businesses with stable and competitive electricity rates
- Offer an opt-out choice for consumers who prefer to remain with the utility's basic service
- Contribute to the city's climate action plan and greenhouse gas emissions reduction targets

The BCCE program operates under the guidance of the City of Boston and is administered by an external consultant selected through a competitive bidding process. The program's electricity supplier is chosen based on their ability to provide competitive rates, clean energy options, and excellent customer service.

Participation in the BCCE program is automatic for Boston's eligible residential and business customers. Customers can opt-out without penalties or fees, allowing them to return to the utility's basic service or choose another competitive supplier. The costs are provided below, in comparison Eversource Winter Rate from January – June 2023 is **$0.25776/kWh**:

Figure 43 BCCE Program Options



Standard (Default)	**Optional Basic** (Opt-down)	**Optional Green 100** (Opt-up)
$0.11290/kWh *(February 2023-December 2023)*	$0.10900/kWh *(February 2023-December 2023)*	$0.13987/kWh *(February 2023-December 2023)*
Renewable energy 32%	*Renewable energy* 22%	*Renewable energy* 100%

Source: City of Boston, 2023-2

Small Businesses and homeowners can "Opt-up" for 100% Renewable energy.

Since its implementation, the BCCE program has increased clean energy use within Boston. The program's electricity supply includes more renewable energy sources than the basic utility service, resulting in a cleaner mix for participating customers.

BCCE program primarily targets small businesses and homeowners. However, larger commercial and multifamily properties might not be automatically enrolled in the program, but they can choose to participate on a case-by-case basis. Large commercial customers and multifamily properties with higher electricity consumption levels typically have more complex energy needs and may negotiate individual contracts with electricity suppliers. This means that the BCCE program, designed to offer competitive rates and increased renewable energy for smaller customers, may not directly cater to the needs of large developers.

Nevertheless, large developers can still take advantage of the program by contacting the City of Boston or the program's external consultant to discuss potential participation. Before deciding, big developers must assess their energy requirements, the offered renewable energy options, and the potential benefits of participating in the BCCE program.

6.4. Impact of BERDO

To better understand the impact of BERDO, this section presents two case studies, each representing a unique scenario: a large developer's single large office building and a neighborhood of smaller buildings. Using a system dynamics model, the analysis will evaluate the decision-making processes of developers in renovating, retrofitting, or demolishing buildings to comply with the ordinance. This approach will illuminate the challenges and opportunities of implementing energy-efficient solutions in Boston's diverse office building landscape.

6.4.1. Big Player, Bigger Impact: The Prudential tower

This section examines the experience of BXP, a major developer in Boston, as they navigate the challenges and opportunities presented by BERDO. This case study highlights the decision-making process, strategies, and solutions the developer employs in renovating or retrofitting the Prudential Tower, a large historical landmark office building, to comply with the ordinance. The system dynamics model developed in 4.2 (Creating an SD Model for Developer Decision-Making) is used as a simulation tool.

Gross Built-up Area (sf)	1,940,299
Rentable Built-up Area (sf)	1,235,538
Year Built	1965
Year Renovated	2017
Rent Estimate	$67 - 82
Vacancy	1.3%
Green Certification	LEED O+M: Existing Building Energy Star Certified

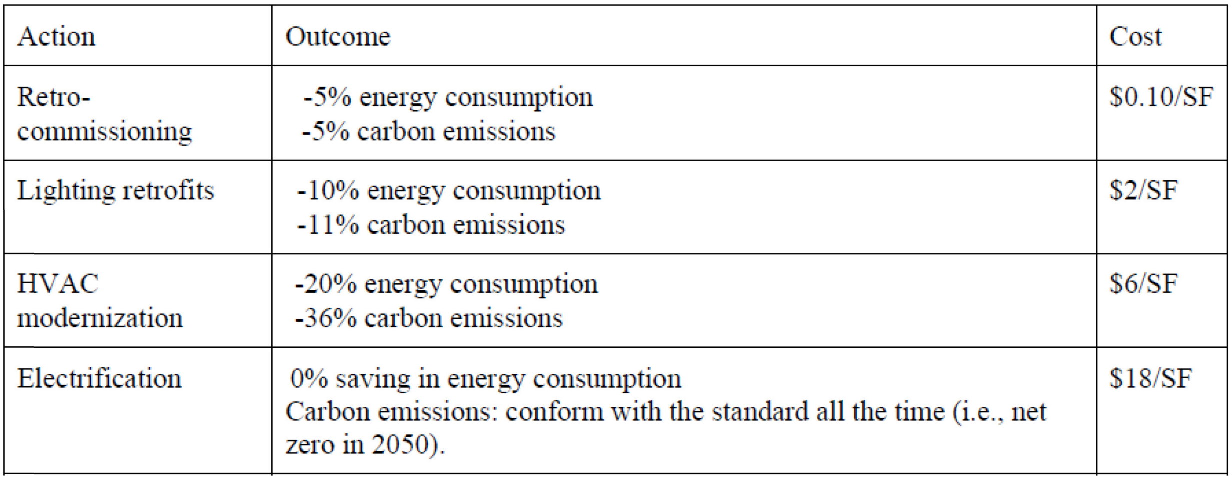
Source: CoStar, 2023-3

GHG Intensity (kgCO2/sf)	5.8
Total Site Energy (kBTU)	127,815,232.2
Electricity %	59.72%
Gas %	19%
Steam %	39.18%

Source: Analyze Boston, 2021

The case study uses the investment package provided in Problem Set 1 from MIT Class 11.350 Sustainable Real Estate

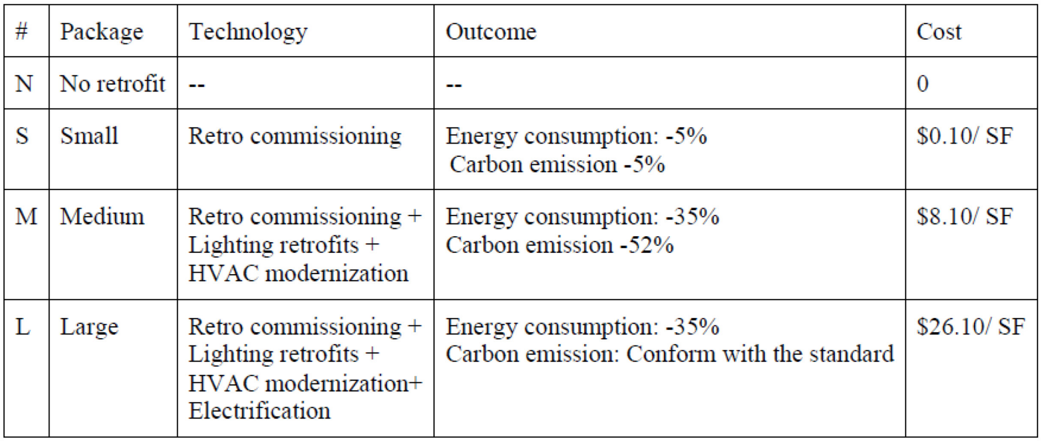
Figure 44 Investment Package



Action	Outcome	Cost
Retro-commissioning	-5% energy consumption -5% carbon emissions	$0.10/SF
Lighting retrofits	-10% energy consumption -11% carbon emissions	$2/SF
HVAC modernization	-20% energy consumption -36% carbon emissions	$6/SF
Electrification	0% saving in energy consumption Carbon emissions: conform with the standard all the time (i.e., net zero in 2050).	$18/SF

Source: Problem Set – 1,MIT 11.350

Figure 45 Retrofit Scenarios



#	Package	Technology	Outcome	Cost
N	No retrofit	--	--	0
S	Small	Retro commissioning	Energy consumption: -5% Carbon emission -5%	$0.10/ SF
M	Medium	Retro commissioning + Lighting retrofits + HVAC modernization	Energy consumption: -35% Carbon emission -52%	$8.10/ SF
L	Large	Retro commissioning + Lighting retrofits + HVAC modernization+ Electrification	Energy consumption: -35% Carbon emission: Conform with the standard	$26.10/ SF

Source: Problem Set – 1,MIT 11.350

The following assumptions are made:

- No alternative pathway: Buildings can have alternative pathways to meet the emission standards, such as installing or purchasing renewable energy. For simplicity, we assume that these alternative pathways are less cost-effective than investing in energy efficiency and electrification
- Discount Rate for NPV Analysis: 10% (Ori, 2019)
- Discount Rate for Net Present Carbon(NPC) Analysis: 2.5% (Interagency Working Group, 2022)
- The analysis is done till the year 2040

