Reducing Greenhouse Gas Emissions from the 'Operations' Phase of the Life Cycle in Commercial Office Buildings

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Abstract

Office buildings, largely occupied by the commercial sector, are not perceived as a large emitter of greenhouse gases, so the companies that occupy them and those that manage them are not required to measure, report, and reduce their greenhouse gas (GHG) emissions (WRI/WBCSD, 2017; US EPA, 2017). Yet buildings are responsible for a surprising 40% of U.S. energy use and over 40% of GHG emissions, with commercial office buildings accounting for approximately half that number (Marks, Lin, Harris, Hewitt, & Holloman, 2010; US DOE, 2014). Published life cycle analyses tend to focus on embodied energy and HVAC energy use (Scope 1 and 2 emissions), but there is little that specifically points to the operation of office buildings as a high-energy consumption service (WRI/WBCSD, 2004; Janda, 2007). What seems to be missing from our knowledge base is a fundamental understanding of the operations phase of the life cycle of an office building, not just the heating and cooling energy, but the GHG emissions generated by day-to-day operations.

More tangible guidance needs to be provided to occupants of commercial office buildings in order to make changes in their energy use and reduce GHG emissions. Building 'green' is not enough, because it will only affect embodied energy and possibly HVAC energy used, but not all the other operational activities engaged in by this sector. Because this industry does not manufacture, a large share of GHG emissions are generated by the Scope 3 categories: upstream purchased goods and services, employee travel, employee commuting mileage, and waste generated in operations.

This study was conducted to examine the hypothesis that in order for a green building to generate less GHG emissions than a conventional building, the operations need to be more sustainable, e.g., the occupants would have to engage in more sustainable practices. Surveys were used to examine the operational practices of ten office buildings in five cities, with four conventional and six green buildings included. The survey results were used to generate a greenhouse gas (GHG) inventory for each building and the results were compared. Representative conventional and green model buildings were created using a Life Cycle Analysis (LCA) modeling tool (GaBi), and the results were normalized using the ReCiPe method.

Green buildings outperformed conventional buildings in the area of Scope 2, purchased electricity and heat, with 17% less than conventional. However, green buildings had greater volume of GHG emissions, as well as per person GHG emissions across all buildings studied. Green buildings yielded 73% greater Scope 3 emissions, driven primarily by business travel and commuting miles. Finally, green buildings also had 10x more embodied energy then conventional.

The GHG Inventory and the LCA demonstrated which factors (square footage, building materials) were responsible for the greatest embodied energy, and which factors (business travel, commuting miles) were responsible for the greatest operational energy. This information can contribute to the knowledge base for offices in the commercial sector by providing insight into which meaningful changes should be implemented to make their operational practices more sustainable.

Acknowledgments

I would like to thank Piers MacNaughton for his help and guidance with this project. In addition to being my Thesis Director, he was the study lead for GBASE (sponsored by the Harvard T.H. Chan School of Public Health, the Green Building Assessment Survey and Evaluation), from which my survey data was acquired. As such, he personally helped me to collect and contextualize my survey data, which formed the basis for my research. His patience and perseverance throughout my many requests for information and guidance are greatly appreciated!

I would also like to thank Ramon Sanchez for suggesting that I try to combine my study with the GBASE study. He had the inspirational idea that I could increase the volume and integrity of data by piggy-backing my research onto a large-scale Harvard study that he was co-sponsoring. He also gave me valuable input into how to conduct the data analysis using LCA software and the ReCiPe method.

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Chapter I

Introduction

The commercial sector (banks, law firms, real estate managers, consultants, and other professional services) is not perceived as a large emitter of greenhouse gases, so those companies are not required to measure, report and reduce their greenhouse gas (GHG) emissions (WRI/WBCSD, 2017; US EPA, 2017). This is because the commercial sector does not engage in manufacturing and is not considered 'heavy industry,' therefore most business-focused programs to cut GHG emissions are focused on manufacturers and utilities (WRI/WBCSD, 2017; Lucon et al., 2014). Yet occupants of office buildings are thought to be largely comprised of the commercial sector (Lucon et al., 2014; Wheaton, 1987), and office buildings account for almost 20% of total U.S. energy consumption (Marks et al., 2010; US DOE, 2014). According to the Center for Climate and Energy Solutions, office buildings are responsible for 20% of U.S. GHG emissions (Center for Climate & Energy Solutions, 2017). Therefore, it seems there is a disconnect between the perceived energy use of office buildings and their actual contribution to total GHG emissions in the U.S.

Life cycle assessments of office buildings confirm that most environmental impacts occur during the operations phase and are largely the result of electricity used in lighting, HVAC systems, and outlets; heat conduction through the structures; water use and wastewater generation; and office waste management (Junnila & Horvath, 2006; Janda, 2007). A life cycle assessment, or LCA, is a factual analysis of a product's entire life cycle in terms of sustainability. The purpose of an LCA is to evaluate the environmental impacts of a product or service from 'cradle to grave' (Goedkoop, Oele, Leitjing, Ponsioen, & Meijer, 2016). The International Organization for Standardization (ISO) provides the standards for the LCA methodology, which ensure it is reliable and transparent.

It would appear that most of the discussion in the published literature focuses on how to build more sustainable structures, and how to keep inhabitants healthier; however, there seems to be little in the way of guidance for how inhabitants of commercial office buildings can make changes in their energy use in order to reduce GHG emissions.

Research Significance and Objectives

Using a sample from six green office buildings and four conventional office buildings inhabited by the commercial sector, based in five U.S. regions (New England, Mid-Atlantic, Rocky Mountains, Pacific Northwest, and Southern West Coast), I conducted surveys in order to characterize the sustainable and non-sustainable practices of the building occupants, as well as determine parameters to measure annual Scope 1 (fugitive emissions), Scope 2, and Scope 3 greenhouse gas (GHG) emissions. A GHG inventory was conducted for six of the ten buildings, and two of the ten buildings yielded enough data to input into a Life Cycle Analysis (LCA).

This LCA was conducted using GaBi, considered to be one of the leading global software tools for modeling LCAs (Hollerud, Bowyer, Howe, Pepke & Fernholz, 2017).

The LCA was used to establish cradle to grave GHG emissions and compare metrics between the green and conventional office buildings. In this context, cradle to grave pertains to energy used to create and transport the materials used to build the offices, the building process itself, the use phase, and the end of life phase, which pertains to demolition and waste disposal (Goedkoop et al., 2016). Quantifying and comparing the GHG emissions of the two building types helped to identify those characteristics that are needed to achieve a significant reduction in GHG emissions in an office building in the commercial sector. It is hoped that this information can contribute to the knowledge base for offices in the commercial sector, by providing some insight into which meaningful changes should be implemented to make their operational practices more sustainable.

Background

In 1998 the United States Green Building Council (USGBC) recognized that there needed to be a set of standards that outlined what constitutes a green building, including a third-party verification process, based on industry consensus. LEED certification was created to meet that need and 20 years later, there are more than 90,000 LEED-certified buildings worldwide (USGBC, 2018). For both new construction and major renovations, LEED certification categories (Certified, Silver, Gold, Platinum) require that a minimum number of points be earned across each of these domains:

- Location and transportation (access to mass transit, diverse uses, land protection, reduced parking footprint, etc.)
- Sustainable sites (pollution prevention at construction site, protect or restore habitat, rainwater management, etc.)
- Water efficiency (outdoor and indoor water use reduction, etc.)

- Energy and atmosphere (advanced energy performance, metering, renewable energy production, carbon offsets, etc.)
- Material and resources (demolition waste management, recycling, sourcing of green material ingredients, etc.)
- Indoor environmental quality (thermal comfort, low-emitting materials, lighting and acoustical performance, etc.)

Worth noting, LEED certification does not give (or take away) credits for the operational practices (Scope 3 emissions) of office building occupants. This certification is meant to encourage sustainable building and renovation practices and does not apply to behavior of building occupants (USGBC, 2018).

Operations Phase of Energy Use

A review of the literature pertaining to the operations phase of the life cycle of office buildings and energy use, as well as energy use in the commercial sector, yielded multiple papers and book chapters that examine technological advancements in building offices using LEED principles (Turner & Frankel, 2008; Anderson, Wulfhorst, & Lang, 2015; Wilson, 2017; USGBC, 2018), retro-fitting office buildings using sustainable principles (Miller & Buys, 2008; Paradis, 2012), and adapting office buildings to deliver better sustainability (Mickaitytê, Zavadskas, Kaklauskas, & Tupênaitê, 2008; WBCSD, 2007; Russell, 2007). Some publications address the economics of sustainability (Daly, 1990; Lovins, Lovins, & Hawken, 1999; WBCSD, 2009), while others examine the life cycle of buildings in general, both residential and commercial (Sartori & Hestnes, 2007). One paper discusses the full life cycle of an office building, in terms of four distinct categories of energy use (Cole & Kernan, 1996). Much has been reported about automated HVAC systems and sustainability in buildings in general (Bordass, Bronley, & Leaman, 1993; Liu, Claridge, & Turner, 2002), as well as the relationship between better energy efficiency and healthier indoor environments (Fisk, 2000; Intuitive Research, 2005; UNEP-SBCI, 2017).

What seems to be missing from our knowledge base is a fundamental understanding of the operations phase of the life cycle of an office building, and the energy used and waste generated by the commercial sector. And while there is guidance for the professional sector as far as which GHG emission categories to measure and report, and how to mitigate those emissions (WRI/WBCSD, 2004; Nicholls et al., 2015), the focus tends to be on Scope 1 and Scope 2 category emissions (gas and electric energy, either generated or purchased) and not Scope 3 category emissions (those that specifically pertain to day-to-day operational categories). Running an office requires far more than just gas and electricity, yet these other factors aren't being discussed. With the lack of debate about the impact of Scope 3 emissions, it is not surprising that commercial office buildings are not viewed as a high-energy consumption service.

Research Questions, Hypotheses and Specific Aims

Overall, the aim of this research project was to examine the characteristics of commercial offices and quantify their GHG emissions in order to provide guidance that could be used to reduce energy consumption, reduce GHG emissions, and save money. In order to do this, these research questions needed to be answered:

1. What is the environmental impact of a 'green' vs conventional US commercial office building in a given year?

2. Can the day-to-day operational practices of office building inhabitants impact the GHG emissions as much, or more than, the application of ‘green’ building principles?
3. Does embodied energy make a significant difference in total GHG emissions, or do sustainable practices make more of an impact?
4. Does the total energy consumption (embodied plus annual usage) of a green building necessarily result in lower GHG emissions than that of a conventional building?

It was my hypothesis that the characteristics with the greatest environmental impact in a typical office building would be found in its operational practices (e.g., Scope 3 emissions) rather than its embodied energy (e.g., building characteristics), and that ‘green’ buildings would yield lower annual GHG emissions than conventional buildings, due to ‘assumed’ lower embodied energy and reduced annual emissions.

Specific Aims

To address my research questions and hypotheses, the process employed involved these steps:

1. Selecting a sample of five ‘green’ office buildings and five conventional office buildings inhabited by the commercial sector, based in five different US regions.
2. Conducting surveys of building managers as well as office inhabitants in order to characterize the sustainable and non-sustainable practices of the office buildings, as well as obtain basic parameters for a greenhouse gas (GHG) inventory.
3. Performing a GHG inventory to measure annual Scope 1, Scope 2, and Scope 3 greenhouse gas (GHG) emissions for the sample offices.

4. Executing a Life Cycle Analysis (LCA) in order to establish emissions resulting from embodied energy from building practices.
5. Employing the ReCiPe method to quantify environmental impacts and compare metrics for the two building types.

Chapter II

Methods

The core methodology for this project focused on measuring greenhouse gas emissions using two approaches: a greenhouse gas (GHG) inventory, and a life cycle analysis (LCA). The GHG inventory was used to obtain Scope 1, 2, and 3 emissions data over a period of one year (2016) in order to understand the buildings' operational energy. The LCA was used to examine the buildings' embodied energy and how that contributed to overall GHG emissions.

Overview

This project is nested within the existing G-BASE study. The G-BASE study aims to assess building systems performance, indoor environment performance, and the health and performance of 109 office workers, using surveys under different operating conditions in five U.S. cities, examining both conventional and green commercial office buildings in each city. In each city, both buildings had the same organization/tenant managing some of the purchasing and some of the Scope 2 and 3 practices, so this was a control built into the G-BASE study. Because this research would optimally involve using a typical green and a typical conventional office building, the G-BASE study design provided the perfect vehicle, because it includes multiple samples of each office building type, with 109 office building occupants included in the survey. A more complete description of the methodology can be found in MacNaughton et al. (2017).

The G-BASE study included a survey administered to the ten building managers as well as a survey for all the occupants of the ten office buildings. This project involved creating survey questions to add to G-BASE surveys for building managers and office occupants in order to capture information to characterize GHG emissions (Scope 1, Scope 2, and Scope 3) for each building. The survey results were tabulated according to six green buildings and four conventional buildings, and survey responses categorized according to Scope 1, Scope 2, and Scope 3 GHG emissions (Table 8). This tabulated information was used to perform a partial GHG Inventory (measure but not report) for six of the ten buildings, and the two buildings with the most complete data were included in a Life Cycle Analysis (LCA).

Using an LCA modeling tool (GaBi), the cradle to grave characteristics that contributed most to GHG emissions for one green and one conventional office building (including embodied energy) were determined, and the ReCiPe normalization method was used to determine the global warming potential (GWP) of each building. These methods were employed to help determine what differences, if any, there were between green and conventional office buildings in order to identify which variables would result in significant GHG emission reductions. A diagram of the methodology is shown in Figure 1.

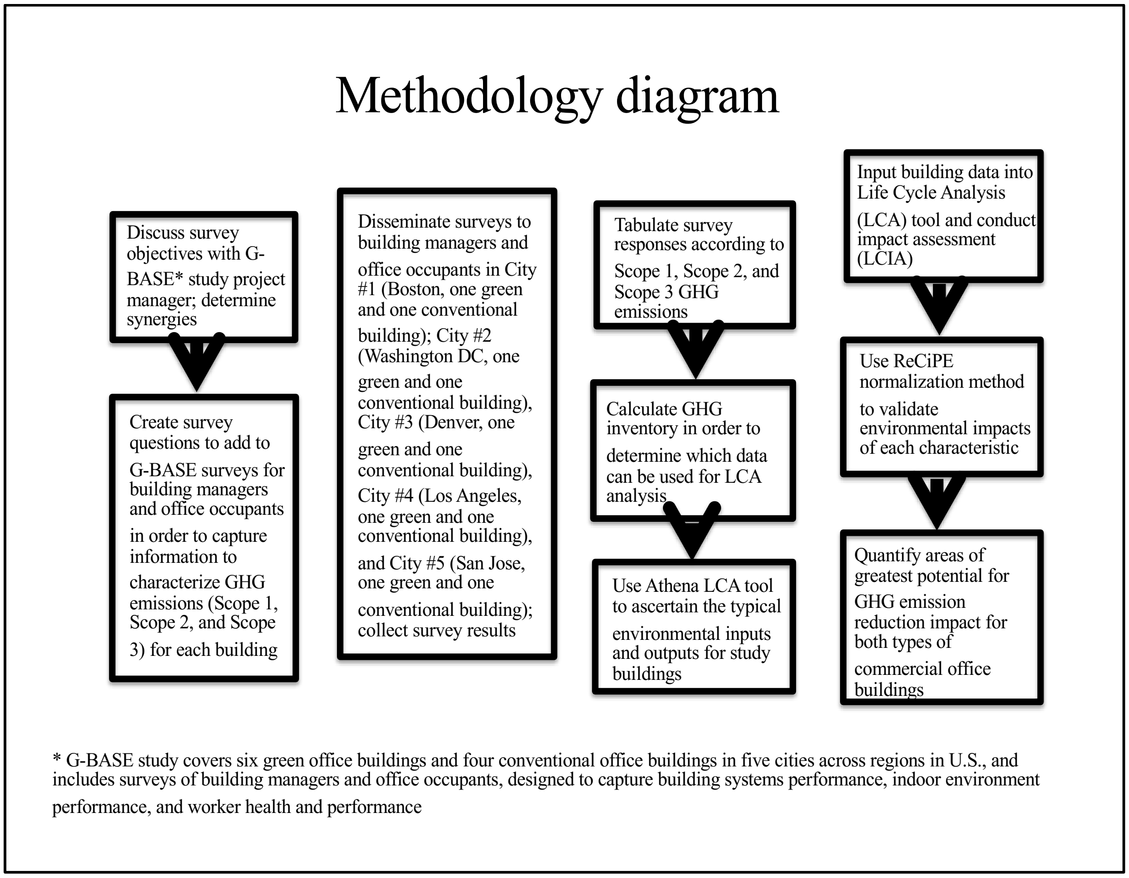

Figure 1. Methodology flow chart.

Surveys

The G-BASE study involved studying the systems performance, indoor environment performance, and the health and performance of 109 office workers, using surveys under different operating conditions in five U.S. cities, using green and conventional commercial office buildings in each city. The conventional offices were those buildings built using traditional building practices; those considered green were built using LEED-approved, sustainable building materials (Table 1).

