Integrating Climate Mitigation and Adaptation Strategies into Low-Income Residential Developments in the City of Santa Barbara

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Signature Page

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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Dr. Mark Buntaine Date

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Abstract

We conducted lifecycle carbon modeling for the Presidio Springs Redevelopment using three scenarios: a Baseline model representing the current design, a Moderate model consisting of low-carbon strategies that remain within a 10% cost increase threshold, and a Reach model exploring deeper decarbonization strategies that require additional design changes or capital investment. Within these models, both lifecycle embodied carbon from material substitutions and operational carbon from building energy use were modeled over a 100-year building lifespan. Results show that embodied carbon is the dominant driver of long-term emissions, particularly from material production (A1-A3), making early material procurement decisions critical.

The largest reductions in the Moderate scenario come from two major design changes: replacing conventional concrete with fly-ash concrete mixes and reducing finish flooring by refinishing exposed concrete slabs to resemble tile, which together account for the majority of emissions savings. Additional low-cost substitutions include switching from standard to recycled-content gypsum wallboard, recycled insulation, and recycled clay tile roofing, further lowering embodied carbon with minimal cost impact. These strategies achieve a 16.7% reduction in embodied carbon, avoiding 2,527,620 kg CO_2e relative to the baseline design. The moderate scenario also incorporates a high-efficiency HVAC system, which reduces modeled operational emissions by approximately 12%.

The Moderate scenario also considers additional strategies such as smart thermostats, which could reduce HVAC energy use by approximately 10-15%, and sustainable deconstruction practices to increase construction and demolition waste diversion beyond the 65% CALGreen requirement. However, these strategies were not directly modeled in the lifecycle carbon assessment and are presented as complementary measures that could further improve environmental performance.

The Reach scenario demonstrates that deeper emissions reductions are possible through additional strategies, such as replacing conventional concrete masonry units with lightweight, high-strength units. Additional operational reductions are achieved through strategies such as tightening the building envelope and improving overall building efficiency, which lower heating and cooling energy demand. Together, these strategies achieve approximately 18% embodied carbon reduction and 14% operational carbon reduction relative to the Baseline design. Greywater reuse systems, which could further reduce potable water demand and the energy associated with water treatment and pumping, were not modeled in this assessment but represent an additional opportunity for future reductions.

In summary, the moderate scenario provides the strongest carbon reduction per dollar invested, while Reach strategies represent a pathway for deeper decarbonization when additional funding, incentives, or policy requirements are available.

Section 1: Introduction

1.1 Presidio Springs Redevelopment - Background and Significance

Affordable housing is a growing challenge in Santa Barbara, where approximately 75% of extremely low-income (ELI) households spend more than half of their income on rent.[1] At the same time, the construction and building sector is a central focus for greenhouse gas mitigation efforts. The building sector accounts for roughly 40-42% of global carbon emissions, when both embodied and operational sources are considered.[2,3] Embodied carbon encompasses building material production, transportation, and construction emissions, while operational carbon refers to the energy-use emissions over a building's lifetime. These impacts are particularly consequential in residential and affordable housing developments, where construction decisions influence not only emissions trajectories but also long-term household energy costs, indoor environmental quality, and public health outcomes.

Affordable housing projects represent a critical intersection of climate mitigation and social equity. Low-income households are disproportionately exposed to climate risks such as extreme heat and poor air quality and often face higher energy burdens due to inefficient building systems.[4,5] As a result, design choices that reduce energy demand and operational emissions can directly improve resident well-being while lowering ongoing utility expenses. However, we must weigh these benefits against strict upfront budget constraints, which often limit the adoption of innovative or low-carbon construction strategies in publicly funded housing.

This project evaluates the redevelopment of Presidio Springs by the Housing Authority of the City of Santa Barbara (HACSB), a senior affordable housing complex in Santa Barbara, which will expand from 100 to over 300 residential units.[6] The scale of this redevelopment presents a meaningful opportunity to integrate low-carbon materials and high-efficiency building systems into an affordable housing context. By addressing embodied and operational carbon simultaneously, the project seeks to identify strategies that achieve measurable emissions reductions without compromising cost feasibility.

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[1] California Housing Partnership. (2024). Santa Barbara housing affordability analysis. California Housing Partnership Corporation.

[2] Architecture 2030. (n.d.). Embodied carbon: The other half of the emissions equation.

[3] World Green Building Council. (2019). Bringing embodied carbon upfront. WorldGBC.

[4] Brown, M. A., Southworth, F., & Sarzynski, A. (2020). Shrinking the carbon footprint of metropolitan America. Brookings Institution.

[5] Sun, Y., Liang, J., Li, N., Zhao, S., & Fang, C. (2021). Energy consumption patterns of low-income households and implications for energy efficiency improvements. Energy Policy, 153, Article 112293.

[6] Housing Authority of the City of Santa Barbara. (2024). Presidio Springs senior affordable housing redevelopment: Project specifications and scope of work. HACSB.

The significance of this work is heightened by California's evolving climate policy landscape. State-level initiatives such as SB 100, which mandates a transition to 100% clean electricity, and emerging embodied-carbon reduction requirements for public projects underscore the need for robust, evidence-based evaluations of low-carbon building practices.[7] Additionally, state policies such as CALGreen require that at least 65% of nonhazardous construction and demolition waste from new construction be diverted from landfills. As jurisdictions increasingly incorporate life-cycle emissions considerations into planning and procurement, housing authorities require practical frameworks to assess not only environmental performance but also economic viability.

The findings aim to inform HACSB's near-term redevelopment decisions while also generating transferable insights for future affordable housing developments across Santa Barbara and similar municipalities. In doing so, the project positions affordable housing as a key lever for achieving climate goals while advancing equity, resilience, and long-term affordability.

1.2 Objectives

1. Identify low-carbon building materials that are practical and affordable: Evaluate the potential of construction materials to lower the carbon footprint without significantly increasing costs in an affordable housing development in Santa Barbara. This includes prioritizing regionally available products and suppliers.

Embodied carbon is a significant source of emissions in new construction because it occurs upfront, during material manufacturing, transportation, and installation, before residents even move into the building.[8] For projects like the Presidio Springs redevelopment, this is important because those upfront emissions remain part of the project's climate impact regardless of how efficient the building becomes during operation. Addressing embodied carbon during the design and procurement stages is a key strategy for reducing the climate impact of new housing developments.

At the same time, cost, durability, code compliance, and supply chains constrain material decisions. A material with low-carbon specifications is not a practical solution if it introduces regulatory risks or is difficult to source locally. Additionally, the material is not a viable option if it performs poorly over time or increases costs beyond what the Presidio Springs housing budget can absorb. Targeting building materials and embodied carbon focuses the analysis on actionable substitutions, products that can realistically be specified and purchased in our region. Using verified EPDs in our region grounds the comparison in transparent, product-specific environmental data rather than generic assumptions. This strengthens both the credibility of our findings and their usefulness in the final decision-making process.[9]

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[7] California Legislature. (2018). Senate Bill 100: 100% clean electricity by 2045. State of California.

[8] Churkina, G., Kuik, F., Bonn, B., Lauer, A., DeClerck, F., Creutzig, F., Hutyra, L. R., Ikova, I., Knohl, A., Kuhlmann, G., Molina, L. T., Schuldenfrei, R., Kolbe, W., & Nehler, C. (2020). Buildings as a global carbon sink. Nature Sustainability, 3(4), 269-276.

[9] International Organization for Standardization. (2018). ISO 21930: Sustainability in buildings and civil engineering works—Core rules for environmental product declarations of construction products and services. ISO.

2. Improve building energy performance to lower emissions and utility costs: Model three different building design scenarios to test changes in insulation, windows, HVAC systems, lighting, and passive design features. Here, we will compare each scenario based on energy use, operational carbon emissions, and electricity costs.

Operational energy use is a long-term driver of both emissions and household costs, and it is especially consequential in affordable housing where electricity costs can significantly affect residents' financial stability. Improving energy performance can reduce electricity demand, making the Presidio Springs redevelopment more resilient to energy price volatility and helping ensure affordability extends beyond rent to the total cost of living.[10] In a climate like Santa Barbara's, design choices such as envelope performance, glazing, ventilation strategies, and efficient HVAC can deliver meaningful reductions in energy use without sacrificing liveability for the residents.[11]

For both objectives, we limited our recommendations to upgrades that remain economically defensible within tight budgets. We are aware that funding requirements and cost caps can limit the ability to adopt higher-cost measures even if they reduce emissions. Using a financial framework helps ensure that sustainability recommendations remain realistic and compatible with project budget constraints.

To support this, we will create a cost analysis that compares upfront construction costs with potential long-term savings from reduced energy use and maintenance. This helps identify which greener design strategies are most likely to deliver financial value over time while still meeting the project's sustainability goal.

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[10] Levine, M. D., Ürge-Vorsatz, D., Blok, K., Geng, L., Harvey, D., Lang, S., Levermore, G., Mongameli Mehlwana, A., Mirasgedis, S., Novikova, A., Rilling, J., & Yoshino, H. (2007). Residential and commercial buildings. In B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, & L. A. Meyer (Eds.), Climate change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 387-446). Cambridge University Press.

[11] California Energy Commission. (2019). 2019 California building energy efficiency standards. Title 24, Part 6.

Section 2: Scenario Framework

2.1 Scenario Framework

We structured the analysis around three building scenarios that represent a progression along a sustainability-cost spectrum. This framework allows HACSB to evaluate tradeoffs between upfront construction costs, long-term operational savings, and carbon performance. The baseline, moderate, and reach scenarios reflect different levels of intervention and feasibility. The moderate scenario is the main focus because it highlights practical, implementable recommendations developed in consultation with HACSB. In this scenario, we cap increases in the cost of individual materials or systems at 10 percent, targeting high-impact carbon reductions through feasible material substitutions and operational design improvements. Importantly, this cap applies to specific components rather than the overall project budget, helping ensure the strategies remain financially realistic for the Housing Authority.

We designed the scenarios to balance three main priorities: reducing life-cycle carbon (both embodied and operational), keeping costs feasible for HACSB, and ensuring the strategies can realistically be built and implemented in the near term.

The baseline scenario reflects current HACSB practices under existing budget and design constraints, serving as the "business-as-usual" reference point. The moderate scenario represents a cost-conscious improvement. It focuses on incorporating the most impactful efficiency and low-embodied-carbon measures while keeping the overall budget and implementation risks manageable. The reach scenario relaxes most near-term budget and feasibility constraints to illustrate what higher levels of performance could look like if more ambitious strategies were pursued.

Across the baseline and moderate scenarios, we made design choices under fixed external constraints including site conditions, durability, code compliance, and affordable housing cost limits while improving carbon and energy outcomes. Within the reach scenario, we applied all of the same constraints, with the exception of budgetary limitations. The three-scenario framework explores different design options to see how the project can move toward lower life-cycle emissions and reduced energy use, while still staying grounded in the financial and operational realities of HACSB's portfolio.

2.1.1 Baseline Scenario

The baseline scenario serves as the primary point of comparison and reflects typical past HACSB construction practices. It includes conventional building envelope assemblies, standard insulation levels, and a traditional HVAC system commonly used in prior affordable housing developments. This scenario establishes reference values for embodied carbon, energy use, operational carbon emissions, and construction costs against which we evaluate alternative designs.

2.1.2 Moderate Scenario

We designed the moderate scenario to achieve meaningful reductions in both embodied and operational carbon while remaining cost-feasible (within a 10% line item increase from baseline) for near-term implementation. Key changes from the baseline include:

- Installation of a higher-efficiency variable refrigerant flow (VRF) HVAC system
- Material replacements:
    - Replaced traditional concrete with low-carbon ready-mix concrete Mix 7335 PS (Kentucky Avenue Plant 155), incorporating ~30% fly ash and CarbonCure technology
    - Replaced conventional clay tiles with recycled clay tiles
    - Replaced rigid foam board insulation with recycled foam board insulation
    - Replaced conventional gypsum wallboard with recycled gypsum wallboard
    - Replaced flooring underlayment on the first floor with refinished concrete flooring (approximately one-third of the building area)
    - Replace PVC with TPO roofing underlayment
- Install smart-thermostats per unit (not modeled)
- Implement sustainable deconstruction strategies to to reduce construction and demolition (C&D) waste (not modeled)

We identified these opportunities through the literature available and a review of baseline energy modeling results. Additional analysis included embodied carbon comparisons for common material substitutions and published best-practice strategies for low-carbon multifamily housing in similar climate zones.

This scenario focuses on strategies that provide meaningful emissions and electricity cost reductions while keeping upfront costs relatively modest. We intend it to represent the most practical and realistic option for adoption by HACSB.

2.1.3 Reach Scenario

The reach scenario represents an optimized, low-carbon design intended primarily for long-term reference rather than for immediate implementation. It builds off measures presented in the preceding moderate model, implementing:

- Installation of high-efficiency multi-split variable refrigerant flow (VRF) systems
- Improve building envelope performance
- Material replacements:
    - Replaced conventional concrete with 30% fly ash concrete for foundation (same as Moderate scenario)
    - Replaced conventional clay tiles with recycled clay tiles (same as Moderate scenario)
    - Replaced conventional gypsum wallboard with recycled gypsum wallboard (same as Moderate scenario)
    - Replaced ⅓ of total flooring underlayment and applied LVP flooring with refinished concrete flooring (same as Moderate scenario)

    - Replaced conventional concrete exterior finish pavers with% limestone pavers
    - Replaced exterior finishing plaster (blend of sand, cement, and lime) with hempcrete ready-mix
    - Replaced low-VOC Dunn Edwards Spartanwall acrylic paint with zero-VOC, lowest GWP alternative - Behr i300 interior paint
    - Replaced conventional concrete masonry units (CMUs) with selective uses of light weight, high strength CMUs, lightweight hollow-core CMUs, and expanded clay CMUs with EPS insulative filling. These specifications were made to fill structural and functional requirements for the original applications.
- On-site water efficiency and reuse strategies, specifically greywater systems (not modeled)

While this scenario requires higher upfront investment, it provides insight into the maximum achievable emissions reductions under currently available technologies. Its model improvements can substantially reduce annual electricity costs and the associated lifetime operational carbon footprint. We considered water recycling systems to improve overall site sustainability metrics, rather than for impacts on the embodied or operational carbon footprint of the building. Financial incentives, such as rebates and grants, can make components of the reach model more attractive and feasible for the Housing Authority to implement. This is especially true for measures with short payback periods that reduce long-term operating costs over the projected 100-year lifespan of the complex.

In developing the moderate and reach scenarios, both models incorporated low-embodied carbon material substitutions.

Section 3: Methodology

3.1 Methodology Introduction

We structured our methodology to answer three practical questions aligned with the core objectives of the Presidio Springs redevelopment:

1. Which financially feasible material substitutions reduce embodied carbon the most, both through lower carbon intensity and reduced replacement over the building's lifetime?
2. Which design upgrades measurably reduce operational energy use and utility costs?
3. Is the moderate design scenario financially reasonable when evaluated over a long-term horizon?

To keep the analysis comparable across options, we used a single consistent building definition (geometry, floor area, and program) and evaluated changes as controlled "scenario" adjustments to the original system assumptions. This allowed us to isolate the impact of specific material and system changes. The workflow then proceeds in linked steps:

1. **Embodied carbon accounting** using manufacturer-published environmental data (Environmental Product Declarations, or EPDs), which report how much carbon is emitted to produce specific materials. We then ran a whole-building life cycle

assessment that captures upfront emissions from construction as well as the carbon associated with replacing and maintaining materials over a 100-year service life.

2. **Operational performance modeling** to estimate annual electricity demand, operational carbon emissions, and utility costs.
3. **Cost and decision relevance** baseline material cost breakdown that aligns directly with the materials analyzed in the carbon assessment, so we could compare cost and carbon consistently. We then conducted a cost-benefit analysis comparing the baseline and moderate scenarios using net present value (NPV) over a 100-year time horizon at a defined discount rate.

We identified three estimations as important to the project evaluation, namely:

- **On-site solar estimation** to account for photovoltaic (PV) generation and compute a net annual electricity balance.
- **Estimation of foundation concrete quantity** as this was not provided in the original architectural design
- **NREL grid decarbonization scenarios** to adjust operational emissions trajectories to reflect a realistic policy and grid-evolution context for the reproducibility of this study outside the bounds of Santa Barbara.

This structure allows us to focus on the highest-impact drivers: energy, major material categories, and the economics of the moderate model. Therefore, our results are clear and easy to update as design and procurement become more specific.

Taken together, these methods create a clear carbon and cost decision framework. They allow HACSB to see not just which scenario reduces emissions the most, but which mix of materials and systems delivers the greatest carbon and energy reductions per dollar. The goal is to identify solutions that are both environmentally meaningful and financially realistic within the constraints of affordable housing development.

3.2 Revit Building Energy and Carbon Modeling

We estimate how design choices change the building's annual energy demand or how much electricity the building needs each year. This is the foundation for comparing utility costs and operational emissions across scenarios.

Operational energy is the clearest pathway linking design decisions (HVAC efficiency, glazing, insulation, internal loads) to real outcomes that matter for affordable housing. This is especially true for tenant energy burden, comfort, and long-term operating costs.[12] Modeling energy annually also provides a consistent basis for comparing scenarios even when the project is not yet fully engineered.

Core inputs reflecting conventional HACSB practices include:

- Building geometry and floor area

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[12] Sun, Y., Liang, J., Li, N., Zhao, S., & Fang, C. (2021). Energy consumption patterns of low-income households and implications for energy efficiency improvements. Energy Policy, 153, Article 112293.

- Envelope assemblies (e.g., walls, roofs, glazing)
    - Glazing: Single-pane windows with 40% window-to-wall ratio
    - Insulation: Standard fiberglass batt insulation (R-13 to R-20 depending on assembly)
    - Envelope: Conventional assemblies meeting Title 24 baseline energy code
    - Hot water: Gas-powered domestic hot water
- HVAC system type/efficiency assumptions
    - HVAC system: Variable air volume (VAV) single-duct system with gas-powered heating

Method:

1. We started from the baseline building definition (geometry + program).
2. Created separate moderate and reach scenarios by adjusting only specific design variables such as envelope performance (insulation R-values, infiltration rate) and mechanical system assumptions (HVAC type, system efficiency). We did this while keeping building geometry, floor area, and program constant.
3. For each scenario, we ran the same annual simulation setup and recorded comparable outputs. The model (EnergyPlus Engine) runs dynamic physical space simulations to produce Energy Use Intensity (EUI), annual electricity consumption, and an estimate of operational emissions.
4. Applied the same location/climate context and 100 year lifespan assumptions across scenarios to keep comparisons consistent.

3.3 Solar Output Estimation

Given the photovoltaic (PV) system directly offsets grid electricity purchases, we estimate annual PV generation and subtract it from modeled building demand.[13] Therefore, we were able to compute net annual electricity consumption per scenario.

Operational performance at Presidio Springs therefore reflects both demand reduction (via envelope and HVAC improvements) and on-site generation. For early-stage comparison, we use an annual net energy balance rather than hourly modeling. This approach captures how PV system size changes total yearly utility consumption and costs, without introducing additional assumptions about hourly load matching or battery dispatch.

To determine net annual electricity use, we estimated annual photovoltaic (PV) generation and subtracted it from modeled building demand.

System Assumptions:

- 167 panels estimated from model
- Southwest orientation with 225 degree azimuth

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[13] U.S. Department of Energy. (2025). PVWatts® Calculator: Documentation and user guide. National Renewable Energy Laboratory.

- We used a fixed roof-mounted system at 34 degrees tilt as the default for the site latitude range to maximize year round energy at the Santa Barbara 34.4 degree Northern latitude[14].

Method:

1. We extracted PV-relevant assumptions from the building model (panel count and roof orientation).
2. Estimated annual PV generation using a location-specific solar model that uses meteorological data and standard loss assumptions; we evaluated plausible panel power ratings and carried forward a conservative annual generation estimate for netting.[15]
   a. Hourly irradiance, seasonal changes, and ambient temperature data set to ASHRAE Climate Zone A
   b. Estimated 14% system loss assumed[16]
3. Compute net annual electricity use as:
   net annual electricity (kWh) = modeled annual building electricity demand - estimated annual PV generation.

Key limitation: This calculation represents an annual energy balance and does not model hourly load matching. Therefore, it does not capture timing mismatches between PV production and building demand.[17]

3.4 Concrete Foundation Estimation

Concrete can dominate embodied emissions and cost, but detailed foundation quantities are not fully specified at this stage of the project. We therefore developed an estimate of foundation concrete volume grounded in site geotechnical context and simplified structural assumptions.

System Assumptions:

- 37-57% fine aggregate material content
- 2000 psf of bearing capacity for shallow foundations on undisturbed soil
- Expansive soil conditions classified as site class D under ASCE 7 seismic provisions
- 3-6 ft below finished grade groundwater table

Method:

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[14] Duffie, J. A., & Beckman, W. A. (2013). Solar engineering of thermal processes (4th ed.). John Wiley & Sons.

[15] Dobos, A. P. (2014). PVWatts version 5 manual. NREL Technical Report (NREL/TP-6A20-62641). National Renewable Energy Laboratory.

[16] U.S. Department of Energy. (2025). PVWatts® Calculator: Documentation and user guide. National Renewable Energy Laboratory.

[17] Denholm, P., Margolis, R., Palmintier, B., Barrows, C., Ibanez, E., Bird, L., Zuboy, J., & McLaren, J. (2016). Methods for analyzing the benefits and costs of distributed photovoltaic generation to the U.S. electric utility system (NREL/TP-6A20-62447). National Renewable Energy Laboratory.

1. Use the geotechnical context and recommended ground improvement approach (deep soil mixing to depth with a mat slab concept) as the basis for a conceptual foundation system.
2. Translate that concept into a volume estimate for the primary elements (Deep Soil Mixing columns and slab). We did this using assumptions for depth, count, layout, and slab thickness/footprint.[18]
3. Increase this calculated volume by a documented waste factor (a small percentage added to account for over-ordering, spillage, over-excavation, and construction variability). This adjustment reflects the typical case where the amount of concrete delivered to a site is greater than the exact geometric volume designed.[19]
4. Use the adjusted total concrete volume in all following embodied carbon and cost calculations.

3.5 EC3 Embodied Carbon Assessment and Associated Costs

We estimate upfront (cradle-to-grave) embodied carbon for high-impact material categories using third-party-verified Environmental Product Declarations (EPDs). This enables a transparent comparison of baseline vs. low-carbon material bundles.

We evaluated alternative materials and suppliers, identified high-impact components, and quantified embodied carbon on a square-foot basis to support low-carbon material selection.