Emissions Caps : (City of Boston, 2023-1)

2025 = 5.3 kgCO2e/SF
2030 = 3.2 kgCO2e/SF
2035 = 2.4 kgCO2e/SF
2040 = 1.6 kgCO2e/SF
2045 = 0.8 kgCO2e/SF
2050 = 0.0 kgCO2e/SF

Compliance Payment = $234 per tonCO2e over the limit

Scenario result assuming renovation done without Tenants moving out:

Scenario	NPV	NPC
N	-$4.87 Mil	146 K ton CO2e
S	-$3.85 Mil	139 K ton CO2e
M	**$5.30 Mil**	**70 K ton CO2e**
L	$2.32 Mil	67 K ton CO2e

When adding the Rental impact, as the lease would need to be canceled to do retrofit, we get the following result:

Scenario	NPV	NPC
N	**-$4.87 Mil**	**146 K ton CO2e**
S	-$51.85 Mil	139 K ton CO2e
M	-$43.30 Mil	70 K ton CO2e
L	-$46.32 Mil	67 K ton CO2e

Although the NPV is negative, a developer might go with the No-Retrofit option as the penalties are marginal compared to the rental income (1.1%)
However, BXP actively promotes growth and operations sustainably and responsibly and is recognized as an international leader in sustainability. It aims to lower Reduce energy use intensity and target a 32% reduction by 2025; and reduce Scope 1, Scope 2, and Scope 3 GHG emissions intensity to achieve net-zero carbon emissions by 2050. In comparison, BERDO targets only Scope 1 and 2 emissions (BXP, 2023).

This can partially be explained by the adoption of political instruments around the world that has significantly impacted the economy towards sustainability and developers like BXP's willing to adopt Sustainability in their daily business. In 2020, 88% of publicly traded, 79% of private equity-backed, and 67% of privately owned firms had Environmental, Social, and Governance (ESG) initiatives in place (NAVEX Global, 2021). For BXP, the decision-making is mapped by the following Qualitative System Dynamic Model:

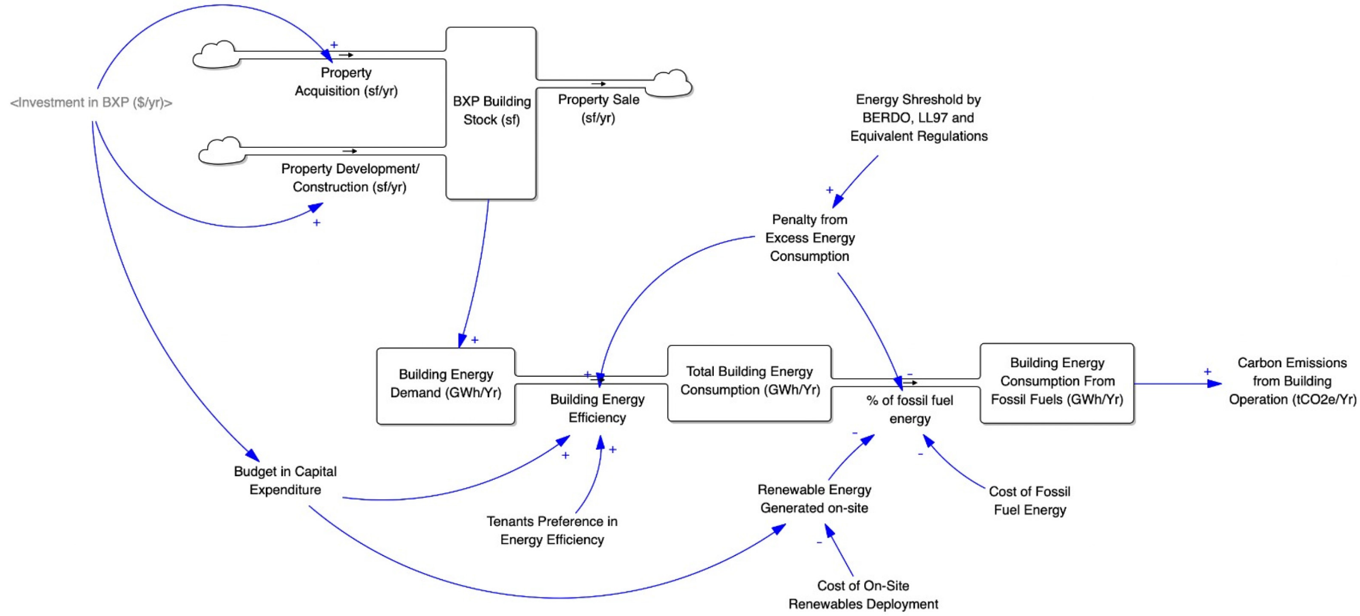
BXP's Decision Model (Qualitative)

Construction/Renovation Loop

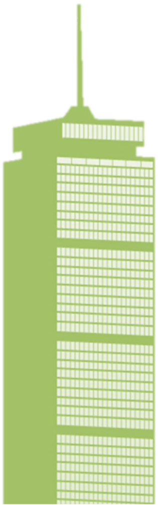
In this loop, the focus is on the relationship between BXP's investments in property acquisition and development, building efficiency, energy demand, and carbon emissions from building operations. BXP's investments increase their building stock, which contributes to the total energy demand. Improving building efficiency reduces energy demand, thereby affecting the total building energy consumption and the percentage derived from fossil fuels, which in turn defines the carbon emissions from building operations.

Regulations like BERDO/LL97 set energy thresholds and penalties, incentivizing BXP to invest in increasing building efficiency and reducing fossil fuel use. The capital budget from BXP's investments can be allocated to improve efficiency and invest in renewable energy sources, with cost factors influencing the choice between renewables and fossil fuels. Tenant preferences also contribute to increased building efficiency.

Figure 46 Construction/Renovation Loop



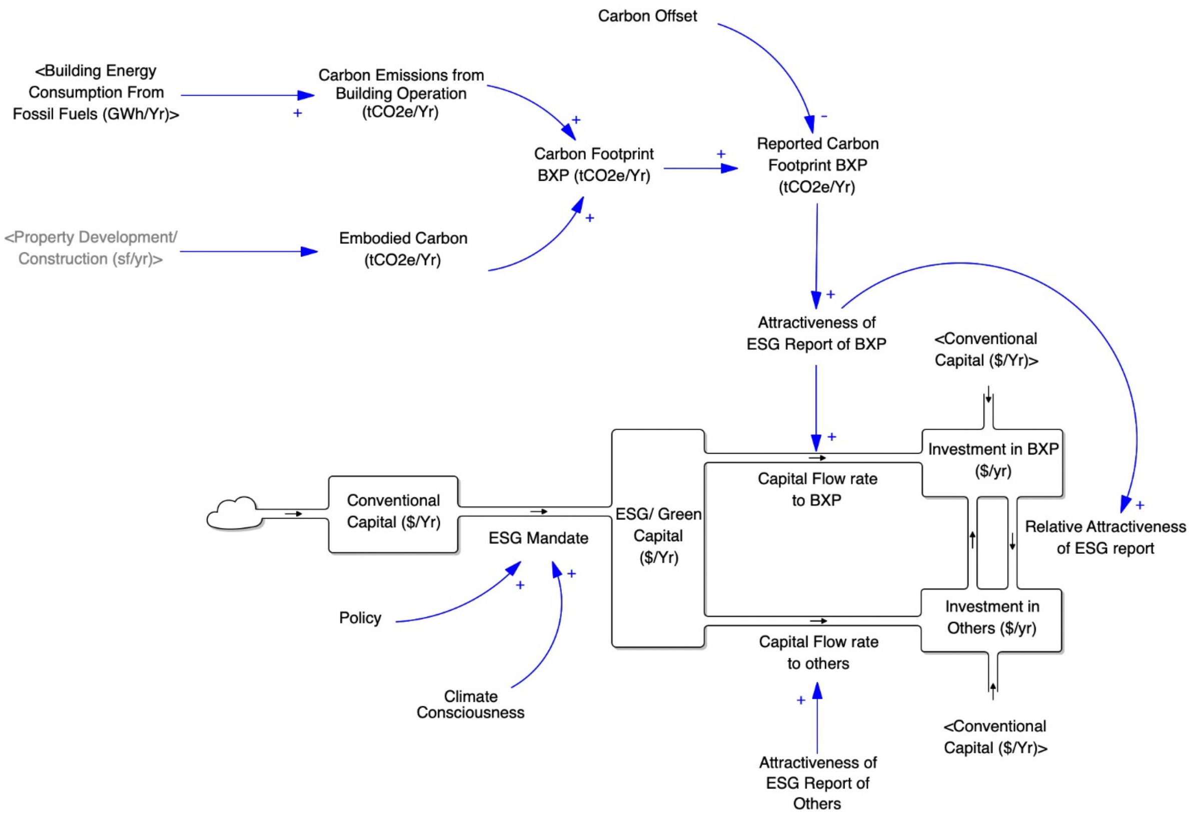
Qualitative SD Model created using Vensim