Table 1. Summary of study sites (Adapted from MacNaughton et al., 2017).

G-BASE STUDY SITES				
City/Abbreviation	**Size (sq ft)**	**Year of construction**	**Type/Year of certification**	**Number of Participants**
Boston conventional	<50,000	1929	Non-certified	12
Boston green	<50,000	1929	LEED EB v3 Platinum in 2012	12
DC conventional	>500,000	1935	Non-certified	11
DC green	>500,000	1917	Pending	12
Denver conventional	50,000-100,000	1938	Non-certified	8
Denver green	50,000-100,000	1938	LEED CI v3 Silver in 2011	12
San Jose conventional	50,000-100,000	1971	Non-certified	9
San Jose green	>500,000	1934	LEED EB v3 Gold in 2015	12
Los Angeles green #1	<50,000	1929	LEED v4 NC Platinum 2018	10
Los Angeles green #2	<50,000	1953	LEED EB v3 Platinum in 2013	11

The G-BASE study included one survey designed for building managers, and one for building occupants. Both surveys were standardized for all cities and buildings. They were comprehensive in terms of ensuring that building performance data and occupant health data were captured. The questions required to obtain the information needed for this research study were added to the G-BASE surveys.

The questions added to the G-BASE surveys were designed to capture Scopes 1, 2, and 3 emissions information, or at least gather enough information to extrapolate data if it wasn't specifically provided. The building manager survey questions centered on obtaining data on the building itself as well as energy usage and waste generation. The occupant survey questions were focused more on office practices, business travel, and commuting travel in order to capture as much Scope 3 data as possible (Table 7).

Greenhouse Gas Inventory

In January of 2017, the EPA developed a guide for conducting a Greenhouse Gas Inventory for companies considered to be 'low emitters.' They also developed a simplified GHG emissions calculator in order to encourage small businesses as well as companies not involved in generating Scope 1 emissions to measure, track, and reduce their GHG emissions (USEPA-CCCL, 2017). According to this guide, a true GHG inventory requires that a company:

1. Create a comprehensive inventory of all GHG emissions
2. Develop a GHG Inventory Management Plan (IMP) for data consistency over time
3. Set a GHG reduction goal and track progress towards that goal

However, since this study does not involve reporting GHG emissions to the EPA's Greenhouse Gas Reporting Program (GHGRP), and the data is only being used as part of a research project, only point #1 needs to be considered. The basic approach to point #1 involves defining a GHG inventory accounting basis, choosing a base year, identifying organizational and operational boundaries, identifying emission source types, and calculating and quantifying GHG emissions (USEPA-CCCL, 2017; Putt del Pino & Bhatia, 2002). For the purposes of this research, the year chosen for base year corresponds to the year the data was collected: 2016. The accounting basis and organizational boundaries are not as relevant, since the inventory isn't being reported, so the focus was on identifying the emissions source types, and calculating and quantifying GHG emissions.

Emission sources of all seven major GHGs are accounted for in this inventory: Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorinated Chemicals (PFCs), Sulfur Hexafluoride (SF_6), and Nitrogen Trifluoride (NF_3) (WRI/WBCSD, 2013).

Guidelines suggest that if some Scope 3 emissions data are impossible to obtain, then the inventory should be conducted using as much data as is available (WRI/WBCSD, 2011). The two Washington DC buildings were excluded because the building managers did not provide critical data needed to perform the inventory. Of the remaining eight buildings, Scope 1 fugitive emissions data were captured in all but San Jose. Those emissions numbers accounted for such a small portion of GHG emissions that San Jose was included in the analysis anyway. Four of the buildings included Scope 3 waste generated in operations, which was included in the analysis, and Boston provided Scope 2 purchased HVAC data, allowing for a more in-depth analysis of those two buildings (Table 2). Fortunately, one building is conventional and the other is green, so a comparison between the two types could still be performed.

Emission Source Types

In selecting which emission categories to include, all the sources of emissions in the study buildings first had to be identified. That list was then compared with all the Scope 1 and 2 categories listed in the GHG Protocol's Corporate Accounting and Reporting Standard, and the Scope 3 categories listed in the GHG Protocol's Corporate

Value Chain (Scope 3) Accounting and Reporting Standard. As might be expected from a business where no manufacturing is taking place, Scope 3 categories are where a large proportion of the study buildings' emissions come from. In order to narrow down which Scope 3 emissions to include in the inventory, the list of categories and their descriptions in the GHG Protocol's corporate value chain and accounting standard had to be examined (WRI/WBCSD, 2011). This was applied to the survey data to determine which categories to rule out and which to leave in (Table 8).

Once the emission sources to include in the inventory were chosen, those sources were categorized according to the appropriate Scope 1, 2, and 3 data. The surveys yielded the necessary Scope 3 data from four of the five cities, and Scope 1 data from three of the five cities, but only Boston provided the necessary Scope 2 data (Table 2).

For Scope 1, fugitive emissions, none of the respondents reported the use of portable air conditioners, but some building managers did report refrigerators and the approximate year they were put into service. Hence the fugitive emissions from refrigerators were included in the GHG inventory. For Scope 3, Category 1: stationary combustion; upstream purchased goods and services, survey respondents did not provide the requested office or kitchen supply data, but there was information on non-production-related goods, namely, desktop computers, printers, copiers, and fax machines (Table 8). Unfortunately, none of the available e-tools include Scope 3, Category 1 data, and manual formulas provided by the GHG protocol [unit of purchased product x emission factor x GWP] require an emissions factor, and none exist (yet) for these specific products. Despite having to exclude Scope 3, Category 1, there was still enough Scope 3 data to analyze for the eight buildings included.

Table 2. Summary of available GHG Inventory data by city.

	GHG Inventory data by city						
Site	Scope 1 Fugitive emissions (refrigerators, ac window units)	Scope 2 Purchased electricity and heat	Scope 3 Stationary combustion; upstream purchased goods and services	Scope 3 Stationary combustion; upstream transport/ distribution	Scope 3 Stationary combustion; waste generated in operations	Scope 3 Mobile combustion; business travel	Scope 3 Mobile combustion; employee commuting
Boston conventional	√	√	√			√	√
Boston green	√	√	√			√	√
DC conventional			√			√	√
DC green			√			√	√
Denver conventional	√		√		√	√	√
Denver green	√		√		√	√	√
Los Angeles green #1	√		√		√	√	√
Los Angeles green #2	√		√		√	√	√
San Jose conventional			√			√	√
San Jose green			√			√	√

Emissions Calculations

As previously elucidated, the initial GHG inventory calculations were confined to eight of the ten buildings. The first step in determining how to represent the GHG data gathered was to separate the total building data from the data gathered from the individuals in the study. For example, the Scope 3 commuting miles data was confined to the approximately twelve participants in each building (Table 10), but the Scope 3 waste generated data (Table 12) and the Scope 1 and 2 data were for the entire building. This was done by using the survey respondents as a representative sample of the total building occupants, (Table 3). By multiplying all the respondents' data by the factors in Table 3, the total 'average' data for all office occupants was extrapolated in order to ensure that all the emissions categories being counted in the inventory represented the entire building. In the Results section there is a breakdown of GHG emissions using this method.

Publicly available calculation tools only help quantify emissions for three categories of Scope 3: employee business travel, employee commuting, and product transport. Consequently, the EPA Simplified GHG Emissions Calculator (SGEC) was used to calculate GHG emissions for everything but Scope 3, Category 1, purchased goods and services, and Category 5, waste generated in operations (Tables 4 & 5). For Category 5, the EPA's Waste Reduction (WARM) model calculation tool was used (Table 12), which calculates CO_2e for landfilling, recycling, and landfill waste converted to combustion (US EPA, 2016). For Category 1, there was not sufficient data to include, as explained further in the next section.

Table 3. Study participants and total building occupants.

Building	# of study participants	Times multiplication factor	Equals total # of building occupants
Boston conventional	12	4.166667	50
Boston green	12	12.5	150
Denver conventional	8	34.61538462	450
Denver green	12	37.5	450
Los Angeles green #1	10	10.90909091	120
Los Angeles green #2	11	17.5	210
San Jose conventional	9	20.83333333	250
San Jose green	12	100	1200

Category 1: purchased goods and services. There were several limitations with Category one, purchased goods and services, because the office managers did not answer any survey questions pertaining to purchases of goods or services. We can assume that everything that is purchased falls into the realm of 'non-production-related products,' because these companies don't actually produce anything. That essentially includes office supplies, kitchen supplies, computers and peripheral equipment, and other office machinery. Of these, there was only survey information on number of and age of computers, photocopiers, printers, and fax machines. In the GHG protocol guidance on calculating Scope 3 emissions, the only viable method to use under these circumstances is the 'average data method,' where the activity data needed is the number of units purchased and the emissions factors are kg/ CO_2e per unit. This was not possible, as there are no emissions factors available for these items, mainly because most of their

emissions are already accounted for in Scope 2 electricity. The tool on eiolca.com, which uses an emission factor based on spend, could have resolved this issue, but there was no spend data provided. Consequently, Scope 3, Category one was left out of the analysis.

Category 5: waste generated in operations. To calculate Category 5, waste generated in operations, an annual amount of trash, recycled paper, and recycled bottles and cans had to be extrapolated, based on the survey questions answered. From the survey responses, we know how many dumpsters each office used, the size, and how often they were collected. The garbage falls under the category of municipal waste, and for an office that usually consists of a combination of 'soiled' paper plates, paper cups, plastic utensils, paper towels, food waste, and all other non-recyclable trash.

Because the recycled waste was mixed in with the other waste, the EPA's municipal waste average rates were used to 'separate' the waste. According to the last report issued by the EPA in 2016, the average recycling rate in the United States is 34.6% and the average landfill rate is 52.6%. The remainder of waste is converted to steam or electric combustion, at 12.8% (US EPA, 2016). Therefore, these percentages were used to categorize the tons of waste reported in the surveys (Tables 4 & 5).

These data was then input into the EPA WARM tool, which calculated the metric tonnes of CO_2e, based on US national waste averages (Table 12, Appendix 2).

Table 4. Activity data for Scope 3/Category 5 emissions. (WRI/WBCSD, 2013)

Building	Activity Data	Conversion needed for calculations	Annual data
Denver conventional	(3) 10 cubic yard dumpsters, collected daily (5x per week)	10 x 250 (pounds per cubic yard)= 2500 lbs; / 2000 to convert to tons=1.25 tons x 3= 3.75 tons per day; x 5 days per week= 18.75 tons per week	x 52 weeks per year = 975 tons
Denver green	(3) 10 cubic yard dumpsters, collected daily (5x per week)	10 x 250 (pounds per cubic yard)= 2500 lbs; / 2000 to convert to tons=1.25 tons x 3= 3.75 tons per day; x 5 days per week= 18.75 tons per week	x 52 weeks per year = 975 tons
Los Angeles green #1	(3) 15 cubic yard dumpsters, collected weekly	15 x 250 (pounds per cubic yard) = 3750 lbs; / 2000 to convert to tons= 1.875 tons x 3 = 5.6 tons per week	x 52 weeks per year = 292.5 tons
Los Angeles green #2	(2) 10 cubic yard dumpsters, collected weekly	10 x 250 (pounds per cubic yard) = 2500 lbs; / 2000 to convert to tons=1.25 tons x 2= 2.5 tons per week	x 52 weeks per year = 130 tons

*250 lbs is average weight per cubic yard of commercial waste (US EPA Volume, 2016)

Table 5. Waste generated in operations.

BUILDING	Total mass of waste (tons)	52.6% landfill	34.6% recycling	12.8% converted to combustion
Denver conventional	975 tons	513 tons	337.2 tons	124.8 tons
Denver green	975 tons	513 tons	337.2 tons	124.8 tons
Los Angeles green #1	292.5 tons	154 tons	101.1 tons	37.4 tons
Los Angeles green #2	130 tons	68.38 tons	44.98 tons	16.64 tons

Life Cycle Analysis

In order to do a cradle to grave LCA, each building had to be treated as if it were a 'product,' so the products were named Boston conventional and Boston green. The boundaries for each product were: the materials used, the transport to the building site, the assembly of the building itself (foundation, columns and beams, floors, exterior walls, interior walls, roof), and the demolition and disposal (end of life) of the building. Items such as fittings and furniture would need to be extrapolated and were therefore left out of the analysis. Also excluded from the analysis were historical energy consumption (operating Scope 2 data), procurement data, and Scope 3 operations data, as the LCA focused on embodied rather than operations energy.

The Inventory Analysis

The inventory analysis provides a quantitative catalog of environmental inputs and outputs for a product, in this case, the office buildings. The inputs and outputs, also referred to as 'flows,' were either elementary (natural resources used and naturally occurring, such as emissions) or non-elementary (those resources that only exist within the technosphere that is the building) (Goedkoop et al., 2016). Inputs were the raw materials used for the buildings, the construction processes, transport data, and the outputs were waste generated (end of life disposal and recycling) and the emissions of pollutants. Because this study aims to make comparisons between two products, and those two products may have different performance characteristics, a basis for comparison that is objective needs to be established (Ciambrone, 1997). This basis for comparison is called a 'functional unit,' and in order to determine the comparative GHG impacts of conventional and green commercial office buildings, the two functional units need to be compared against each other (Bruce-Hyrkäs, 2017). In this case, the functional unit used was 1 cubic meter (m^3) of building space. Although 1 square foot would have been preferable, the databases within GaBi did not use square feet as units of measurement, so it made the most sense to use a unit compatible with the data available.

Because LCA software requires inputs from someone knowledgeable about the materials used, some preliminary research needed to be done in order to come up with a materials list. The information gleaned from the surveys, along with photographs of both buildings made it possible to create a list of assumptions for each building to use as a basis for a construction inventory. But this was not enough to input into the GaBi LCA modeling tool. Fortunately, the Athena Sustainable Materials Institute has an LCA tool which is intuitive and full of U.S. construction data, as well as built-in U.S. defaults for most inputs. It allows for a model of a building to be constructed according to foundation assembly, columns and beams assembly, floor assembly, exterior walls assembly, interior walls assembly, and roof assembly. It guides the user through each step, indicating exactly what needs to be input, and enabling choices to be made according to year built (Tables 16 & 17). Although both buildings were erected in 1926, Boston green was re-built in 2011, and specific data on materials used was available (Harvard University Sustainability, 2012; Harvard Green Campus Initiative, 2007). Bearing in mind that both buildings had the same organization/tenant controlling some of the purchasing and other Scope 3 practices, the key point of differentiation between the inputs for the two buildings had to do with use of older vs. modern materials. Although the Athena tool can generate an LCA impact report, it does not contain a sensitivity analysis or a ReCipe normalization feature, so it was only used as a ‘step’ in the LCA process.

Life Cycle Impact Assessment (LCIA)

The impact assessment is the phase where the magnitude and significance of the potential environmental impacts for the products can be evaluated (Bayer, Gamble, Gentry, & Joshi, 2010). According to the ISO 14044 standard, classification and characterization are mandatory in an LCA; normalization, ranking, and weighting are considered optional (Goedkoop et al., 2016). Since so many impact assessment methodologies already exist within GaBi, one did not need to be created for this LCA. The relevant impact categories from GaBi’s library (e.g., land use, emissions, GWP, acidification, eutrophication, etc.) merely needed to be selected. More information about the LCIA will be in the Results section.

Normalization. GaBi has a built-in ReCiPe function, which enables a normalization analysis of the LCIA. ReCiPe has a normalization set which was calculated from inventories which include records of all emissions and resource extractions globally from 2016 (UK National Institute for Public Health & the Environment, 2016). The GaBi LCIA results for climate change, human toxicity, and several other impact categories are compared to the ReCiPe annual input in order to generate environmental impact scores, based on 3 core endpoint indicators and 16 midpoint indicators (UK National Institute for Public Health & the Environment, 2016). Figure 2 demonstrates the relationship between

LCA parameters, midpoints, and endpoints. The results of the ReCiPe analysis will be discussed in the Results section.

