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Quantifying the Comprehensive Greenhouse Gas Co-Benefits of Green Buildings

FINAL REPORT

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Disclaimer

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ABSTRACT

This report quantifies, for the first time, the greenhouse gas (GHG) emissions co-benefits associated with water, waste and transportation usage in certified green commercial office buildings in California. The study compares the measured values of water, waste and transportation usage self-reported by a set of office buildings certified under the Leadership in Energy and Environmental Design rating system for Existing Building Operations and Maintenance (LEED-EBOM) to both baseline values of conventional California office buildings and predicted values based upon state standards for green buildings and GHG impact prediction methods. The green buildings in the LEED-EBOM dataset produced 50% less GHGs due to water consumption than baseline buildings, 48% less due to solid waste management, and 5% less due to transportation. If applied to the entire California office building stock, performance typical of the certified green buildings would save 0.703 $MMTCO_2e$/yr from transportation, 0.084 $MMTCO_2e$/yr from water, and 0.044 $MMTCO_2e$/yr from waste, for a total potential savings of about 0.831 $MMTCO_2e$/yr relative to conventional construction. In addition, buildings earning additional credits for specified performance thresholds for water and waste in the LEED-EBOM code attained performance levels even higher than required by the code provisions, suggesting that such code provisions in other contexts may help incentivize larger GHG emissions reductions than anticipated.

EXECUTIVE SUMMARY

This report quantifies, for the first time, the greenhouse gas (GHG) emissions co-benefits associated with water, waste and transportation usage in certified green commercial office buildings in California. The study compares the measured values of water, waste and transportation usage self-reported by a set of office buildings certified under the Leadership in Energy and Environmental Design rating system for Existing Building Operations and Maintenance (LEED-EBOM) to both baseline values of conventional California office buildings and predicted values based upon state standards for green buildings and GHG impact prediction methods.

Background

Transportation, water use and decomposition of waste in landfills account for more than 40% of California's greenhouse gas emissions. While each of these resource areas is the subject of emissions control strategies within the AB 32 Scoping Plan that requires GHG emissions levels to return to 1990 levels by 2020, the plan and its 2014 Update also identify green buildings as an emissions control strategy that cuts across a variety of resource areas. Previous research has focused on the operational energy performance of green buildings and its GHG consequences, but little has been done to quantify the GHG consequences of other building operations and management strategies rewarded by green building certification systems like LEED. Quantification of these GHG co-benefits may therefore contribute to future GHG policy and regulatory decisions made for the post-2020 period.

Objectives and methods

The objective of this research project was to compile and analyze a database of certified green buildings in California that includes performance metrics that can be used to measure the impact of these buildings on GHG emissions due to transportation, water use, and solid waste disposal. This was accomplished by obtaining access to the project reports submitted by buildings applying for certification under LEED-EBOM in California, which include data reported by the LEED-certified professionals on behalf of building operators, and subject to third-party review, on water use, waste disposal, and transportation usage. The research team also had to develop methods to identify baseline and predicted values for usage of each of these resource areas. Baseline values (usage rates typical of conventional non-green buildings) were generated by assembling disparate information from previous studies, building codes, and the U.S. Census. Predicted values (usage rates expected of green buildings in California) were generated by consulting state laws and green building codes, as well as the GHG quantification guidance issued by the California Air Pollution Control Officers Association (CAPCOA).

In addition, the research team identified GHG intensities for water, waste and transportation that were used to establish emissions levels associated with the baseline, predicted and measured values for each of the three resource areas. Because some of the baselines and GHG intensities vary regionally, the research team divided the state into five major regions – the Bay Area, Los Angeles, Sacramento, San Diego, and the rest of California – and performed each step of the analysis for each of these regions independently, before re-combining them into statewide results. Regional-scale results for the Bay Area and Los Angeles regions are also reported.

Results

The green buildings in the LEED-EBOM dataset produced 50% less GHGs due to water consumption than baseline buildings, 48% less due to solid waste management, and 5% less due to transportation. If applied to an average-sized California office building of almost 13,000 square feet, performance typical of the certified green buildings would save 8.00 $MTCO_2e$/yr from transportation, 0.96 $MTCO_2e$/yr from water, and 0.50 $MTCO_2e$/yr from waste, for a total potential savings of 9.46 $MTCO_2e$/yr relative to conventional construction. If applied to the entire California office building stock (about 1.14 billion square feet), performance typical of the certified green buildings would save 0.703 $MMTCO_2e$/yr from transportation, 0.084 $MMTCO_2e$/yr from water, and 0.044 $MMTCO_2e$/yr from waste, for a total potential savings of about 0.831 $MMTCO_2e$/yr relative to conventional construction. In addition, buildings earning additional credits for specified performance thresholds for water and waste in the LEED-EBOM code attained performance levels even higher than required by the code provisions, suggesting that such code provisions in other contexts may help incentivize larger emissions reductions than anticipated. Finally, GHG emissions associated with measured values for the LEED-EBOM buildings out-performed predicted values for water and waste, but were about 6% worse than prediction for transportation.

Conclusions

The results show that there are important GHG co-benefits being realized in commercial office buildings relative to typical construction. While the percentage improvement relative to baseline is lower in transportation than in water or waste, transportation improvements are by far the most important in absolute terms. Transportation is over 100 times more GHG-intense per square foot of office building than either water or waste, and is also more than twice as GHG-intense per square foot of office building as operational energy, so increased attention to building-level transportation strategies is essential. Prediction methods should also be improved to enable better estimation of GHG co-benefits for policy making. Overall, these results support the idea that greater GHG co-benefits than those quantified here are available from future updates to green building standards, especially if increased emphasis is placed on transportation, and that such standards can play an important role in future GHG emissions control efforts.