ESG Investment Loop

This loop examines the interplay between BXP's carbon footprint, ESG reporting, and attracting investments from ESG-focused investors. The carbon emissions from operations (from Loop 1) and embodied carbon from new construction contribute to BXP's total carbon footprint, which can be partially offset through carbon offset purchases. A reduced carbon footprint enhances the attractiveness of BXP's ESG report, drawing capital from ESG-minded investors, who are driven by policy or climate consciousness and influenced by BXP's ESG report compared to competitors.

Figure 47 ESG Investment Loop



Qualitative SD Model created using Vensim

The model emphasize the complex interconnections and feedback mechanisms between investment, energy efficiency, carbon emissions, ESG reporting, and attracting capital from ESG-focused investors within the context of the BERDO policy. Utilizing system dynamics modeling, these loops provide insights into factors influencing BXP's decision-making and BERDO policy effectiveness.

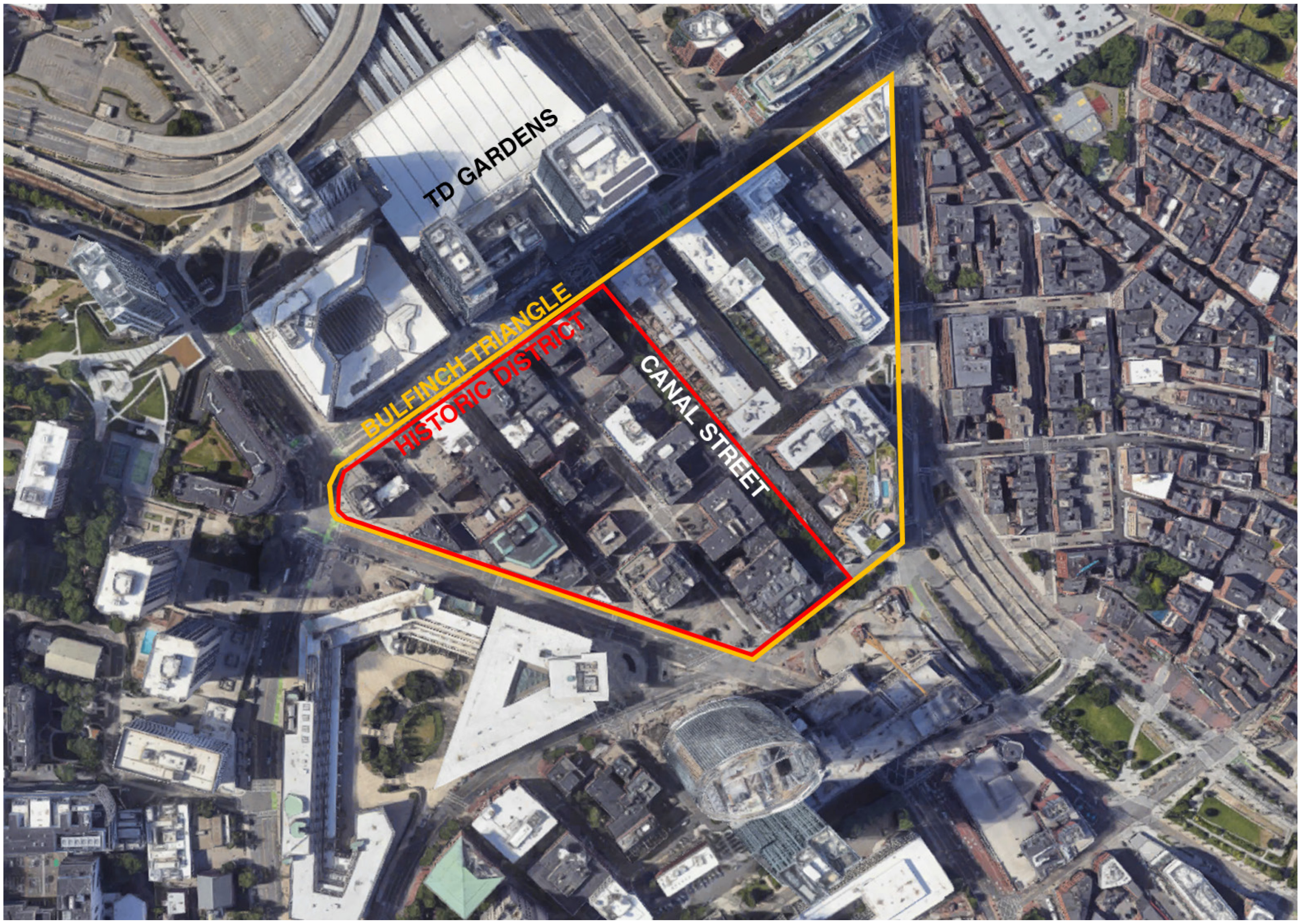
Understanding these dynamics can assist the city in refining and improving BERDO to achieve its objectives better. Although the penalties imposed by BERDO may be relatively small compared to BXP's Net Operating Income (NOI) from buildings, the model perspective reveals how other factors, such as ESG performance and investor preferences, can contribute to BXP's compliance with BERDO and prioritize energy efficiency.

By identifying and leveraging these factors, the city can enhance the effectiveness of BERDO, encouraging broader adoption of energy efficiency measures and attracting more ESG-focused capital. The city can also assess the potential impact of policy changes or new incentives, enabling data-driven decision-making and better-informed strategies for promoting energy efficiency and reducing carbon emissionsThis will ultimately contribute to the city's sustainability goals and foster a more resilient, environmentally responsible built environment.

6.4.2. Neighborhood Narrative: Uncovering Bulfinch Triangle

The Bulfinch Triangle is a historic Boston, Massachusetts, district in the West End neighborhood. This triangular-shaped area is characterized by a mix of residential, commercial, and retail buildings, many of which are older structures with significant architectural and cultural value. As the City of Boston seeks to reduce greenhouse gas emissions under the Building Energy Reporting and Disclosure Ordinance (BERDO), the Bulfinch Triangle represents a unique opportunity to study the impact of these policies on a specific urban area from both an environmental sustainability and urban economics perspective