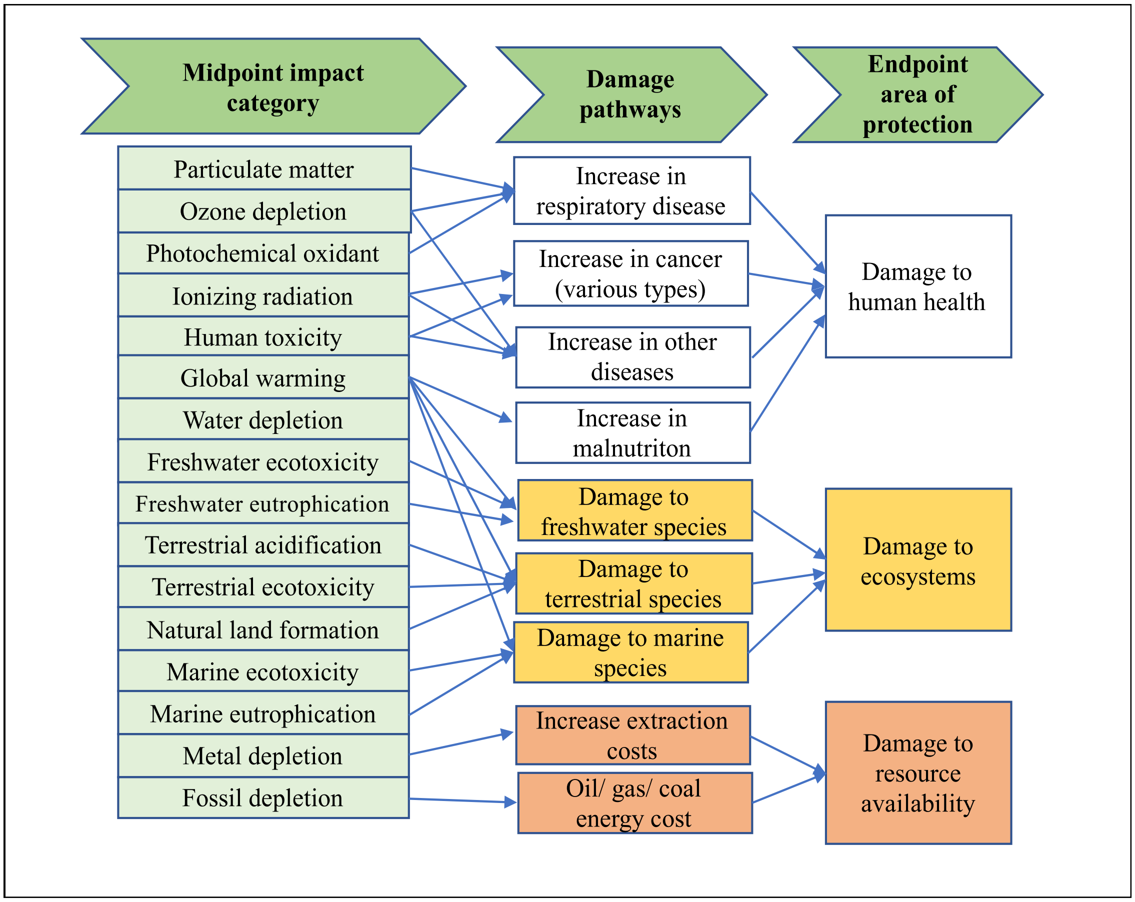

Figure 2. ReCiPE structure, adapted from UK National Institute for Public Health & the Environment, 2016, p17.

Interpretation of the Study

Since LCA data have some uncertainty, statistical methods need to be employed to handle the uncertainty. In this case, some subjective choices had to be made when modeling the system (e.g., choice of functional unit, choice of attributional modeling, etc.), leading to uncertainty in the correctness of the model (Goedkoop et al., & Meijer, 2016). To address this, the sensitivity analysis in GaBi was employed, which allows for switching results by changing assumptions. This made it possible to see which assumptions affected the results and which were most reliable. Further details about the final interpretation of the LCA will be described in the Results section.

Chapter III

Results

The expected results from this research project were the identification of those characteristics most crucial to achieving significant reductions in GHG emissions in an office building in the commercial sector. The assumption was that the variables would involve operational practices (e.g., Scope 3 emissions) rather than embodied energy (e.g., building characteristics).

Greenhouse Gas Inventory

Once the data were calculated and compiled, the conventional and green buildings were compared, but represented separately from that comparison was the waste generated for the few buildings who provided that data. Two main results were apparent, the greatest share of GHG emissions were from business travel, followed by commuting mileage, and, the green buildings tended to have higher GHG emissions than the conventional buildings (Figure 3).

- Boston green had four times the total GHG emissions of Boston conventional, and had higher GHG emissions per person in every category studied except Scope 2 purchased HVAC. Half of Boston conventional's emissions were Scope 2 purchased electricity and heat, with the other half divided between Scope 3 business travel and commuting miles. Boston green's Scope 2 emissions

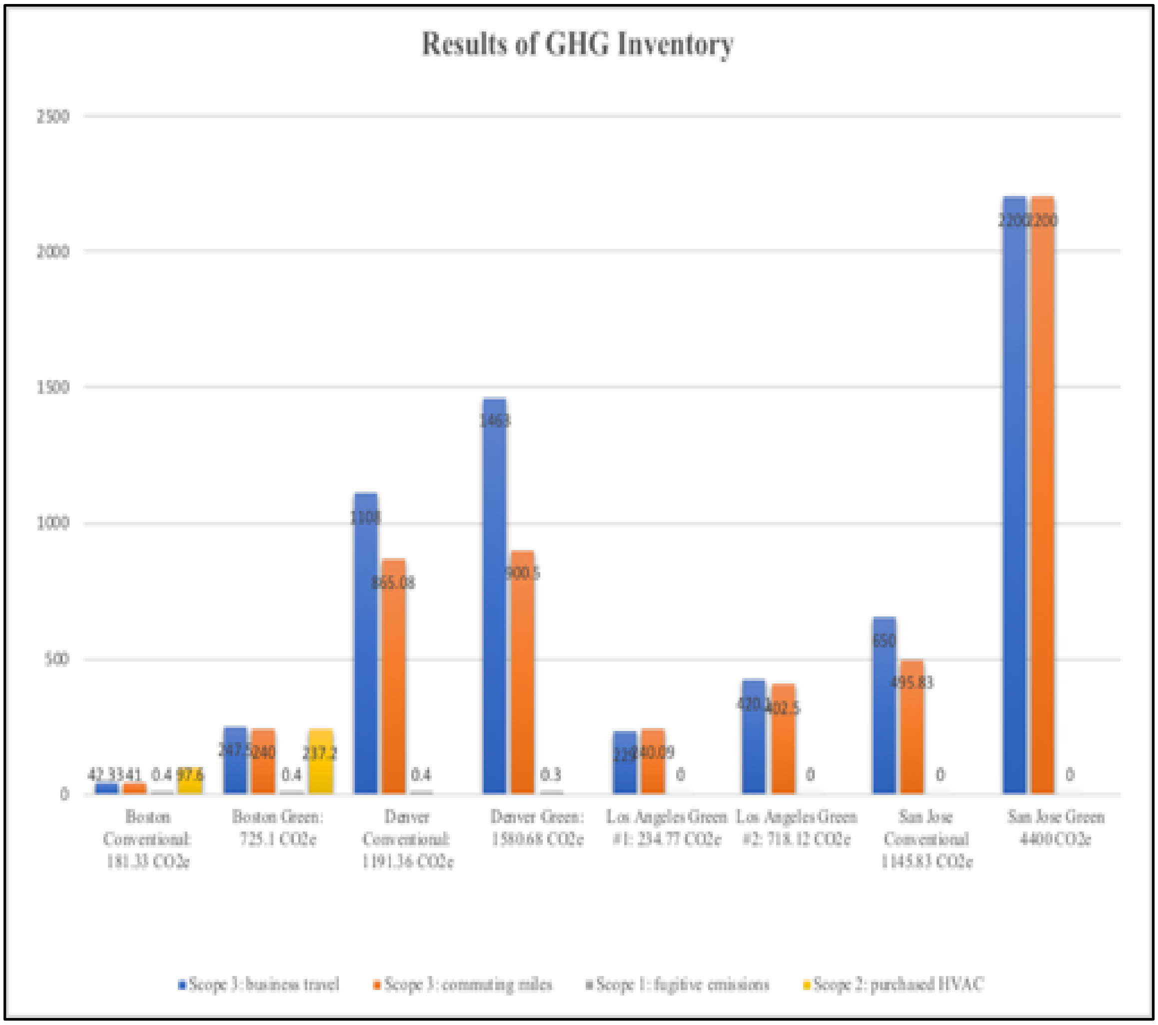

Figure 3. Results of GHG inventory in metric tonnes of CO2 equivalent.

accounted for approximately one third of its GHG emissions, with the other two thirds being divided nearly evenly between business travel and commuting miles. Scope 1 fugitive emissions were less than 1% for both buildings.

- Denver green had nearly 25% greater GHG emissions than Denver conventional. The Scope 3 waste generated/recycled in operations cut the totals of both Denver buildings by 30-40%. Scope 3 business travel took up 56% of Denver conventional's remaining GHG emissions, and Scope 3 commuting miles took up 44%. Denver green's Scope 3 business travel accounted for 62% of emissions, with Scope 3 commuting miles accounting for 38%. Scope 1 fugitive emissions was less than 1% for both buildings.

- Los Angeles green #2 had three times the GHG emissions of Los Angeles green #1. The other primary difference between the two buildings was that the Scope 3 commuting miles dominated Los Angeles green #1 at 51% vs. 49% for Scope 3 business travel, whereas Scope 3 business travel dominated Los Angeles green #2 at 52% vs. 48% for Scope 3 commuting miles. The Scope 3 waste generated/recycled in operations cut the totals of both Los Angeles buildings by 30-40%. Scope 1 fugitive emissions was less than 1% for both buildings.
- San Jose green had nearly four times the total GHG emissions of San Jose conventional, with a perfectly even split of 50/50 between Scope 3 business travel and Scope 3 commuting miles. San Jose conventional had GHG emissions comprised of 56% Scope 3 business travel and 44% Scope 3 commuting miles.

Upon closer inspection, there are apparent reasons for this. In every city except Denver, the green buildings had greater occupied square feet and more employees than the conventional buildings. For that reason, a 'per person' metric was used in some of the more detailed analyses (Table 13).

This is not representative of a typical analysis, because a typical analysis would include energy data for the buildings being compared. Since the only energy data obtained was for the two Boston buildings, those two buildings were examined separately. Boston green has several more employees than Boston conventional (150 vs 50), and is a larger building (40,000 occupied square feet vs. 30,000 occupied square feet), so one would expect their total GHG emissions to be higher. And as is apparent from Figure 4, Boston green did have a higher per person GHG emissions total. However, the HVAC used per person was higher for Boston conventional than Boston green. This is consistent with what we would expect to see, based on the assumption that Boston green would be more energy efficient than Boston conventional (Figure 4).

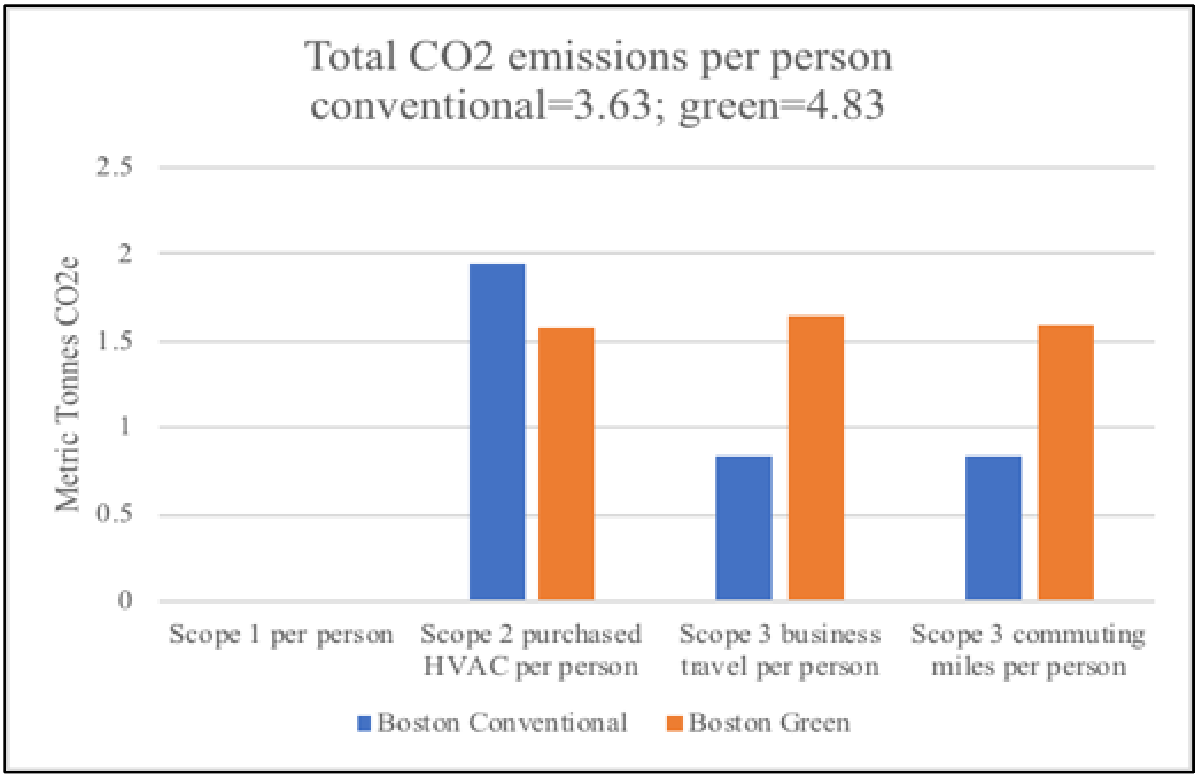

Figure 4. Per person CO2 emissions for Boston conventional vs Boston green.

Looked at another way, a higher proportion of per person CO_2 emissions for Boston conventional was taken up by Scope 2, purchased heat and electricity, whereas Scope 3 commuting miles took up the largest proportion of Boston green per person CO_2 emissions. This is a notable finding because it demonstrates two important points:

- One, that despite overall higher emissions from Boston green, its Scope 2 HVAC emissions were still lower than Boston conventional per person, validating that its energy efficiency was superior, and,
- Two: Scope 3 emissions resulting from employee operational practices can actually exceed total HVAC emissions for a given year.

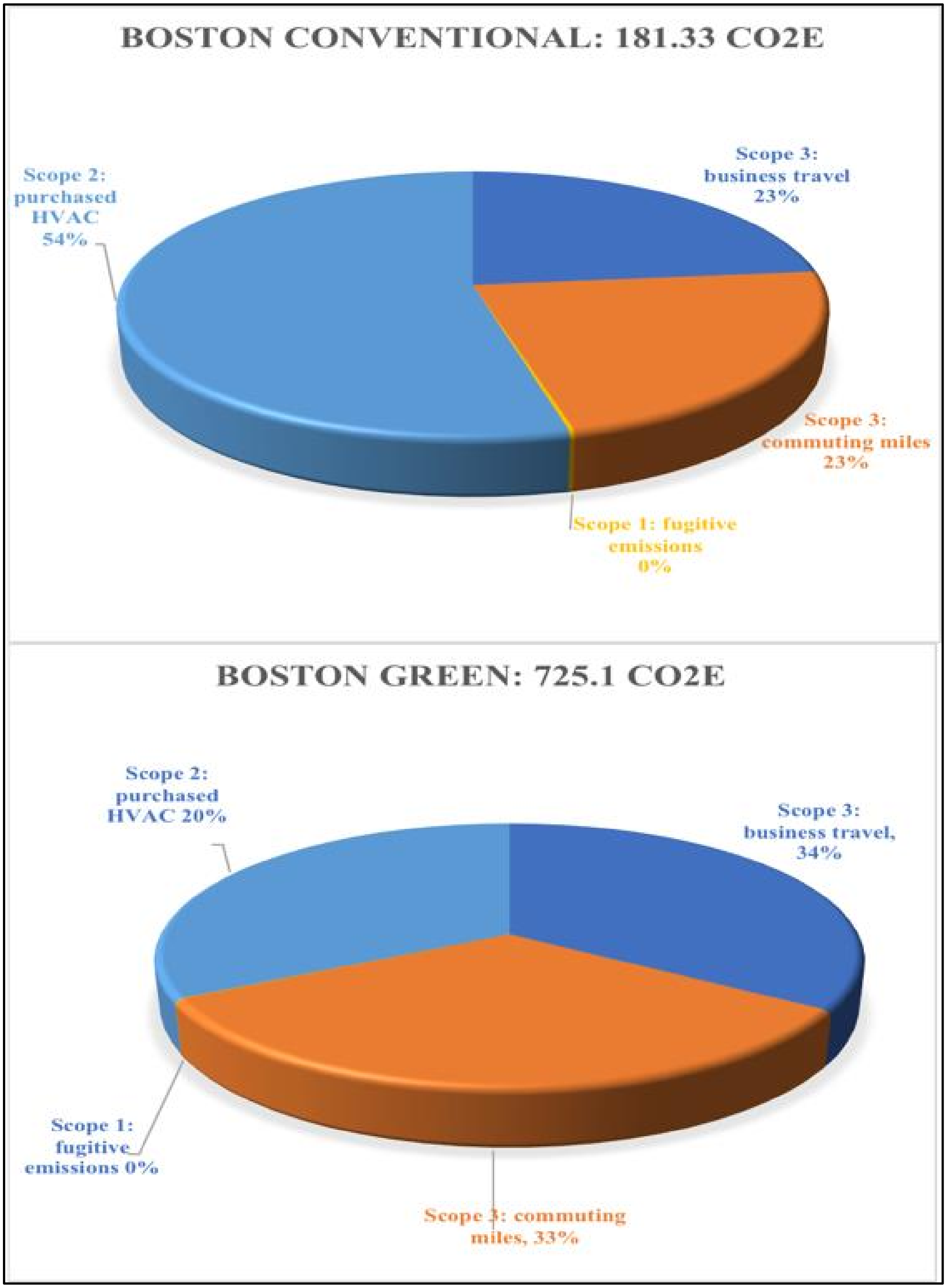

Figure 5. Boston conventional and Boston green total GHG emissions.