- We sourced material quantities (per square foot) from the architect's Revit material takeoffs for major, high-impact material categories rather than all materials used in the building. We compiled these large material buckets into separate Excel spreadsheets for the traditional (baseline) and green building material scenarios.
- For each scenario, we multiplied material quantities by life-cycle emission factors ($kgCO_2e/ft^2$) derived from regionally appropriate, third-party-verified EPDs accessed through EC3, resulting in total embodied carbon estimates ($kgCO_2e$).
- We calculated the embodied carbon reduction of the green building scenario by comparing total embodied emissions from the green materials against the traditional materials baseline. We focused particularly on high-impact components such as concrete and wood.

Our reproducible method is as follows:

1. Compile Revit material takeoffs for the major, high-impact material categories (rather than every minor material), organized into consistent "material buckets" for baseline and alternate scenarios.
2. For each bucket, select regionally appropriate EPDs and extract the declared emissions intensity ($kgCO_2e$ per declared unit).

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[18] Day, R. W. (2010). Geotechnical and foundation engineering: Design and construction. McGraw-Hill.

[19] AACE International. (2020). Cost estimate classification system—As applied in engineering, procurement, and construction for the process industries (Recommended Practice No. 18R-97). AACE.

3. Convert quantities into total embodied carbon by multiplying quantity × emissions factor, then sum across buckets to obtain scenario totals.
4. Compute the embodied carbon reduction as the difference between baseline and alternative model totals, with attention to high-impact categories (e.g., concrete, wood).

Using the same EPD-defined material buckets and declared units, we assigned unit costs from public supplier/manufacturer references and multiplied by quantities to estimate baseline material costs by category. This treats EPDs as the consistent standard for what is being priced.

3.6 OneClickLCA Embodied Carbon Assessment

Our screening results are useful for near-term procurement decisions, but they can understate long-run impacts if replacement cycles are important.[20] We therefore also used a whole-building LCA approach that covers additional life-cycle stages and includes maintenance/replacement over a long service life.

The method we used for LCA takes this into account:

1. We imported building material quantities from the Revit model to create a whole-building material inventory.
2. Mapped materials to EPDs in the LCA database, prioritizing the closest available matches to project context, and recorded the chosen assumptions for later refinement.
3. Ran a cradle-to-grave assessment across life-cycle stages (including construction, use/maintenance and replacement, and end-of-life), using a long service-life framing to capture replacement dynamics.

OneClickLCA, the software we used, accepts material quantity data directly from our Revit model and automatically maps those materials to Environmental Product Declarations (EPDs) in its global database, significantly reducing manual data entry and improving traceability.[21] This included all structural and envelope materials, mechanical systems, finishes, and cladding defined in the Revit model material inputs. We selected EPDs from sources as close to the project location as possible. We will review and refine these EPD choices at a later date to ensure alignment with client procurement strategy. The database includes associated material lifespans, essential for defined replacement needs.

3.7 Cost analysis

We conducted a cost analysis to evaluate the economic feasibility of the moderate green building scenario relative to a traditional construction baseline. The moderate scenario represents the

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[20] Cabeza, L. F., Rincón, L., Vilariño, V., Pérez, G., & Castell, A. (2014). Life cycle assessment (LCA) and life cycle cost (LCC) analysis: A review of methods and applications related to energy efficiency in buildings. Renewable and Sustainable Energy Reviews, 41, 372-390.

[21] One Click LCA. (2024). One Click LCA for Revit: User guide and methodology notes (software documentation). One Click LCA.

combined use of low-embodied-carbon materials and a high-efficiency HVAC system (VRF), selected to balance meaningful emissions reductions with cost feasibility.

- **Analytical framework:** The analysis uses an ex ante, net present value (NPV) framework over a 100-year building lifetime, consistent with standard public-sector CBA practice. We discounted all costs at a 5% real discount rate.
- **Costs calculation:** We divided costs into fixed (year 0) and annual (recurring) components. Fixed costs include construction and material costs, as well as embodied carbon emissions. Annual costs include electricity expenditures and ongoing operational and maintenance costs.
    - Construction and material costs: We sourced baseline construction costs from a comparable Housing Authority of Santa Barbara project. For the moderate scenario, we estimated cost differentials for green materials and the VRF HVAC system using supplier price quotes and applied them as percentage adjustments to baseline cost categories.
    - Operational energy costs: we estimated annual electricity use using energy use intensities (EUIs) generated from Revit energy models for the traditional and moderate scenarios. We calculated electricity consumption by multiplying EUI by total building area and valuing it with the local electricity price for Santa Barbara.

Comparison approach: We then compared the moderate green building scenario to the traditional baseline by calculating the discounted lifecycle costs for each scenario, including both upfront construction costs and ongoing operational energy expenditures. This approach allows the analysis to evaluate whether the moderate green design results in higher or lower total lifecycle costs relative to conventional construction.

3.8 Material Performance Properties Framework: Non-Cost Criteria for Material Selection

Materials can seem advantageous on carbon and cost but still be a poor choice if it fails durability, code-relevant performance, or resident comfort requirements. We therefore apply a structured feasibility screen to interpret embodied carbon options through the lens of Santa Barbara's coastal conditions and multifamily performance needs.[22]

Method:

1. Defining performance criteria that must be met for a substitution to be considered viable (thermal conductivity, specific heat capacity, density).
2. Conducted an industry-standard literature review detailing the performance criteria of materials used in moderate and reach scenarios.

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[22] Modern Mill. (2025). Sustainable building materials for coastal living.

https://modern-mill.com/insights/sustainable-building-materials-for-coastal-living/

3. Applying these criteria consistently when comparing baseline vs. alternative materials so recommendations reflect "low-carbon + feasible," not "low-carbon only."

While embodied carbon and cost are essential decision criteria (addressed in Sections 3.5-3.7), performance properties are equally important for determining whether a material substitution is viable and appropriate for the Presidio Springs context. A material with lower embodied carbon or cost may not be suitable if it:

- Fails to perform adequately in Santa Barbara's climate, leading to higher operational emissions and costs for the building
- Reduces acoustic performance in multifamily separating walls, compromising resident privacy and comfort[23]
- Compromises structural resilience under California seismic conditions (ASCE 7 Seismic Design Category D-E[24])
- Increases maintenance burden or reduces long-term durability

This methodology framework directly addresses Objective 1 (identify low-carbon, practical, and affordable materials) by establishing transparent, evidence-based criteria for evaluating when material alternatives are truly suitable for adoption. By explicitly documenting performance trade-offs, HACSB and the design team can make informed decisions that balance environmental technical considerations.

3.9 SBCE and grid-adjusted operational emissions

Because electricity grids are expected to decarbonize over time, a building's operational carbon footprint is not fixed - it depends on the emissions intensity of the grid in each future year. We addressed this on two fronts:

1. Santa Barbara is unique due to the Santa Barbara Clean Energy program (SBCE) which effectively supplies 100% clean energy through renewables and battery energy storage (BESS). This means that, under current policy, operational carbon across the building's lifespan is near net-zero and design changes to reduce electricity consumption primarily have a cost impact, not a carbon one. This means our end result will not incorporate operational carbon emissions even though we built our models on state-grid assumptions and we have included those numbers for reference.

2. The importance of keeping our analysis using the California power grid is that it provides a means to reproduce our findings beyond the city of Santa Barbara. Energy supply from community choice aggregation (also called municipal aggregation), where the city or county procures as opposed to private investors, is rarely present throughout the country and uncommon even across

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[23] Hillis, T. (2020). Sound isolation code requirements. The Construction Specifier. https://www.constructionspecifier.com/sound-isolation-code-requirements/

[24] Federal Emergency Management Agency. (n.d.). Seismic design requirements (H-18-8) [PDF].

https://www.nehrp.gov/pdf/H-18-8.pdf

cities and counties in California. We therefore run a counterfactual where SBCE does not exist to showcase how an analysis would work under normal state grid conditions. This analysis is viewable in our appendix section "*9.5 NREL Operational Emissions Trajectories and Scenario-Driven Lifetime Impacts*".

With reproducibility in mind, to avoid reporting operational emissions based only on today's grid conditions, we used the National Renewable Energy Laboratory's (NREL) grid-policy scenarios to estimate how the emissions associated with the Presidio Springs project's electricity use could change over its lifespan under different policy pathways. We intend this analysis to provide a sensitivity range, not a precise forecast, that links our building energy model outputs to credible projections of grid decarbonization.

We used NREL's scenario outputs for California electricity supply and emissions. We selected three scenarios that represent a clear spread of plausible futures. These scenarios provide yearly values that allow us to compute a grid emissions intensity for each modeled year (kg CO_2e per kWh). For more detail see appendix 9.5.

Section 4: Results

4.1 Baseline Model Results

The baseline scenario represents typical Housing Authority of Santa Barbara (HACSB) construction practices and serves as the reference point for all scenario comparisons. This section presents the embodied and operational carbon results from associated tools. We evaluate the baseline model over a 100-year building service life, consistent with the project's lifecycle assessment framework.

4.1.1 Concrete Foundation and Solar PV Model Contribution Estimates

CONCRETE FOUNDATION:

From our foundation and soil analysis results, Deep Soil Mixing (DSM) columns treatment is recommended up to approximately 35 ft to improve and mitigate expansive soil behavior with a mat slab system.[25,26] This would be around 476 columns distributed in a rectangular grid beneath the building footprint to support combined dead and live loads of the residential structures. Cylindrical volumetric analysis assuming a 1.75 ft radius and depth results in around 160,273 cubic feet of concrete.

$$Volume = \pi(1.75ft)^2 \times 35ft \times 476\ columns$$

A reinforced concrete slab serves as a primary load distribution element. A combined dead (avg. of 50-60 psf per floor) and live (40 psf per floor) loads estimate of around 95 psf multiplied by our 3 stories estimate resulted in about 33,589 kips. Given around a 38,627 square feet footprint of both

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[25] Federal Highway Administration. (1999). An introduction to the deep soil mixing methods as used in geotechnical engineering [PDF].

[26] Entact. (2025). Deep soil mixing—Soil improvement—Ground stability.

buildings, assumed loading conditions and a 2ft slab thickness, we estimate 77,254 cubic feet of concrete. Combining these with an estimated waste factor of 5.5% average from calculated dry concrete volume finds around a total of 250,522.2 cubic feet of concrete. We used this estimate in the subsequent embodied-carbon analysis in EC3 and OneClickLCA.

Through industry-standard calculations, we estimated around 250,522 ft^3 of concrete as required for the deep soil mixing columns and mat slab foundation system, based on site geotechnical conditions and structural assumptions. Using a representative 5,000 PSI ready-mix concrete EPD, this contributes approximately 2.4 $MtCO_2e$ to A1-A3 embodied carbon (15% of total baseline), underscoring foundations as a high-leverage target for decarbonisation.

SOLAR PV:

We estimate that a 67 kWdc rooftop PV array (167 × 400 W panels, southwest orientation, 34° tilt) will generate 107 MWh annually using NREL PVWatts with Santa Barbara meteorology and 14% system losses.[27] This may increase up to an estimated 120,379 kWh annually with the use of 450 W panels. Assuming 400 W panels, this would offset 25% of baseline annual electricity demand, reducing net operational emissions by an equivalent amount over the 100-year study period.

4.1.2 Autodesk Insight Operational Carbon

We estimated operational carbon using expected annual electricity consumption and California grid emissions factors for the building. We multiplied this over the expected building lifecycle (100 years). We sourced current grid emission factors from Autodesk Insight energy model assumptions of local Santa Barbara grid composition of clean and fossil fuel based energy production. These grid assumptions are addressed and analyzed further in Appendix 9.5.

We calculated a baseline energy use intensity (EUI) of 155.17 kWh/m2 per year per conditioned floor area from the energy model.

Our calculation using state grid emissions, although not applicable to Presidio Springs, is still critical to note for the reproducibility of our findings. It demonstrates significant operational carbon impacts over the building's lifecycle, with an estimated 50,175,553 kgCO2e from annual operational emissions alone over the 100 year service life. This represents the building's annual GHG footprint from purchased electricity and district energy services under current California grid conditions. We calculate this using a fixed-grid approach, multiplying annual energy use by a static California grid emissions factor over the full 100-year analysis period.

4.1.3 Autodesk Insight Embodied Carbon

Autodesk Insight provides a preliminary embodied carbon estimate based on industry-average Environmental Product Declarations (EPDs) for materials in the Revit model. This estimate covers only the cradle-to-gate (A1-A3) lifecycle stages including material extraction, processing, and

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[27] National Renewable Energy Laboratory. (n.d.). PVWatts® calculator.

manufacturing, but does not account for material replacement, maintenance, or end-of-life processes over the building's 100-year service life.

We estimated a baseline embodied carbon value of 790,994 kg CO2e directly applying industry average EPDs to all materials within the Revit model. Major contributing categories included exterior walls and insulation, raised floor, and concrete slabs. However, this approach may severely underestimate the true lifecycle embodied carbon due to exclusion of material replacement over building lifecycle and lack of concrete foundation integration.

4.1.3 OneClickLCA Embodied Carbon

We estimated a baseline of 15,163,988 kg CO2e over the building lifecycle. This is around 19 times higher than Autodesk's estimate, reflecting a more accurate embodied carbon impact when material replacement and concrete foundation estimates are included. This difference of magnitude is further discussed in Section 5.1.

Table 4.1.3A OneClickLCA material embodied carbon output table (Baseline): This figure presents current estimates of embodied carbon under the baseline scenario by life cycle phase. Global warming potential associated with construction materials (A1-A3), emissions associated with material transit and installation (A4-A5), replacements at material end of life (B4-B5), emissions at end of life (C1-C4), biogenic carbon storage, and the total emissions.

Life Cycle Phase	A1-A3 Construction Materials	A4-A5: Transit, Construction, Installation	B4-B5: Material Replacement	C1-C4: End of Life	Biogenic Carbon Storage	Total
Global Warming Potential (kg CO_2e)	8,307,908	1,307,609	5,095,381	453,088	477,625	15,163,988

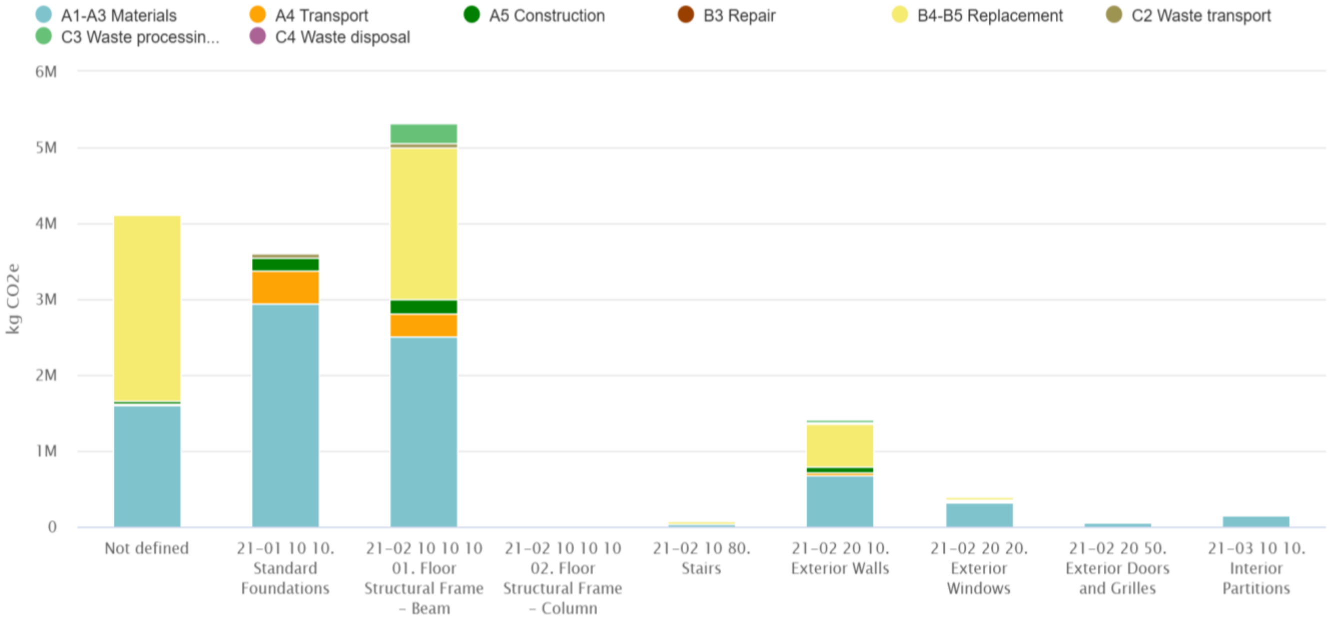

Figure 4.1.3B. Global warming potential (in tCO_2e) by omniclass building element for the baseline scenario disaggregated by life-cycle stage (A1-A3 materials, A4 transport, A5 construction, B use/replacements, C end-of-life). Stage D benefits beyond the system boundary are excluded so that bars represent only in-system embodied emissions.

The baseline Omniclass breakdown highlights that floor structural framing and undefined elements are the dominant contributors to embodied carbon across A-C stages. Floor structural frame-beams alone account for the largest share of total GWP, reflecting both the mass of repeated floor systems across multiple stories and the high emission intensity of reinforced concrete and steel used in these members.

The large “not defined” category indicates that a substantial portion of materials imported from Revit could not cleanly map to standard Omniclass classes. These elements seem to be dominated by some mechanical and systems-related components like air-to-water heat pumps and battery front loaders among other HVAC and electrical equipment defined as systems over specific omniclasses. Many of these elements also show sizable contributions in the B-stage use/replacement band, suggesting that they include finishes, partitions, and equipment with shorter service lives that turn over multiple times within the 100-year assessment period. This pattern underscores that while structural elements dominate initial emissions, high-turnover materials can accumulate significant life-cycle impacts through repeated replacement cycles.

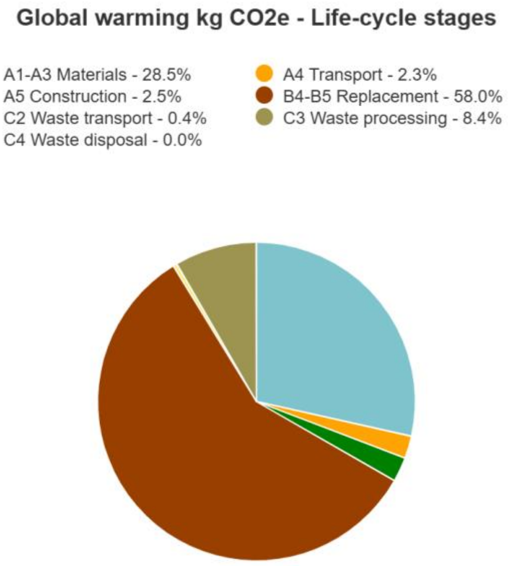

Figure 4.1.3D: Embodied carbon emissions by life-cycle stage for the baseline scenario. Material production (A1-A3) dominates at 54.8% of total emissions, reflecting the front-loaded nature of construction impacts. Use and replacement (B-stages) contribute 40.4%, driven by shorter-service-life components such as finishes and equipment. Construction/transport (A4-A5) and end-of-life (C-stages) remain minor at under 5% combined.

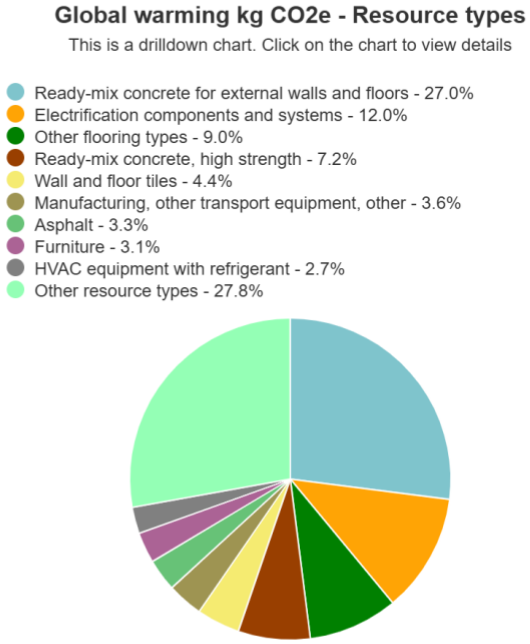

Figure 4.1.3E Embodied carbon emissions by resource type for the baseline scenario. Ready-mix concrete for external walls represents 27% of total emissions, underscoring the outsized impact of cement-based structural materials.

4.1.4 Baseline Cost Analysis Using Product EPDs

The baseline cost analysis translates the Revit material takeoffs into an estimated baseline material budget, with the goal of identifying where cost is concentrated and where targeted substitutions or specification refinements are most likely to matter. Using the same material buckets employed in EC3, we assigned unit costs on the EPD-aligned declared unit basis (e.g., $/cubic yard, $/square foot, $/board foot) and multiplied those by the project quantities to estimate total baseline material costs by category. The resulting baseline estimate indicates an estimated total material cost of ~$5.60 million for the high-impact materials included in this scope (as summarized in the cost table in the appendix). The total cost and material break up are visualized in figure 4.1.4A.

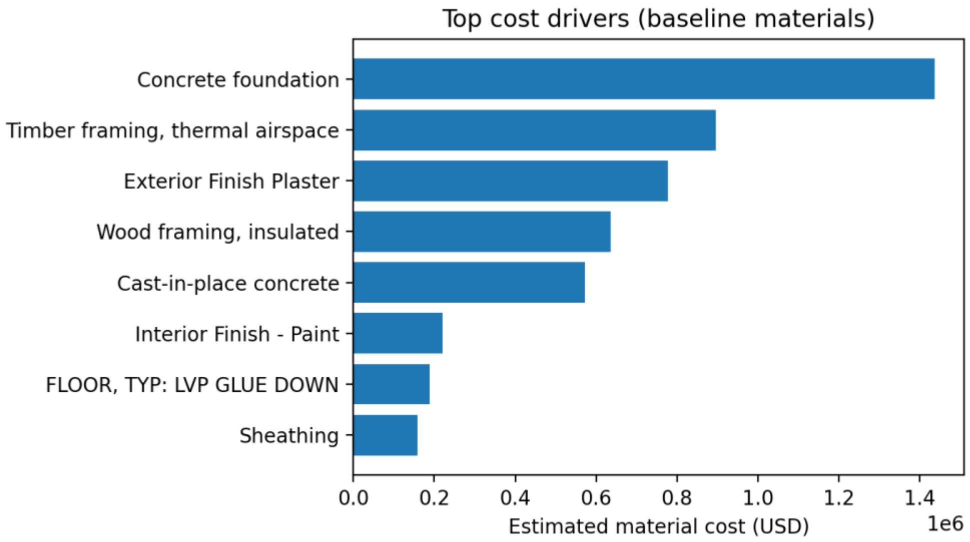

Figure 4.1.4A Total cost and product specific composition. This highlights that cost concentration is highly uneven, meaning the project can focus on a short set of "cost drivers" rather than attempting to optimize all categories at once.