Figure 48 Bulfinch Triangle

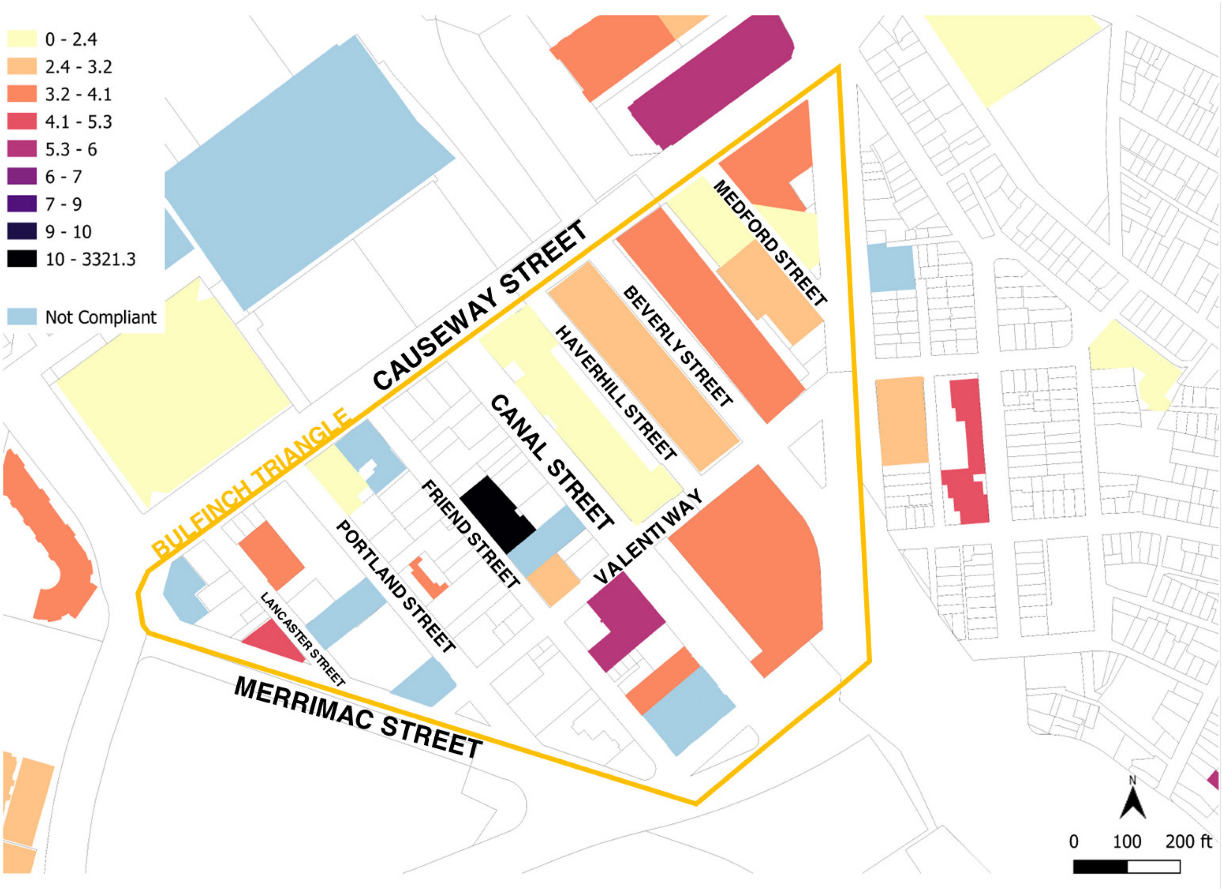


Created Using Google Maps

BERDO Impact on Bulfinch Triangle:

As a part of the City of Boston's efforts to mitigate climate change, BERDO mandates that large commercial and residential buildings over 30,000 square feet report their energy usage and greenhouse gas emissions annually (City of Boston, 2023-1). These buildings must also undertake energy audits and implement energy efficiency measures if they fail to meet specific energy performance standards. In the Bulfinch Triangle, many older buildings may not meet the current energy efficiency standards and could be significantly impacted by these regulations. This scenario creates a microeconomic challenge, as the costs of retrofitting and upgrading these buildings must be balanced against the potential benefits of reduced emissions and energy consumption.

Figure 49 Self Reported Carbon Intensity in Bulfinch Triangle (kgCO2e/sf)



Created using Data Source: City of Boston, 2023-1

Simple Regression analysis using Building Type, Year Built, year renovated, and the total area is used to find building emissions of non-compliant buildings and buildings not covered by BERDO

Summary:
Total No. of Building: 59
Buildings Covered by BERDO: 22
Buildings not compliant in reporting: 6
Buildings above BERDO limit in 2030: 11
Buildings below BERDO limit in 2030: 5

Total yearly Emissions reported by BERDO: 9,752.65 Ton CO2e
Total Yearly Emissions using Regression: 13,114.38 Ton CO2e

The system dynamics model developed in 4.2 (Creating an SD Model for Developer Decision-Making) is used as a simulation tool. The simulation considers the 59 buildings (both covered by BERDO and not ceovered under BERDO):

The following assumptions are used:

- Existing Office Class – B & C
- Existing Multi-Family Class – A & B
- Existing Rent - $35 /sf (CoStar, 2023-3)
- B Rated Office Rent for New Building - $43 /sf (CoStar, 2023-1)
- Multi-Family (A & B Star rated) - $4.77 /sf (CoStar, 2023-2)
- Existing Office Vacancy – 35% (CoStar, 2023-3)
- New Office Building Vacancy – 15% (CoStar, 2023-1)
- Multi-Family Vacancy – 4% (CoStar, 2023-2)
- New Office Construction Cost - $740 /sf (RLB, 2023)
- Office Caprate – 7% (CBRE, 2023)
- Residential Capate – 4.5% (CBRE, 2023)
- Discount Rate for NPV Analysis – 10% (Ori, 2019)
- Discount Rate for Net Present Carbon (NPC) Analysis – 2.5% (Interagency Working Group, 2022)

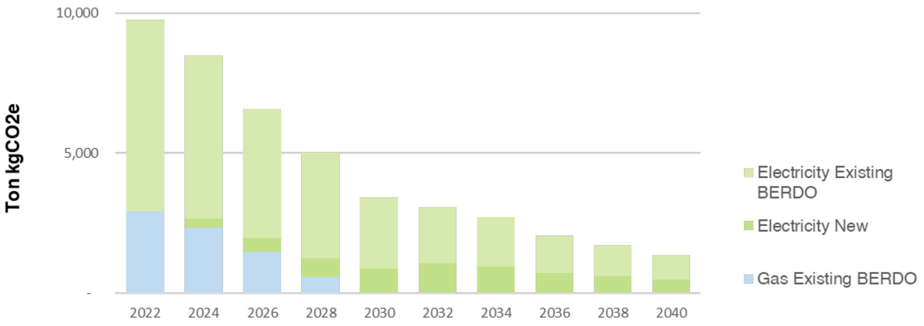
Result:
8 Class C and 5 Class B office covered under BERDO will be at risk for demolition due to close to $0 NPV after BERDO penalties.
Buildings not covered under BERDO do not have any impact on NPV.

Scenario 1:

In Scenrio 1, we assume that the buildings at risk of demolition are replaced by new Class B offices.

The below graph showcases carbon emssions as tracked by BERDO (i.e., without considering embodied carbon and not cosidering the operational emissions of buildings not covered by BERDO)
When only considering BERDO emssions, it will seem that that emissions have decreased by 75% in 2040 in comparison to 2022.

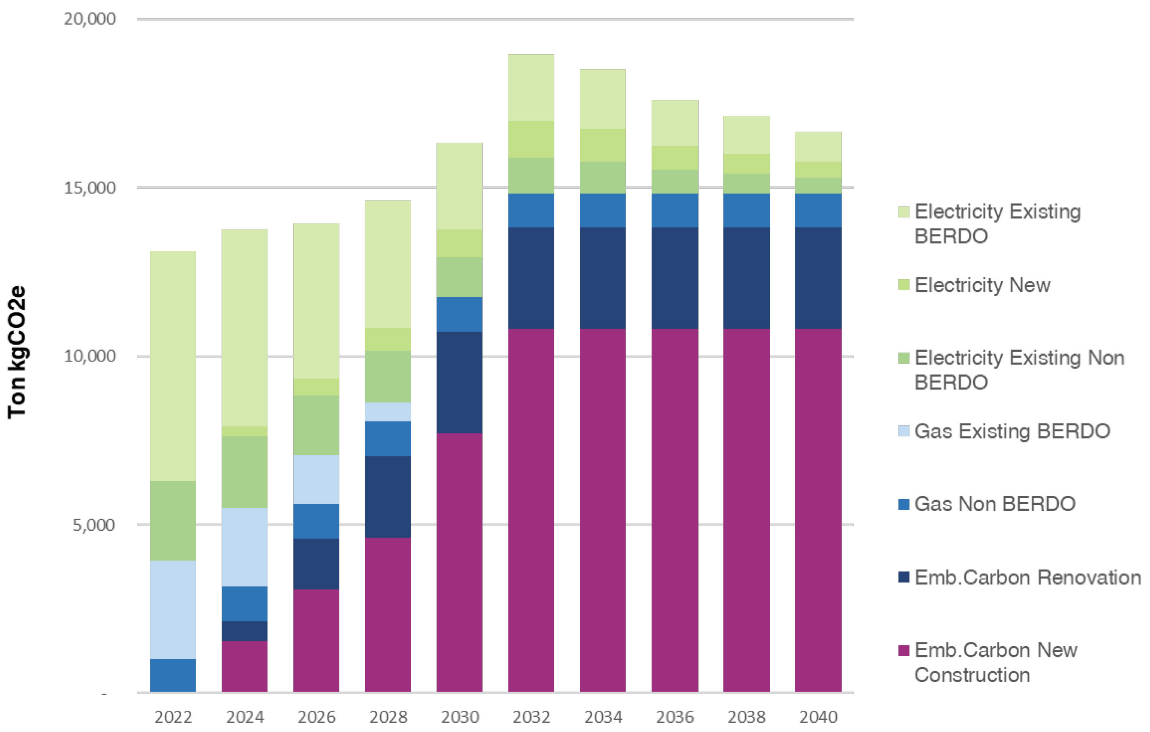
Figure 50 Operational CO2e of Buildings covered by BERDO



Own calculations using Data Source: City of Boston, 2023-1

When we analyze the total carbon footprint of Bulfinch Triangle (BERDO + Non-BERDO buildings + Embodied carbon of construction/demolition), we find that the impact of embodied carbon of renovation and demolition is considerable compared to the reduction in operational carbon emssions.
Moreover, since the buildings less that 25,000sf that are not covered by BERDO had no incentive to renovate, there is no reduction in their emissions from gas.