Of the four buildings that provided waste data, all of them had an active recycling program. As discussed previously, recycling can result in a negative GHG emissions number, and that was the case here, for all four buildings studied. This lowered the total GHG emissions for each building, and per person (Table 6).

Table 6. Scope 3 recycling lowers overall GHG emissions.

Building	**Scope 3: business travel**	**Scope 3: commuting miles**	**Scope 3: waste generated**	**Scope 1: fugitive emissions**	**Total CO_2e without recycling**	**Total CO_2e with recycling**
Denver conventional	1108	865.08	-782.12	0.4	1973.48	1191.36
Los Angeles green #1	229	240.09	-234.32	0	469.09	234.77
Denver green	1463	900	-782.12	0.3	2363.3	1581.18
Los Angeles green #2	420	402.5	-104.48	0	822.5	718.02

Out of interest, the per person difference with and without recycling was examined. As seen in Figure 6, recycling resulted in a significant reduction in per person GHG emissions for all four buildings. There was no significant difference between conventional and green buildings, as both types had recycling programs. This supports the hypothesis that green practices in the operations phase of a building have a positive impact on GHG emissions.

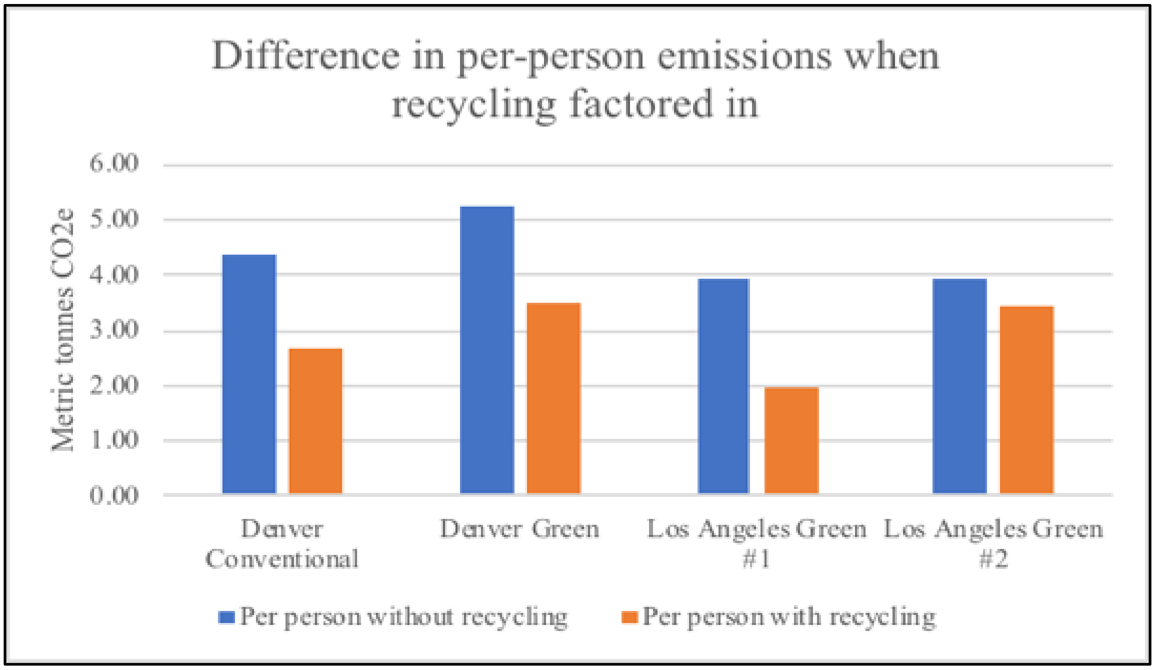

Figure 6. Difference in per-person emissions when recycling factored in.

Life Cycle Analysis

The LCA tool does not allow for the inputting of one year's worth of operational data; the operational data for the entire life cycle of each building would need to be input in order for it to make any sense, and that would be too imprecise, using the limited data available. What can be done is to aggregate the results of the GHG inventory (operational energy) and the Life Cycle Impact Analysis (LCIA) reports (embodied energy) to assess which characteristics contributed most to GHG emissions for each building.

GaBi Modeling Tool

LCA modeling tools require that a representative model be built for each product being studied. In this case, the products were Boston conventional and Boston green.

Because the processes for both models were identical, the key differences lay in the input and output flows. The process for both included these key stages:

- Transportation of building materials to construction site
- Fuel used for transport of materials
- Grid energy used for transport of materials
- Building materials
- Construction process, including foundation, columns and beams, floors, exterior walls, interior walls, roof
- Use phase, which defined the functional unit as 1 cubic meter m^3
- End of life, which included demolition, waste disposal, and emissions to air, land and water
    - End of life waste disposal included energy back to the grid

The main difference in the processes between the two buildings was that Boston conventional had the majority of its waste go to a landfill, while Boston green had the majority of its waste recycled (Figure 7).

The input flows were mainly the materials used for each building, which varied greatly between the two buildings. Although Boston green used more modern, sustainable materials, its embodied energy did not have a smaller carbon footprint than Boston conventional. Despite the fact that the Boston green end of life specified that most building materials be recycled rather than landfilled, it still resulted in a greater

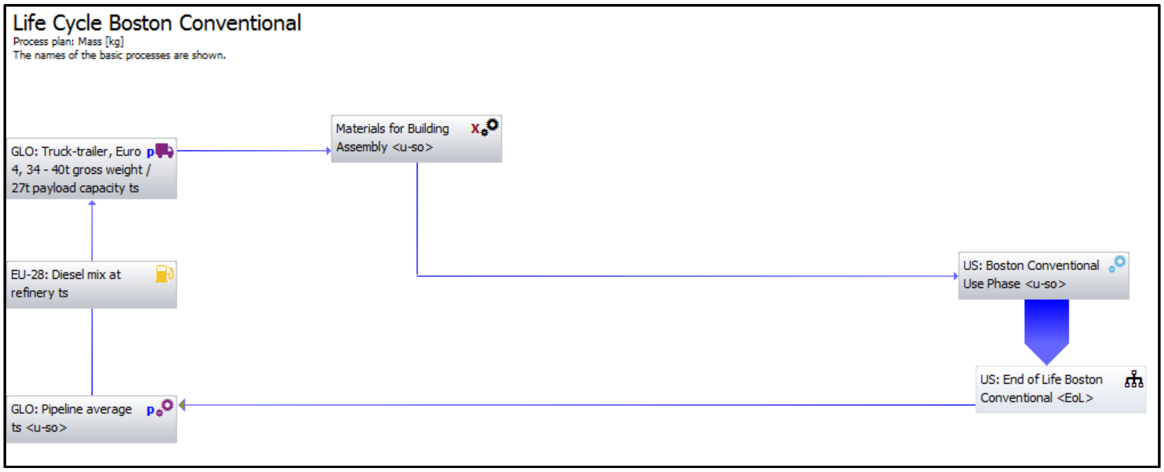

Figure 7. GaBi LCA plan for Boston conventional.

global warming potential (GWP) than Boston conventional. This is likely because the volume of the building was larger by 10,000 square feet, or because it needed more materials to make the building more energy efficient, resulting in a greater mass of GWP.

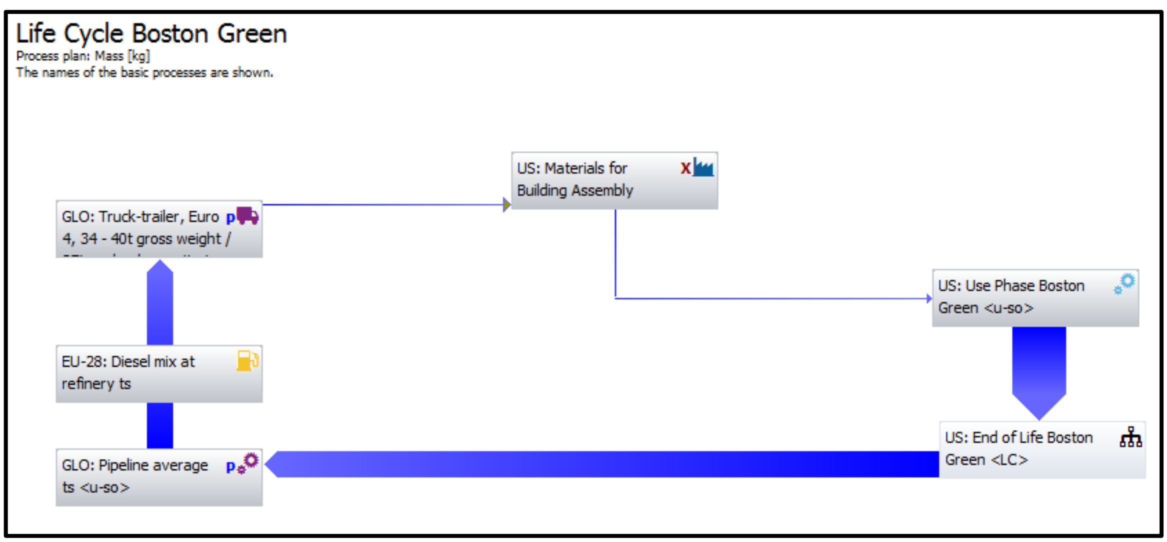

Figure 8. GaBi LCA plan for Boston green.

The full details can be found in The Ancilliary Appendix, but after adding the inputs and outputs for each model, GaBi generated a Life Cycle Impact Analysis (LCIA) which calculated total global warming potential for each building. The ReCiPe normalization tool was employed as another step to validate the LCIA. The total GWP in metric tonnes for Boston conventional is 43,440 and 671,264 for Boston green (Figure 9). If we look at the GWP per functional unit (1 cubic meter), the result for Boston conventional is 12 and 145 for Boston green.

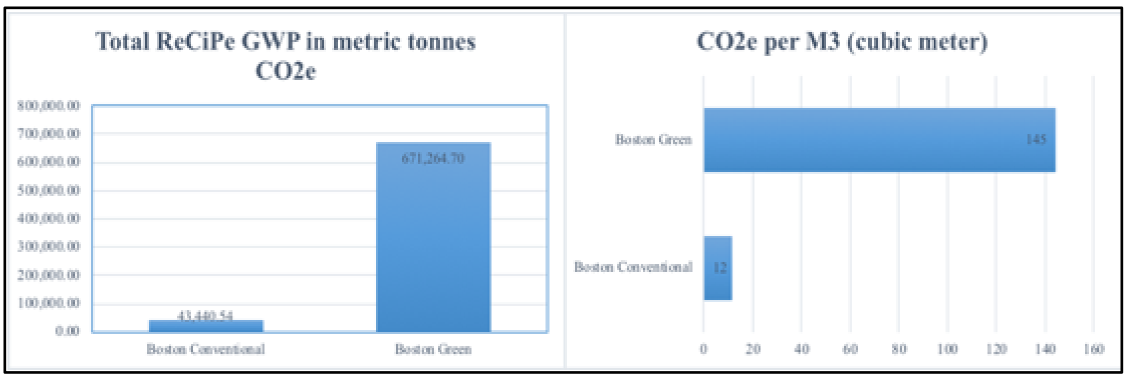

Figure 9. GaBi LCIA results for Boston conventional and Boston green.

Boston green is more than ten times the overall GWP and per cubic meter CO_2e. What is driving such a high impact for Boston green? First, it is important to note the difference between mass and GWP impact. Boston green has greater mass in terms of materials used and deposited at end of life, but the breadth of global warming potential still belongs to Boston conventional, as will be described in the next section.

Interpretation of the Study

For each building model, the ReCipe analysis provided the GWP number for all the inputs combined, all the outputs combined, and the total GWP number for each building. Therefore, all the results reported in this section and Ancillary Appendix are based on the final ReCiPe numbers. GaBi generated graphs showing the GWP for each of the 16 ReCiPe midpoint impact categories for Boston conventional and Boston green (Figure 10). Both had a score of 0 for natural land transformation, freshwater eutrophication and terrestrial ecotoxicity. In these midpoint impact categories, Boston conventional had greater GWP numbers:

- Climate change
- Terrestrial acidification
- Freshwater ecotoxicity
- Human toxicity
- Ionizing radiation
- Marine ecotoxicity
- Marine eutrophication
- Particulate matter formation
- Photochemical oxidant formation
- Metal depletion
- Water depletion

In these midpoint categories, Boston green had greater GWP numbers in only these two categories: Fossil depletion and Ozone depletion.

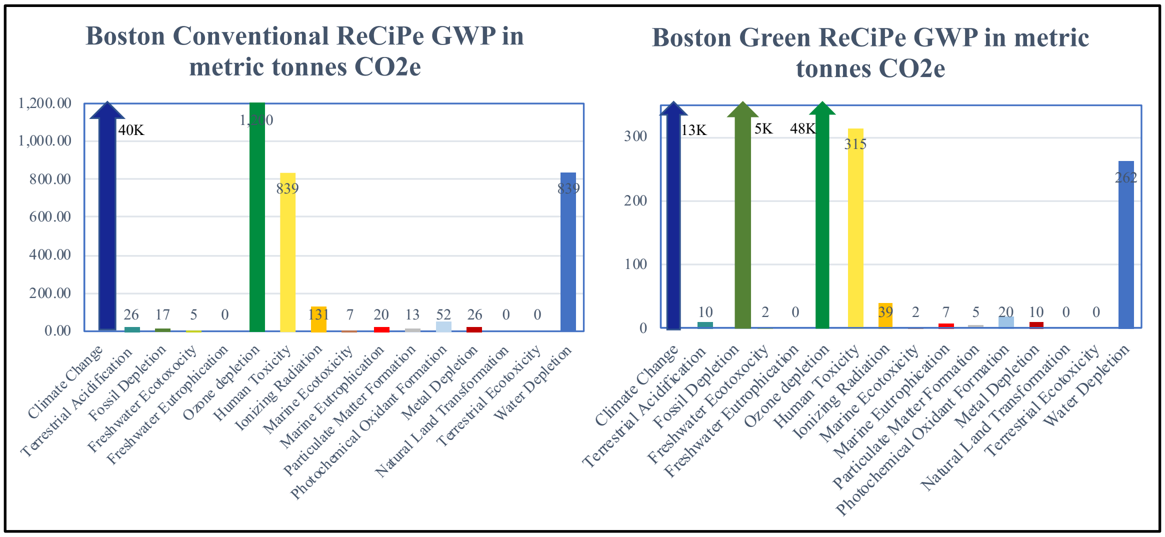

Figure 10. Total global warming potentials (GWP) based on ReCiPe midpoint impact categories for Boston conventional and Boston green.

Fossil and ozone depletion appear to be the result of the materials used and deposited at end of life in the model for Boston green. This could be because of some of the building materials selected to use in the Boston green model; materials with mineral content have moderately high ozone deposition, but generate fewer byproducts, and so are preferred for green building (Cheng, Lin, & Hsu, 2015). The mass in metric tonnes is likely greater for Boston green because of some of the particular building materials used (steel beams, joists, and sheets, concrete, rebar, glass facer, etc.), but Boston conventional has greater GWP in so many categories, because the materials used in the model were not recycled at end of life, and some of the older materials used (concrete, mortar, asphalt shingles, regular gypsum board, fiberglass batt, linoleum, etc.) have a longer half-life (Sharrard, Matthews, & Roth, 2007).

The two areas that yielded the greatest GWP potential for both models were the emissions related to end of life and materials used. One anomaly of GaBi is that items that should be labeled construction materials were instead labeled as valuable materials, so concrete and brick fell under that category instead of construction materials. In order to assess the actual contribution of construction materials, that category had to be combined with valuable materials, as shown in Figure 11, which depicts the significant contribution of materials during the ‘Materials for Building Assembly’ (construction) and ‘End of Life’ (demolition and disposal) phases for Boston conventional and Boston green.

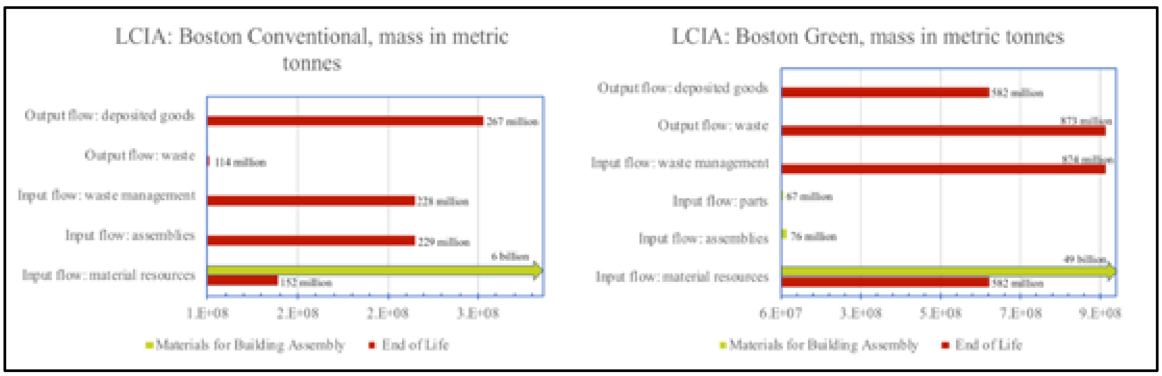

Figure 11. GaBi end of life GHG outputs and GWP of materials used.