The largest baseline cost category is concrete foundation, which represents roughly one quarter of total estimated material cost. The next largest contributors are timber framing and wood framing (insulated), followed by exterior finish plaster, and cast-in-place concrete - together representing the majority of the baseline materials budget. This ranking is important because it clarifies where value engineering and supplier engagement will have the biggest payoff. For example, concrete is both a cost driver and (per the EC3 results) a major embodied-carbon driver, making it a high-leverage category for *joint* cost and carbon optimization. By contrast, some categories may have visible carbon savings but represent a smaller share of total cost, which can be helpful when looking for wins that improve carbon performance without materially affecting the budget. In the discussion section we will highlight the necessary steps to finalize this cost analysis as it is currently just a screening-level estimate.

4.2 Moderate Model Results

4.2.1 Moderate Model Operational Carbon

The moderate building model demonstrates meaningful reductions in operational energy use and carbon emissions relative to the baseline scenario. We estimate annual operational carbon emissions for the moderate model at approximately 44.66 million kgCO_2e over a 100-year building lifespan given state grid considerations. In comparison, the baseline model produces approximately 50.17 million kgCO_2e over the same period. This represents a 12.34% reduction in operational carbon emissions.

Energy performance improvements are also evident in the moderate scenario. The modeled Energy Use Intensity (EUI) is 136.26 kWh/m^2, compared to 155.17 kWh/m^2 for the baseline model. The lower EUI reflects reduced electricity demand resulting solely from the use of a high-efficiency variable refrigerant flow (VRF) HVAC system and improved glazing performance, both of which enhance thermal efficiency and reduce heating and cooling loads. Additionally, because EUI measures the amount of energy consumed per square meter of floor area, a lower EUI directly translates to reduced total electricity consumption for the building.

Overall, the moderate model illustrates targeted system upgrades like efficient HVAC technology and improved envelope performance that can achieve substantial operational carbon reductions without requiring the more costly interventions included in the reach scenario. While VRF systems typically carry an upfront cost premium of approximately 10% compared to conventional VAV systems, lower operating costs and improved energy efficiency over the building's lifespan partially offset this increase.[28] Similarly, the upgraded glazing option is also estimated to be approximately 10% more expensive than the baseline double-pane glazing but contributes to reduced heating and cooling demand, improving overall energy performance.[29] These results support the moderate scenario as a cost-effective pathway for reducing emissions in affordable housing developments.

4.2.2 Moderate Model Embodied Carbon

The updated material substitutions reduced total embodied carbon from 15,163,988 kg CO_2e to 12,636,368 kg CO_2e (12,636 tonnes CO_2e). This represents an absolute reduction of 2,527,620 kg CO_2e, corresponding to an overall decrease of approximately 16.7%. Using the same floor area and lifespan assumptions as before, this equates to approximately 10.78 kg CO_2e/m^2/year, indicating a substantial lifecycle emissions reduction at the building-scale.

These reductions were primarily achieved through direct substitution of high-impact materials with lower-embodied-carbon alternatives, while maintaining comparable structural and functional performance. Most notably, we replaced cast-in-place concrete with Mix 7335 PS, which

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[28] Ambient Edge. *"How Much Does a VRF System Cost?"* AmbientEdge.com

[29] EcoLine Windows. *Triple Pane vs Double Pane Windows Cost Comparison*.

incorporates 30% fly ash-based ready-mix concrete. Additional substitutions included conventional gypsum wallboard replaced with recycled gypsum wallboard, rigid foam insulation replaced with insulation containing 30% recycled content, and PVC roofing replaced with TPO roofing. For these materials, we identified Environmental Product Declarations (EPDs) directly within One Click LCA and implemented substitutions using the resource-level substitution workflow to ensure methodological consistency.

Three exceptions required alternative modeling approaches. First, the design incorporates refinished exposed concrete foundation on the first floor, eliminating the need for flooring underlayment and finish layers at that level. Because the buildings are three-story, flooring finishes are only required in two-thirds of the building area. Accordingly, we adjusted all flooring finish materials - including luxury vinyl tile, stone plastic composite, and commercial wood plastic composite - with a 0.67 quantity multiplier, rather than assuming full elimination.

Second, because EPDs for recycled clay tiles were not available in the One Click LCA database, we conservatively approximated embodied carbon impacts for this material by applying a 10% reduction in material quantity to reflect expected reductions associated with recycled content. While this introduces some uncertainty, the approach avoids overstating benefits and demonstrates that substantial embodied carbon reductions can be achieved through material selection and finish-layer reduction strategies, even under conservative assumptions.

Third, we evaluated the replacement of PVC roofing with TPO roofing during initial modeling. However, due to durability concerns, we do not recommend TPO in the final material strategy. Because roofing materials represent a relatively small share of the building's total embodied carbon, excluding TPO had a negligible impact on the overall emissions reduction (less than 0.3%).

Table 4.2A OneClickLCA Material Embodied Carbon Output Table (Moderate). This figure presents current estimates of embodied carbon under the moderate scenario by life cycle phase. Global warming potential associated with construction materials (A1-A3) decreased from 8,307,908 kg CO_2e in the baseline scenario to 5,996,245 kg CO_2e under the moderate scenario. Emissions from construction and installation (A4-A5) were also reduced, declining from 1,307,610 to 1,122,863 kg CO_2e. Overall, total embodied carbon decreased from 15,163,988 to 12,636,368 kg CO_2e, representing approximately a 17% reduction relative to the baseline.

Life Cycle Phase	Baseline Scenario (kg CO_2e)	Moderate Scenario (kg CO_2e)	Reduction (kg CO_2e)	Reduction (%)
A1-A3: Material Production	**8,307,908**	**5,996,245**	**2,311,663**	**27.83%**
A4-A5: Transit, Construction, Installation	**1,307,610**	**1,122,863**	**184,747**	**14.13%**

B4-B5: Material Replacement	**5,095,382**	**5,077,490**	**17,891**	**3.51%**
C1-C4: End of Life	**453,088**	**439,769**	**13,319**	**2.94%**
Total Embodied Carbon	**15,163,988**	**12,636,368**	**2,527,620**	**16.67%**

Embodied Carbon by Structural Classification

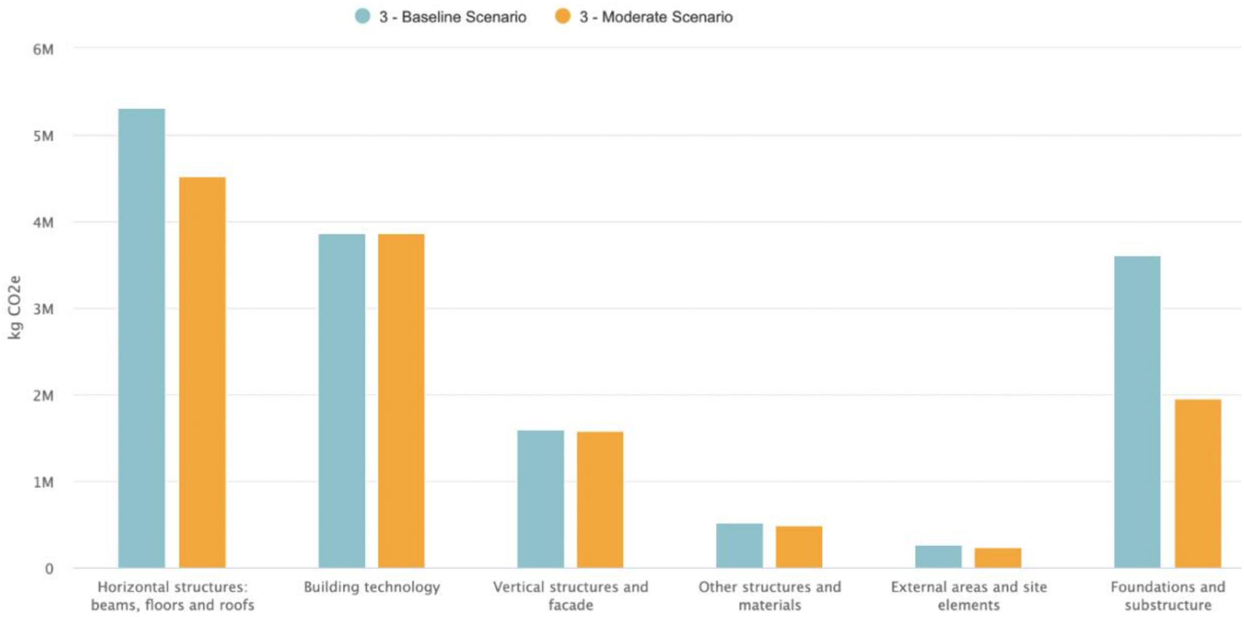

Figure 4.2A Embodied carbon by structural classification. The foundation category decreased from 3,612,128 kg CO_2e in the baseline scenario to 1,949,431 kg CO_2e in the moderate scenario, with total emissions reducing by 46%. Emissions from the horizontal structures such as frame beams and flooring reduced by 797,826 or 15%.

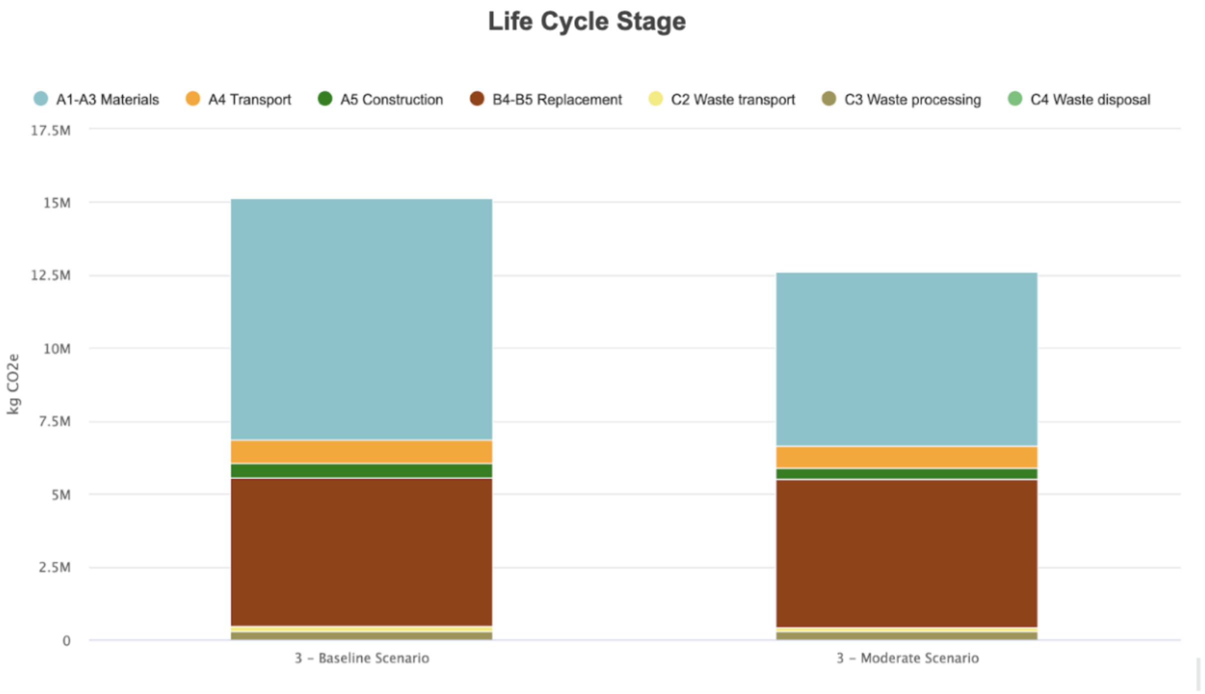

Figure 4.2B: Breakdown of embodied carbon emissions by life cycle stage. Material production stages (A1-A3) accounted for the largest share of embodied carbon at 5,996,245 kg CO_2e, representing a 28% reduction from the baseline value of 8,307,908 kg CO_2e. The replacement stage also contributed a substantial share in both scenarios but decreased only marginally, by 17,891 kg CO_2e or 0.03%. This minimal change reflects the building's long operational lifespan and limited material turnover over time.

4.2.3 Additional Efficiency Measures (Not Modeled)

SMART THERMOSTATS:

To further enhance energy efficiency and optimize HVAC performance, the installation of smart thermostats and occupancy-based controls provides a great opportunity. Unlike traditional programmable thermostats, smart systems dynamically adjust heating and cooling based on real-time occupancy, weather conditions, and usage patterns. These systems can detect when spaces are unoccupied and automatically adjust temperature settings to reduce unnecessary energy use while maintaining occupant comfort.

Studies conducted by Southern California utilities and energy agencies indicate that smart thermostat programs can reduce HVAC-related electricity consumption by approximately 10-15% in multifamily residential buildings, depending on climate zone, occupancy patterns, and baseline system efficiency.[30] Because heating and cooling account for a substantial share of operational energy use in this project, these improvements could translate to an estimated 3-7% reduction in

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[30] California Energy Commission. *Residential Appliance Saturation Survey (RASS).* California Energy Commission

total building operational carbon emissions for a Santa Barbara-climate multifamily development.[31] Based on typical electricity costs for multifamily units in California, this level of HVAC efficiency improvement could also translate to approximately $35-$105 in annual energy savings per unit, depending on baseline HVAC usage and occupancy patterns.[32] In addition, many California utilities offer rebates of approximately $60 per unit for installing ENERGY STAR® certified smart thermostats, further improving the cost-effectiveness of adoption.

While these savings would primarily benefit tenants in properties where residents pay their own utilities, this strategy could be particularly valuable for housing authority developments or property managers that cover electricity costs, since the building owner would then directly capture the operational savings. In these cases, smart thermostats could provide both environmental benefits and measurable reductions in operating expenses.

[33]We did not include these potential savings in the operational emissions modeling for the Moderate or Reach scenarios, because the energy modeling tool used in this analysis did not allow us to implement smart thermostat or occupancy-based control strategies. As a result, we also did not include these measures in the cost analysis. The estimates discussed here should therefore be interpreted as potential additional savings rather than assumptions built into the modeled scenarios. Future design development and commissioning phases could explore smart controls in greater detail to capture operational efficiencies beyond those included in the current analysis.

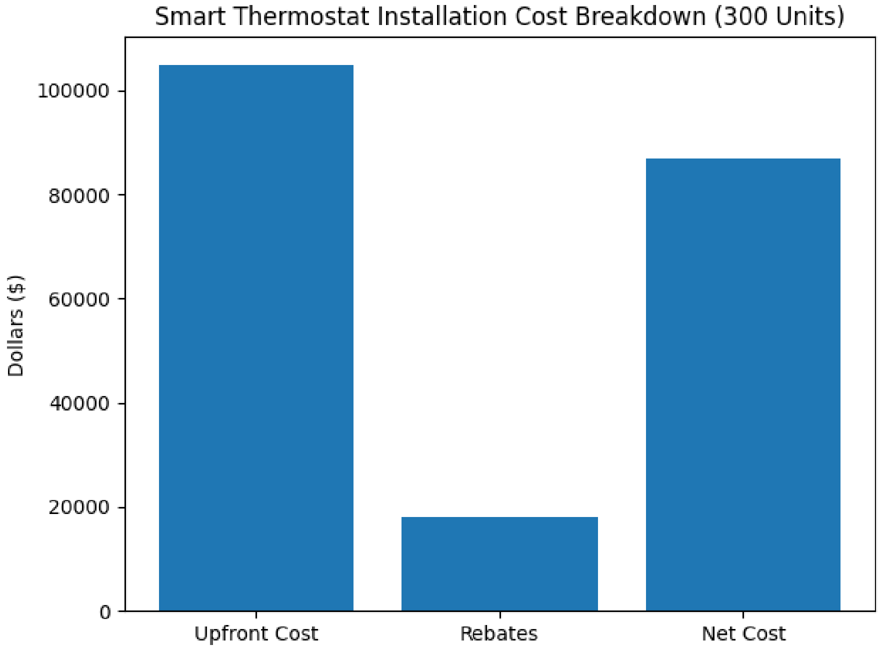

Figure 4.3A. Smart thermostat installation cost breakdown for the 300-unit development.

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[31] Energy Star. *Smart Thermostats.* U.S. Environmental Protection Agency

[32] U.S. Energy Information Administration. *Residential Energy Consumption Survey (RECS)*

[33] Southern California Edison. *Smart Thermostat Demand Response Program Evaluation Report*

This figure shows the estimated upfront installation cost of smart thermostats across the building and the impact of available rebates. Assuming an installed cost of $350 per unit, the total installation cost for 300 units is $105,000. With an estimated $60 California energy rebate per unit, the total rebate equals $18,000, reducing the net installation cost to $87,000.

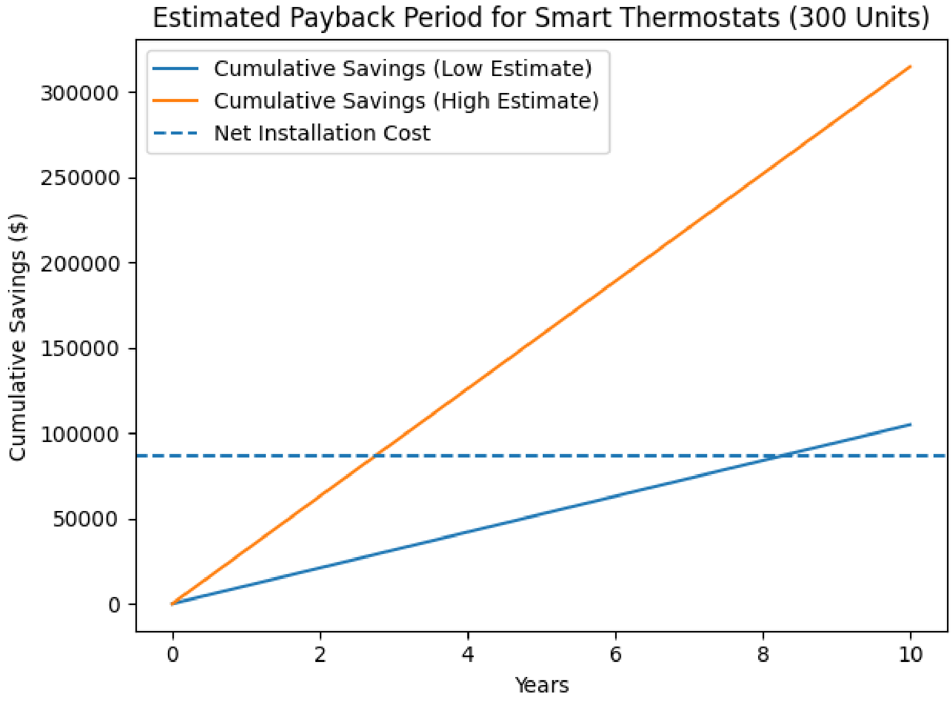

Figure 4.3B. Estimated cumulative energy savings and payback period for smart thermostat installation. This figure illustrates cumulative energy savings over time compared to the net installation cost. Estimated savings of $35-$105 per unit per year translate to building-wide savings of approximately $10,500-$31,500 annually across the 300-unit development. Using the conservative (low) savings estimate results in a payback period of approximately 8.3 years, while the higher savings estimate results in a payback period of approximately 2.8 years.

SUSTAINABLE DECONSTRUCTION:

Sustainable deconstruction represents an important opportunity to reduce construction and demolition (C&D) waste while recovering valuable materials that can be reused or recycled. The deconstruction of the current buildings onsite present a major opportunity to reduce potential wastestreams. Unlike traditional demolition, which typically sends most building materials directly to landfill, deconstruction carefully dismantles structures to salvage components such as doors, windows, fixtures, framing lumber, flooring, and structural beams. These materials can either be reused directly in other projects or recycled into new construction products, supporting a more circular materials economy.

This strategy is particularly relevant in California, where construction and demolition debris accounts for roughly 21% of the state's landfill waste stream.[34] As a result, state policies such as CALGreen require that at least 65% of nonhazardous construction and demolition waste be diverted from landfills through reuse, recycling, or salvage.[35] In Santa Barbara specifically, commonly recovered materials include concrete and metals, which can be crushed and reused as aggregate for new construction or site infrastructure such as road base or retaining walls.

The Reuse People of America and the MarBorg Construction and Demolition facility in Santa Barbara show diversion rates of more than 65%. This means that sustainable deconstruction can typically divert around two-thirds of demolition waste from landfill. For example, California generates approximately 8.7 million tons of construction and demolition (C&D) debris annually. If projects achieve the 65% diversion rate, roughly 5.66 million tons of material could be diverted from landfill each year, leaving approximately 3.05 million tons requiring disposal.[36] By recovering large materials, sustainable deconstruction can substantially reduce landfill waste while supporting a more circular building materials economy.

Beyond reducing landfill waste, deconstruction also provides measurable environmental benefits. Studies show that deconstructing just a typical 2,000-square-foot house can save approximately 2,400 gallons of water, prevent the harvesting of about 33 mature trees, and reduce greenhouse gas emissions equivalent to removing three cars from the road for one year.[37] These benefits arise from reducing the need for newly manufactured building materials and avoiding emissions associated with material production and disposal. Although deconstruction can involve higher upfront labor costs than conventional demolition, organizations such as The ReUse People of America note that material salvage value and potential tax deductions for donated materials can offset these costs. This makes deconstruction a viable strategy for reducing both environmental impacts and construction waste across housing developments in California.

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[34] California Department of Resources Recycling and Recovery (CalRecycle). *Construction and Demolition Debris Recycling.*

[35] California Building Standards Commission. *CALGreen Building Standards Code.*

[36] California Integrated Waste Management Board. *2004 Waste Characterization Study.* California Integrated Waste Management Board, 2004.