Figure 51 Scenario 1: Total CO2 emissions of Bulfinch Triangle



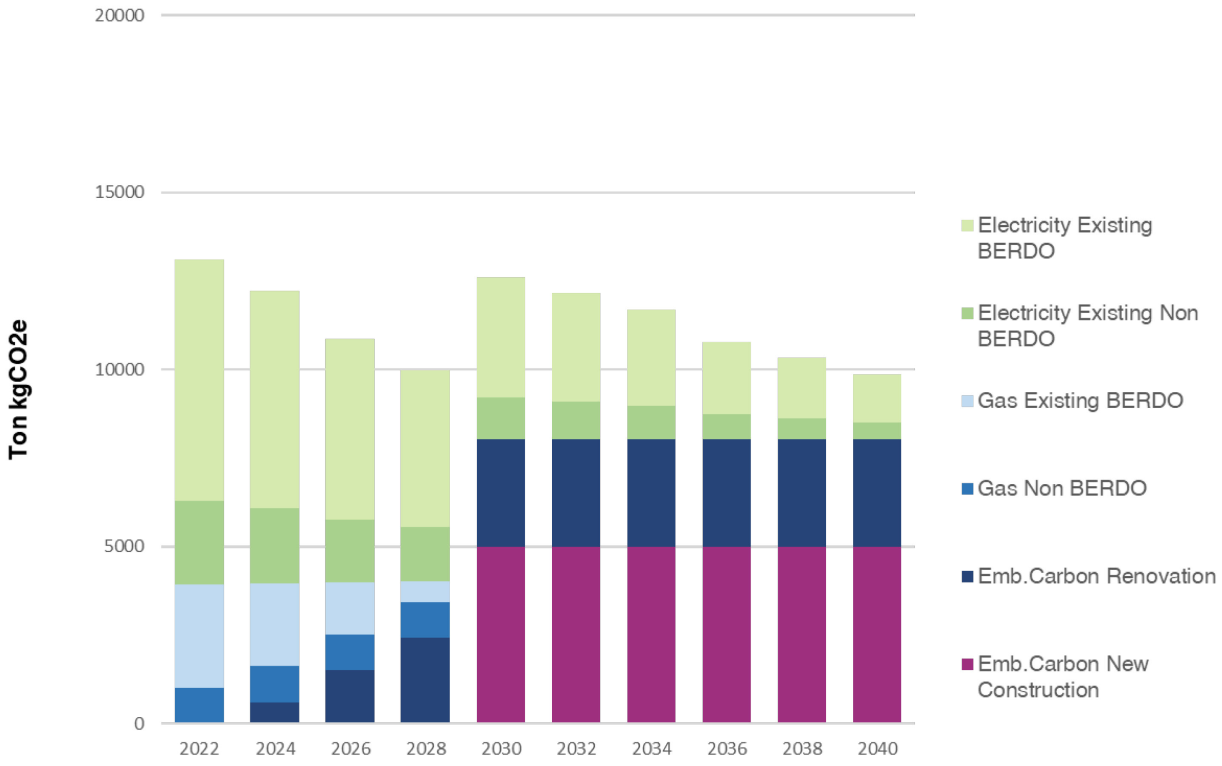
Own calculations using Data Source: the City of Boston, 2023-1

Net Present Carbon of Scenario 1: 120,674.71 Ton CO2e

Scenario 2:

In Scenario 2, we assume that a district heating and cooling center is constructed in the neighborhood. Buildings will be able to connect to the District center and will not need to invest in individual heat pumps. This will also avoid major renovations in older buildings as only the façade and minor internal renovations to lighting and HVAC ducting would be needed. We also assume that the saving from the District center will incentivize non-BERDO-covered buildings to connect to it. The embodied carbon of new construction is from the construction of the District heating and Cooling Center. The cost of construction is not considered in the NPV analysis.

Figure 52 Scenario 2: Total CO2 emissions of Bulfinch Triangle



Net Present Carbon of Scenarion 1: 80,927.38 Ton CO2e

There is a reduction of 33% (39,757.33 Ton CO2e) Net Presenent Carban from the base case scenario.

District Electric Heating and Cooling as a Solution for Emission Reduction

District heating and cooling (DHC) systems provide centralized production and distribution of heating and cooling services for multiple buildings in a specific area. These systems can utilize various energy sources, including renewable energy, to provide cost-effective and environmentally friendly heating and cooling solutions. DHC systems have the potential to significantly reduce greenhouse gas emissions and improve energy efficiency in urban areas contributing to macroeconomic benefits in terms of reduced environmental externalities and resource conservation (IEA, 2022).

In the context of the Bulfinch Triangle, implementing a district heating and cooling system could help older buildings meet BERDO's energy efficiency requirements by providing a more sustainable and efficient heating and cooling source. It will also help buildings not covered under BERDO to reduce their carbon emission significantly. By leveraging economies of scale and integrating renewable energy sources, DHC systems can offer significant emission reductions compared to the traditional, individual building-based heating and cooling system.

The Bulfinch Triangle presents a unique case study for understanding the impact of BERDO on a specific urban area and the potential benefits of implementing district heating and cooling systems. By addressing the unique challenges of older buildings in this historic district, Boston can serve as a model for other cities looking to reduce greenhouse gas emissions and improve energy efficiency in their building stock.

7. Wider Horizons: Exploring Federal and State Policies

7.1. Stateside

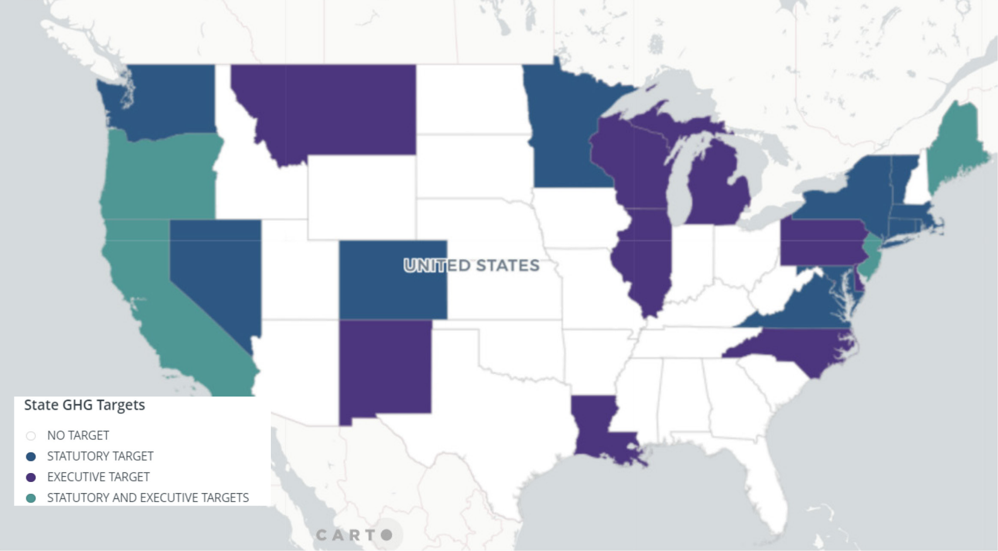
Although 25 states and the District of Columbia have established economy-wide greenhouse gas emissions targets, a majority of US states do not have any targets or regulations related to emissions. The map includes economy-wide targets establishing GHG targets through statutory action (e.g., legislation) or legally binding executive action (e.g., a governor's executive order).