Although Figure 11 depicts the greatest input and output flows that Boston conventional and Boston green have in common, it is worth noting these key points:

- Both buildings had the greatest mass from *input flow: material resources* used at the Building Assembly phase. This refers to the building materials and their entire life cycle up to that point.
- The waste attributed to Boston conventional was greatest in the *output flow: deposited goods* phase, and the waste attributed to Boston green was greatest in the *input flow: waste management* phase. This means that Boston conventional

generated more GHG emissions from deposited goods waste at the demolition and disposal phase, whereas Boston green generated more GHG emissions during the creation of its construction materials. This is likely because the Boston green model allocated much of its deposited goods (at end of life) to recycling.

- The *input flow: assemblies* is attributed to the End of Life phase for Boston conventional and the Building Assembly phase for Boston green. This essentially means that more GHG emissions were emitted during the building assembly phase for Boston green, whereas more GHG emissions were emitted from building assemblies at end of life for Boston conventional. Again, this difference may be explained by the Boston green model allowing for construction assemblies to be recycled at end of life (Figures 14 & 15).
- Across all domains, Boston green had greater mass than Boston conventional, except in *input flow: assemblies*, where Boston green's number was much lower. This seems to indicate that Boston conventional emitted more GHG emissions at end of life for its building assemblies than Boston green emitted for its assemblies during the construction phase (Figures 14 & 15).

Chapter IV

Discussion

In this study, we found that green buildings can have higher Scope 3 emissions and embodied energy than conventional buildings. Green buildings are designed to reduce GHG emissions through more efficient energy use, and generally, findings pertaining to Scope 1 and Scope 2 emissions reductions in buildings confirm this (Vizian, 2016). This study confirms that Boston green had lower per person Scope 2 emissions than Boston conventional. So while Boston green lived up to expectations in the Scope 2 emissions category, the Scope 3 and embodied energy emissions were unexpected.

Green building schemes put a focus on activities that can potentially reduce Scope 1 and Scope 2 emissions, such as: green power and carbon offsets; optimizing energy performance; renewable energy production, and enhanced refrigerant management. While LEED awards credits related to embodied energy (building life cycle impact reduction; construction and demolition waste management) and sustainable travel (access to quality transit; bicycle facilities; green vehicles), these constitute a relatively small percentage of the total possible credits or are ineffective at significantly impacting Scope 3 emissions or embodied energy (USGBC, 2018).

The great disparity between Boston conventional and Boston green's GWP cannot only be the result of Boston green's additional 10,000 square feet: normalizing the GWP by square feet, Boston conventional has a GWP per square foot of 1.45 CO_2e, whereas Boston green has a GWP per square foot of 16.78 CO_2e. As already demonstrated in the results section, the building materials used in the model—its embodied energy, played a central role in determining its GWP potential.

While we all expect green buildings to save energy operationally, the real finding here is that the people occupying those buildings can consume more per person than in a conventional building. The business travel miles (34%) and the commuting miles (33%) generated by the occupants of Boston green contributed to a greater percentage of GHG emissions than Scope 2 gas and electric (22%) (Figure 5).

Research Limitations

The main limitation of this research was that there was no way to validate whether the data input by the survey respondents was accurate. That would have required access to the records of the building managers and office managers, which was not feasible, nor was it part of the G-BASE study. There has to be an 'assumption' that the survey responses are accurate.

Although the variables chosen for the GHG inventory were correct, missing data confined the scope of the final analysis. Of the ten building managers, only two (Boston) provided complete information, two provided none (Washington DC), and two (San Jose) left out Scope 1 data. There were queries made to the building managers to obtain missing information (as part of the G-BASE study), but once the G-BASE study was completed, there were no more opportunities to ask for missing information. Because of this, only eight of the ten buildings were analyzed in terms of Scope 3 emissions data, and only six included Scope 1 data, and only two (Boston) were included in the final analysis. If any of the other four cities had provided Scope 2 purchased HVAC data, it would have helped validate some of the conclusions drawn about Boston conventional and Boston green. Conversely, had the Boston buildings provided waste generated/recycling data, the analysis may have yielded a different result. This resulted in a smaller sample, but the analysis done was based on the most robust information provided, and there was still the opportunity to compare conventional vs green buildings.

Another major limitation pertains to the fact that most available LCA building databases exist for Europe but not for the United States. The major LCA modeling tools such as Ecoinvent, Simapro, and GaBi (which was used for this analysis) contain some U.S. LCI data, but the most comprehensive data for the construction industry has been compiled outside the U.S. According to the Athena Sustainable Materials Institute, a non-profit that is dedicated to increasing the body of LCA construction data in the U.S., this work is still in its early stages and much more still needs to be added to the databases to allow for a complete LCIA (Athena Sustainable Materials Institute, 2018). There were some specifications input into the Athena tool with absolute certainty: the year built (or renovated), the total square footage, the occupied square footage, the height, the type of cladding used, the type of roofing. However, in some instances, surrogate data had to be used (e.g., gypsum board from the U.K. instead of sheetrock manufactured in the U.S.). It is possible that the materials list generated by the Athena LCA tool and input into the GaBi modeling tool were not perfect surrogates for the real thing. This did not ultimately change the course of the analysis, but the level of precision would have been greater had all the database inputs been from the U.S.

In summary, missing survey results and missing data pertaining to the construction of both buildings were the greatest limitations to the study.

Recommendations for Further Research

As a follow-up to this research, it is recommended that this same methodology be used, with a focus on getting complete data for the two buildings being compared. This would involve not only ensuring that all survey questions were answered thoroughly, but also obtaining actual 'bills of materials' for the construction of each building. This actual data would ensure that the LCA inputs were as accurate as possible. Purchasing a U.S. construction industry database would ensure that the inputs of the LCA model were as close to real-life as possible. The US dataset (USLCI) that comes with GaBi and Simapro has very little actual construction data in it, so that data had to be pulled from Ecoinvent, which is primarily European. At present, the cost for purchasing any LCA databases is prohibitive, and the educational licenses provided by the LCA modeling companies are restricted. But this investment is necessary to ensure that the LCA model is as accurate as possible, and that it will yield an LCIA that will reflect the actual global warming potential of a conventional vs. green building.

Conclusions

This research only partially supported my original hypothesis. Based on the office buildings analyzed, the characteristics with the greatest environmental impact were found in its operational practices (e.g., Scope 3 emissions) rather than its embodied energy (e.g., building characteristics). However, the 'green' buildings did not yield lower annual GHG emissions than conventional buildings, as the embodied energy and annual emissions were not, in fact, lower.

The most important finding is that this research supports the view that owners and occupants of commercial buildings can help reduce GHG emissions during the operations phase of an office building. Cutting back on commuting mileage and business mileage, as well as ensuring that recycling programs are in place, will have a significant impact on Scope 3 emissions. Green building standards should account for embodied energy in buildings by requiring earned credits for low GWP materials (not just energy efficient ones), or at the very least, an LCA analysis should be performed to compare the use of materials for building, renovations, or upgrades to the operational benefits of those same materials. For example, if a type of insulation provides excellent energy efficiency but has a high GWP potential, another material should be considered. LEED currently offers five credits for reducing life cycle impact for buildings and offers two credits for optimizing material ingredients for buildings, but these are not mandatory and are interchangeable with other categories (USGBC, 2018). Unless this level of diligence is required, there is little incentive for doing it. Green building standards should also provide credit to companies seeking certification for reducing business travel. LEED currently provides credit for access to mass transit public and use of green vehicles and bicycles, but it doesn't provide credits for encouraging employees to telecommute to work or cut back on business travel by employing video conferencing equipment (USGBC, 2018). Finally, developing sustainable end of life strategies for construction waste from either renovations or demolition is an essential way to lower the GWP of a building, and therefore should be required in green building standards.

Appendix 1

Survey Data Not Included in Body of Thesis

Table 7. Summary of survey questions for building managers and office building occupants.

BUILDING MANAGER SURVEYS					
CATEGORY	**QUESTIONS**				
Building characteristics	What year was the building constructed?	In what year was the latest building addition?	What is the gross floor area of the building? (square feet)	How many floors above grade?	How many floors below grade?
Occupancy data	What is the amount of occupied space (not mechanical or storage) of the building? (square feet)	Number of occupants?	Days per week building is occupied?	Hours per day that the building is occupied? (weekdays)	Hours per day that the building is occupied? (weekends)
Energy usage data	Does building management pay for gas/ electricity/ water?	Are utilities billed to tenants based on square footage, or based on actual usage?	How much gas was used in 2016 (in Therms*)?	How much electricity was used in 2016 (in kWh)?	How much water was used in 2016 (cubic feet)?
Fugitive emissions data	How many refrigerators are in this building?	When was each refrigerator installed? (eg, before 1993;	What is the number of window a/c units used in this building?	What is the number of portable heating units used in this building?	When was each window a/c or portable heating unit installed? (eg,

		before 2004; before 2010; after 2010)			before 1993; before 2004; before 2010; after 2010)
Waste data	How many garbage dumpsters does this building use?	What size are the dumpsters?	How often are the dumpsters emptied?	Do you have a recycling program?	What does the recycling program include? (e.g., paper, cardboard, plastic, glass, aluminum)
BUILDING OCCUPANT SURVEYS					
CATEGORY	**QUESTIONS**				
Basic identifier data	What is the name of the building where you work?	What floor is your office on/what is the room number of your office?	How many years have you worked in this building? If less than 1 year, how many months?	On average, how many hours a week do you work in this building, and which days do you work?	Which best describes the space in which your current workstation is located (eg, desk, cubicle, office), etc.)?
Energy usage data	Do you work with a computer or word processor?	How old is your computer or word processor?	How many of the following are in your office? (photocopier, laser printer, facsimile machine)	How often do you use them at work? (times per day, times per week)	When were they installed? (eg, before 1993; before 2004; before 2010; after 2010)
Business travel data	Do you travel for business?	Approximately how many miles do you travel by	Approximately how many miles do you travel	Approximately how many miles do you	Approximately how many miles do you travel by

		automobile for business per month?	by train for business per month?	travel by airplane for business per month?	company car for business per month?
Commuting travel data	How many miles was your commute each way today? (asked every day of study period)	Did you commute to work by car today? (asked every day of study period)	Did you commute to work by bus today? (asked every day of study period)	Did you commute to work by train today? (asked every day of study period)	Did you commute to work by bicycle today? (asked every day of study period)
Data from office admins/ managers	How much money is spent annually (or monthly) on office supplies? [Note: office supplies include stationery supplies, copier and printer paper and toner]	How much money is spent annually (or monthly) on kitchen supplies? [Note: kitchen supplies include plastic utensils, paper towels, napkins, disposable dishware and cups, coffee, tea, and dairy]	How much money is spent annually (or monthly) on postal and courier services? [Note: this includes US mail, UPS, Fedex, and other courier services]		

*not in cubic meters, and no oil tanks

Appendix 2

Greenhouse Gas Inventory Data

Table 8. Emission sources by Scope. (Adapted from: Table 1 and page 41 Putt del Pino & Bhatia, 2002); Table 5.3 WRI/WBCSD, 2011).

Baseline Information	**Scope**	**Type of Combustion**	**Category**	**Sub-Category**	**Information Needed**	**Status, based on survey responses**
Total number of subjects in study					Number of employees/building inhabitants	All but DC √
Total space being studied, in square feet					Total square footage of occupied building space	All but DC √
	Scope 1	Stationary combustion			Assume we don't need to consider this category because they do not produce anything	
	Scope 1	Stationary combustion	Purchase of production -related products		Assume we don't consider this because all purchased products are 'non-production related' products	
	Scope 1	Mobile combustion			Assume we don't need to consider this category because they do not own or lease business vehicles	

	Scope 1	Fugitive emissions	Fugitive emissions from refrigerators, portable A/C or heating units		Can extrapolate if we know number of refrigerators and any portable A/C or heating units as well as dates they were put in service	Only have for Denver, LA, and Boston
	Scope 2	Purchased electricity and heat			Need HVAC and heating bills, or, annual kilowatt hours and thermal units used per office	Only have complete data from 2 Boston buildings
	Scope 3	Stationary combustion	Upstream purchased goods and services	Office supplies	Need annual spend on stationery goods	No survey respondents provided this
	Scope 3	Stationary combustion	Upstream purchased goods and services	Kitchen supplies	Need annual spend on coffee, tea, milk, paper plastic goods	No survey respondents provided this
	Scope 3	Stationary combustion	Upstream purchased goods and services	Electronic computers, phones, and peripheral equipment	Surveys yielded numbers and ages of equipment	No emissions factors available for calculating GHG
	Scope 3	Stationary combustion	Upstream purchased goods and services	Copies/printers	Surveys yielded numbers and ages of equipment	No emissions factors available for calculating GHG

	Scope 3	Stationary combustion	Upstream transport/distribution	Postal and courier (UPS/Fedex) services	Need annual spend	No survey respondents provided this
	Scope 3	Stationary combustion	Waste generated in operations	Garbage	Need to know approximate waste generated per week	Only have for Denver and LA
	Scope 3	Stationary combustion	Waste generated in operations	Recycling data	Need information about recycling practices, types of waste recycled, and amount	Only have for Denver and LA
	Scope 3	Mobile Combustion	Business Travel		Need: Miles traveled by employees for business (train, auto, air) or list of destinations and mode of transport	√
	Scope 3	Mobile Combustion	Employee Commuting		Miles traveled by employees for commuting (auto, train, bus) or a list of approximate addresses and modes of transport	√

Table 9. Scope 3, mobile combustion, business miles data.

Location	Business miles per month by airplane	Business miles per month by train	Business miles per month by car	Business miles per month by company car
Boston conv (n=12)	0	1251	1810	0
Boston green (n=12)	4600	210	2900	0
DC conv (n=7)	0	155	2688	4
DC green (n=9)	0	1684	1499	0
Denver conv (n=8)	3900	0	6170	0
Denver green (n=12)	0	60	8920	440
San Jose conv (n=9)	1800	0	6780	0
San Jose green (n=12)	0	1000	4825	0
Los Angeles green #1 (n=10)	4000	0	3488	0
Los Angeles green #2 (n=11)	0	0	4702	1000

Table 10. Scope 3, mobile combustion, commuting miles data.

Location	Train miles per week	Car miles per week	Bus miles per week
Boston conv (n=12)	480	360	75
Boston green (n=12)	170	980	135
DC conv (n=10)	750	550	500
DC green (n=11)	325	310	685
Denver conv (n=8)	0	1430	0
Denver green (n=12)	0	1375	0
San Jose conv (n=9)	0	1370	0
San Jose green (n=12)	0	1290	0
Los Angeles green #1 (n=10)	0	1235	180
Los Angeles green #2 (n=11)	0	1350	15

Table 11. GHG emissions summary of Boston, Denver, Los Angeles and San Jose buildings from the EPA Simplified GHG Emissions Calculator (SGEC).

Emissions Summary

Guidance

The total GHG emissions from each source category are provided below. You may also use this summary sheet to fill out the *Annual GHG Inventory Summary and Goal Tracking Form* as this calculator only quantifies one year of emissions at a time.

https://www.epa.gov/climateleadership/center-corporate-climate-leadership-annual-ghg-inventory-summary-and-goal-tracking

By entering the data below into the appropriate cell of the *Annual GHG Inventory Summary and Goal Tracking Form,* you will be able to compare multiple years of data.

If you have multiple Calculator files covering sub-sets of your inventory for a particular reporting period, sum each of the emission categories (e.g. Stationary Combustion) to an organizational total, which then can be entered into the *Annual GHG Inventory Summary and Goal Tracking Form*.

(A) Enter organization information into the orange cells. Other cells on this sheet will be automatically calculated from the data entered in the sheets in this workbook. Blue cells indicate required emission sources if applicable. Green cells indicate scope 3 emission sources and offsets, which organizations may optionally include in their inventory.

(B) The "Go To Sheet" buttons can be used to navigate to the data entry sheets.