[37] StopWaste. *Construction & Demolition Debris.*

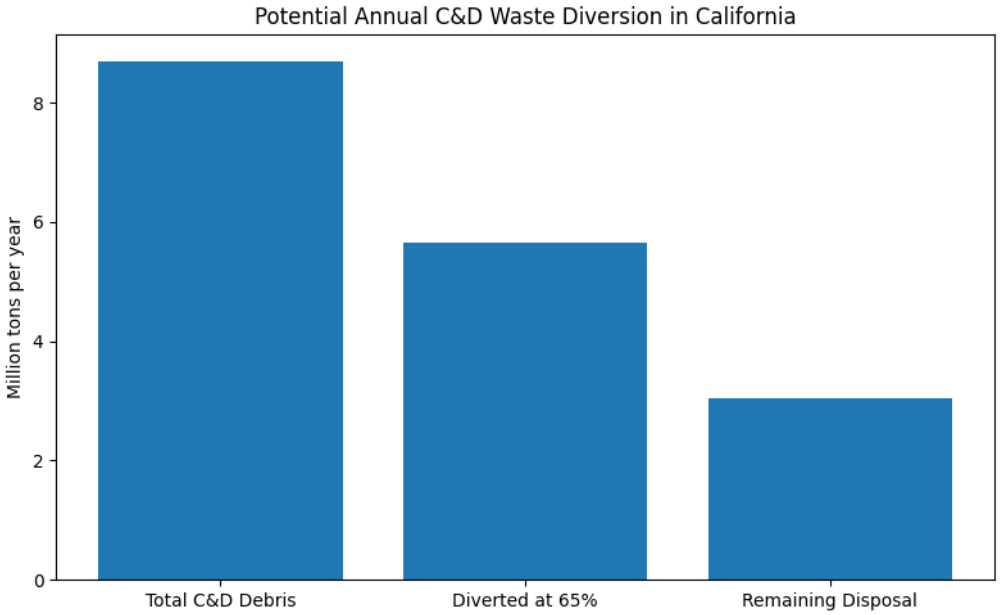

Figure 4.3C. Potential construction and demolition waste diversion through sustainable deconstruction in California. This figure illustrates the potential reduction in landfill waste if sustainable deconstruction and material recovery practices are implemented statewide. If projects achieve the 65% diversion rate required under CALGreen, 5.66 million tons of material could be diverted from landfill each year. This highlights the significant waste reduction potential associated with large-scale adoption of deconstruction and recycling strategies.

4.3 Reach Model Results

The reach scenario looks to make substantial reductions in embodied and operational carbon relative to both the moderate and baseline models by implementing optimized building envelope and high-performance building systems, unconstrained by cost. It represents a “what if” scenario prioritizing efficiency and low carbon life cycle footprints, and is guided by stringent green building standards such as those set by the Passive House Institute (PHI), known as PHIUS within the United States. Its purpose is to serve as a resource for the Housing Authority in the case that innovative technologies become less cost-prohibitive and more widely available over time, including increased access to funding sources and incentives. We evaluated emissions for this model annually and across a 100-year expected building lifespan, enabling ease of comparison across model results.

4.3.1 Reach Model Operational Carbon

Annual operational carbon emissions for the reach model were estimated at approximately 430,139.42 $kgCO_2e$, which translates to 43.01 million $kgCO_2e$ over the expected 100-year building lifespan. The model improvements result in a substantial 14.27% reduction in operational carbon emissions relative to baseline, and a 3.69% reduction from the moderate scenario. This represents a meaningful improvement from the Baseline and Moderate scenarios, primarily driven by substitutions to the building envelope, ventilation strategy, and HVAC performance.

Under the Reach scenario, the site's energy use intensity (EUI) declined to 126.25 kWh/m^2 per year, a reduction of 28.92 kWh/m^2 relative to the baseline scenario, and 10.01 kWh/m^2 compared to the moderate scenario in energy usage. A host of simulated performance upgrades drives this increased efficiency to the HVAC system, building envelope, and ventilation, implemented primarily through adjustments made to schematic type settings within Revit.

Within the schematic settings: we calibrated ventilation rates to align with both ASHRAE 62.2[38] and Passive House Institute (PHI)[39] standards. We reduced window-to-wall ratios and applied high-performance triple-pane window assemblies for improved thermal performance and reduced conductive heat transfer[40]. Additional upgrades included insulated slab and roof assemblies, which further reduce heat loss and improve the building internal temperature stability.

Mechanical system efficiency was also improved via high-efficiency heat pumps applied at the unit-level, paired with a ventilated refrigerant flow (VRF) system. In combination with tighter building envelope assumptions and improved ventilation performance within the model, these changes lower overall energy demand and improve operational efficiency.

4.3.2 Reach Model Embodied Carbon

Building off of the five primary material substitutions made within the moderate model, the reach model implements five additional material category substitutions: exterior finish pavers, exterior finishing plaster, interior paint, masonry, and sheathing. This model integrates innovative materials: Polycor limestone pavers, exterior wall-applied hempcrete, low GWP and zero VOC paint, lightweight and high-strength concrete masonry units (CMUs), lightweight hollow core concrete masonry units, expanded clay CMU with EPS filling, and oriented strand board (OSB) to fulfill these roles. While these selections require greater upfront investment, their carbon benefits beyond Moderate are relatively modest because the affected material quantities represent a small share of the total building mass. With these five substitutions, embodied carbon emissions from the material production phases (A1-A3) decreased from 8,307,908 kg CO_2e in the moderate scenario to 5,833,331 kg CO_2e under the reach scenario, a 29.79% reduction. Emissions from construction and installation (A4-A5) were also reduced, declining from 1,307,610 to 1,094,319 kg CO_2e, a 16.31% reduction. Overall, total embodied carbon decreased from 15,163,988 to 12,441,839 kg CO_2e, representing an approximate 18% reduction relative to the baseline.

Table 4.3.2A OneClickLCA material embodied carbon output table (Reach). This figure presents current estimates of embodied carbon under the reach scenario by broad life cycle phase, relative to baseline and moderate scenario projected values. While the reach scenario introduces five select material substitutions, the resulting reductions beyond the moderate scenario are

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[38] ANSI/ASHRAE Standard 62.2: Ventilation and Acceptable Indoor Air Quality in Residential Buildings.

[39] Passive House Institute (PHI). *Passive House Standard: Passive House Requirements for Quality Approved Passive Houses.*

[40] U.S. Department of Energy (DOE). High-Performance Windows Volume Purchase Program Technical Specifications. Building Technologies Office.

relatively small, indicating that the majority of embodied carbon savings were captured within the moderate design's improvements.

Life Cycle Phase	Baseline Scenario (kg CO_2e)	Moderate Scenario (kg CO_2e)	Reach Scenario (kg CO_2e)	Reduction (kg CO_2e)	Reduction (%)
A1-A3: Material Production	**8,307,908**	**5,996,245**	**5,833,332**	**2,474,577 from baseline; 162,914 from moderate (increase)**	**29.79% from baseline; 2.72% from moderate**
A4-A5: Transit, Construction, Installation	**1,307,610**	**1,122,863**	**1,094,319**	**213,291 from baseline; 28,544 from moderate**	**16.31% from baseline; 2.54% from moderate**
B4-B5: Material Replacement	**5,095,382**	**5,077,490**	**5,075,139**	**20,242 from baseline; 2,350 from moderate**	**0.40% from baseline; 0.05% from moderate**
C1-C4: End of Life	**453,088**	**440,040**	**439,049**	**14,039 from baseline; 991 from moderate**	**3.10% from baseline; 0.23% from moderate**
Total Embodied Carbon	**15,163,988**	**12,636,637**	**12,441,839**	**2,722,149 from baseline; 194,529 from moderate**	**17.95% from baseline; 1.54% from moderate**

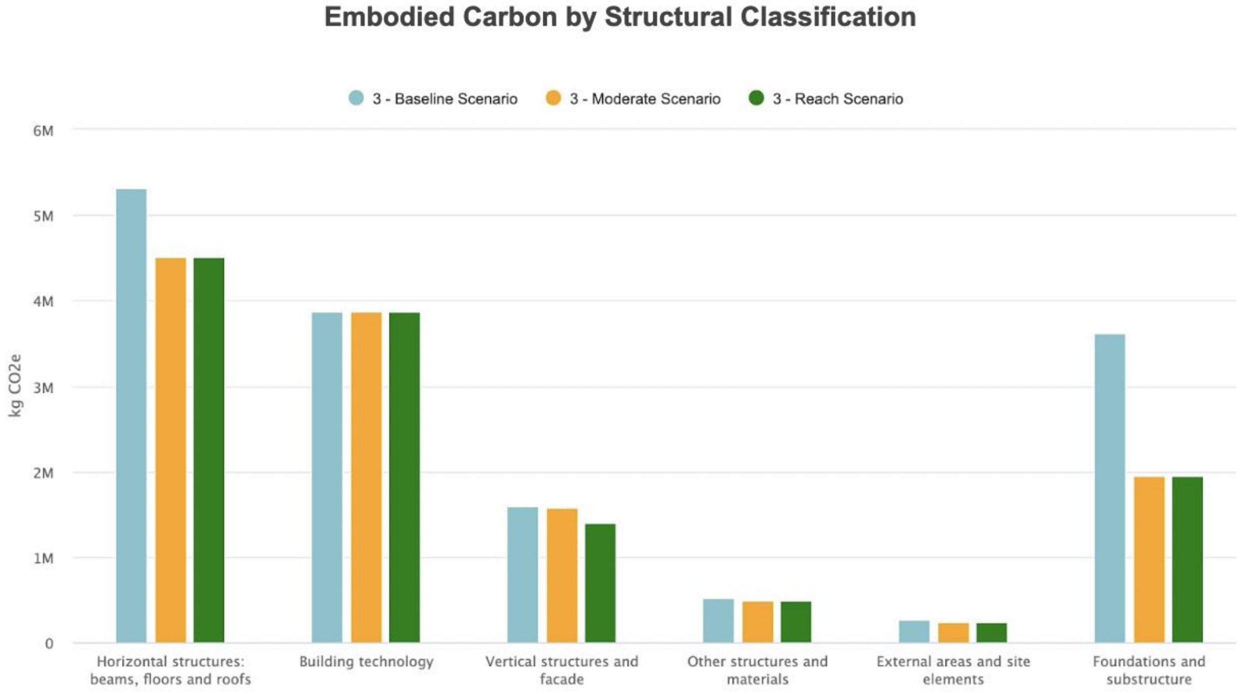


Figure 4.3.2A Embodied carbon by structural classification. The foundation category substitutions were the same as moderate, amounting to 1,949,432 kg CO_2e. We found a reduction of 1,662,696 kg CO_2e, or 46.03% from the baseline scenario. Emissions from the horizontal structures such as frame beams and flooring were reduced minimally from moderate, from 4,516,676 to 4,509,429 kg CO_2e (7,247 decrease), or 0.16%. From baseline, it is a reduction of approximately 15.15%. The most notable reduction that sets the Reach results apart is the change in vertical structures and facade embodied emissions, which captures changes such as hempcrete for exterior plaster mortar. The reduction from baseline was 191,799 kg CO_2e, or 12.06%. From moderate, it was a reduction of 177,948 kg CO_2e, or 11.29%.

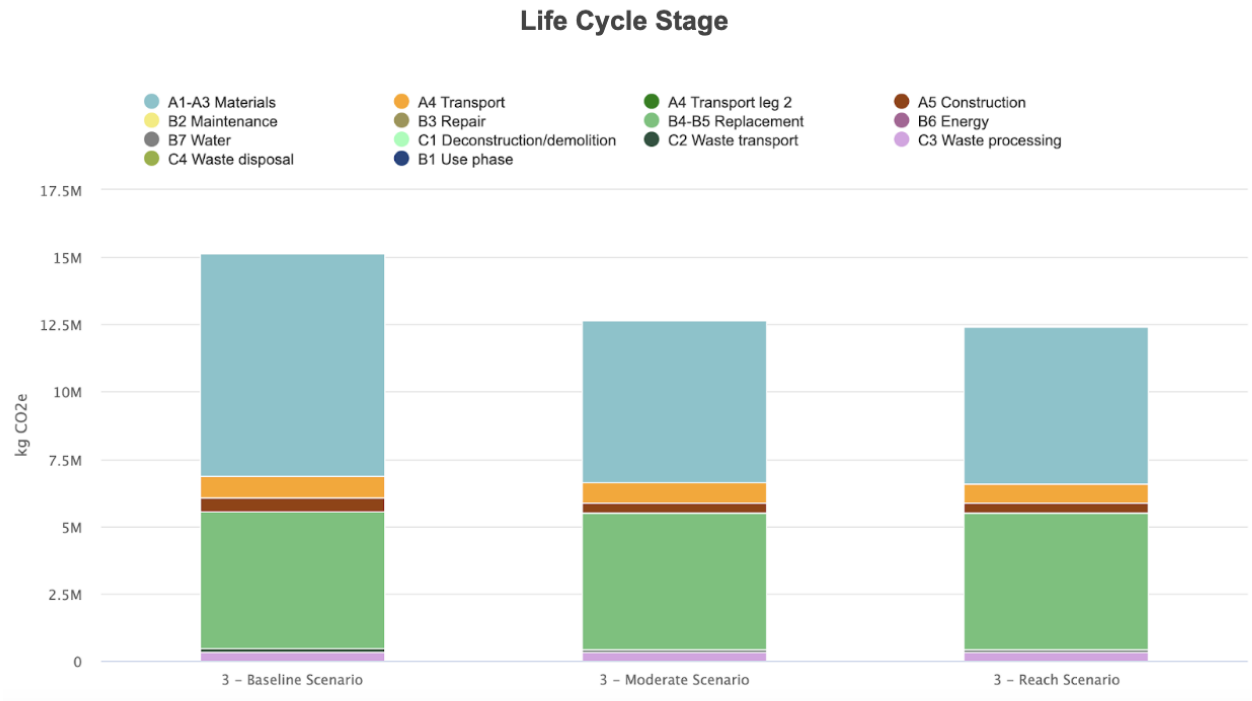
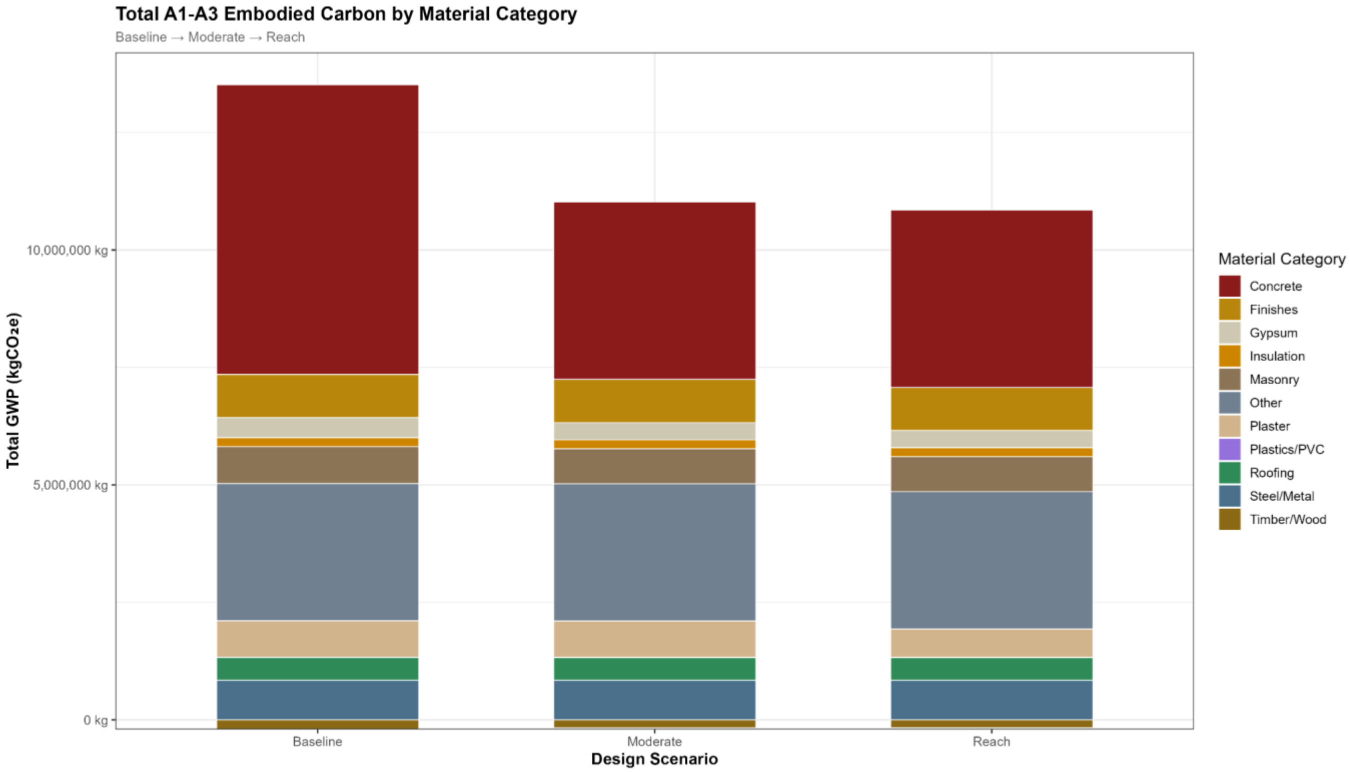
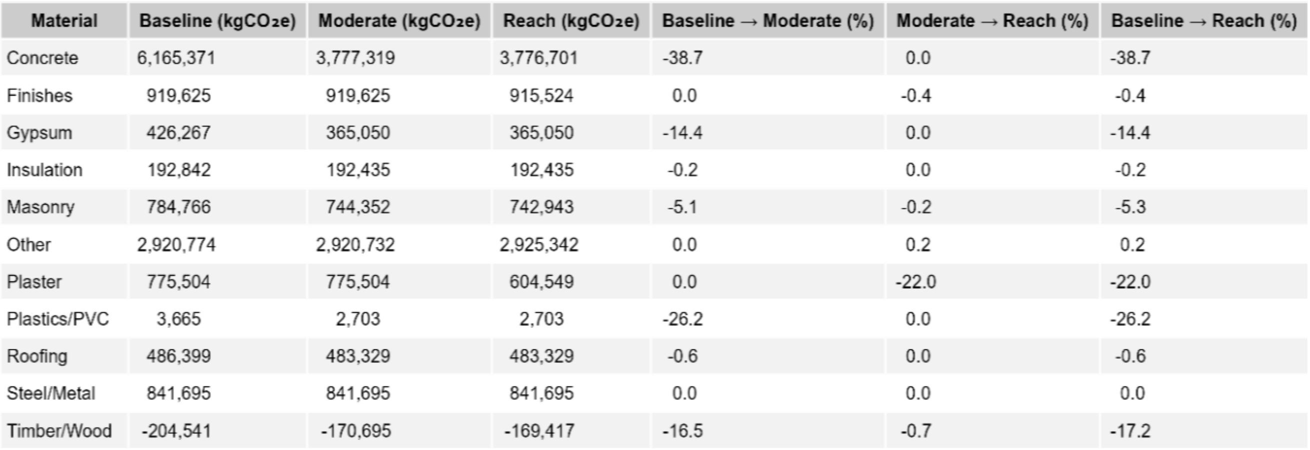


Figure 4.3.2B: Breakdown of embodied carbon emissions by life cycle stage. Material production stages (A1-A3) accounted for the largest share of embodied carbon at 5,833,332 kg CO_2e, representing a 29.79% reduction from baseline, and 2.72% from Moderate. This is primarily due to low-carbon material substitutions, although the change is minimal from Moderate due to the additional changes of Reach applying to smaller material quantities. Transport emissions amounted to 744,617 kg CO_2e, a reduction of 7.78% from baseline, 0.45% from Moderate. We made this marginal reduction by using the closest regional suppliers for the additional changes made within Reach from Moderate. The replacement stage contributed similarly to the Baseline and Moderate scenarios, decreasing only marginally, by 5,075,140 kg CO_2e or 0.40% from baseline. From Moderate, it decreased by 0.05%. Overall, the moderate scenario captures most achievable reductions, with the reach scenario providing smaller incremental improvements.





Material	Baseline (kgCO$_2$e)	Moderate (kgCO$_2$e)	Reach (kgCO$_2$e)	Baseline → Moderate (%)	Moderate → Reach (%)	Baseline → Reach (%)
Concrete	6,165,371	3,777,319	3,776,701	-38.7	0.0	-38.7
Finishes	919,625	919,625	915,524	0.0	-0.4	-0.4
Gypsum	426,267	365,050	365,050	-14.4	0.0	-14.4
Insulation	192,842	192,435	192,435	-0.2	0.0	-0.2
Masonry	784,766	744,352	742,943	-5.1	-0.2	-5.3
Other	2,920,774	2,920,732	2,925,342	0.0	0.2	0.2
Plaster	775,504	775,504	604,549	0.0	-22.0	-22.0
Plastics/PVC	3,665	2,703	2,703	-26.2	0.0	-26.2
Roofing	486,399	483,329	483,329	-0.6	0.0	-0.6
Steel/Metal	841,695	841,695	841,695	0.0	0.0	0.0
Timber/Wood	-204,541	-170,695	-169,417	-16.5	-0.7	-17.2

Figure 4.3.2C Total Embodied Carbon by Material Category. The stacked bar chart shows a reduction in total embodied carbon from Baseline to Moderate to Reach. The Moderate scenario reflects targeted low-carbon substitutions in concrete mixes, gypsum boards and roofing membranes, while Reach further reduces structural concrete volumes and replaces a portion of mineral materials with biogenic alternatives such as higher-recycled-content gypsum. Totals are calculated from raw material results from OneClickLCA for each material accounting for cumulative group totals across life cycle stages.

4.3.3 Additional Efficiency Measure (Not Modeled)

GREYWATER SYSTEMS:

To improve water efficiency and reduce potable water demand, the project could incorporate a greywater system that captures and reuses wastewater from showers, sinks, and laundry for non-potable uses such as toilet flushing and landscape irrigation. This approach is particularly beneficial in water-scarce regions such as California, where reducing reliance on potable water supplies can provide both environmental and economic benefits.

Greywater systems can significantly reduce building water consumption. Studies indicate that these systems can lower total water use by approximately 30-45%, which could translate to millions of gallons of water saved annually in a multifamily building. [41] Reduced water consumption also lowers utility costs for building operators and tenants. In addition, reusing water on-site helps conserve freshwater resources and reduces the volume of wastewater sent to municipal treatment facilities.

Modern greywater systems can be designed to comply with the California Plumbing Code and are scalable for multifamily developments. Centralized systems can be integrated into new construction with treatment, filtration, storage tanks, pumps, and monitoring controls. These systems can also be paired with other water-efficiency strategies, such as rainwater harvesting or building management systems, to improve overall water monitoring and resource efficiency.

Greywater reuse can also improve building resilience during drought conditions by reducing dependence on municipal water supplies during water shortages or usage restrictions. In California, some local water agencies may offer rebates, permitting assistance, or other incentives for water reuse systems, which can improve project economics.

For a centralized greywater system in a multifamily development, estimated installation costs may range from $700,000 to $1 million, depending on system size, system complexity, and treatment requirements.[42] A system of this scale could offset approximately 20,000 gallons of potable water per day, assuming that roughly 30 - 40% of total residential water use is captured and reused for toilet flushing and landscape irrigation.[43]

This amounts to approximately 7.3 million gallons of potable water saved per year (calculation of 20,000 gallons/day × 365 days). Based on typical water rates, this could translate to an estimated

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[41] "Benefits and Costs of Installing a Grey Water Recycling System." *Hydraloop Info Center*, 17 Sept. 2024

[42] Wahaso Water Harvesting Solutions. "What Is the Cost To Install a Greywater System?" *Wahaso*, 10 Apr. 2022

[43] University of California Agriculture and Natural Resources (UC ANR). *Graywater Systems for Landscape Irrigation.*

Greywater Action*. Manufactured Greywater Systems.* https://greywateraction.org/manufactured-greywater-systems annual cost savings of $73,000-$146,000, resulting in a potential payback period of approximately 6-13 years, with faster payback and benefit possible if rebates or incentives are applied.