In urban economics, net zero policies in Boston and New York can provide a competitive advantage and attract environmentally conscious businesses and investments from the states with any targets. A study by (Bento, et al., 2014) found that cities with solid environmental policies experience high economic growth and productivity rates. Thus, the lack of net zero policies in other cities and states may result in economic growth and development opportunities for Boston and New York.

While solid environmental policies in Boston and New York may attract environmentally conscious businesses, it is also essential to consider that some businesses may prefer cities without net zero policies, especially those without penalties. The rationale behind this preference is primarily cost-driven, as businesses may aim to reduce building development and operation expenses. In cities without climate policies, businesses might experience lower costs in terms of energy efficiency requirements, construction materials, and retrofitting expenses (Kahn, 2007). These lower costs can benefit businesses with smaller profit margins or prioritize short-term financial gains over long-term sustainability. In addition, businesses that are less concerned about their environmental reputation may be more inclined to operate in cities with less stringent climate policies (Brounen, et al., 2012).

However, it is worth noting that this preference for cities with lax environmental policies may not be sustainable in the long run as public awareness of climate change and the demand for environmentally responsible practices continue to grow. Furthermore, businesses that fail to adapt to stricter environmental regulations may face reputational damage and increased compliance costs in the future (Kolk & Pinkse, 2008).

Figure 53 States with GHG targets



Source: (Center for Climate & Energy Solutions, 2022)

7.2. **United for Net Zero:** The Potential of Federal-Level Strategies

Federal policies can play a significant role in addressing climate change and supporting cities with net zero policies. National-level initiatives can create a level playing field for businesses across the country and help to reduce the potential for businesses to seek locations with less stringent environmental regulations—this section discusses Carbon pricing and Carbon-based trade.

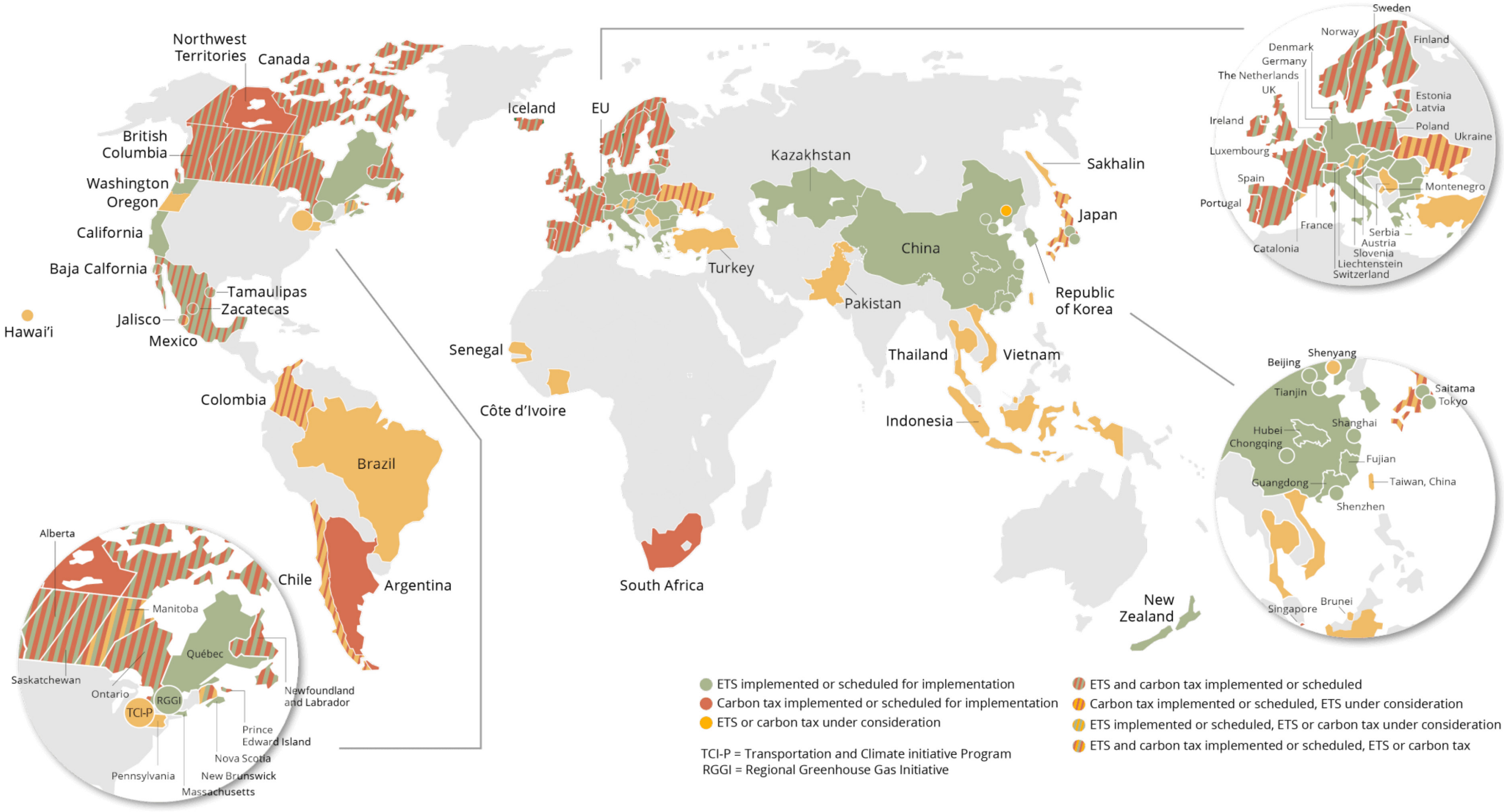
a. Carbon Pricing

Carbon pricing is a cost-effective policy tool that governments and companies can use in their broader climate strategy. It creates a financial incentive to mitigate emissions through price signals. With federal-level policy incorporating climate change costs into economic decision-making, carbon pricing can help encourage changes in production and consumption patterns, thereby underpinning low-carbon growth to help the US achieve NET Zero Targets.

In developed countries, ex-post evidence suggests that carbon pricing has improved productivity and innovation rather than negatively affecting economic development. There has also been little evidence that carbon pricing has undermined a jurisdiction’s competitiveness. (J. Ellis, 2019)

In 2021, 21.5% of global GHG emissions will be covered by operating carbon pricing instruments. There are 64 carbon pricing instruments (CPIs) in operation and three scheduled for implementation.

Figure 54 Map of carbon taxes and emissions trading systems



Source: (PMI, 2023)

b. Carbon-based Trade

Carbon border adjustment mechanisms (CABM) are an emerging set of trade policy tools that aim to prevent carbon-intensive economic activity from moving out of places with relatively stringent climate policies and into those with laxer rules. Federal-backed border adjustments can potentially increase the environmental effects of climate policies by averting shifts in economic activity that could lead to higher total greenhouse emissions—a phenomenon known as “carbon leakage.” They also promote fundamental fairness, “leveling the playing field” between domestic and foreign producers.

In July 2021, the European Commission released a package of proposals to help the European Union (EU) achieve its updated climate targets of reducing net greenhouse gas emissions 55 percent below 1990 levels by 2030 and becoming carbon neutral by 2050. The proposals include establishing a CBAM that would put a carbon price on imports of covered goods to ensure that ambitious climate action in Europe does not lead to carbon leakage. Under the proposal, the CBAM would be introduced in a transitional period from 2023 to 2025. During this period, a reporting system would apply to importers of covered goods to facilitate a smooth program rollout, gather data, and facilitate dialogue with non-EU countries. Starting in 2026, the CBAM would become fully operational, and importers would start paying a financial adjustment as the CBAM phases in; the existing system of free allowances under the European Union Emission Trading System (EU ETS) for sectors covered by the CBAM would be phased out. The goal is to transition from a system of free allowances to the CBAM so EU producers will be incentivized to reduce emissions through carbon price exposure while maintaining leakage protections. Under the program, importers must purchase certificates equal to the total embedded emissions of the covered well each year. The price of the CBAM certificate would be based on the weekly average auction price of EU ETS allowances.

Carbon Border Adjustment = Price × Emissions Intensity of a Good × Quantity of Good

8. Conclusion

8.1. Piecing Together the Decarbonization Puzzle

This thesis has explored various dimensions of urban decarbonization, focusing on embodied and operational carbon emissions, the role of policy-making, and the application of system thinking in understanding the complex dynamics of the real estate market. In this conclusion, we connect the different pieces of the puzzle in two parts: the first part discusses the general aspects of embodied emissions and developers' decision-making in policies, while the second part delves into the specific strengths, weaknesses, and limitations of LL97 and BERDO.