Organizational Information:

Organization Name:	Conventional
Organization Address:	Boston
Inventory Reporting Period:	*calendar Year 2016* — Start: *1/1/16* End: *12/31/16*
Name of Preparer:	Claudia Piano
Phone Number of Preparer:	
Date Prepared:	Mar-18

Summary of Organization's Emissions:

Scope 1 Emissions		
Stationary Combustion	0	CO_2-e (metric tons)
Mobile Sources	0	CO_2-e (metric tons)
Refrigeration / AC Equipment Use	0	CO_2-e (metric tons)
Fire Suppression	0	CO_2-e (metric tons)
Purchased Gases	0	CO_2-e (metric tons)
Location-Based Scope 2 Emissions		
Purchased and Consumed Electricity	32	CO_2-e (metric tons)
Purchased and Consumed Steam	57	CO_2-e (metric tons)
Market-Based Scope 2 Emissions		
Purchased and Consumed Electricity	48	CO_2-e (metric tons)
Purchased and Consumed Steam	46	CO_2-e (metric tons)
Total organization Emissions		
Total Scope 1 & Location-Based Scope 2	90	CO_2-e (metric tons)
Total Scope 1 & Market-Based Scope 2	94	CO_2-e (metric tons)
Reductions		
Offsets	0	CO_2-e (metric tons)
Net Scope 1 and 2 Location-Based Emissions	90	CO_2-e (metric tons)
Net Scope 1 and 2 Market-Based Emissions	94	CO_2-e (metric tons)
Scope 3 Emissions		
Employee Business Travel	10	CO_2-e (metric tons)
Employee Commuting	10	CO_2-e (metric tons)
Product Transport	0	CO_2-e (metric tons)

Emissions Summary

Guidance

The total GHG emissions from each source category are provided below. You may also use this summary sheet to fill out the *Annual GHG Inventory Summary and Goal Tracking Form* as this calculator only quantifies one year of emissions at a time.

https://www.epa.gov/climateleadership/center-corporate-climate-leadership-annual-ghg-inventory-summary-and-goal-tracking

By entering the data below into the appropriate cell of the *Annual GHG Inventory Summary and Goal Tracking Form,* you will be able to compare multiple years of data.

If you have multiple Calculator files covering sub-sets of your inventory for a particular reporting period, sum each of the emission categories (e.g. Stationary Combustion) to an organizational total, which then can be entered into the *Annual GHG Inventory Summary and Goal Tracking Form*.

(A) Enter organization information into the orange cells. Other cells on this sheet will be automatically calculated from the data entered in the sheets in this workbook. Blue cells indicate required emission sources if applicable. Green cells indicate scope 3 emission sources and offsets, which organizations may optionally include in their inventory.

(B) The "Go To Sheet" buttons can be used to navigate to the data entry sheets.

Organizational Information:

Organization Name:	Green
Organization Address:	Boston
Inventory Reporting Period:	*calendar Year 2016*
	Start: *1/1/16* End: *12/31/16*
Name of Preparer:	Claudia Piano
Phone Number of Preparer:	
Date Prepared:	Mar-18

Summary of Organization's Emissions:

Scope 1 Emissions		
Stationary Combustion	0	CO_2-e (metric tons)
Mobile Sources	0	CO_2-e (metric tons)
Refrigeration / AC Equipment Use	0	CO_2-e (metric tons)
Fire Suppression	0	CO_2-e (metric tons)
Purchased Gases	0	CO_2-e (metric tons)
Location-Based Scope 2 Emissions		
Purchased and Consumed Electricity	95	CO_2-e (metric tons)
Purchased and Consumed Steam	117	CO_2-e (metric tons)
Market-Based Scope 2 Emissions		
Purchased and Consumed Electricity	139	CO_2-e (metric tons)
Purchased and Consumed Steam	93	CO_2-e (metric tons)
Total organization Emissions		
Total Scope 1 & Location-Based Scope 2	212	CO_2-e (metric tons)
Total Scope 1 & Market-Based Scope 2	233	CO_2-e (metric tons)
Reductions		
Offsets	0	CO_2-e (metric tons)
Net Scope 1 and 2 Location-Based Emissions	212	CO_2-e (metric tons)
Net Scope 1 and 2 Market-Based Emissions	233	CO_2-e (metric tons)
Scope 3 Emissions		
Employee Business Travel	20	CO_2-e (metric tons)
Employee Commuting	19	CO_2-e (metric tons)
Product Transport	0	CO_2-e (metric tons)

Emissions Summary

Guidance

The total GHG emissions from each source category are provided below. You may also use this summary sheet to fill out the *Annual GHG Inventory Summary and Goal Tracking Form* as this calculator only quantifies one year of emissions at a time.

https://www.epa.gov/climateleadership/center-corporate-climate-leadership-annual-ghg-inventory-summary-and-goal-tracking

By entering the data below into the appropriate cell of the *Annual GHG Inventory Summary and Goal Tracking Form,* you will be able to compare multiple years of data.

If you have multiple Calculator files covering sub-sets of your inventory for a particular reporting period, sum each of the emission categories (e.g. Stationary Combustion) to an organizational total, which then can be entered into the *Annual GHG Inventory Summary and Goal Tracking Form*.

(A) Enter organization information into the orange cells. Other cells on this sheet will be automatically calculated from the data entered in the sheets in this workbook. Blue cells indicate required emission sources if applicable. Green cells indicate scope 3 emission sources and offsets, which organizations may optionally include in their inventory.

(B) The "Go To Sheet" buttons can be used to navigate to the data entry sheets.

Organizational Information:

Organization Name:	Conventional		
Organization Address:	Denver		
Inventory Reporting Period:	*calendar Year 2016*		
	Start: *1/1/16*	End:	*12/31/16*
Name of Preparer:	Claudia Piano		
Phone Number of Preparer:			
Date Prepared:	Mar-18		

Summary of Organization's Emissions:

Scope 1 Emissions		
Stationary Combustion	0	CO_2-e (metric tons)
Mobile Sources	0	CO_2-e (metric tons)
Refrigeration / AC Equipment Use	0	CO_2-e (metric tons)
Fire Suppression	0	CO_2-e (metric tons)
Purchased Gases	0	CO_2-e (metric tons)
Location-Based Scope 2 Emissions		
Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)
Market-Based Scope 2 Emissions		
Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)
Total organization Emissions		
Total Scope 1 & Location-Based Scope 2	0	CO_2-e (metric tons)
Total Scope 1 & Market-Based Scope 2	0	CO_2-e (metric tons)
Reductions		
Offsets	0	CO_2-e (metric tons)
Net Scope 1 and 2 Location-Based Emissions	0	CO_2-e (metric tons)
Net Scope 1 and 2 Market-Based Emissions	0	CO_2-e (metric tons)
Scope 3 Emissions		
Employee Business Travel	32	CO_2-e (metric tons)
Employee Commuting	25	CO_2-e (metric tons)
Product Transport	0	CO_2-e (metric tons)

Emissions Summary

Guidance

The total GHG emissions from each source category are provided below. You may also use this summary sheet to fill out the *Annual GHG Inventory Summary and Goal Tracking Form* as this calculator only quantifies one year of emissions at a time.

https://www.epa.gov/climateleadership/center-corporate-climate-leadership-annual-ghg-inventory-summary-and-goal-tracking

By entering the data below into the appropriate cell of the *Annual GHG Inventory Summary and Goal Tracking Form,* you will be able to compare multiple years of data.

If you have multiple Calculator files covering sub-sets of your inventory for a particular reporting period, sum each of the emission categories (e.g. Stationary Combustion) to an organizational total, which then can be entered into the *Annual GHG Inventory Summary and Goal Tracking Form*.

(A) Enter organization information into the orange cells. Other cells on this sheet will be automatically calculated from the data entered in the sheets in this workbook. Blue cells indicate required emission sources if applicable. Green cells indicate scope 3 emission sources and offsets, which organizations may optionally include in their inventory.

(B) The "Go To Sheet" buttons can be used to navigate to the data entry sheets.

Organizational Information:

Organization Name:	GREEN
Organization Address:	DENVER
Inventory Reporting Period:	*calendar Year 2016*
Start:	*1/1/16*
End:	*12/31/16*
Name of Preparer:	Claudia Piano
Phone Number of Preparer:	
Date Prepared:	Mar-18

Summary of Organization's Emissions:

Scope 1 Emissions

Stationary Combustion	0	CO_2-e (metric tons)
Mobile Sources	0	CO_2-e (metric tons)
Refrigeration / AC Equipment Use	0	CO_2-e (metric tons)
Fire Suppression	0	CO_2-e (metric tons)
Purchased Gases	0	CO_2-e (metric tons)

Location-Based Scope 2 Emissions

Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)

Market-Based Scope 2 Emissions

Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)

Total organization Emissions

Total Scope 1 & Location-Based Scope 2	0	CO_2-e (metric tons)
Total Scope 1 & Market-Based Scope 2	0	CO_2-e (metric tons)

Reductions

Offsets	0	CO_2-e (metric tons)

Net Scope 1 and 2 Location-Based Emissions	0	CO_2-e (metric tons)
Net Scope 1 and 2 Market-Based Emissions	0	CO_2-e (metric tons)

Scope 3 Emissions

Employee Business Travel	39	CO_2-e (metric tons)
Employee Commuting	24	CO_2-e (metric tons)
Product Transport	0	CO_2-e (metric tons)

Emissions Summary

Guidance

The total GHG emissions from each source category are provided below. You may also use this summary sheet to fill out the *Annual GHG Inventory Summary and Goal Tracking Form* as this calculator only quantifies one year of emissions at a time.

https://www.epa.gov/climateleadership/center-corporate-climate-leadership-annual-ghg-inventory-summary-and-goal-tracking

By entering the data below into the appropriate cell of the *Annual GHG Inventory Summary and Goal Tracking Form,* you will be able to compare multiple years of data.

If you have multiple Calculator files covering sub-sets of your inventory for a particular reporting period, sum each of the emission categories (e.g. Stationary Combustion) to an organizational total, which then can be entered into the *Annual GHG Inventory Summary and Goal Tracking Form*.

(A) Enter organization information into the orange cells. Other cells on this sheet will be automatically calculated from the data entered in the sheets in this workbook. Blue cells indicate required emission sources if applicable. Green cells indicate scope 3 emission sources and offsets, which organizations may optionally include in their inventory.

(B) The "Go To Sheet" buttons can be used to navigate to the data entry sheets.

Organizational Information:

Organization Name:	Conventional			
Organization Address:	Los Angeles			
Inventory Reporting Period:	*calendar Year 2016*			
	Start:	*1/1/16*	End:	*12/31/16*
Name of Preparer:	Claudia Piano			
Phone Number of Preparer:				
Date Prepared:	Mar-18			

Summary of Organization's Emissions:

Scope 1 Emissions		
Stationary Combustion	0	CO_2-e (metric tons)
Mobile Sources	0	CO_2-e (metric tons)
Refrigeration / AC Equipment Use	0	CO_2-e (metric tons)
Fire Suppression	0	CO_2-e (metric tons)
Purchased Gases	0	CO_2-e (metric tons)
Location-Based Scope 2 Emissions		
Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)
Market-Based Scope 2 Emissions		
Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)
Total organization Emissions		
Total Scope 1 & Location-Based Scope 2	0	CO_2-e (metric tons)
Total Scope 1 & Market-Based Scope 2	0	CO_2-e (metric tons)
Reductions		
Offsets	0	CO_2-e (metric tons)
Net Scope 1 and 2 Location-Based Emissions	0	CO_2-e (metric tons)
Net Scope 1 and 2 Market-Based Emissions	0	CO_2-e (metric tons)
Scope 3 Emissions		
Employee Business Travel	21	CO_2-e (metric tons)
Employee Commuting	22	CO_2-e (metric tons)
Product Transport	0	CO_2-e (metric tons)

Emissions Summary

Guidance

The total GHG emissions from each source category are provided below. You may also use this summary sheet to fill out the *Annual GHG Inventory Summary and Goal Tracking Form* as this calculator only quantifies one year of emissions at a time.

https://www.epa.gov/climateleadership/center-corporate-climate-leadership-annual-ghg-inventory-summary-and-goal-tracking

By entering the data below into the appropriate cell of the *Annual GHG Inventory Summary and Goal Tracking Form,* you will be able to compare multiple years of data.

If you have multiple Calculator files covering sub-sets of your inventory for a particular reporting period, sum each of the emission categories (e.g. Stationary Combustion) to an organizational total, which then can be entered into the *Annual GHG Inventory Summary and Goal Tracking Form*.

(A) Enter organization information into the orange cells. Other cells on this sheet will be automatically calculated from the data entered in the sheets in this workbook. Blue cells indicate required emission sources if applicable. Green cells indicate scope 3 emission sources and offsets, which organizations may optionally include in their inventory.

(B) The "Go To Sheet" buttons can be used to navigate to the data entry sheets.

Organizational Information:

Organization Name:	Green		
Organization Address:	Los Angeles		
Inventory Reporting Period:	*calendar Year 2016*		
Start:	*1/1/16*	End:	*12/31/16*
Name of Preparer:	Claudia Piano		
Phone Number of Preparer:			
Date Prepared:	Mar-18		

Summary of Organization's Emissions:

Scope 1 Emissions		
Stationary Combustion	0	CO_2-e (metric tons)
Mobile Sources	0	CO_2-e (metric tons)
Refrigeration / AC Equipment Use	0	CO_2-e (metric tons)
Fire Suppression	0	CO_2-e (metric tons)
Purchased Gases	0	CO_2-e (metric tons)
Location-Based Scope 2 Emissions		
Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)
Market-Based Scope 2 Emissions		
Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)
Total organization Emissions		
Total Scope 1 & Location-Based Scope 2	0	CO_2-e (metric tons)
Total Scope 1 & Market-Based Scope 2	0	CO_2-e (metric tons)
Reductions		
Offsets	0	CO_2-e (metric tons)
Net Scope 1 and 2 Location-Based Emissions	0	CO_2-e (metric tons)
Net Scope 1 and 2 Market-Based Emissions	0	CO_2-e (metric tons)
Scope 3 Emissions		
Employee Business Travel	24	CO_2-e (metric tons)
Employee Commuting	23	CO_2-e (metric tons)
Product Transport	0	CO_2-e (metric tons)

Emissions Summary

Guidance

The total GHG emissions from each source category are provided below. You may also use this summary sheet to fill out the *Annual GHG Inventory Summary and Goal Tracking Form* as this calculator only quantifies one year of emissions at a time.

https://www.epa.gov/climateleadership/center-corporate-climate-leadership-annual-ghg-inventory-summary-and-goal-tracking

By entering the data below into the appropriate cell of the *Annual GHG Inventory Summary and Goal Tracking Form,* you will be able to compare multiple years of data.

If you have multiple Calculator files covering sub-sets of your inventory for a particular reporting period, sum each of the emission categories (e.g. Stationary Combustion) to an organizational total, which then can be entered into the *Annual GHG Inventory Summary and Goal Tracking Form*.

(A) Enter organization information into the orange cells. Other cells on this sheet will be automatically calculated from the data entered in the sheets in this workbook. Blue cells indicate required emission sources if applicable. Green cells indicate scope 3 emission sources and offsets, which organizations may optionally include in their inventory.

(B) The "Go To Sheet" buttons can be used to navigate to the data entry sheets.

Organizational Information:

Organization Name:	Conventional		
Organization Address:	San Jose		
Inventory Reporting Period:	*calendar Year 2016*		
	Start: *1/1/16*	End:	*12/31/16*
Name of Preparer:	Claudia Piano		
Phone Number of Preparer:			
Date Prepared:	Mar-18		

Summary of Organization's Emissions:

Scope 1 Emissions

Stationary Combustion	0	CO_2-e (metric tons)
Mobile Sources	0	CO_2-e (metric tons)
Refrigeration / AC Equipment Use	0	CO_2-e (metric tons)
Fire Suppression	0	CO_2-e (metric tons)
Purchased Gases	0	CO_2-e (metric tons)

Location-Based Scope 2 Emissions

Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)

Market-Based Scope 2 Emissions

Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)

Total organization Emissions

Total Scope 1 & Location-Based Scope 2	0	CO_2-e (metric tons)
Total Scope 1 & Market-Based Scope 2	0	CO_2-e (metric tons)

Reductions

Offsets	0	CO_2-e (metric tons)

Net Scope 1 and 2 Location-Based Emissions	0	CO_2-e (metric tons)
Net Scope 1 and 2 Market-Based Emissions	0	CO_2-e (metric tons)

Scope 3 Emissions

Employee Business Travel	31	CO_2-e (metric tons)
Employee Commuting	24	CO_2-e (metric tons)
Product Transport	0	CO_2-e (metric tons)

Emissions Summary

Guidance

The total GHG emissions from each source category are provided below. You may also use this summary sheet to fill out the *Annual GHG Inventory Summary and Goal Tracking Form* as this calculator only quantifies one year of emissions at a time.

https://www.epa.gov/climateleadership/center-corporate-climate-leadership-annual-ghg-inventory-summary-and-goal-tracking

By entering the data below into the appropriate cell of the *Annual GHG Inventory Summary and Goal Tracking Form,* you will be able to compare multiple years of data.

If you have multiple Calculator files covering sub-sets of your inventory for a particular reporting period, sum each of the emission categories (e.g. Stationary Combustion) to an organizational total, which then can be entered into the *Annual GHG Inventory Summary and Goal Tracking Form*.

(A) Enter organization information into the orange cells. Other cells on this sheet will be automatically calculated from the data entered in the sheets in this workbook. Blue cells indicate required emission sources if applicable. Green cells indicate scope 3 emission sources and offsets, which organizations may optionally include in their inventory.

(B) The "Go To Sheet" buttons can be used to navigate to the data entry sheets.