Section 5: Cross-Scenario Results and Synthesis

5.1 Comparing OneClickLCA and Revit Embodied Carbon Estimates

Embodied carbon estimates for the baseline scenario differed substantially between OneClickLCA (8,307,908 $kgCO_2e$) and Autodesk Insight (790,994 $kgCO_2e$), a factor of ~10x despite identical Revit geometry and reliance on industry-average environmental product declarations (EPDs).[44] This discrepancy is attributable to five methodological differences between the tools, which are well documented in comparative tool reviews and BIM-LCA validation studies.[45]

1. **First, material scope varies markedly** with OneClickLCA quantifying all Revit materials including interiors, finishes, MEP equipment, and sitework. This gives thousands of detailed rows mapped to its 250K+ EPD database.[46] Insight is constrained to major structural and envelope assemblies (e.g., floors, walls, roofs, and slabs), systematically excluding smaller components that can represent large portions of total A1-A3 GWP in residential projects.[47]
2. **Second, EPD resolution and factors differ** with OneClickLCA applying region-specific averages and granular mix designs, transport distances, and upstream processes, resulting in 20-50% higher factors for concrete and steel than Insight's global generic values from the ICE database.[48]
3. **Third, assembly treatment contrasts**: OneClickLCA disaggregates composite elements (e.g., roof slab + membrane + insulation) into separate EPD-backed layers, whereas Insight uses blended assembly averages that understate multi-layer impacts.[49]
4. **Fourth, A1-A3 boundaries are not identical**: OneClickLCA includes comprehensive A3 phase manufacturing impacts, such as factory energy and production waste, while Insight relies on simplified cradle-to-gate assembly averages. As a result, there may be an omission or aggregation of some manufacturing-stage processes. [50]
5. **Finally, Revit integration granularity differs**: OneClickLCA's plugin extracts quantities plus material properties for hidden layers and small items, while Insight's analytical model simplifies geometry and omits non-energy materials.

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[44] Eleftheriadis, S., & Duffour, P. (2025). Trade-offs between accuracy and efficiency in BIM-LCA integration. Engineering, Construction and Architectural Management, 32(1), 237-258.

[45] Dash, B. (2025). Assessing the carbon footprint of building materials: A comparative study using Autodesk Revit and One Click LCA. International Journal of Research Publication and Reviews, 6(4), 1-10.

[46] One Click LCA. (2025). Top 7 building LCA software 2025.

[47] One Click LCA. (2025). Life-cycle assessment from Revit.

[48] One Click LCA. (2025). Life-cycle assessment from Revit.

[49] One Click LCA. (2025). Life-cycle assessment from Revit.

[50] Loftus, J. (2024). Navigating the carbon analysis ecosystem for architects [Conference handout AS3358]. Autodesk University.

Tool comparisons consistently show OneClickLCA yielding around 10x higher A1-A3 totals than Insight for identical models due to these scope and detail differences. Insight thus serves as a rapid structural screening tool, while OneClickLCA provides near-whole-building fidelity suitable for LEED Whole-Building Life Cycle Assessment (WBLCA) and detailed reporting. The 8.3 $MtCO_2e$ OneClickLCA result is therefore the more complete baseline for comparative analysis.

5.2 Cost Analysis Results

The cost analysis shows that the moderate building scenario outperforms the traditional construction baseline in terms of long-term cost effectiveness. We estimate annual electricity costs for the conventional building at approximately $708,000 per year, compared to $621,718 per year for the moderate green design. This difference is driven by the lower energy use intensity (EUI) of the green building, which results in reduced electricity consumption.

The reduction in electricity use leads to an approximate 12% decrease in annual operating costs for the green building relative to the conventional model. While the green building design requires higher upfront investment due to material substitutions and high-efficiency HVAC systems, these additional capital costs are offset by energy savings over time. The analysis indicates a payback period of approximately 7 years in Housing Authority properties where the Authority pays utilities, after which the green building generates net cost savings. However, in the case of developments where tenants pay their own utilities, the direct financial savings primarily benefit residents rather than the Housing Authority itself. As such, the strategy remains transferable to future projects in which the Housing Authority is responsible for utility payments and would directly realize the financial return.

When we evaluate costs over a 100-year building lifespan, the conventional construction scenario is estimated to be approximately $1,113,064 more expensive than the green building scenario at a 5% discount rate. Total lifecycle costs amount to $34,814,123 for the conventional design compared to $33,701,059 for the green building. Discounted present value (PV) calculations show that the green building has lower total lifetime costs, as sustained operational savings outweigh the higher initial construction costs. Even under higher financing assumptions, the green building remains more cost-effective, with lifecycle costs of $26,469,040 for the conventional scenario and $26,219,664 for the green building scenario at a 10% discount rate. These results suggest that moderate green building strategies can reduce both long-term operating expenses and total life-cycle costs while delivering environmental benefits.

Table 2 and Figure 4.3 below were generated using a discounted cash flow analysis comparing lifecycle costs for the conventional and green building scenarios over the assumed building lifespan. We calculated net present value (NPV) by discounting upfront capital costs and annual operating costs using a range of discount rates to test sensitivity to financing assumptions. This analysis evaluates financial costs only and does not incorporate the social cost of carbon, so the results do not reflect monetized climate damages. All calculations were performed in R, and the resulting NPV outputs were visualized using R-based plotting tools. This approach allows for comparison of cost performance across financial assumptions, highlighting the consistency of the green building scenario under conservative conditions.

Table 5.2A Net present value of lifecycle costs for the traditional and green building scenarios under varying discount rates (r) assumptions. The table illustrates that across conservative financial assumptions (high discount rates), the green building scenario consistently results in lower total costs than the traditional building scenario.

Table 5.2A: Costs Under Varying Discount Rates

Assumptions	**Traditional**	**Green**
r = 5%	$34,814,123	$33,701,059
r = 10%	$26,469,040	$26,219,664

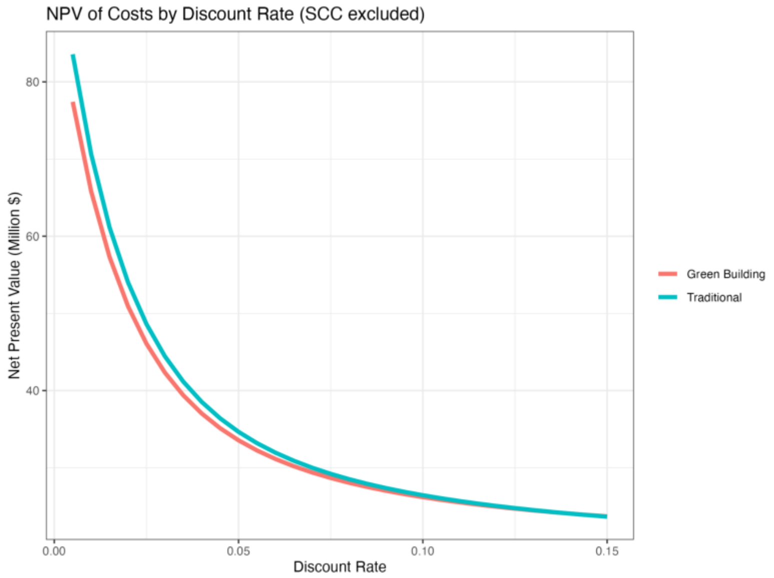

Figure 5.2 Net present value of cost by discount rate excluding the social cost of carbon. Even in the most conservative scenario where the discount rate is at 10% and there is no discount rate, the NPV of costs in the traditional building scenario is higher than the green building scenario.

5.3 Currently Available Financial Incentives and Rebates

The following funding sources provide incentive for the Housing Authority of the City of Santa Barbara (HACSB) to implement green material and operating systems, with particular weight in electrification:

Table 5.3A Table of Available Financial Incentives and Rebates

Program	**Administering Agency**	**Best Fit / Eligible Measures**	**Typical Incentives**	**How Presidio Springs Meets Eligibility Criteria**	**Modeling Applications**

CEC BUILD (Building Initiative for Low-Emissions Development)	California Energy Commission (CEC)	All-electric systems (i.e.: heat pumps and heat pump water heaters) and envelope improvements	Provides project incentives and technical assistance; Design Award is available for up to ~$100k for first all-electric project	Slated to be all-electric, low-income housing, and a new development	A major capital incentive tied to electrification, heat pumps, and envelope upgrades Note: if this is not the Housing Authority's first all-electric development by year it is in development (2027), the project may not be eligible to compete for the design award funding
SOMAH (Solar on Multifamily Affordable Housing)	CEC via TECH Clean CA	Heat-pump HVAC and central heat-pump water heaters in multifamily buildings	Up to $3.50/W for tenant-serving PV and $1.19/W for common-area PV	It is affordable senior housing (327 units after redevelopment)	Model high PV adoption scenario within Revit (end feasibility may be limited by applicable surface area, costs, and labor required after offset)
3C-REN Multifamily Home Energy Savings (MHES)	Tri-County Regional Energy Network (SLO, SB, Ventura)	Multifamily energy efficiency upgrades: heat pumps, HPWH, envelope improvements	~$1,000+ per unit base rebates, plus measure-specific rebates; no-cost technical assistance	It is located in SB County and is a multifamily development.	Can act as a per-unit incentive for all-electric design

Southern California Edison Multifamily Energy Programs	California Public Utilities Commission	Solar PV for deed-restricted affordable housing	Rebates and technical support; sometimes on-bill financing (inquire)	Site falls within SCE service territory and serves income-qualified residents	Model distributed solar PV capacity scenarios to estimate potential electricity generation offsets and reductions in grid electricity demand for common-area loads.
Santa Barbara Clean Energy (SBCE) Electrification & EV Programs	Community Choice Energy Provider	Electrification support and EV charging infrastructure	Incentives and permitting assistance for EV chargers and electrification measures	SBCE electricity service consumers are eligible.	Model EV charging infrastructure scenarios to estimate additional electricity demand and assess compatibility with on-site solar generation and building electrical capacity.

5.4 Material Performance Properties Table: Non-Cost Criteria for Material Selection

This section presents the comprehensive results of the material performance properties assessment, documenting how baseline and alternative materials perform across key non-cost decision criteria relevant to Santa Barbara's coastal climate, seismic context, and multifamily housing requirements. The assessment synthesizes findings from peer-reviewed, industry-standard, and field-experience sources compared across key performance considerations. These cannot be necessarily adapted into the Insight model but will be significant considerations nonetheless for the Housing Authority to adopt into design practices. Final material recommendations are discussed in Section 7.1

Table 5.4A Comparison of key thermal and physical properties for selected low-embodied-carbon material substitutions relative to baseline materials. The analysis demonstrates that overall envelope performance is generally maintained - and in some cases modestly improved - while achieving reductions in embodied carbon. Substitutions from cast-in-place concrete through concrete pavers represent the moderate scenario, and beyond concrete pavers, materials reflect the reach scenario.

Material Substitution	Thermal Conductivity (W/m·K)	Specific Heat Capacity (J/kg·K)	Density (kg/m^3)	Operational Carbon Impact	Additional Notes
Cast-in-place concrete → Fly ash concrete	**1.7 → 1.5**	**880 → 900-960**	**2400 → 2300**	**Yes (↓)**	Fly ash reduces conductivity and increases heat capacity, improving thermal lag and peak load reduction.
Clay tiles → Recycled clay tiles	**0.32-0.40 → 0.32-0.38**	**800-900 → 800-900**	**1900 → 1850-1900**	**Yes (↓)**	Increased porosity can reduce conductivity and diffusivity, delaying heat transfer under solar loads. Marginal reduction in solar heat.
LVT flooring → Exposed concrete slab	**Lower (with overlay) → Slightly higher (bare slab)**	**Same material, higher effective participation**	**2400 → 2400**	**Mixed (±)**	Removing overlays reduces R-value but increases exposed thermal mass, improving temp buffering. Beneficial if thermal ventilation strategy planned.
Gypsum wallboard → Recycled gypsum wallboard	**0.17 → 0.16**	**1090 → 1120**	**800 → 770-780**	**Yes (↓)**	Retained porosity lowers conductivity while increasing heat capacity, improving insulation and thermal lag. Acoustic, durability, and fire performance are similar.
Rigid foam board → Recycled foam board insulation	**0.020-0.038 → 0.022-0.040**	**1300-1500 → 1300-1500**	**30-50 → 30-40**	**Minimal (±)**	Recycled-content foam boards maintain nearly identical thermal performance while reducing embodied carbon through reduced virgin petrochemical inputs.
PVC roofing → TPO roofing	**0.15-0.17 → 0.16-0.18**	**Low → Low (thin membrane)**	**1400 → 900-1200**	**Durability (↓)**	Higher initial solar reflectance of TPO reduces cooling loads. However, TPO reflectance significantly decays over 3

					years (20-30 year lifespan PVC vs. 15-20 year TPO).
Concrete pavers → limestone pavers	**1.1–1.5 → 1.3–2.0**	**880–920 → 790–900**	**2100–2400 → 2400–2700**	**Negligible (0)**	As exterior hardscape elements, these pavers are not part of the building thermal envelope and contribute no meaningful operational impact. The main interest would be lowered GWP value (kg CO2e per m2, which it does achieve.
Standard interior paint → Low-VOC paint (GREENGUARD Gold)	**~0.14-0.16 → ~0.12-0.15**	**Very low mass**	**Very low mass**	**None (0)**	Paint does not affect thermal envelope. Benefit is indoor air quality (VOC <5 g/L).
Medium weight, high strength (MW-HS), 22 MPa CMUs → Light weight, high strength (LW-HS), 22 MPa CMUs	**~0.7–0.9 → ~0.35–0.5**	**~837 → ~837 (same)**	**~1900 - 2100 → ~1500 - 1700**	**Yes (↓)**	Alternative sourced from the closest plant to reduce transport emissions. Lightweight CMU maintains the same structural strength while lowering density and embodied carbon. Lower-density aggregates slightly improve thermal resistance. Expected service life: 50–100+ years, similar to conventional CMU.
Normal weight Hollow-core CMUs (12×8×16 in; 2000 kg/m^3 density) → Light weight Hollow-core CMUs (12×8×16 in; 1680 kg/m^3 density)	**~0.81 → ~0.38**	**~837 → ~837 (same)**	**2000 → 1680**	**Yes - slight reduction (↓)**	Maintains the same block geometry and hollow-core structure. Lightweight CMU is typically less conductive, slightly reducing heat transfer through the masonry portion of the wall, though overall impact may be limited by other insulation layers. Expected service life: 50–100+ years, depending on reinforcement, mortar condition, and moisture exposure..

Insulated CMU (expanded clay block with PUR insulation filling) → Insulated CMU (expanded clay block with EPS insulation filling)	**0.022 → 0.035**	**~1600 → ~1213**	**644 → 644**	**Yes (↓)**	Maintains insulated masonry function while reducing embodied carbon compared to the previous PUR-filled option. The fill material may degrade faster than the block itself. Expected service life: 50–75+ years.
Conventional stucco / plaster mortar → hempcrete (wet-applied)	**0.6-1.0 → 0.07-0.20**	**900-1,100 → 1,300-1,800**	**1,600-2,000 → 300-500**	**Minimal (±)**	Has minimal impact on the thermal envelope unless applied at significant thickness. Hempcrete is lower density and more vapor-permeable, improving moisture and heat transfer (hygrothermal performance) and reducing thermal bridging.

The material substitutions for the moderate scenario evaluated show that lower embodied-carbon alternatives generally maintain comparable or slightly improved thermal performance relative to conventional materials.[51] These findings are based on a targeted literature review and comparative analysis of published material thermal and physical properties and their documented impacts on building performance. In several cases such as fly ash concrete, recycled gypsum wallboard, and recycled clay tiles, thermal conductivity is reduced while specific heat capacity is maintained or slightly increased.[52] This improves thermal lag and dampening short-term temperature fluctuations that can reduce peak heating and cooling demand.[53] Even where conductivity increases slightly (insulation), equivalent thermal performance can be achieved through design adjustments such as increased insulation thickness or improved air sealing. One exception is the replacement of PVC with TPO roofing, as the reduced durability makes this substitution less feasible. Aside from this case, none of the other material substitutions meaningfully degrade envelope performance.

For substitutions for the reach scenario, operational impacts remain limited as well.[54] Exterior pavers and interior finishes such as low-VOC paint and pavers do not meaningfully influence the

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[51] ASHRAE. (2021). *ASHRAE handbook—Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

[52] Department of Energy, U.S. (2022). *Energy efficiency & renewable energy building technologies office: Building envelope and thermal performance resources*. U.S. Department of Energy.

[53] Hammond, G., & Jones, C. (2019). *Inventory of carbon and energy (ICE) database* (Version 3.0). University of Bath, Sustainable Energy Research Team.

[54] International Energy Agency. (2019). *EBC Annex 69: Strategy and practice of adaptive thermal comfort in low energy buildings*. IEA Energy in Buildings and Communities Programme.

conditioned envelope and have negligible operational carbon effects. Additionally, CMUs and hempcrete have minimal changes in thermal performance.[55]

Overall, none of the substitutions meaningfully degrade envelope performance besides TPO roofing. Operational carbon effects are minimal or yield small annual reductions depending on material selection. This analysis proves that embodied carbon savings can be achieved without increasing operational energy use, and in some cases with added benefits such as reduced peak loads and improved thermal stability.

5.5 Sensitivity Analysis

We performed a comparative whole-building LCA for the three design scenarios. Figures 5.5.1A and B summarize A1-A3 (product-stage) embodied carbon across the three design scenarios (Baseline, Moderate, Reach) after grouping OneClickLCA export materials into nine functional categories (Concrete, Steel/Metal, Gypsum, Timber/Wood, Roofing, Insulation, Plaster, Masonry, Other). We intentionally grouped the materials to support interpretation at the structural + enclosure system level, rather than at the level of individual products.

Across all scenarios, concrete is the dominant contributor to A1-A3 global warming potential, followed by “Other” (the broad cumulative of all sub-categories) and Steel/Metal, with Gypsum, Roofing, Insulation, Plaster, and Timber/Wood contributing smaller but still meaningful shares. This pattern matches common findings in the literature and other studies of multi-unit residential buildings, where concrete and steel typically account for a majority of product-stage impacts.

To reflect uncertainty in the generic carbon data that is automatically assigned by OneClickLCA to many materials, we conducted a Monte Carlo uncertainty analysis for each major material group. For every category and design, we treated the reported A1-A3 carbon value as the center of a lognormal distribution, which is a standard way to model quantities that cannot go below zero and are often skewed to the high side.[56] We then assigned a reasonable “spread” (coefficient of variation or CV) to each category based on published studies of how much real products vary from one another:

- Concrete: CV ≈ 30 %, reflecting variation in cement content, SCM substitution, and plant performance.[57]
- Steel/Metal and Masonry: CV ≈ 25 %, driven by recycling rates and regional process differences.[58]

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[55] DOE Building America. (2022). *Building America best practices series: High-performance building enclosure strategies*. U.S. Department of Energy.

[56] Feng, H., Zhao, J., Zhang, H., Zhu, S., & Li, D. (2022). Uncertainties in whole-building life cycle assessment: A systematic review. Developments in the Built Environment, 10, 100073.

[57] Marsh, E., Orr, J., & Ibell, T. (2021). Quantification of uncertainty in product stage embodied carbon calculations for buildings. Energy and Buildings, 251, 111340.

[58] Feng, H., Zhao, J., Zhang, H., Zhu, S., & Li, D. (2022). Uncertainties in whole-building life cycle assessment: A systematic review. Developments in the Built Environment, 10, 100073.

- Gypsum and Plaster: CV ≈ 35 %, due to recycled content and manufacturing route variability.[59]
- Roofing and Insulation: CV ≈ 50 %, capturing particularly high dispersion in polymeric products and insulation EPDs.[60]
- Timber/Wood: CV ≈ 20 %, reflecting species mix and moisture content while remaining lower than concrete and polymers.[61]
- Other: CV ≈ 40 %, assigned as a conservative default for heterogeneous residual materials.[62]

Using these spreads, we generated 1,000 simulated values for each category and design option. This produced a distribution of possible A1-A3 carbon outcomes, from which we calculated the mean and a 95 percent confidence interval for each category. In building life-cycle assessment, running 1,000 to 10,000 simulations is generally accepted as enough to get a stable estimate of these confidence ranges.[63]

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[59] Arslan, D., Mohammadpourkarbasi, H., & Sharples, S. (2024). A case study using expanded polystyrene insulation for the retrofit of a mid-rise building: Impacts of selecting different EPDs on LCA results. Building Services Engineering Research & Technology, 45(2).

[60] Arslan, D., Mohammadpourkarbasi, H., & Sharples, S. (2024). A case study using expanded polystyrene insulation for the retrofit of a mid-rise building: Impacts of selecting different EPDs on LCA results. Building Services Engineering Research & Technology, 45(2).

[61] Zhang, Y., Sattar, S., Cook, D. T., Johnson, K. J., & Fung, J. F. (2024). Systematic review of embodied carbon assessment and reduction in building life cycles: An integrated approach to resilience and sustainability (NIST Special Publication 1324). National Institute of Standards and Technology.

[62] Mendoza Beltran, M. A., Pomponi, F., & Guinée, J. B. (2018). Uncertainty analysis in embodied carbon assessments: What are the implications of its omission? In F. Pomponi, C. De Wolf, & A. Moncaster (Eds.), Embodied carbon in buildings: Measurement, management, and mitigation (pp. 3-22). Springer International Publishing.

[63] Pozzer, A. E., Rausch, C., & Leite, F. (2025). Methodology for evaluating the uncertainty of embodied carbon assessments in construction projects across project phases. Journal of Construction Engineering and Management, 151(10).