Part I: Embodied Carbon Emissions and Developers' Decision-Making in Policies

Embodied carbon emissions are a crucial aspect of the decarbonization process. These emissions, which result from the production, transportation, and construction of building materials, can represent a significant portion of a building's total carbon footprint. A critical aspect of understanding and managing these emissions is considering the time value of carbon, as emissions released into the atmosphere today will have a more significant environmental impact than those released in the future. By acknowledging the time value of carbon, policy-makers and developers can make more informed decisions that prioritize immediate carbon reduction efforts.

In the broader global and national economic context, embodied carbon emissions are emerging as a critical factor in decarbonization. As countries around the world, including the United States, commit to reducing greenhouse gas emissions, the construction and real estate industries are under increasing pressure to minimize the environmental impact of their activities.

As we transition towards a low-carbon economy, the demand for low-emission building materials and sustainable construction practices will likely grow. This shift will affect the global supply chain, requiring increased production and distribution of eco-friendly materials, such as renewable timber, low-carbon concrete, and recycled steel. The transition will also necessitate innovation in the real estate sector as developers and builders adapt to new materials and techniques to meet stringent emissions targets.

At the same time, macroeconomic factors, such as interest rates, inflation, and government spending, will influence the real estate market and developers' decision-making processes. For instance, low-interest rates from green loans can stimulate investment in low-carbon construction projects, increasing the demand for sustainable building materials and driving up their prices. Similarly, government incentives or subsidies for low-carbon building practices can lower the costs for developers, encouraging them to adopt low-carbon strategies.

Developers and builders are essential stakeholders in the decarbonization process, and their decision-making should be considered when designing policies. A system dynamics approach can help policy-makers account for the complex interactions between economic factors, urban planning, and developers' preferences. Policy-makers can design more targeted and effective policies that address embodied and operational carbon emissions by understanding how these factors influence developers' choices.

Integrating Net Present Carbon (NPC) as a decision-making tool can facilitate more informed choices for both developers and policy-makers, helping them address the challenges of embodied and operational carbon emissions in the built environment. The NPC concept aligns with familiar financial evaluation methods such as Net Present Value (NPV), making it more accessible and adaptable for stakeholders than complex methodologies like Life Cycle Assessment (LCA). While NPC may not be as precise as LCA, it offers a practical means for evaluating projects, both existing and new buildings, based on the time value of carbon today. Incorporating NPC into the decision-making process allows stakeholders to factor in the externalities of carbon emissions in their financial analyses, promoting a more comprehensive understanding of a project's environmental impact in terms of $C0_2$ emissions.

Addressing embodied carbon emissions and developers' decision-making processes in policy design requires understanding the interplay between global and national economic factors, urban planning, and the construction industry's evolving landscape. By incorporating these factors into a system dynamics framework, policymakers can design more effective policies that drive urban decarbonization while addressing the diverse needs of the built environment.

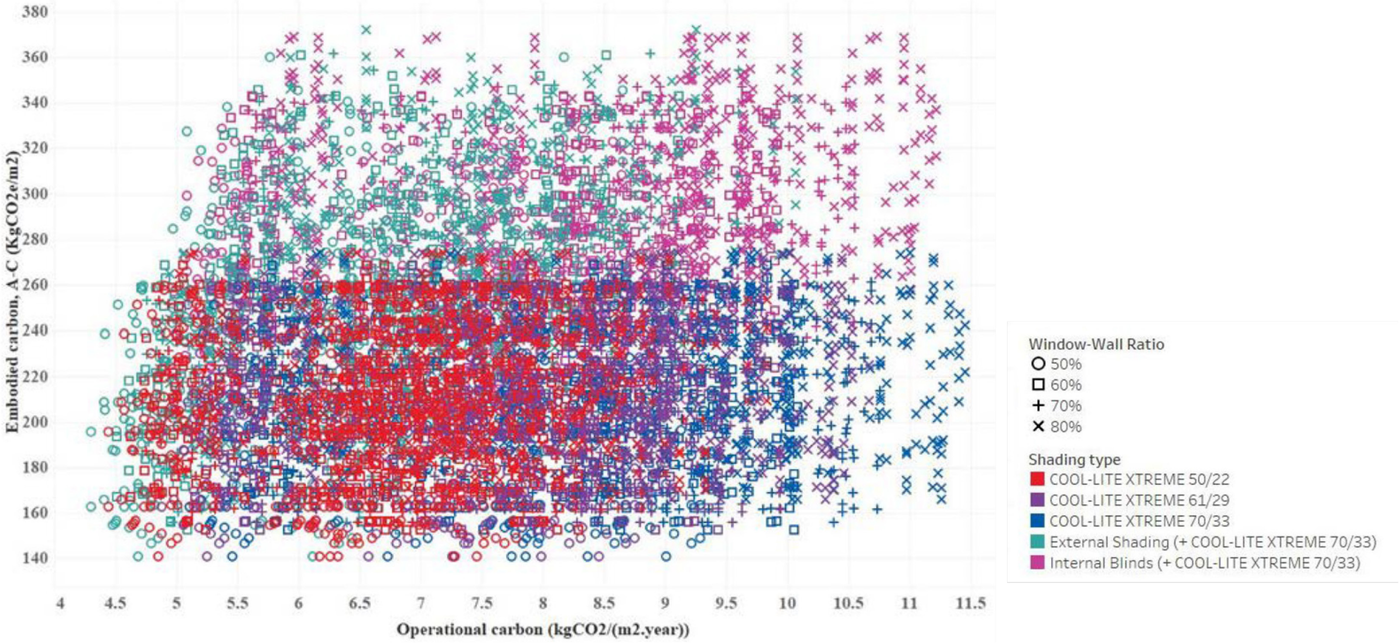
Part II: LL97 and BERDO

LL97 and BERDO represent pioneering efforts in the United States to address the significant contributions of buildings to greenhouse gas emissions and promote the transition towards a net-zero carbon future. These policies have raised awareness of the need for energy efficiency and carbon reduction measures in the building sector and have set ambitious goals for large buildings in both cities. LL97 and BERDO have laid the groundwork for more sustainable urban development by establishing clear targets and requirements.

However, the study also identified these policies' potential challenges and unintended consequences. One such concern is that the focus on operational carbon emissions might inadvertently lead to increased embodied carbon, as developers might choose to demolish older, less efficient buildings and replace them with new, energy-efficient ones. The demolition and construction process generates significant embodied carbon emissions, which may outweigh the operational carbon savings, especially in the short term.

Even in the case of retrofitting existing buildings, a lack of knowledge and regulation related to embodied carbon may lead developers to choose a less sustainable option. Research by Arup and Saint-Gobain analyzed the carbon footprint of 16 different façade systems running 18,000 simulations for residential and commercial models. In the figure below, the Y axis shows the embodied carbon of the façade system, and the X axis shows the operational carbon per year (Operational carbon for a wall with no window was set at 0 kg CO2e/m^2/year). (Arup; Saint-Gobain, 2022)

Figure 55 Glazing Embodied vs. Operational



Source: Arup; Saint-Gobain, 2022

Without any embodied carbon regulation, a developer might choose an option with 5 kgCO2e/m2/year but a high embodied carbon of 330 kg kgCO2e/m2. The emission savings from this ‘energy efficient’ façade system will not be enough to offset the embodied carbon, especially if the grid achieves zero carbon emissions by 2040/2050. Understanding the relationship between embodied carbon and operational performance is critical to strategically reducing emissions across supply chains and design processes.

Another limitation is the exclusion of smaller buildings (20,000 sf in Boston and 25,000 sf in New York) from the policies, which means that a considerable portion of the building stock is not subject to emissions regulations. As a result, these smaller buildings may continue to emit greenhouse gases even after the grid has been decarbonized in 2050.

Furthermore, the research emphasized the importance of federal policies in creating a level playing field for businesses, supporting the adoption of clean technologies nationwide, and the need to carefully consider the balance between operational and embodied carbon emissions in policy design and implementation.