Organizational Information:

Organization Name:	Green
Organization Address:	San Jose
Inventory Reporting Period:	*calendar Year 2016*
	Start: *1/1/16* End: *12/31/16*
Name of Preparer:	Claudia Piano
Phone Number of Preparer:	
Date Prepared:	Mar-18

Summary of Organization's Emissions:

Scope 1 Emissions

Stationary Combustion	0	CO_2-e (metric tons)
Mobile Sources	0	CO_2-e (metric tons)
Refrigeration / AC Equipment Use	0	CO_2-e (metric tons)
Fire Suppression	0	CO_2-e (metric tons)
Purchased Gases	0	CO_2-e (metric tons)

Location-Based Scope 2 Emissions

Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)

Market-Based Scope 2 Emissions

Purchased and Consumed Electricity	0	CO_2-e (metric tons)
Purchased and Consumed Steam	0	CO_2-e (metric tons)

Total organization Emissions

Total Scope 1 & Location-Based Scope 2	0	CO_2-e (metric tons)
Total Scope 1 & Market-Based Scope 2	0	CO_2-e (metric tons)

Reductions

Offsets	0	CO_2-e (metric tons)

Net Scope 1 and 2 Location-Based Emissions	0	CO_2-e (metric tons)
Net Scope 1 and 2 Market-Based Emissions	0	CO_2-e (metric tons)

Scope 3 Emissions

Employee Business Travel	22	CO_2-e (metric tons)
Employee Commuting	22	CO_2-e (metric tons)
Product Transport	0	CO_2-e (metric tons)

Table 12. Emissions analysis of waste, including recycling from WARM tool.

GHG Emissions Analysis -- Summary Report
Version 14
GHG Emissions Waste Management Analysis for Denver Conventional
Prepared by: Claudia Piano
Project Period for this Analysis: 01/01/16 to 12/31/16
Note: If you wish to save these results, rename this file (e.g., WARM-MN1) and save it. Then the "Analysis Inputs" sheet of the "WARM" file will be blank when you are ready to make another model run.

GHG Emissions from Baseline Waste Management ($MTCO_2E$): -782.12

Material	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested	Total $MTCO_2E$
Mixed Recyclables	337.00	-	-	NA	NA	(952.01)
Mixed MSW	NA	513.00	124.80	NA	NA	169.89

GHG Emissions from Alternative Waste Management Scenario ($MTCO_2E$): -782.12

Material	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested	Total $MTCO_2E$
Mixed Recyclables	NA	337.00	-	-	NA	NA	(952.01)
Mixed MSW	NA	NA	513.00	124.80	NA	NA	169.89

GHG Emissions Analysis -- Summary Report
Version 14
GHG Emissions Waste Management Analysis for Denver Green
Prepared by: Claudia Piano
Project Period for this Analysis: 01/01/16 to 12/31/16
Note: If you wish to save these results, rename this file (e.g., WARM-MN1) and save it. Then the "Analysis Inputs" sheet of the "WARM" file will be blank when you are ready to make another model run.

GHG Emissions from Baseline Waste Management ($MTCO_2E$): -782.12

Material	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested	Total $MTCO_2E$
Mixed Recyclables	337.00	-	-	NA	NA	(952.01)
Mixed MSW	NA	513.00	124.80	NA	NA	169.89

GHG Emissions from Alternative Waste Management Scenario ($MTCO_2E$): -782.12

Material	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested	Total $MTCO_2E$
Mixed Recyclables	NA	337.00	-	-	NA	NA	(952.01)
Mixed MSW	NA	NA	513.00	124.80	NA	NA	169.89

GHG Emissions Analysis -- Summary Report
Version 14
GHG Emissions Waste Management Analysis for Los Angeles Conventional
Prepared by: Claudia Piano
Project Period for this Analysis: 01/01/16 to 12/31/16
Note: If you wish to save these results, rename this file (e.g., WARM-MN1) and save it. Then the "Analysis Inputs" sheet of the "WARM" file will be blank when you are ready to make another model run.

GHG Emissions from Baseline Waste Management ($MTCO_2E$): -234.32

Material	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested	Total $MTCO_2E$
Mixed Recyclables	101.00	-	-	NA	NA	(285.32)
Mixed MSW	NA	154.00	37.40	NA	NA	51.00

GHG Emissions from Alternative Waste Management Scenario ($MTCO_2E$): -234.32

Material	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested	Total $MTCO_2E$
Mixed Recyclables	NA	101.00	-	-	NA	NA	(285.32)
Mixed MSW	NA	NA	154.00	37.40	NA	NA	51.00

GHG Emissions Analysis -- Summary Report
Version 14
GHG Emissions Waste Management Analysis for Los Angeles Green
Prepared by: Claudia Piano
Project Period for this Analysis: 01/01/16 to 12/31/16
Note: If you wish to save these results, rename this file (e.g., WARM-MN1) and save it. Then the "Analysis Inputs" sheet of the "WARM" file will be blank when you are ready to make another model run.

GHG Emissions from Baseline Waste Management ($MTCO_2E$): -104.48

Material	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested	Total $MTCO_2E$
Mixed Recyclables	45.00	-	-	NA	NA	(127.12)
Mixed MSW	NA	68.38	16.70	NA	NA	22.64

GHG Emissions from Alternative Waste Management Scenario ($MTCO_2E$): -104.48

Material	Tons Source Reduced	Tons Recycled	Tons Landfilled	Tons Combusted	Tons Composted	Tons Anaerobically Digested	Total $MTCO_2E$
Mixed Recyclables	NA	45.00	-	-	NA	NA	(127.12)
Mixed MSW	NA	NA	68.38	16.70	NA	NA	22.64

Table 13. Summary of GHG inventory results, with per person CO2e.

Building	Scope 3 Co2e based on study participants	x multipli-cation factor	= Scope 3 Co2e for total # of building occupants	Plus Scope 3 waste generated /recycling	Total Scope 3	Plus Scope 1 fugitive emissions	Plus Scope 2 purchased HVAC	Total CO2e for building	Per person CO2e
Conventional buildings									
Boston conventional	20	4.166667	83.3333		83.33333	0.4	97.6	181.3333	3.63
Denver conventional	57	34.61538	1973.08	-782.12	1190.96	0.4		1191.36	2.65
Los Angeles green #1	43	10.90909	469.09	-234.32	234.77	0		234.77	1.96
San Jose conventional	55	20.83333	434.03		434.03	0		434.03	1.74
Green buildings									
Boston green	39	12.5	487.5		487.5	0.4	237.2	725.1	4.83
Denver green	63	37.5	2362.5	-782.12	1580.38	0.3		1580.68	3.51

Los Angeles green #2	47	17.5	822.5	-104.48	718.02	0		718.02	3.42
San Jose green	44	100	4400		4400	0		4400	3.67

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Ancillary Appendix: Additional Athena and GaBi Data

The Athena LCA tool allowed for the input of basic specifications for each building (square footage, height, age, # of windows and doors, type of façade) and then it generated a comprehensive materials report for each building, including everything needed to input into the GaBi tool to conduct the LCA. While the Athena materials reports provided mostly 'volume' measurements (square feet, cubic feet, board feet, etc.), GaBi uses 'mass' measurements, so most of items on the materials list had to be converted to short tons or pounds (Moselle, 2017).

As is apparent in the tables below, the primary differences between the conventional and green building models could be found in the square footage attributed to each building (40,000 vs 50,000) and the materials used. The LCA model for the green building used a steel framing system instead of wood, polyiso foam board instead of fiberglass insulation, sustainable sheetrock instead of standard, sustainable bamboo flooring instead of linoleum, and a solar-reflectant high albedo roof. There were more differences, which can be seen in the materials lists in Tables 16 and 17.

Table 14. LCA specifications provided by Athena LCA tool for Boston conventional building.

Boston conventional building			
General Specs/Assumptions			
Building height 30 feet, 3 floors Gross floor area 44000 sq ft Life expectancy 60 years Used Imperial units Used defaults for commercial buildings Assumes built in 1926			
Foundation: basement/concrete slab Floors: carpet, linoleum Exterior walls: cement, wood studs Insulation: fiberglass Cladding: brick Interior walls: regular gypsum Roof: assume asphalt tiles Doors: solid wood exterior doors Windows: aluminum framed double-pane			
Assembly #1	**Specifications**	**Envelope**	**Openings**
Foundation	80 x 125 feet, 4" thick, concrete 3000 psi (default)	Fiberglass batt R-11-15 (25.381000 mm) insulation	N/A
Assembly #2	**Specifications**	**Envelope**	**Openings**
Columns and Beams: 2 floors and basement (3 floors)	-Column type softwood lumber; beam type: glulam -Column height: 10 ft -Live load: 50 psf -# of columns: 720	N/A	N/A

	-# of beams: 540 -Supported area: 20,000 sq ft -Bay size: 10 ft -Supported span: 14 ft		
Columns and Beams: roof	-Column type softwood lumber; beam type: glulam -Column height: 10 ft -Live load: 50 psf -# of columns: 240 -# of beams: 180 -Supported area: 10,000 sq ft -Bay size: 10 ft -Supported span: 14 ft	N/A	
Assembly #3	**Specifications**	**Envelope**	**Openings**
Walls: Exterior	-410' length x 30' height -Concrete block -Wood stud framing	-Brick cladding -Regular gypsum sheetrock, ½" -Fiberglass batt R11-14 (63.4525000 mm) insulation -Alkyd solvent based exterior paint	-80 aluminum frame, double pane, double glazed no coating windows; 1440 sq ft -4 solid wood entry doors
Assembly #4	**Specifications**	**Envelope**	**Openings**
Walls: interior side of 125' x 2 floors (basement and attic not included)	-Assumes (30) 25' walls each floor; total length of 1500' x 10' height -Wood stud framing	-Regular gypsum sheetrock, ½" -Fiberglass batt R-11-15 (25.381000 mm) insulation -Latex water based paint	-Assumes 18 doors per floor; 36 hollow core wood interior doors
Walls: interior side of 80' x 2 floors (basement and attic not included)	-Assumes (28) 20' walls each floor; total length of 1120' x 10' height -Wood stud framing	-Regular gypsum sheetrock, ½" -Fiberglass batt R-11-15 (25.381000 mm) insulation	

		-Latex water based paint	
Walls: interior basement and attic	-Assumes perimeter walls (410 each floor) & no other interior walls; total length of 820' x 10' height -Wood stud framing	-Regular gypsum board, ½" -Fiberglass batt R-11-15 (25.381000 mm) insulation -Latex water based paint	
Assembly #5	**Specifications**	**Envelope**	**Openings**
Floors	-Assume 10,000 sq ft each floor; with a span of 14 feet, this equals a total length of 714.3 per floor -Live load: 50 psf -Decking type" ½" thick plywood -Linoleum covering	Regular gypsum sheetrock, ½"	
Assembly #6	**Specifications**	**Envelope**	**Openings**
Roof	-Roof area: 1000 sq ft; had to be expressed as: 714.3' wide with span of 14 feet -Plywood decking, ½ inch thick -Live load 50 psf (default)	-Asphalt-fiberglass batt R-11-15, -Glass felt (25.381000 mm) -Fiberglass loose fill cavity R-15 (25.381000 mm)	
Input #7			
One year's operating energy	126648.3 kWh electricity	814 million BTUs steam from natural gas	

Table 15. LCA specifications provided by Athena LCA tool for Boston green building.

Boston green building			
General specs/assumptions			
Building height 45 feet Gross floor area 50,000 sq ft Life expectancy 60 years Used Imperial units Used defaults for commercial buildings Assumes total renovation in 2011			
Foundation: basement/concrete slab Floors: Plyboo bamboo and Forbo Marmoleum flooring. Shaw recycled carpet Insulation: Board-type insulation at foundations, a spray-applied Icynene foam insulation everywhere else Exterior walls: cement, steel stud (recycled) Cladding: brick Interior walls: Fire and water retardant gypsum, recycled Roof: ENERGY STAR, cool/high-albedo, solar reflectant roof Doors: steel solid exterior doors; hollow core interior, recycled Windows: recycled, aluminum framed double-pane low e argon			
Assembly #1	**Specifications**	**Envelope**	**Openings**
Foundation	100 x 100 feet, 4" thick, concrete 3000 psi (default)	Polyisocyanurate foam (25.381000 mm) insulation	N/A
Assembly #2	**Specifications**	**Envelope**	**Openings**
Columns and Beams: 4 floors	-Column type hollow structural steel; beam type: WF -Column height: 10 ft -Live load: 100 psf -# of columns: 960	N/A	N/A

	-# of beams: 720 -Supported area: 40,000 sq ft -Bay size: 10 ft -Supported span: 14 ft		
Columns and Beams: roof	-Column type hollow structural steel; beam type: WF -Column height: 10 ft -Live load: 100 psf -# of columns: 240 -# of beams: 180 -Supported area: 10,000 sq ft -Bay size: 10 ft -Supported span: 14 ft	N/A	
Columns and Beams: basement	-Column type hollow structural steel; beam type: WF -Column height: 10 ft -Live load: 100 psf -# of columns: 120 -# of beams: 90 -Supported area: 5,000 sq ft -Bay size: 10 ft -Supported span: 14 ft	N/A	
Assembly #3	**Specifications**	**Envelope**	**Openings**
Walls: exterior	-410' length x 30' height -Concrete block -Steel stud framing	-Brick cladding -Gypsum moisture-resistant sheetrock, ½" -Polyisocyanurate foam board (25.381000 mm) insulation -Alkyd solvent based exterior paint	-244 aluminum frame, double pane, double glazed no coating windows; 4392 sq ft -6 steel glazed entry doors
Assembly #4	**Specifications**	**Envelope**	**Openings**

Walls: interior 100' x 100' x 4 floors (basement and attic not included)	-Assumes (60) 20' walls each floor; total length of 4800' x 10' height -Wood stud framing	-Gypsum moisture-resistant sheetrock, ½" -Polyisocyanurate foam board (25.381000 mm) insulation -Latex water based paint	-Assumes 25 doors per floor; 100 hollow core wood interior doors
Walls: interior basement and attic	-Assumes perimeter walls (400 each floor) & no other interior walls; total length of 800' x 10' height -Wood stud framing	-Gypsum moisture-resistant sheetrock, ½" -Polyisocyanurate foam board (25.381000 mm) insulation -Latex water based paint	
Assembly #5	**Specifications**	**Envelope**	**Openings**
Floors	-Assume 10,000 sq ft each floor; with a span of 14 feet, this equals a total length of 714.3' per floor -½ inch thick OSB decking, 16" steel gauge, joist type 1 5/8" x 6", joist spacing 16" -Assume bamboo wood flooring on occupied floors	-Gypsum moisture-resistant sheetrock, ½" -Latex water based paint	N/A
Floors: basement and attic	-Assume 5000 sq ft each floor; with a span of 14 feet, this equals a length of 357.2' per floor -½ inch thick OSB decking, 16" steel gauge, joist type 1 5/8" x 6", joist spacing 16" -Assumes laminate flooring	-Gypsum moisture-resistant sheetrock, ½" -Latex water based paint	
Assembly #6	**Specifications**	**Envelope**	**Openings**
Roof	-Roof area: 10,000 sq ft; had to be expressed as: 714.3' wide with span of 14 feet	-EPDM membrane roofing system -Softwood lumber	N/A

	-½ inch thick OSB decking, 16" steel gauge, joist type 1 5/8" x 6", joist spacing 16"	-Polyisocyanurate foam board (25.381000 mm) insulation -Softwood plywood -Aggregate stone filler -Glass facer -Extruded polystyrene -Polyethylene 6 mil vapor barrier	
Input #7			
One year's operating energy	370486.1 kWh electricity	1651 million BTUs steam from natural gas	

Table 16. Materials list provided by Athena LCA tool and conversion of measures for input into GaBi for Boston conventional (End Memo, 2017).