5.5.1 Comparative results across scenarios

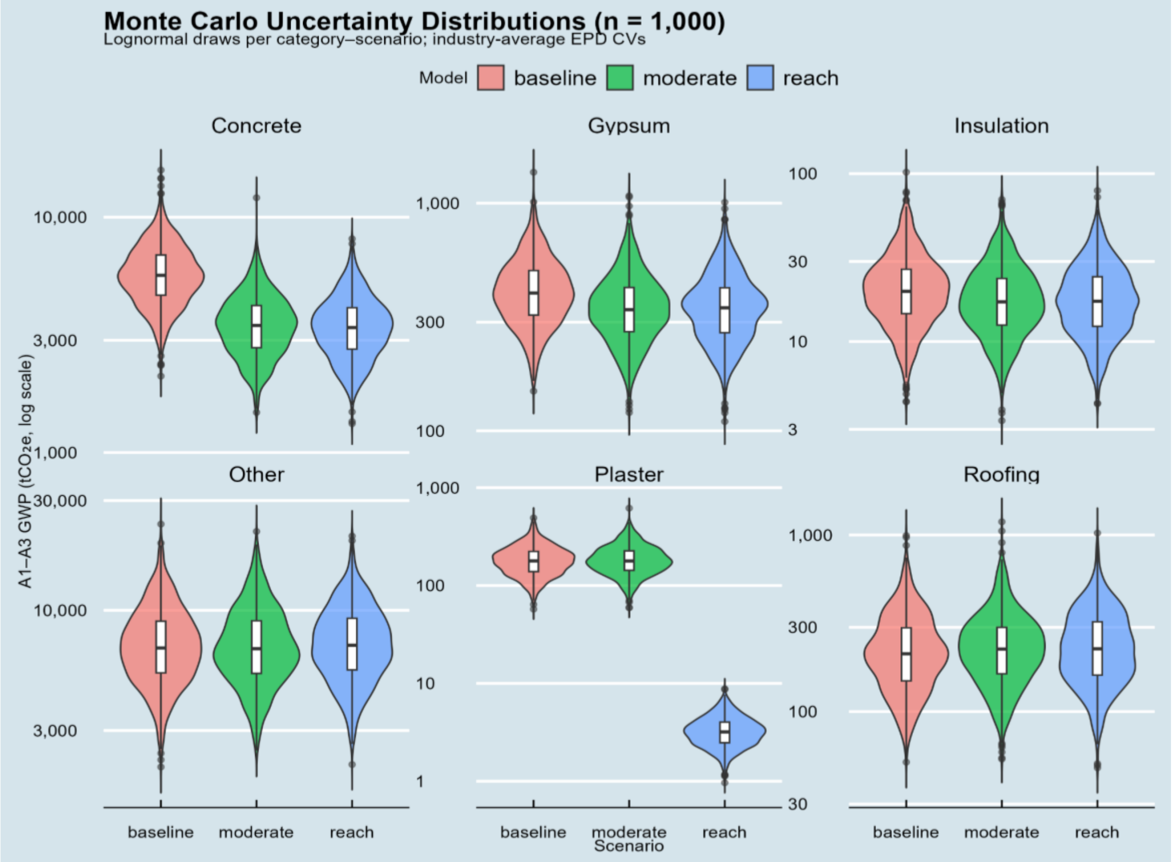

Figure 5.5.1A Monte Carlo uncertainty distributions for industry average EPDs (n=1,000). This figure shows violin plots of simulated A1-A3 global warming potential (GWP, tCO_2e, log scale) for six major material categories across the Baseline, Moderate, and Reach scenarios. Each violin summarizes 1,000 lognormal Monte Carlo draws for a given category-scenario pair, with embedded boxplots indicating the median and interquartile range, so the width of the shape reflects the spread of plausible GWP values rather than just a single estimate.

The Monte Carlo simulation propagates uncertainty in industry-average EPD coefficients to estimate the range of plausible A1-A3 embodied carbon outcomes per material category across the three design scenarios. Across most categories - including Gypsum, Insulation, Roofing, and Other - the simulated distributions span similar ranges of values. This reflects the structure of the analytical approach, which introduces variability around each scenario's assumed material quantities, rather than testing differences in system design. As a result, Figure 5.5.1 primarily illustrates uncertainty in embodied carbon estimates across material categories, driven by variability in material GWP values, rather than serving as a statistical comparison between scenarios. Visualization of 95% confidence intervals are visible in Appendix 9.5.

Within that uncertainty framework, the distributions also highlight how different material groups contribute to project-level carbon variability. Concrete shows the largest absolute GWP values and the widest simulated ranges, indicating that uncertainty in concrete emissions dominates the overall embodied carbon distribution of the project. Gypsum, insulation, roofing, and the "other" category exhibit narrower ranges relative to concrete, suggesting that while uncertainty in the GWP values reported in their EPDs is present, their influence on total carbon variability is comparatively smaller.

Plaster diverges from this larger pattern. The Baseline and Moderate scenarios remain largely aligned, while the Reach scenario shifts noticeably lower, reflecting the substitution of conventional plaster with hempcrete.

5.5.2 Justification of confidence interval ranges

The chosen CVs and resulting 95 % CIs are intentionally conservative with respect to automatically assigned, industry-average EPDs in OneClickLCA. OneClickLCA's own guidance notes that default or average EPDs may represent sectoral means rather than plant- or product-specific data, and recommends uncertainty analysis or data-quality flags when such datasets are heavily relied upon[64]. Recent reviews of WBLCA uncertainty for buildings report typical relative uncertainties on the order of 20-50 % at the material level, depending on product class, geography and LCI database.[65]

We assume lognormal distributions because they are consistent with the observed right-skew of environmental inventory data and avoids negative draws, while CVs in the 20-50 % range align with published ranges for concrete, steel, timber and insulation EPDs.redun

5.6 Results Synthesis

Across all three design scenarios, lifecycle emissions at Presidio Springs are ultimately governed by embodied carbon rather than operations. To demonstrate this, we evaluate operational emissions under progressively more realistic energy assumptions before comparing them to whole-building embodied impacts.

Under a static California grid assumption using Autodesk Insight's current emissions factors, modeled 100-year operational emissions are approximately 50.17 million kgCO_2e (Baseline), 44.66 million kgCO_2e (Moderate), and 43.01 million kgCO_2e (Reach). These reductions of 12-14% relative to Baseline reflect improved envelope performance and higher-efficiency HVAC systems. However, this assumption holds grid carbon intensity constant for a full century and therefore overstates long-term operational impact relative to California's policy trajectory.

To reflect more realistic conditions, we incorporate a 67 kWdc rooftop PV system, which offsets roughly 25% of baseline annual electricity demand, and apply NREL's projected grid decarbonization scenarios. Under this framework, 100-year operational emissions decline dramatically to approximately 8.6-10.1 million kgCO_2e, with an average of 9.2 million kgCO_2e for

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[64] One Click LCA. (2022). Understanding and using environmental product declarations (EPDs).

[65] Feng, H., Zhao, J., Zhang, H., Zhu, S., & Li, D. (2022). Uncertainties in whole-building life cycle assessment: A systematic review. Journal of Building Engineering, 52, Article 104371. https://doi.org/10.1016/j.jobe.2022.104371

multiple different policy scenarios regarding grid emissions intensity. Given Santa Barbara Clean Energy's current provision of 100% renewable electricity, emissions associated with this purchased electricity may already be considered negligible. In this context, differences in energy use intensity (155.17, 136.26, and 126.25 kWh/m^2/year for Baseline, Moderate, and Reach) would primarily affect cost, thermal comfort, and system resilience rather than long-term operational carbon emissions outcomes.

In contrast, embodied carbon does not depend on grid evolution. Whole-building OneClickLCA modeling over a 100-year service life yields total cradle-to-grave embodied emissions of 15.16 million kgCO$_2$e (Baseline), decreasing to 12.64 million kgCO$_2$e (-16.7%) for the Moderate scenario and 11.33 million kgCO$_2$e (- 25%) for the Reach scenario. Reductions are driven primarily by lower-cement concrete mixes and shifts toward lower-carbon envelope materials and biogenic components.

Comparisons across tools clarify life cycle assessment boundary differences while reinforcing the same conclusion. Autodesk Insight estimates approximately 790,994 kg CO$_2$e for material production stages only. This value is significantly lower because Insight captures only major structural and envelope assemblies using generalized factors. An EC3 screening of high-impact material categories (concrete, gypsum, sheathing, and key finishes) produces 5.32 million kgCO$_2$e for the Baseline material bundle and 4.58 million kgCO$_2$e for a low-carbon alternative, a 13.9% reduction (739,000 kg CO$_2$e) within that partial scope. OneClickLCA, which captures a full whole-building inventory including interiors and MEP systems, yields higher totals consistent with its broader boundary definition.

When all methods are reconciled to a consistent 100-year horizon incorporating realistic solar generation and NREL grid trajectories, the best estimate for the Baseline scenario is approximately 15,160 tonnes CO$_2$e embodied and 9,218 tonnes CO$_2$e operational. This implies that embodied emissions account for about 1.64 tonnes CO2e for every expected tonne of operational carbon.

Under a decarbonizing grid however, embodied carbon is the only lever for long-term climate performance, and material substitution decisions ultimately control the majority of lifecycle impact.

5.6.1 Embodied Carbon Assessment: Methods, Assumptions, and Addressing Uncertainty

Neither One Click LCA nor EC3 automatically provides a formal 95% confidence interval for the development's total embodied carbon. Both tools primarily generate a single total value for each scenario. This single value does not account for the range of potential values inherent in any LCA from the propagated range from varied EPD assumptions and findings. Each tool also accounts for uncertainty in different ways.

In One Click LCA, uncertainty is addressed through data-quality adjustments.[66] When a material uses a generic database value instead of a product-specific Environmental Product Declaration

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[66] One Click LCA. (2025, September 21). A guide to generating compliant RICS V2 whole-life carbon assessments with One Click LCA.

(EPD), the software may apply a "top-up" factor, typically around 10-20%.[67] This simply increases the carbon value slightly to reflect that generic data is less precise. Certain reporting standards require this type of adjustment so that projects using less specific data do not underestimate emissions.[68] However, One Click LCA does not translate these adjustments into a building-level range.[69]

EC3 shows uncertainty more clearly, but only at the material level given many EPDs include a reported range of possible carbon values as they are developed using statistical modeling.[70] If a product does not include this range, EC3 estimates one based on data quality. EC3 shows these ranges visually within the platform, but it does not automatically combine them into a single range for total building emissions.[71]

Given both tools treat uncertainty at the material level, there is no standard building-level range that can be directly reported for the Presidio Springs scenarios.

To address this, we estimate a reasonable range around each total embodied carbon value rather than presenting a single fixed number. Research shows that carbon data for materials often varies by roughly 20-50% (Section 5.7). However, when many materials are combined into a whole-building total, overall variability tends to decrease because differences partially balance out.[72]

Based on this, we assume a 25% variability range for the Baseline scenario (which relies more heavily on generic data) and 20% for the Moderate and Reach scenarios (which use more product-specific EPDs).[73] We then calculate an approximate 95% range using[74]:

$$mean \pm 1.96 \times SD$$

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[67] One Click LCA. (2024, August 2). RICS whole life carbon (WLC) v2 infrastructure tool.

[68] One Click LCA. (2025, September 21). A guide to generating compliant RICS V2 whole-life carbon assessments with One Click LCA.

[69] One Click LCA. (2025, March 5). Uncertainty quantification

[70] Carbon Leadership Forum. (2024). EC3 tool overview: Material uncertainty visualization.

[71] Building Transparency. (2025). EC3 v4.1 user guide: Data quality scoring and uncertainty estimation.

[72] Marsh, E., Orr, J., & Ibell, T. (2021). Quantification of uncertainty in product stage embodied carbon calculations for buildings. Energy and Buildings, 251, Article 111340.

[73] Feng, H., Zhao, J., Zhang, H., Zhu, S., & Li, D. (2022). Uncertainties in whole-building life cycle assessment: A systematic review. Journal of Building Engineering, 52, Article 104371.

[74] Pozzer, A. E., et al. (2025). Probabilistic life-cycle assessment of building materials under uncertainty. Journal of Construction Engineering and Management, 151(10).

This 95% CI upper bound extends to 2 standard deviations (± 49% of the mean). This means we calculated the uncertainty ranges shown here to reflect material variability, not automatically generated by One Click LCA or EC3.

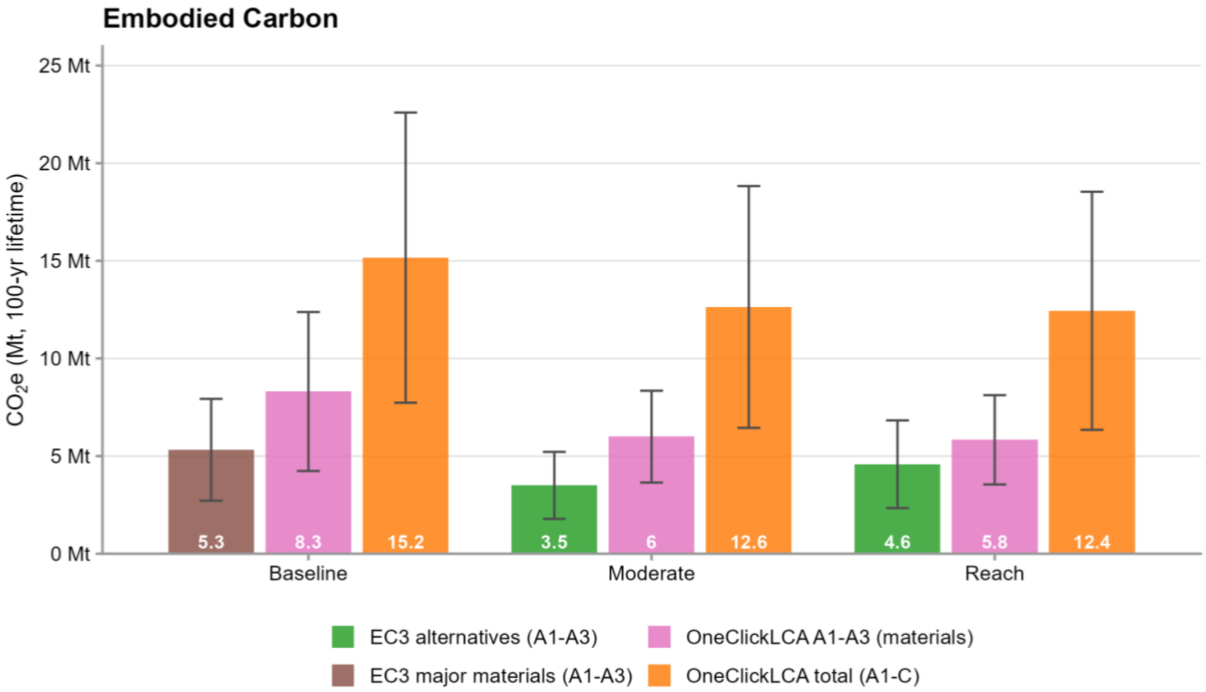

Figure 5.6.1A Estimated lifetime embodied carbon emissions (Mt CO_2e, 100-year building lifetime) across project design scenarios and LCA tools.

This figure compares total embodied carbon across the three design scenarios and LCA tools over a 100-year building life. Using OneClickLCA's full building results (including all life-cycle stages), emissions decreased from 15.2 million kg CO_2e in the Baseline design to 11.3 million kg CO_2e in the Reach design, representing a 25% reduction. When focusing only on material production stages (A1-A3), the same pattern holds, with emissions declining from 8.3 million kg to 5.1 million kg CO_2e as material substitutions increase.

EC3 produces lower totals because it evaluates only selected high-impact materials rather than the entire building. Under this narrower scope, embodied carbon is 5.3 million kg CO_2e for the Baseline and approximately 3.5-4.6 million kg CO_2e for the Moderate and Reach designs. The EC3 alternative totals are slightly lower than the Reach case because not all substitutions included in the full building analysis are captured in the EC3 screening. Error bars represent estimated 95% CI ranges, reflecting reasonable variability in material carbon data and quantity assumptions.

5.6.2 Operational Carbon Assessment: Methods, Assumptions, and Addressing Uncertainty

Autodesk Insight does not provide built-in uncertainty ranges for operational carbon or energy use intensity (EUI). The results come from energy simulations that produce a single predicted value based on the inputs provided.[75]

To stay consistent with the embodied carbon section, we estimate a reasonable range around the operational totals instead of presenting only one fixed number. Research shows that early-stage energy models typically exhibit standard deviations of 15-25% around mean predictions due to uncertain inputs such as occupancy schedules, air leakage rates, equipment loads, and internal gains, with coefficients of variation (CV) in this range well-documented across validation studies.[76,77]

Based on literature documenting coefficients of variation (CV) of 15-25% for early-stage energy models, we assume CV = 20% for Baseline (reflecting heavy reliance on generic assumptions) and CV = 18% for Moderate/Reach (more refined design parameters). Here CV = standard deviation/mean, so these translate to standard deviations of 20% and 18% of the mean EUI prediction, respectively.[78] We then calculate an approximate 95% CI range using:

$$mean \pm 1.96 \times SD$$

These represent expected modeling uncertainty from occupancy schedules, air leakage, equipment loads, etc. and not measurement error, providing reasonable statistical bounds around Autodesk Insight predictions. We show NREL grid projection cases as single values since we did not perform full uncertainty propagation for those scenarios.

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[75] Autodesk Community. (2025, January 23). Different energy values from Insight and report analysis.

[76] Page, J., & Altwies, J. (2005). The impact of the building occupant on energy modeling results. Stanford University.

[77] Tian, W. (2013). Uncertainty analysis in building energy simulation. Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, 2131-2138.

[78] Jacob, D. (n.d.). Optimizing building energy simulation models in the face of uncertainty. University of Colorado.

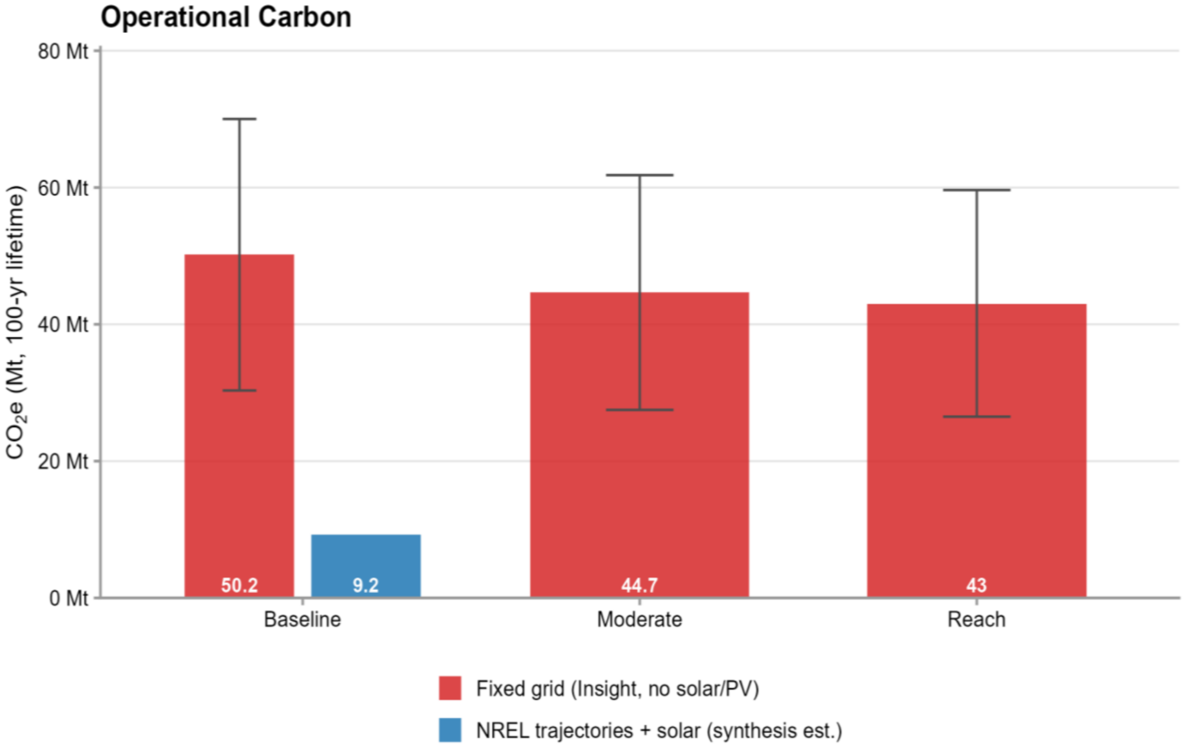

Figure 5.6.2A Estimated lifetime operational carbon emissions (Mt CO_2e, 100-year building lifetime) under two grid decarbonization trajectories.

This figure shows estimated lifetime operational carbon emissions over a 100-year building life under two different grid assumptions. The first scenario, labeled "Fixed grid," assumes that California's electricity carbon intensity remains constant over time. Under this assumption, operational emissions are 50.2 million kgCO_2e for the Baseline, 44.7 million kgCO_2e for Moderate, and 43.0 million kgCO_2e for Reach. This represents about a 14% reduction across design scenarios, driven mainly by improved energy efficiency in the building envelope and HVAC systems.

The second scenario, labeled "NREL + solar," assumes the grid becomes significantly cleaner over time based on NREL projections and includes on-site solar PV generation. Under this more realistic decarbonization pathway, lifetime operational emissions for the Baseline case drop to 9.2 million kgCO_2e. Error bars in the figure show estimated 95% CI ranges to reflect uncertainty in energy use assumptions and grid factors. We show the NREL case as a single value because it uses fixed projection inputs, and Moderate and Reach scenarios were not recalculated under this decarbonization pathway.

Section 6: Discussion

6.1 Embodied and Operational Emissions Implications

Beyond the Presidio Springs analysis finding the core strategies used to reduce embodied carbon at Presidio Springs like fly-ash concrete, recycled gypsum and roofing products, and durability-oriented finish selections, insinuations can be made that these strategies are not unique to a single affordable housing site. Concrete, steel, and gypsum consistently appear as dominant contributors to embodied emissions across residential, commercial, and institutional building case studies, which implies that the relative impact of substituting lower-carbon mixes and high-recycled-content assemblies is likely to be repeatable in a wide range of building types so long as local supply chains can deliver comparable products and verified EPDs.[79] In that sense, the moderate scenario functions as a template for how a housing authority can articulate "default" low-carbon specifications for future projects rather than a one-off design experiment tied only to Presidio Springs.

If HACSB used similar material bundles systematically across new projects and, by extension, to other public housing authorities, the cumulative effect could be substantial. National benchmarking work indicates that achieving 20-30% upfront embodied carbon reductions at the project level is both technically feasible and consistent with sectoral targets that call for roughly 40% reductions in embodied emissions for all new construction by 2030.[80] Given our moderate scenario achieves a 17-20% whole-building embodied reduction using only currently available products and a modest cost constraint, it demonstrates that housing-sector projects can contribute meaningfully toward those global targets without waiting for radical new technologies or major code changes. Scaling such specifications through design standards, template RFP language, and portfolio-wide procurement policies would allow housing authorities to aggregate many small project-level improvements into a measurable contribution to the national building-sector decarbonization effort.