8.2. Strengthening the Policy Framework: Recommendations

To enhance the effectiveness of LL97 and BERDO and promote urban decarbonization, the following recommendations can be considered:

a. Incentivize Retrofitting Over Demolition

Given the study's identification of the potential for increased embodied carbon due to the demolition of older buildings, policymakers should create targeted incentives to encourage retrofitting over demolition for both LL97 and BERDO. These incentives could include tax breaks or grants, encouraging building owners to invest in energy-efficient retrofits rather than opting for demolition and new construction. This approach would contribute to reducing embodied carbon emissions and preserving the existing building stock.

b. Addressing Smaller Buildings and Expanding Coverage

LL97 and BERDO policies primarily focus on larger buildings, with respective thresholds of 25,000 and 20,000 square feet. However, smaller buildings also contribute significantly to overall urban carbon emissions. Expanding the scope of these policies to encompass smaller buildings will be a more comprehensive approach to emissions reduction can be achieved, promoting energy efficiency across all building sizes. The penalties for smaller buildings should be adjusted based on a system-thinking analysis not to encourage demolishing/abandonment of smaller, older buildings.

c. Encourage District Energy Systems and Renewable Energy Integration

Promoting district energy systems and renewable energy integration into the grid would contribute to the effectiveness of LL97 and BERDO. District energy systems can enhance efficiency by heating and cooling multiple buildings, thus reducing overall energy consumption. Furthermore, integrating renewable energy sources, such as photovoltaic solar panels or wind turbines, into the grid would reduce the electricity supply's carbon intensity.

d. Holistic Approach to Operational and Embodied Carbon Emissions

LL97 and BERDO should incorporate a more comprehensive approach that considers operational and embodied carbon emissions. Policymakers could set targets for embodied carbon reductions and offer incentives for adopting low-carbon construction materials and methods. Utilizing Net Present Carbon (NPC) as a decision-making tool can assist developers and policymakers in evaluating carbon emissions and prioritizing reduction strategies. Although NPC is less precise than Life Cycle Assessment (LCA) methodologies, it offers a more accessible approach for policymakers to evaluate projects, accounting for the time value of carbon emissions

e. Strengthen Federal Support for Clean Technologies and Net-Zero Policies

As the study highlighted the importance of federal policies in supporting clean technologies and net-zero policies, strengthening federal support for such initiatives is crucial. This could include funding for research and development of clean technologies, providing financial incentives for adopting clean energy systems, and promoting national-level policies encouraging the transition to a low-carbon economy.

f. Increasing Consumer Awareness

Developers and residents must have access to comprehensive knowledge and resources to understand the importance of both embodied and operational carbon emissions. Policymakers should invest in educational programs, workshops, and easily accessible online resources to facilitate informed decisions about building design, construction materials, and energy efficiency strategies.

g. Incorporating System Dynamics in Policymaking

Incorporating a system dynamics approach to analyze developer decision-making can contribute to a deeper understanding of the limitations of policies such as LL97 and BERDO and suggest improvements. By simulating developer decision-making, policymakers can identify potential gaps and unintended consequences in the policies and refine them to better cater to the diverse needs of the built environment.

By addressing these recommendations and building on the strengths of LL97 and BERDO, these policies can contribute more effectively to decarbonizing the built environment and serve as inspiring examples for other cities and countries to follow.

8.3. Avenues for Future Research

Today's problems often arise as unintended consequences of yesterday's solutions. Policies often suffer from the tendency of well-intentioned interventions to be beaten by the system's response to the intervention itself. For example, Boston's Net Zero policy (BERDO) to reduce carbon emissions by 2050 might have the united consequence of leaving older buildings stranded and eventually to be demolished. The newer buildings that replace them meet the carbon emission standards, but the embodied carbon of these buildings will negate the net gain. The policy also strains the existing Affordable housing crisis due to the rise in construction costs.

Creating a test system for Policies present unique challenges, including long time horizons, issues that cross disciplinary boundaries, the need to develop reliable models to understand social impact and existing inherent biases, and the great difficulty of experimental testing. It also requires the active participation of a wide range of people in the system dynamics test modeling and policy design process. System Dynamics for Cities (Urban Dynamics) is a method that integrates the design of a dynamic model and the provision of scenarios for public decision-makers. Doing so can produce valuable tools, helping to perceive present trends and informing on achieving preferred future outcomes. It also explores the effects of various changes in urban management policies and identifies their systemic impacts (Diemer & Nedelciu, 2020).

Future Research Proposal

1. Focus

This research focuses on creating a road map for an Urban Dynamic model for a City.
The research will involve the following:

- Studying the existing Policies focusing on City Policies.
- Studying other State level and federal policies affecting the city.
- Mapping the relationship between these policies and their effects on the city.
- Studying the current policy methodologies.
- It maps existing city and community-level initiatives that provide input for Policymaking and do a gap analysis.

2. Significance

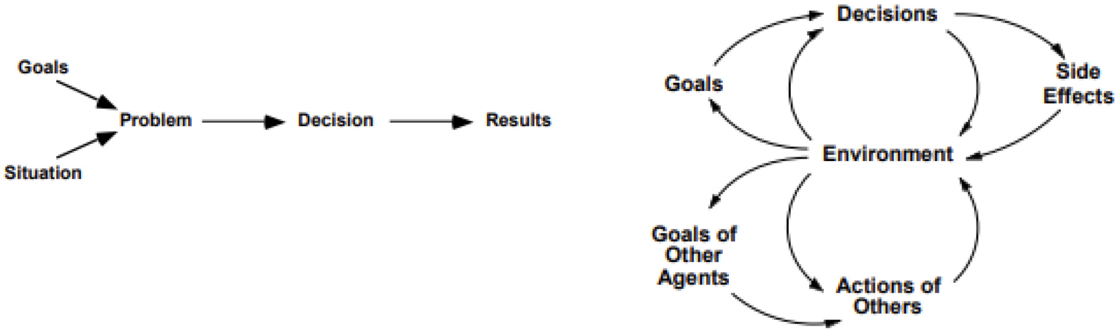
The publication of Urban Dynamics in 1969 by Jay W. Forrester was one of the most insightful applications of the system dynamics methodology. Urban Dynamics presented system dynamics as a computer simulation model of how a city grows, stagnates, or decays. The book generated many controversies. First, there was a boundary problem: several observations invalidate the assumption that the environment does not substantially influence the urban area. Second, there was the problem of the limitless environment: people are available from the outside for migration into the area whenever this one appears more attractive than the point from which people may come and vice versa. Lastly, the use of the data issue: the theory was formulated without recording empirical data.

Since then, the original idea from Forrester has been improved. However, very few had practical applications, and almost none have looked at any effect on city residents. In the book Sustainable Cities and Communities, Arnaud Diemer and Claudiu Eduard Nedelciu explain how the Urban Dynamics process provides an integrated, cross-sectoral urban planning approach, which can understand the complex behavior and demands in urban areas, reconciling local urban processes with global challenges like climate change (Diemer & Nedelciu, 2020). However, it falls short of providing any real-world application.

In 2009, Portland partnered with IBM to create a system dynamics model to "allow leaders to observe how the core systems of a city - such as the economy, housing, education, public safety, transportation, health care, government services, and utilities -- work together and affect one another" (EngagingCities, 2011). Although an example of implementation, there is no publicly available data on the process and results of this modeling. As the then chief city planner, Joe Zehnder, noted – "We will not be able to convince our constituents to trust anything coming out of a black box. The whole act of choosing variables is a political one, a value-laden one” (LINDSAY, 2011); choosing what to measure and omit compromises the model’s integrity.

System Dynamics, until now, has followed the traditional top-down approach, where the existing policymakers help make a tool using professional system dynamic modelers. It builds upon the existing system and, in turn, has the built-in biases of the decision-makers. However, the tool can also be used to change the system. This research looks at an approach that helps bring community feedback into the decision-making and make the process more transparent by helping map out the existing policies and effects. It will help change the current event-oriented open loop of opaque Policymaking that looks at goals and solutions into a feedback-based one where we can visualize how our policy decision alter a city’s environment leading to a need for new decisions.

Figure 56 Existing Policy Approach: **Proposed Approach:**



Source: (Sterman, 2002)

3. Approach

The suggested research will involve interviewing policymakers and involving existing community-based Participatory Action Research in Boston. It will focus on creating a Qualitative System Dynamics model that helps policymakers and the community understands existing policies and the effects of new/proposed policies. It will also involve a literature review of the existing policy, the city’s administrative processes, and also a review of the existing Urban Dynamics model done for other cities.

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10. Table of Figures