Boston conventional building			
Materials list for Foundation	**Conversion factor #1**	**Conversion factor #2**	**Input into GaBi**
Concrete benchmark 3000 psi: 127.4443 cubic yards	Convert cubic yards to short tons	Provided by Athena	258.48 short tons
Welded wire mesh/ladder wire: 0.9255 short tons	Already expressed in short tons		0.9255 short tons
Fiberglass (glass wool) batt R11-15 (1"): 10,316.1169 square feet	Convert square feet to cubic yards (38807.0489)	x 47 lbs per cubic yard	1823931.2 lbs
Nails: 0.0633 short tons	Already expressed in short tons		0.0633 short tons
Materials list for Columns and Beams	Conversion factor #1	Conversion factor #2	Input into GaBi
GluLam (LVL lumber): 1,620.2959 cubic feet	GaBi allows volume instead of mass for this input		1,620.2959 cubic feet
Small dimension softwood lumber, kiln dried: 40.0127 Mbfm (thousand board feet)	Convert board feet (40012.7) to cubic feet	Convert cubic feet (3334.391681) to cubic meters	94.419 cubic meters
Materials list for Exterior Walls	Conversion factor #1	Conversion factor #2	Input into GaBi
Double-glazed no coating air windows: 4,506.1235 square feet	Count # of units instead of square feet		80 units
Aluminum window frames: 4,059.2229 lbs	Count # of units instead of square feet		80 units
8" normal weight concrete block: 12,751.3279 blocks	Multiply each block by 28 pounds		317088.77 lbs

Concrete brick: 11,324.5995 square feet	Multiply total square feet by 2.25 bricks per square foot	Multiply bricks by 12.57 lbs	320287.96 lbs
Solvent-based alkyd paint: 330.4700 gallons	Convert gallons to pounds	Paint is density of 1.66	4578.12469 lbs
Materials list for Interior Walls	Conversion factor #1	Conversion factor #2	Input into GaBi
Small dimension softwood lumber, kiln-dried: 35.4245 Mbfm (thousand board feet)	Convert board feet (35424.5) to cubic feet	Convert cubic feet (2952.0416) to cubic meters	83.59251099 cubic meters
Softwood plywood, (3/8" thick): 26.5132 msf (thousand square feet)	Convert square feet (26513.2) to cubic feet		4317111.0658 cubic feet
Regular gypsum board ½": 48,964.6647 square feet	GaBi allows volume instead of mass for this input		48,964.6647 square feet
Fiberglass (glass wool) batt R11-15 (1" thick): 62,609.8886 square feet	Convert square feet to cubic yards (580230.60)	x 47 lbs per cubic yard	27270838 lbs
Cold rolled steel sheet: 0.2231 short tons	Already expressed in short tons		0.2231 short tons
Joint compound: 5.0044 short tons	Already expressed in short tons		5.0044 short tons
Mortar: 78.6841 cubic yards	Convert cubic yards to short tons	Provided by Athena	84.8809 short tons
Nails: 0.9528 short tons	Already expressed in short tons		0.9528 short tons
Paper tape: 0.0574 short tons	Already expressed in short tons		0.0574 short tons
Rebar, rod, light sections: 16.1958 short tons	Already expressed in short tons		16.1958 short tons
Water-based latex paint: 1,190.0999 gallons	Convert gallons to pounds	Paint is density of 1.66	16486.899 lbs
Materials list for Floors	Conversion factor #1	Conversion factor #2	Input into GaBi
Regular gypsum board ½": 44,000.8783 square feet	GaBi allows volume instead of mass for this input		44,000.8783 square feet

Galvanized steel sheet: 0.6819 short tons	Already expressed in short tons		0.6819 short tons
Joint compound: 4.4971 short tons	Already expressed in short tons		4.4971 short tons
Large dimension softwood lumber, kiln-dried: 56.6122 mbfm (thousand board feet)	Convert board feet (56612,2) to cubic feet	Convert cubic feet (4717.6833) to cubic meters	133.5899152 cubic meters
Softwood plywood (3/8" thick): 53.0541 msf (thousand square feet)	Convert square feet (53054.1) to cubic feet		12220203.1988 cubic feet
Nails: 0.6329 short tons	Already expressed in short tons		0.6329 short tons
Paper tape: 0.0516 short tons	Already expressed in short tons		0.0516 short tons
Linoleum flooring (30,000 square feet)	Convert square feet to cubic yards (192450.0897)	x 35 lbs per cubic yard	6735752.8 lbs
Materials list for Roof	Conversion factor #1	Conversion factor #2	Input into GaBi
Roofing asphalt: 41,338.8044 lbs	Already expressed in lbs		41,338.8044 lbs
#15 felt (under-roof membrane): 684.0361 units of 100 square feet	Convert square feet (68403.61) to cubic yards	x 47 lbs per cubic yard	66,2605.09 lbs
Type III glass felt (asphalt supporting layer): 1,368.0721 units of 100 square feet	Convert square feet (136807.21) to cubic yards	x 47 lbs per cubic yard	187,413.01 lbs
Ballast (aggregate stone): 132,827.9976 lbs	Already expressed in lbs		132,827.9976 lbs
Fiberglass (glass wool) Batt R11-15 (1" thick): 10,500.3293 square feet	Convert square feet to cubic yards (39851.127)	x 47 lbs per cubic yard	1873002.9 lbs
Fiberglass loose fill R11 (1" thick): 10,316.3232 square feet	GaBi allows volume instead of mass for this input		10,316.3232 square feet

Galvanized steel sheet: 1.3908 short tons	Already expressed in short tons		1.3908 short tons
Large dimension softwood lumber, kiln-dried: 14.1530 mbfm (thousand board feet)	Convert board feet (14153) to cubic feet		1179.4167 cubic feet
Softwood plywood (3/8" thick): 13.2635 msf (thousand square feet)	Convert square feet (1326.35) to cubic feet		1527521.0811 cubic feet
Nails: 0.7384 short tons	Already expressed in short tons		0.7384 short tons

Table 17. Materials list provided by Athena LCA tool and conversion of measures for input into GaBi for Boston green (End Memo, 2017).

Boston green building			
Materials list for Foundation	**Conversion factor #1**	**Conversion factor #2**	**Input into GaBi**
Concrete benchmark 3000 psi: 127.4443 cubic yards	Convert cubic yards to short tons	Provided by Athena	258.48 short tons
Polyiso foam board insulation (1" thick): 10,499.9996 square feet	Convert square feet to cubic yards (39849.2507)	x 47 lbs per cubic yard	1872914.7 lbs
Welded wire mesh/ladder wire: 0.9255 short tons	Already expressed in short tons		0.9255 short tons
Nails: 0.0633 short tons			0.0633 short tons
Materials list for Columns and Beams	Conversion factor #1	Conversion factor #2	Input into GaBi
Hollow structural steel: 175.2238 short tons	Already expressed in short tons		175.2238 short tons
Screws, nuts & bolts: 12.1218 short tons	Already expressed in short tons		12.1218 short tons
Wide flange steel beams: 62.5039 short tons	Already expressed in short tons		62.5039 short tons
Materials list for Exterior Walls	Conversion factor #1	Conversion factor #2	Input into GaBi
Aluminum window frames: 7,428.6191 lbs	Count # of units instead of square feet		244 units
Double glazed hard coated argon windows: 16,096.3605 square feet	Count # of units instead of square feet		244 units
8" normal weight concrete block: 15,956.1058 blocks	Multiply each block by 28 pounds		44,6770.94 lbs

Concrete brick: 14,170.7993 square feet	Multiply total square feet by 2.25 bricks per square foot (31884.297)	Multiply bricks by 12.57 lbs	40,0785.61 lbs
Glazing panel (steel doors): 0.3175 short tons	Already expressed in short tons		0.3175 short tons
Solvent based alkyd paint: 0.5741 gallons	Convert gallons to lbs	Paint is density of 1.66	7.95322 lbs
Materials list for Interior Walls	Conversion factor #1	Conversion factor #2	Input into GaBi
Small dimension softwood lumber, kiln-dried: 1.5863 mbfm (thousand board feet)	Convert board feet (1586.3) to cubic feet	Convert cubic feet (63179.7621) to cubic meters	1789.0516 cubic meters
Softwood plywood, 3/8" thick: 18.8473 msf (thousand square feet)	Convert square feet (188473) to cubic feet		2,587,460.42 cubic feet
½" Moisture-resistant gypsum board: 74,392.2636 square feet	GaBi allows volume instead of mass for this input		74,392.2636 square feet
Air barrier: 63,254.7942 square feet	Convert square feet to cubic yards (589218.5439)	x 47 lbs per cubic yard	27,693,271 lbs
Cold rolled steel sheet: 0.2792 short tons	Already expressed in short tons		0.2792 short tons
Polyiso foam board (1" thick): 71,060.5046 square feet	Convert square feet to cubic yards (701582.3689)	x 47 lbs per cubic yard	32,974,370 lbs
Expanded polystyrene (1" thick): 257.6880 square feet	Convert square feet to cubic yards (153.2066)	x 47 lbs per cubic yard	7200.71 lbs
Galvanized steel sheets: 0.6212 short tons	Already expressed in short tons		0.6212 short tons
Galvanized steel studs: 23.3409 short tons	Already expressed in short tons		23.3409 short tons
Rebar, rod, light sections: 30.3963 short tons	Already expressed in short tons		30.3963 short tons

Joint compound: 7.6033 short tons	Already expressed in short tons		7.6033 short tons
Mortar: 98.5357 cubic yards	Convert cubic yards to short tons		199.85 short tons
Nails: 0.9567 short tons	Already expressed in short tons		0.9567 short tons
Paper tape: 0.0873 short tons	Already expressed in short tons		0.0873 short tons
Screws, nuts & bolts: 1.0382 short tons	Already expressed in short tons		1.0382 short tons
Water-based latex paint: 2,393.6423 gallons	Convert gallons to lbs	Paint is density of 1.66	33,160.0233 lbs
Materials list for Floors	Conversion factor #1	Conversion factor #2	Input into GaBi
½” m-resistant gypsum board: 55,002.6379 square feet	GaBi allows volume instead of mass for this input		55,002.6379 square feet
Galvanized steel studs: 56.3732 short tons	Already expressed in short tons		56.3732 short tons
Oriented particle board (3/8” thick): 66.3195 msf (thousand square feet)	GaBi allows volume instead of mass for this input	Convert to cubic feet	17,078,977.4432 cubic feet
Joint compound: 5.6215 short tons	Already expressed in short tons		5.6215 short tons
Nails: 0.0527 short tons	Already expressed in short tons		0.0527 short tons
Paper tape: 0.0645 short tons	Already expressed in short tons Already expressed in short tons		0.0645 short tons
Screws, nuts & bolts: 0.7384 short tons	Already expressed in short tons		0.7384 short tons
Materials list for Roof	Conversion factor #1	Conversion factor #2	Input into GaBi
EPDM membrane (60 mil): 13,032.6964 lbs	Already expressed in lbs.		13,032.6964 lbs
Aggregate stone/ballast: 407,483.9928 lbs	Already expressed in lbs.		407,483.9928 lbs

3 mil polyethylene vapor barrier: 10,608.2117 square feet	Convert square feet to cubic yards (40,466.8596)	x 47 lbs per cubic yard	1,901,942.3 lbs
6 mil polyethylene vapor barrier: 10,200.2036 square feet	Convert square feet to cubic yards (38,154.8277)	x 47 lbs per cubic yard	1,793,276.8 lbs
Extruded polystyrene (1" thick): 10,507.6795 square feet	Convert square feet to cubic yards (39,892.9784)	x 47 lbs per cubic yard	1,874,960.8 lbs
Galvanized steel sheet: 0.4442 short tons	Already expressed in short tons		0.4442 short tons
Galvanized steel studs: 11.2743 short tons	Already expressed in short tons		11.2743 short tons
Glass facer/fibers: 21,000.4192 square feet	Convert square feet to cubic yards (112,714.0829)	x 47 lbs per cubic yard	5,297,561.7 lbs
Oriented particle board: (3/8" thick): 13.2635 msf (thousand square feet)	GaBi allows volume instead of mass for this input	Convert to cubic feet	1,527,521.0811 cubic feet
Polyiso Foam Board (1" thick): 10,024.5501 square feet	Convert square feet to cubic yards (37,173.5102)	x 35 lbs per cubic yard	1,301,072.8 lbs
Nails: 0.1477 short tons	Already expressed in short tons		0.5907 short tons
Small dimension softwood lumber, kiln-dried: 1.3069 mbfm (thousand board feet)	Convert board feet (1306.9) to cubic feet	Convert cubic feet (108.9083) to cubic meters	3.0839 cubic meters
Softwood plywood (3/8" thick): 0.2035 msf (thousand square feet)	Convert square feet (203.5) to cubic feet		2902.9972 cubic feet
Screws, nuts & bolts: 0.1477 short tons	Already expressed in short tons		0.1477 short tons

Table 18. GaBi LCIA results for Boston conventional.

Life Cycle Inventory: Boston Green mass, in kg										
	Total Life Cycle	**End of Life**	**EU-28: Diesel mix at refinery**	**GLO: Pipeline average**	**GLO: Truck-trailer, 27t payload capacity**	**Materials for Building Assembly**	**Use Phase**	**CO2e per M3 (cubic meter)**	**Total ReCiPe GWP in kg**	**Total ReCiPe GWP in metric tonnes**
Input Flows	5.04943E+13	1.45671E+12	1134652204	0	5408117.864	4.99137E+13	2006705.664	10870332413		
Resources	1134652204	0	1134652204	0	0	0	0			
*Energy resources	6162853.665	0	6162853.665	0	0	0	0			
*Land Use	0	0	0	0	0	0	0			
*Material resources	1128489350	0	1128489350	0	0	0	0			
Valuable substances	5.04897E+13	5.82684E+11	0	0	5408117.864	4.9907E+13	2006705.664			
*Energy carrier	0	0	0	0	5408117.864	0	0			
*Materials	5.0346E+13	5.82684E+11	0	0	0	4.97633E+13	0			
*Systems	1.43741E+11	0	0	0	0	1.43741E+11	2006705.664			
**Assemblies	76167054375	0	0	0	0	76167054375	0			
**Infrastructure	646824827.6	0	0	0	0	646824827.6	2006705.664			
**Parts	66927345983	0	0	0	0	66927345983	0			
Ecoinvent	4919215.968	8.74026E+11	0	0	0	4919215.968	0			
*Construction materials	4919215.968	0	0	0	0	4919215.968	0			
*waste management	0	8.74026E+11	0	0	0	0	0			
Others	0	0	0	0	0	3164567632	0			
US LCI Database	3496350977	0	0	0	0	3496350977	0			
Output Flows	1.45472E+12	1.45671E+12	1161144552	0	17305081.8	2006705.664	8.74026E+11	313169220.6		
Valuable substances	0	0	5408117.864	0	0	2006705.664	0			
*Energy carrier	0	0	5408117.864	0	0	0	0			
*Systems	0	0	0	0	0	2006705.664	0			
Ecoinvent	0	0	0	0	0	0	8.74026E+11			
*waste management	0	0	0	0	0	0	8.74026E+11			
Others	8.70862E+11	8.74026E+11	0	0	0	0	0			
Deposited goods	5.82685E+11	5.82684E+11	935546.7707	0	0	0	0			
Emissions to air	345819268.1	0	328514186.3	0	17305081.8	0	0			
Emissions to fresh water	822932538	0	822932538	0	0	0	0			
Emissions to sea water	3354124.766	0	3354124.766	0	0	0	0			
Emissions to agricultural soil	30.34312967	0	30.34312967	0	0	0	0			
Emissions to industrial soil	8.280609573	0	8.280609573	0	0	0	0			
TOTAL	**5.19491E+13**							11183501633	**67126470**	**671264.7**

Table 19. GaBi LCIA results for Boston green.

Life Cycle Inventory: Boston Conventional mass, in kg										
	Total Life Cycle	**End of Life**	**EU-28: Diesel mix at refinery**	**GLO: Pipeline average**	**GLO: Truck-trailer, 27t payload capacity**	**Materials for Building Assembly**	**Use Phase**	**CO2e per M3 (cubic meter)**	**Total ReCiPe GWP in kg**	**Total ReCiPe GWP in metric tonnes**
Input Flows	6.28644E+12	3.81524E+11	3217016511	0	15333336.86	6.13958E+12	10245364.53	1691666086		
Resources	3217016511	0	3217016511	0	0	0	0			
*Energy resources	6.27966E+12	1.5261E+11	0	0	15333336.86	6.12705E+12	10245364.53			
*Land use	0	0	0	0	15333336.86	0	0			
*Material resources	6.27051E+12	1.5261E+11	0	0	0	6.1179E+12	0			
Valuable substances	9152782684	0	0	0	0	9152782684	10245364.53			
*Energy carrier	8660112.022	0	0	0	0	8660112.022	0			
*Materials	0	0	0	0	0	0	10245364.53			
*Systems	9144122572	0	0	0	0	9144122572	0			
**Assemblies	100614669	2.28914E+11	0	0	0	100614669	0			
**Infrastructure	51365207.94	0	0	0	0	51365207.94	0			
**Parts	49249461.06	0	0	0	0	49249461.06	0			
Ecoinvent	0	0	0	0	0	0	0			
*Construction materials	0	0	0	0	0	0	0			
*waste management	0	2.28914E+11	0	0	0	0	0			
Others	0	0	0	0	0	8972323228	0			
US LCI Database	3456372049	0	0	0	0	3456372049	0			
Output Flows	3.75877E+11	3.81524E+11	3292128799	0	49064139.37	10245364.53	2.28914E+11	101147773.4		
Valuable substances	0	0	15333336.86	0	0	10245364.53	0			
*Energy carrier	0	0	15333336.86	0	0	0	0			
*Systems	0	0	0	0	0	10245364.53	0			
Ecoinvent	0	0	0	0	0	0	2.28914E+11			
*waste management	0	0	0	0	0	0	2.28914E+11			
Others	1.05485E+11	1.14457E+11	0	0	0	0	0			
Deposited goods	2.67069E+11	2.67067E+11	2652503.911	0	0	0	0			
Emissions to air	980482205.6	0	931418066.3	0	49064139.37	0	0			
Emissions to fresh water	2333215018	0	2333215018	0	0	0	0			
Emissions to sea water	9509764.063	0	9509764.063	0	0	0	0			
Emissions to agricultural soil	86.03019394	0	86.03019394	0	0	0	0			
Emissions to industrial soil	23.47755341	0	23.47755341	0	0	0	0			
TOTAL	**6.66231E+12**							1792813860	**43440541**	**43440.541**