However, there are limits to how directly our findings can be transferred. Presidio Springs is a multi-family development in a mild coastal climate, with building typologies dominated by steel or mass-concrete structures or located in very cold or hot climates potentially seeing very different relative benefits from the same substitutions given that structural systems, code requirements, and envelope performance vary. The EPD-based whole-building LCA, scenario comparisons, and Monte Carlo uncertainty analysis are likely widely applicable, but the absolute magnitudes and cost trade-offs will depend on local material markets, labor practices, and policy drivers such as state-level embodied-carbon procurement rules. In other words, the methodological framework is repeatable, and the direction of effects is likely to be consistent (e.g., fly-ash concrete almost always reduces GWP), but project teams should re-evaluate with its own quantities, suppliers, and regulatory context rather than assuming the exact same percent reductions.

Finally, our operational findings and their interaction with embodied strategies suggest implications that extend beyond affordable housing. Many of the measures tested here like high-efficiency VRF systems, improved envelopes, and on-site PV are already being deployed in offices, schools, and mixed-use buildings. The literature indicates that a combined focus on envelope efficiency and electrification is a robust decarbonization approach across building

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[79] Zhang, Y., Sattar, S., Cook, D. T., Johnson, K. J., & Fung, J. F. (2024). Systematic review of embodied carbon assessment and reduction in building life cycles: An integrated approach to resilience and sustainability (NIST Special Publication 1324). National Institute of Standards and Technology.

[80] World Green Building Council. (2025). Bringing embodied carbon upfront: Coordinated action for the building and construction sector to tackle embodied carbon.

sectors.[81] As grids decarbonize, the relative importance of embodied emissions increases for all new buildings, not only housing. This reinforces the relevance of the Presidio Springs material package as a prototype for low-carbon practice in other typologies. For HACSB and peer agencies, a major potential implication shows one flagship project can produce design patterns, specification language, and decision tools that are portable across portfolios.

6.2 Caveats and Next Steps

The following summarizes caveats that are applicable to our project:

Analysis	Discussed Caveats
Embodied Carbon (OneClickLCA/EC 3)	● **Generic vs. project-specific EPDs:** Some materials are matched to "typical" EPDs rather than the exact product/supplier Presidio Springs would buy from. ○ *Why it matters:* totals can shift once procurement is locked. ○ *Next step:* request supplier specific EPDs for the biggest material categories (especially concrete, gypsum, insulation, and major finishes) and rerun the comparison. ● **Replacement cycles are assumed:** The long-life (100-year) model uses default service life assumptions for when materials get replaced (finishes, membranes, some equipment). ○ *Why it matters:* lifecycle totals can move a lot if replacement intervals are wrong. ○ *Next step:* verify key service lives using warranties/specs (roofing, flooring systems, exterior finishes) and align the model with Presidio Springs' expected maintenance approach.
Operational Energy (Insight)	● **Single point energy use intensity (EUI) outputs:** The energy model produces one EUI per scenario, not a range. ○ *Why it matters:* it can give a false sense of precision. ○ *Next step:* treat results as "directional" and validate with sensitivity checks on the biggest drivers (infiltration, thermostat setpoints, occupancy). ● **Simplified schedules (occupancy + usage):** Early stage energy models rely on standardized schedules for when people are home and how spaces are used. ○ *Why it matters:* it affects heating/cooling loads and total electricity use.

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[81] Larsen, P. H., Koomey, J., Rosenquist, G., & Ting, M. (2023). Efficiency, flexibility, and electrification can cut U.S. buildings sector emissions 91% by 2050 [Issue brief]. Lawrence Berkeley National Laboratory.

	o *Next step:* align schedules with likely senior housing patterns if available (or compare against data from similar HACSB buildings). ● **Infiltration/air leakage assumed, not tested:** Air leakage is often guessed at this stage. o *Why it matters:* it can swing heating/cooling demand noticeably. o *Next step:* set a realistic leakage target (e.g., tighter envelope in Moderate/Reach) and document what construction details or testing (blower door) would support it.
Grid Decarbonization (NREL)	● **Grid emissions factor does not reflect SBCE reality:** The model's default operational-carbon outputs reflect broader grid assumptions, but Presidio Springs is served by SBCE's clean procurement. o *Why it matters:* operational carbon results can be overstated relative to local policy, even if energy and cost results remain valid. o *Next step:* treat the modeled operational carbon values as a transferable "state-grid" benchmark, and add an SBCE-adjusted operational carbon line for the Presidio Springs interpretation.
Solar PV Output	● **The solar analysis relies on default system values** rather than site-specific design inputs. o *Why it matters:* These assumptions are not as granular and accurate as they should be. o *Next step:* Assumptions related to system losses, roof tilt optimization, and long-term performance degradation will need to be verified as designs are finalized. ● **Annual netting (not hourly matching):** PV is compared to annual building use, not hourly load. o *Why it matters:* it can slightly over-credit PV if production doesn't align with demand. o *Next step:* keep the annual approach for screening, but note that storage/load shifting would be needed to capture maximum on-site use. ● **Degradation + inverter replacement not included:** Panels degrade and inverters may be replaced over a long horizon. o *Why it matters:* lifetime output and lifecycle costs shift. o *Next step:* add a simple degradation assumption and flag inverter replacement timing as a future refinement.

Concrete	● **Concrete foundation quantity estimate:** Foundation volume is based on a conceptual deep soil mixing + mat slab approach, not final structural drawings. o *Why it matters:* concrete volume is one of our biggest embodied-carbon and cost drivers, and the changes here ripple through results. o *Next step:* replace the conceptual quantity with engineer-validated quantities when available, and update the concrete mix/EPD assumptions at the same time. This information would be available once the preliminary site design is completed by the architectural team. ● **Parking lot concrete exclusion:** We did not include concrete from the parking lot in the waste or embodied carbon analysis. o *Why it matters:* this material could represent a significant share of demolition waste and recycling potential. o *Next step:* note this as a boundary limitation and include a separate estimate of diversion potential if the parking lot concrete is removed.
Cost-Benefit (NPV)	● **Project cost and quantity estimates:** The analysis did not have access to the actual material quantities or costs for the HACSB Presidio Springs project, so estimates were based on data from the Bella Vista project. o *Why it matters:* relying on a comparable project introduces uncertainty because material quantities, costs, and design specifications may differ. o *Next step:* update the analysis with Presidio Springs–specific material quantities and cost data once finalized project documents or procurement information become available. ● **Maintenance + soft costs generalized:** operation maintenance, redesign effort, and procurement admin costs aren't fully captured. o *Why it matters:* some "green" measures require extra coordination that isn't free. o *Next step:* add a simple "implementation overhead" placeholder (even a rough percent) so decision-makers aren't surprised later.
Material Performance	● **Literature-based properties:** Thermal/acoustic/fire/durability claims often come from general literature, not a project-specific assembly test. o *Why it matters:* performance is assembly-dependent (details and installers matter).

	○ *Next step:* for the final recommended substitutions, list the minimum documentation needed to approve them (ICC-ES report, ASTM testing, fire rating, acoustic rating, warranty). ● **Installer learning curve:** Some alternatives require different installation practices. ○ *Why it matters:* execution risk can undermine performance. ○ *Next step:* specify where manufacturer training or experienced installers are required (especially for envelope systems and specialty finishes).
Sustainable Deconstruction	● **Waste diversion benchmarking:** The HACSB analysis does not estimate how much construction and demolition material could be diverted from the waste stream. ○ *Why it matters:* without benchmarking against similar affordable housing projects, it is difficult to estimate realistic diversion potential ○ *Next step:* review comparable projects to estimate total waste generated and the percentage typically diverted through sustainable deconstruction

Section 7: Conclusion

This lifecycle assessment shows that embodied carbon is the primary driver of Presidio Springs' long-term emissions profile. Because California's electricity grid is expected to continue decarbonizing over time, material selection and construction decisions play an especially important role in reducing total lifecycle emissions. In the baseline OneClickLCA results, replacement and refurbishment (B4–B5) account for 58% of total embodied emissions, highlighting that both upfront material choices and long-term durability are critical decision points for lowering lifecycle carbon.

The moderate scenario achieves a 16.7% reduction in total embodied carbon, avoiding 2,527,620 kg CO_2e and lowering lifecycle carbon intensity to 10.78 kg CO_2e/m^2 per year. This reduction is driven by material substitutions in concrete, flooring, clay tile roofing, wallboard, and insulation. We excluded TPO roofing from the final model after further durability analysis indicated it would not meet long-term performance requirements for the project. The largest reductions occur in material production (A1-A3), which declines by 27.83%.

Ready-mix concrete accounts for a large share of total project emissions. Using fly-ash substitution significantly reduces this impact, lowering emissions from 5,279,960 kg CO_2e in the baseline to 2,926,456 kg CO_2e when using Ready-mix concrete Mix 7335 PS (Kentucky Avenue Plant 155). This mix includes ~30% fly ash and CarbonCure technology, reducing embodied carbon by about 45% compared to traditional concrete, though it is estimated to cost 9% more. Alternatively, specifying

Portland cement concrete with 30% fly-ash SCM replacement would likely have little to no cost premium, but would achieve a smaller emissions reduction of about 30%.

Flooring reductions also contribute meaningfully to overall savings through finish-layer optimization. Refinishing one-third of the flooring can reduce flooring-related emissions by about 30%. These results indicate that low-carbon concrete procurement (highest priority) and flooring reduction strategies (second priority) represent the most impactful embodied-carbon interventions.

Importantly, the embodied carbon reductions in the moderate scenario are achieved without increasing long-term replacement burdens or creating operational energy penalties. Material substitutions were screened against key thermal properties - including density, thermal conductivity, and specific heat capacity - to ensure we maintained envelope performance. With the exception of TPO roofing, which can slightly reduce thermal performance depending on assembly configuration, the selected materials do not degrade modeled energy performance.

The moderate model also reduces annual electricity costs by approximately 12%, with a 7 year payback in projects where the Housing Authority pays utilities. Over a 100-year lifespan at a 5% discount rate, the green building scenario results in lower lifecycle costs by over $1,113,064 than the traditional design. This confirms that moderate strategies are not only environmentally effective but financially viable in affordable housing contexts.

Not modeled are the benefits of smart thermostats, which could generate building-wide savings of approximately $10,500-$31,500 annually across the 300-unit development while reducing HVAC-related electricity consumption by about 10-15%. This would benefit in projects where the Housing Authority pays utilities. Many California utilities also offer rebates of roughly $60 per unit for installing ENERGY STAR® certified smart thermostats, which can further improve cost-effectiveness and shorten the payback period to about 3-8 years. Sustainable deconstruction could increase waste diversion to well above the 65% CALGreen requirement. If adopted across California, it could divert roughly 5.66 million tons of material from landfills each year. The ReUse People of America also note that material salvage value and potential tax deductions for donated materials can help offset these costs.

Based on these findings, the most actionable path forward for HACSB is to:

1. Prioritize low-carbon concrete procurement (CalPortland SCM 30% fly-ash mixes with verified EPDs).
2. Refinish concrete flooring to resemble tile where feasible and only install additional flooring where it is truly necessary, reducing both embodied carbon and long-term replacement impacts.
3. Include recycled-content gypsum wallboard, locally sourced recycled clay tiles, and recycled-content insulation as standard procurement requirements.
4. Include high-efficiency HVAC systems and smart thermostats in developments where HACSB pays utilities, ensuring HACSB captures operational savings directly.
5. Prioritize sustainable deconstruction where feasible to reduce demolition waste, recover valuable materials, and support higher diversion rates beyond conventional practices.

The reach scenario demonstrates that deeper reductions are technically achievable given approximately 18% embodied carbon reduction and 14% operational carbon reduction relative to baseline. However, these strategies involve greater design shifts and cost sensitivity. They are most appropriate when grant funding, rebates, or higher budgets are available, or when policy requirements demand higher performance standards.

In summary, the moderate scenario delivers the strongest "carbon reduction per dollar invested" and should serve as the default design strategy for Presidio Springs. Reach strategies can be selectively layered in as funding conditions allow. By targeting concrete, flooring, and durable material procurement early in design, HACSB can secure meaningful emissions reductions without increasing lifecycle costs or compromising long-term building performance.

7.1 Final Alternative Material Recommendations

This section synthesizes embodied carbon results from EC3 alongside baseline material costs derived from supplier pricing aligned to EPD declared units. EC3 provides GWP values from EPDs for baseline and low-carbon substitute materials. OneClickLCA embodied carbon values were not used due to specific EPDs foundational for research not being used within the OneClickLCA model. Cost values reflect current California market pricing for conventional baseline materials; alternative material costs would require supplier quotes tied to the specific low-carbon EPDs recommended.

For each material system, critical non-cost considerations address constructability, code compliance, durability, seismic performance, moisture management, fire/acoustic ratings, and regional supplier availability. Recommendations balance carbon savings against these practical constraints, with supplier information provided where specific products have been identified. Three alternatives (ITPO roofing) are explicitly not recommended despite favorable EPDs due to unresolved implementation risks detailed in Section 5.2.

Table 7.1A Final Alternative Material Recommendations for Moderate Scenario

Material	Cost	Embodied Carbon (kg CO_2e)	Key Non-Cost Consideration	Suggested Alternative	Supplier
Ready-mix Concrete					
Baseline: Cast-in-place concrete (3000-4000 psi, standard Portland cement)	$150-$200 per cubic yard (ready-mix, 2500-3000 psi)	5,279,960	Fly ash reduces conductivity and increases heat capacity, improving thermal lag and peak load reduction.	Yes	CalPortland (local supplier): Email: amendez@calportland.com
Alternative: Fly-ash concrete with	Same: $150-$200 per	2,926,456			Ready-mix concrete Mix

~30% SCM replacement and reduced total concrete use.	cubic yard (ready-mix, 2500-3000 psi)				7335 PS (Kentucky Avenue Plant 155): reduces embodied carbon by ~45%. CalPortland Portland concrete with 30% fly-ash substitution: reduces emissions by ~30%.
Clay Tile Roofing					
Baseline Material: 2-piece clay tile roofing (standard fired clay)	$15-$30/sq ft (2-piece)	8,130	Increased porosity can reduce conductivity and diffusivity, delaying heat transfer under solar loads.	Yes	MCA Tile in Santa Barbara Email/Call Dustin: (951) 741-9486 dustin@mca-tile.com
Alternative: Recycled clay tile (S-type mission tile, 60% pre-consumer recycled content)	Same price and supplier: $15-$30/sq ft (2-piece)	7,427			*Same: MCA Tile contact
LVP Flooring					
Baseline: LVP glue-down applied to all floors including ground floor (~54,100 sf);	N/A (quote from construction)	289,600	Removing overlays reduces R-value but increases exposed thermal mass, improving temp buffering. If an	Yes	ShawContract Flooring

ShawContract Pivot 4499V 2.5 mm PVC-Free EcoWorx™ Resilient flooring			active thermal ventilation strategy is planned for building, LVP maximises benefit.		
Alternative: Ground floor removed; concrete refinished and sealed (reduces applied flooring area by ~23%)	Reduce flooring cost by ⅓ t (due to one of three floors having no added flooring)	187,070			N/A
Gypsum Wall Board					
Baseline: Standard Type X gypsum board (fire-rated, 5/8 in. drywall)	$18.88 for 4ft by 8ft	23,800	Straightforward drop-in replacement; no change to fire ratings or interior finishes; widely available with EPDs; low implementation risk.	Yes	Home Depot
Alternative: USG Sheetrock Brand 5/8 in EcoSmart Firecode 30 Drywall (same fire rating, ~30-50% recycled gypsum)	Same price: $18.88 for 4ft by 8ft	474			Home Depot
Rigid Foam Insulation					
Baseline: Rigid foam insulation board (XPS or EPS, ~3.5 in., R-18-R-20) *Note: EPS is lower R-value, likely that XPA would meet the	$0.90-$1.25/sq ft for EPS; $1.40-$1.75/sq ft for XPS	11,012	Improves thermal performance and reduces operational energy; familiar installation methods; compatible with wood framing; moisture management must be detailed but	Yes	Home Depot

specifications			within standard practice.	🟩	
Alternative: FOAMULAR® NGX® to FOAMULAR® NGX XPS (Owens Corning) with 30% recycled material	$50.97 for 2 in. x 4 ft. x 8 ft.	8,416			Home Depot
PVC Standard vs. TPO Roofing					
Baseline: Sarnafil G-410 PVC membrane (60 mil, thermoplastic, low-slope roofing)	$1000 (5 ft × 100 ft roll, 80 mil)	70,000	Polymer membrane with durability and repair-path uncertainties over 100-year life; UV and puncture resistance concerns; end-of-life management unclear relative to tile or other robust roofing.	No	Supplier: Roofing4Us
Alternative: SPRI TPO membrane (TPO 60 mil, thermoplastic polyolefin, low-slope)	$881.25 (5 ft × 100 ft roll, 80 mil); $1,737.50 (10 ft × 100 ft roll, 80 mil)	53,000			Supplier: Roofing4Us Email and Number: sales@4us-group.com 415-527-0855

7.2 Implications for Future Housing Authority Developments

Low-carbon affordable housing is a critical pathway toward tackling climate change at the local level, made possible when climate goals are translated into procurement and design decisions early enough to shape the project. For future Housing Authority developments, the value of this work is not only in identifying high-impact strategies, but in showing a practical pathway for applying them within the realities of public budgets, code compliance, and construction delivery.

1. Translate material recommendations into bid-ready requirements

The final materials recommendations in Section 7.2 are most effective when used as procurement criteria rather than advisory guidance. Requiring product-specific EPDs, declared units, and GWP values for priority materials allows embodied carbon to be evaluated alongside cost, schedule, and code compliance. This creates a clear implementation pathway in which low-carbon performance becomes part of standard submittal review rather than a separate sustainability exercise.

2. Use concrete as the first implementation lever
Across the scenarios, concrete remains the largest embodied-carbon opportunity. Future projects can capture the greatest impact by addressing concrete first through early supplier coordination, performance-based specifications, and product-specific EPD review. Once that approach is established, the same workflow can be extended to other recommended substitutions (including gypsum, insulation, and selected finishes), creating a repeatable process rather than a one-time intervention.

3. Make durability part of carbon decision-making
Durability is a critical consideration; it is part of the carbon mitigation strategy. Because replacement and refurbishment can become a major share of lifecycle embodied carbon, material and assembly choices are strongest when they are screened for service life, maintenance demands, moisture vulnerability, and detailing sensitivity at the same time they are evaluated for upfront global warming potential. This strengthens implementation by reducing the risk of selecting materials that look favorable in product-stage carbon terms but create higher impacts and costs over time.

4. Frame energy upgrades around affordability, comfort, and resilience
For Presidio Springs and similar projects operating under SBCE's clean electricity procurement conditions, energy upgrades remain highly valuable even when operational carbon is not the dominant lifecycle driver. Efficient HVAC systems, envelope improvements, and glazing upgrades support lower utility costs, improved thermal comfort, and more resilient building performance. This framing keeps energy decisions aligned with Housing Authority priorities while preserving the long-term benefits of the moderate design package.

5. Integrate incentives into the same implementation timeline
Incentives and rebates are most useful when they are linked directly to the material and systems decisions already identified in the final recommendations. Pairing shortlisted measures with likely funding pathways, documentation requirements, and application timing during design development increases the likelihood that strong low-carbon options remain feasible through bidding and construction. In this way, funding strategy becomes part of implementation planning rather than a late-stage add-on.

These pathways represent a holistic approach for Housing Authority developments. affordable housing projects can serve as a model for climate-responsive construction when carbon reduction is embedded in the same workflows that already govern design quality, procurement discipline, and long-term operations. The central lesson from Presidio Springs is not simply that lower-carbon choices exist, but that they can be implemented in a structured, practical, and scalable way. With early coordination and clear procurement criteria, future projects can deliver housing that is not only potentially more affordable to build and operate in the long term, but also more durable, more resilient, and better aligned with long term public climate goals.

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Section 9: Appendices

9.1 Benefits of Modular Construction

Modular or prefabricated construction involves manufacturing building components off-site in a controlled facility and assembling them on-site. This construction method commonly uses wood, steel, and concrete as primary structural materials due to their strength, durability, and suitability for prefabrication. Wood is often the most common material used in modular construction because it is lighter than steel or concrete, making transportation and installation easier. Mass timber systems have also emerged as promising materials for modular construction. Examples include cross-laminated timber (CLT) and insulated sandwich panels. The specific system selected typically depends on the building's structural requirements, including the scale of the project and number of floors.

For multifamily housing, modular construction can offer several benefits compared to traditional construction methods. Because site preparation and module fabrication can occur simultaneously, overall construction timelines can be reduced by up to 30%.[82] Shorter construction timelines can lower labor costs and allow buildings to reach occupancy sooner. Modular construction can also improve quality control because modules are produced in factory settings, where conditions are more consistent than traditional construction sites. In addition, prefabrication can reduce material waste because manufacturers can produce components with more precise measurements. When wood-based systems are used, modular construction may also reduce embodied carbon compared to conventional concrete construction.

However, several constraints may affect the feasibility of modular construction. Projects often need to work with regional modular construction firms to reduce transportation costs and emissions. Transportation regulations can also limit module dimensions, typically to approximately 16 feet in width and 70 feet in length, which may restrict design flexibility. In some cases, modular construction may also involve additional permitting or approval processes depending on local building regulations. Additionally, mid-rise developments may experience smaller cost advantages compared to high-rise projects.

One regional modular construction firm operating in California is Assemblage Works, which specializes in prefabricated structural systems.[83] Case studies from this firm highlight the potential performance benefits of prefabricated construction compared to conventional concrete buildings, while also noting that mass timber panel systems can be particularly effective for high-value urban sites.

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[82] Modular Building Institute. (n.d.). *Modular construction for multi-family housing*.

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9.2 Fire-Resistant Strategies in California

In wildfire-prone regions such as California, incorporating fire-resistant materials and defensible design strategies can significantly reduce the risk of building ignition. Research shows that embers are responsible for up to 90% of home ignitions during wildfires, as they can travel long distances and enter buildings through vents, gaps, roofs, windows, and eaves.[84] As a result, building hardening strategies typically focus on preventing ember intrusion and reducing combustible materials near the structure.

One of the most important strategies is installing ember-resistant vents. Attic and crawlspace vents are common entry points for embers, which can ignite insulation or other materials inside the building. Ember-resistant vents use fine metal mesh (typically 1/8 inch or smaller) or intumescent baffles that expand under high heat to block embers from entering. While some specialized ember-resistant vents can be more expensive than standard vents, lower-cost options such as Wildfire Defense Mesh or Vulcan Vent covers can provide effective protection while keeping costs relatively low.

Another important measure is enclosing eaves and soffits with non-combustible materials. Open or vented eaves can trap embers and heat, increasing ignition risk.[85] Enclosing these areas with materials such as fiber-cement board, stucco, metal, or fire-retardant-treated wood can help prevent ember accumulation and reduce vulnerability to wildfire exposure.

Windows can also be a point of weakness during wildfire events. Radiant heat from nearby fires can break standard windows, allowing embers to enter the building. Installing dual-pane tempered glass windows, potentially combined with metal mesh screens, can significantly improve fire resistance and reduce the likelihood of window failure during extreme heat exposure.[86]

Exterior materials such as siding and decking also influence wildfire risk. Non-combustible siding materials such as fiber-cement siding or stucco can help prevent ignition when exposed to embers or radiant heat.[87] Additionally, enclosing the underside of decks can prevent embers from accumulating beneath elevated structures where they may ignite debris or wood framing.

Another critical concept in wildfire hardening is maintaining a Zone 0 clearance area, which refers to the first 0-5 feet surrounding the building.[88] This area should be kept free of vegetation, mulch, and combustible materials. Instead, materials such as gravel, decomposed granite, or permeable pavers can be used to reduce ignition potential while still supporting stormwater drainage.

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[84] "Embers Cause Up To 90% Of Home & Business Ignitions During Wildfire Events." *PR Newswire*, 12 Mar. 2019

[85] "Hardening Your Home." *Ready for Wildfire*, State of California

[86] "Windows." *Lake County Fire Safe Council*, https://firesafelake.org/windows/

[87] Sneath, Noah. "4. Protect Your Home: Best Siding for Fire Risk Areas." *Wildfire Action Plan*, 28 Oct. 2025

[88] "Defensible Space." *Ready for Wildfire*, State of California

Within the building envelope, materials such as mineral wool insulation can provide additional fire resistance. Mineral wool is naturally non-combustible and can withstand temperatures exceeding 2,000°F, making it an effective option for wall or attic assemblies. It also provides additional thermal and acoustic insulation benefits.

Air and vapor barriers can further strengthen the building envelope. For example, products such as Blueskin VP100 act as self-adhered air barriers that help seal gaps and penetrations in exterior wall assemblies. This can reduce pathways where embers or moisture could enter the building while also improving overall building performance.

Overall, the most effective wildfire hardening strategies typically focus on three primary measures: installing ember-resistant vents, maintaining defensible space within the Zone 0 clearance area, and sealing the building envelope through enclosed eaves, soffits, and fire-resistant materials. Together, these strategies can significantly reduce the likelihood of ember-driven ignition and improve the resilience of buildings located in wildfire-prone environments.

Table 9.2A Table of Fire-Resilient Materials and Suppliers

Feature	Why It Matters	Recommended Action	Example Suppliers / Resources
Ember-Resistant Vents	Embers are responsible for up to 90% of wildfire ignitions and commonly enter buildings through attic and crawlspace vents.	Install ember-resistant vents with 1/8-inch mesh screens or intumescent baffles to block ember intrusion.	Wildfire Defense Mesh; Vulcan Vent. Resource: Montecito Fire Home Hardening Guide.
Eaves and Soffits	Open or vented eaves can trap embers and heat, increasing the likelihood of ignition.	Enclose eaves and soffits with non-combustible materials such as fiber-cement board, stucco, or metal.	Royal Trim & Mouldings; Fiber-Cement Board (Home Depot).
Windows (dual paned, tempered glass)	Radiant heat from nearby fires can break windows, allowing embers to enter the building interior.	Install dual-pane tempered glass windows and consider metal screens for additional protection.	Home Depot; One Day Glass sealed window units.
Decks and Siding	Embers can accumulate beneath decks or along exterior walls, igniting combustible materials.	Use non-combustible siding such as fiber cement or stucco and enclose the underside of decks.	James Hardie Fiber Cement (Lowes).

Zone 0 Clearance (0-5 ft)	The first 0-5 feet surrounding the building is the highest ignition risk area during wildfires.	Remove combustible vegetation and mulch; replace with gravel, decomposed granite, or permeable pavers.	Ready for Wildfire Retrofit Guide.
Mineral Wool Insulation	Mineral wool is non-combustible and can withstand temperatures above 2,000°F, helping delay fire spread.	Use mineral wool insulation in wall and attic assemblies to increase fire resistance and improve thermal performance.	Rockwool; Thermafibre.
Sealed Building Envelope	Gaps in wall assemblies can allow embers to enter and ignite internal materials.	Install air barriers such as Blueskin VP100 beneath siding to seal cracks and penetrations.	Henry / Carlisle Construction Materials.

9.3 Stormwater Management

To improve on-site stormwater management and reduce runoff, several low-impact landscape strategies are recommended. For walkways and pathways, decomposed granite (DG) is recommended as a permeable surface alternative to traditional concrete. Decomposed granite is thinly crushed stone that allows water to infiltrate into the ground while still providing a stable walking surface. When stabilized and compacted with fines, DG creates a firmer and more durable pathway that is suitable for pedestrian use while maintaining permeability. In addition to its stormwater benefits, DG is typically more cost-effective than concrete walkways and is widely available through suppliers such as Home Depot.

Another recommended strategy is disconnecting roof downspouts from direct drainage systems and instead directing them toward on-site landscaping. Redirecting downspouts to gardens, planted areas, or large planters allows rainwater to infiltrate into the soil, which helps reduce localized flooding while also providing irrigation for vegetation. In some cases, downspouts can also be connected to rain barrels to capture and store water for later landscape use, further reducing potable water demand.

Where hard surfaces are necessary, permeable pavers are recommended. These pavers allow water to pass through joints and underlying aggregate layers, promoting infiltration and reducing stormwater runoff. Together, these strategies can help improve site drainage, reduce pressure on municipal stormwater infrastructure, and support more sustainable landscape design.

Link to Guide of Stormwater Mitigation Strategies

9.4 NREL Operational Emissions Trajectories and Scenario-Driven Lifetime Impacts

In our counterfactual, incorporating NREL grid evolution dramatically changes the project's implied 100 year operational footprint relative to a static grid assumption. Our initial baseline and moderate building models run under fixed grid conditions and produce approximately 50.17 million kg CO_2e and 44.66 million kgCO_2e over a 100 year life, respectively.

When we instead apply scenario based grid composition to the same annual project load, lifetime totals fall to the 8.6-10.1 million kgCO_2e range, illustrating how sensitive long-horizon operational carbon is to grid decarbonization assumptions. Figure 5.5A maps out this trend.

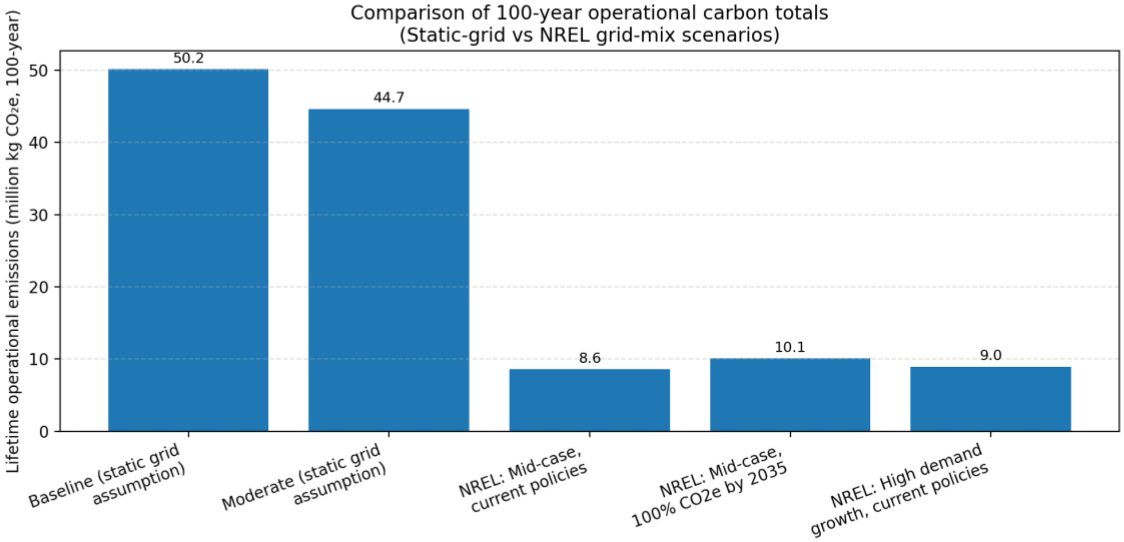
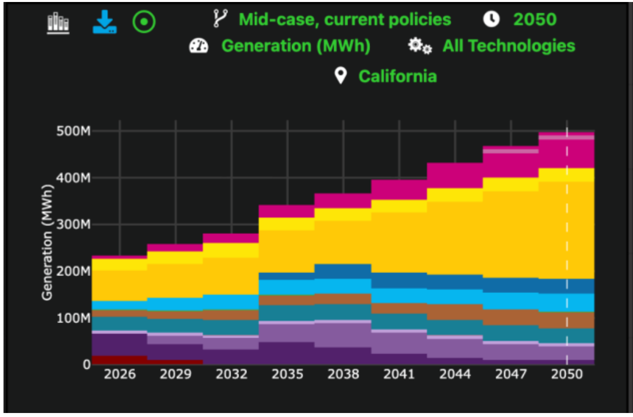


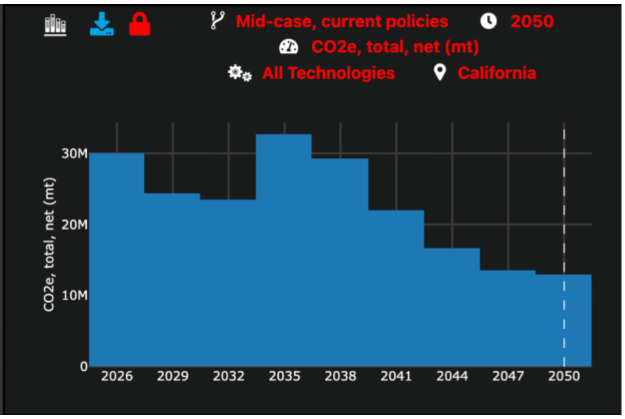
Figure 9.4A Lifetime Operational Carbon Under Different Scenarios and Assumptions

We chose three NREL scenarios that project different ways in which the Californian power grid could develop:

Scenario 1: Mid-case, current policies rises to ~196 tCO_2e/yr in 2035, then declines to ~64 tCO_2e/yr by 2050 as clean generation expands and fossil share falls.

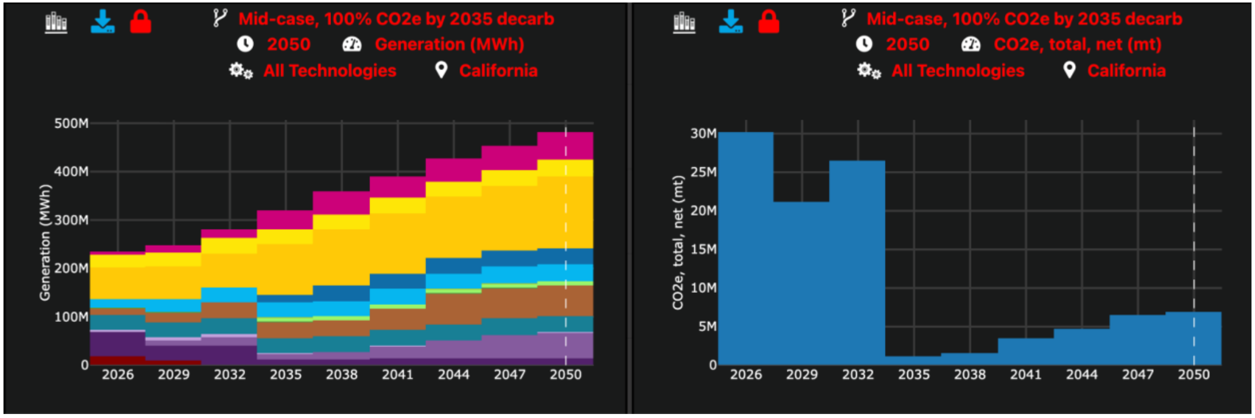


Mid-case, current policies 2050
Generation (MWh) All Technologies
California

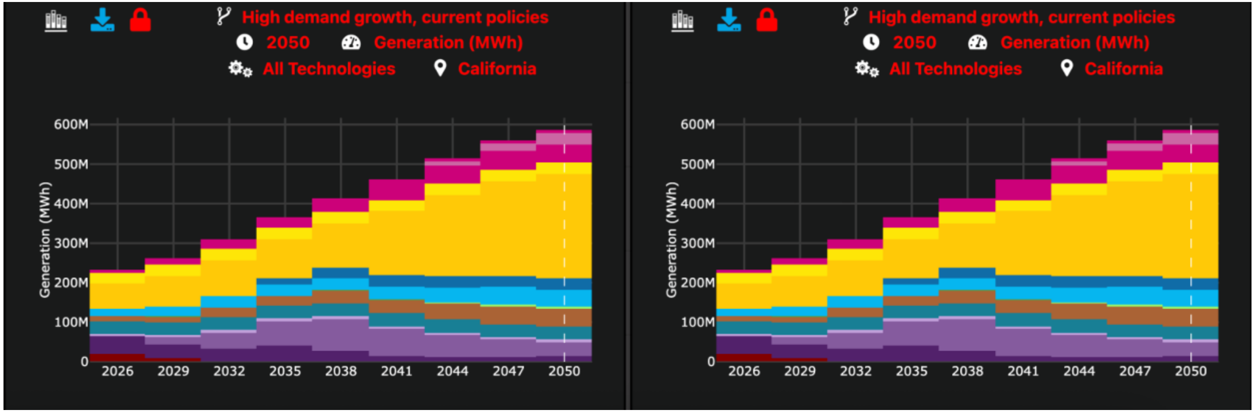


Mid-case, current policies 2050
CO2e, total, net (mt)
All Technologies California

Scenario 2: Mid-case, 100% CO_2e reduction by 2035 shows the sharpest near-term improvement,dropping to ~24 tCO_2e/yr in 2035 (consistent with an enforced decarbonization constraint). However, it then rebounds to ~100 tCO_2e/yr by 2050.



Scenario 3: High demand growth, current policies peaks higher (~213 tCO_2e/yr in 2035) because rapid load growth requires additional generation and system flexibility, which—under current policies—often comes from dispatchable fossil resources. It still declines by 2050 (~67 tCO_2e/yr), but remains slightly above Scenario 1 through much of the mid-century.



The three scenarios are guided by different policy assumptions. Scenario 1 assumes that current policies remain the same over time, in this way it acts as a baseline not a true assumption. The lifetime outcome of scenario 2 is driven by two interacting effects. First, the scenario's post-2035 rebound indicates that, even after rapid decarbonization, there can still be residual fossil generation later due to reliability needs, resource adequacy constraints, and the economics of firm capacity as demand and electrification grow. Second (and most importantly for this lifecycle calculation), we assumed that the 2050 grid mix persists through 2126. That means Scenario 2's higher 2050 annual emissions rate is effectively applied for decades, causing it to accumulate the largest 100-year total despite being the cleanest in 2035.

These results support using scenario 3, the high demand growth case as a "most-likely risk" sensitivity for planning: California's load is plausibly pushed upward by EV adoption, building electrification (heat pumps), increasing cooling demand under warming, and growing industrial electricity use. If the project's lifetime assessment were instead anchored to a static present-day Californian grid, operational totals would be far higher (tens of millions of kg CO_2e), potentially overstating long-run operational impacts and distorting the relative importance of operational vs. embodied carbon interventions.

The relationship amongst these can be seen in figure 5.5B and table 3.

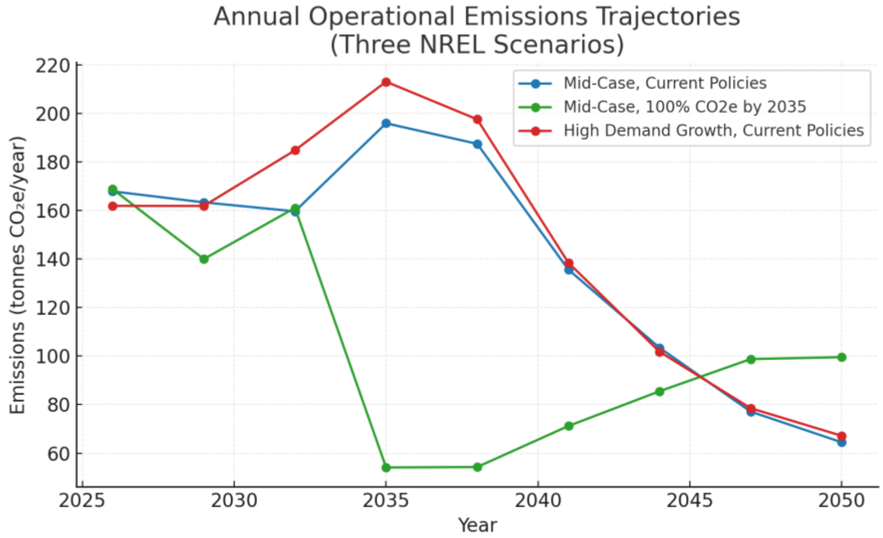


Figure 9.4B Annual Operational Emissions Trajectories

Table 9.4A Total Life Time Operational Carbon Emissions of 3 NREL Scenarios

Year	Current policies	100% CO2e Reduction by 2035	High Demand Growth, Current Policies
2026	167,892.28	168,798.75	161,916.14
2035	195,951.57	24,268.23	213,094.24
2050	64,467.88	99,580.88	67,139.98
Lifetime total:	**8,600,322.00**	**10,103,002.29**	**8,951,272.88**

The numbers indicate that it is critical to incorporate future energy demand and grid evolution into any calculation of a building's operational lifetime carbon footprint, as this has a serious impact if the building is part of a mixed grid. Although in the case of the Presidio Springs redevelopment this is mitigated by the SBCE program's 100% clean energy procurement.

9.5 Uncertainty and robustness of results

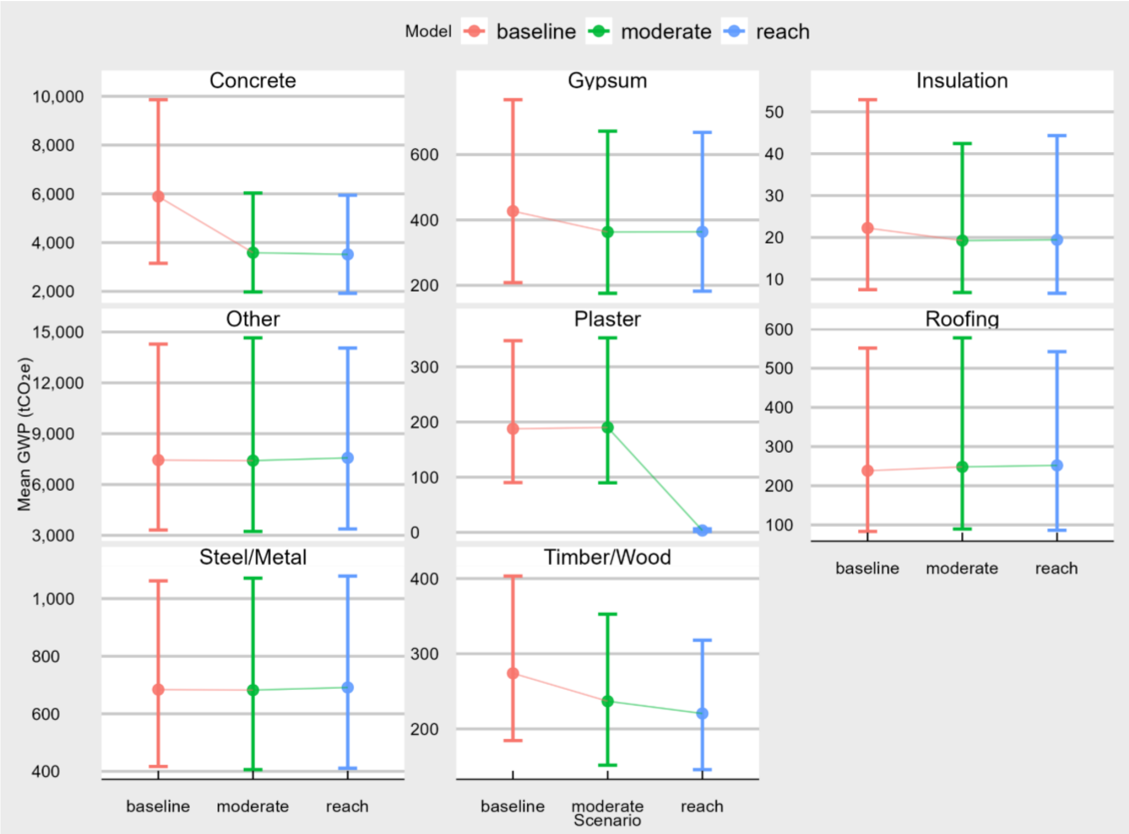
The violin plots (Figure 5.4.1A) and confidence interval summaries (Figure 9.5B) allow us to evaluate whether the observed scenario differences remain robust after accounting for uncertainty in industry-average EPD values.

Concrete demonstrates the clearest scenario separation, with Baseline distributions centered higher than Moderate and Reach on both the violin shapes and 95% confidence intervals. This indicates that fly ash substitution produces reductions that exceed typical cement mix variability

(CV = 30%). Plaster shows a Baseline and Moderate distributions cluster tightly at ~200 tCO_2e, while Reach collapses below 100 tCO_2e with non-overlapping confidence intervals. This discontinuity signals a fundamental specification shift that delivers genuine savings beyond data noise (CV = 35%).

By contrast, Gypsum, Steel/Metal, Timber/Wood, Roofing, and Insulation exhibit overlapping distributions across all three scenarios. While Moderate and Reach show modest downward shifts in central tendency, their 95% CIs remain statistically indistinguishable from Baseline given high EPD variability (CV = 20-50%). These categories contribute to cumulative whole-building savings but lack category-level evidence of transformative impact.[89]

These results suggest that procurement strategies targeting supplementary cementitious materials (SCMs) in concrete and low-GWP plaster systems offer the most reliable pathways to reducing embodied carbon at Presidio Springs, as their reductions remain robust under uncertainty.



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[89] Marsh, E., Orr, J., & Ibell, T. (2021). Quantification of uncertainty in product stage embodied carbon calculations for buildings. Energy and Buildings, 251, Article 111340.

Figure 9.5B: Mean GWP with 95% Confidence Intervals. This figure summarizes the expected A1-A3 global warming potential (GWP, tCO_2e) for six material categories across the Baseline, Moderate, and Reach scenarios. Points represent the means of the Monte Carlo simulations, while error bars show 95% confidence intervals. Overlap among confidence intervals indicates that many material categories fall within the expected range of industry-average data variability (~20-50% coefficient of variation).