Introduction

Transportation, water use and decomposition of waste in landfills account for well more than 40% of greenhouse gas emissions (GHG) in California, according to the AB 32 Scoping Plan (ARB 2008). Thoughtful building design and siting can ensure that a building is accessible via shorter trips and by non-automobile transportation, as well as reducing on-site water consumption and waste generation. This has the co-benefit of reducing GHG emissions associated with the consumption of automobile fuel and of the energy needed to transport, distribute and process water and waste.

The California Air Resources Board (ARB) and other agencies are increasingly looking to green building policies to help meet climate goals. The First Update to the Climate Change Scoping Plan (ARB 2014, p. 82) states that green buildings "offer a comprehensive approach to support California's climate change goals across multiple sectors" and "represent a fundamental shift toward a cross-sector and integrated climate policy framework," but quantifying the GHG emissions reductions due to the non-energy building strategies used in green building is challenging. No full accounting of the potential GHG co-benefits from non-energy green building strategies has previously existed, making it difficult for state and local climate policies to quantify and incorporate the effects of these strategies in climate planning.

This project fills a critical part of this gap by assessing, for the first time, the GHG emissions co-benefits associated with water, waste and transportation strategies in certified green commercial office buildings in California. The results serve as an important guidepost for future updates to state GHG emissions reduction plans, local climate action plans, and commercial building standards.

The analysis herein is based upon a dataset of California commercial office buildings certified under the Leadership in Energy and Environmental Design rating system for Existing Building Operations and Maintenance (LEED-EBOM)[1]. Unlike various other LEED rating systems that apply primarily to the design and construction phases, buildings seeking certification under this rating system must measure and report *operational* performance data related to the credits they are seeking. These data – referred to in this study as "measured values" – provided the basis for quantitative analysis of these buildings' performance with respect to water, waste and transportation, compared both to conventional non-green commercial office buildings and to the performance expected of California green buildings at the time these buildings were certified (see Table 1).

Quantification of conventional building performance – referred to in this study as "baseline values" – was assembled from a variety of data sources, including the U.S. Census, the American Community Survey, statewide waste characterization reports, and technical studies on water conservation potential. Quantification of expected green building performance – referred to in this study as "predicted values" – was assembled from state green building standards, state waste management legislation, and the California Air Pollution Control Officers Association's (CAPCOA) guidance on quantification of GHG emissions control strategies. In addition, GHG intensities for water, waste and

[1] The name of this rating system has changed a number of times and is now known as LEED O&M: Building Operations and Maintenance. This report uses the name that applied to the versions of the rating system that provided the data used herein.

transportation were calculated and applied to measured, baseline and predicted values in order to quantify the GHG emissions avoided (or not) by certified green buildings. These were assembled from a combination of CAPCOA guidance, Air Resources Board (ARB) guidance, and previous technical reports.

Table 1. Definitions of baseline, measured and predicted values

	Definition	***Major data sources***		
		Water	*Waste*	*Transportation*
Baseline value	Performance of typical, non-green office buildings in California	Gleick et el (2003)	CalRecycle (2006)	2008-2012 American Community Survey
Measured value	Performance expected of green office building at the time of certification	California Green Building Standards Code, 2010 edition (CalGreen)	AB 341	CAPCOA (2010)
Predicted value	Actual performance of green office buildings	Performance data from certified LEED-EBOM office buildings	Performance data from certified LEED-EBOM office buildings	Performance data from certified LEED-EBOM office buildings

The study also takes into account important regional variations within California. The energy intensity of water, for example, varies substantially between the major urban regions of the state, depending upon the origins of their water supplies. Though the energy and GHG intensity of transportation modes is constant throughout the state, the baseline transportation performance of conventional commercial office buildings varies regionally, especially in the transit-rich Bay Area. For these reasons, the research team created separate transportation baseline values for five major California regions (the Bay Area, Los Angeles, San Diego, and Sacramento metropolitan areas, as well as a "rest-of-state" region), and calculated separate GHG intensities for water for the five regions. These regional differences informed the statewide comparisons between measured, baseline, and predicted values. In two regions, the Bay Area and Los Angeles, there were enough measured building performance values in the LEED-EBOM dataset to enable reporting of region-specific comparisons that further inform the overall conclusions.

Finally, the study also recognizes that GHG co-benefits may be achieved by buildings certified under different green rating systems or by buildings that are uncertified by any rating system. Though the results were generated using data from existing buildings, this report explores the implications of the findings for new office construction and the commercial office building stock as a whole. LEED-EBOM contains credits that reward higher performance in water efficiency and waste management, and analysis of the performance of buildings achieving these credits enables additional insight into the role that green rating systems can play with respect to new construction, not just existing buildings. This report also contains recommendations for data gathering strategies that would enable analysis of GHG co-benefits of building design and management strategies undertaken by commercial office buildings not certified under any rating system. The results reported herein will therefore advance best practice in setting building design and construction standards, as well as assisting state and local climate planners in setting additional GHG emissions reductions goals.

Materials and Methods

The discussion below describes how the dataset of certified green California office buildings was compiled, and what methods were used to determine baseline, predicted, and measured values for water, waste and transportation usage respectively. Because the study involves comparing three different data points for three different resource areas, several different data sources and methods were used.

Office building dataset acquisition and processing

A central task for the successful execution of this project was the acquisition of measured data on green building performance in California. The primary source of this data was the U.S. Green Building Council (USGBC), the organization that created and oversees the Leadership in Energy and Environmental Design (LEED) rating systems. The research team obtained permission to access the data submitted by buildings seeking certification under the LEED Existing Buildings Operations and Maintenance (LEED-EBOM) rating system, versions 2008 and 2009, via USGBC's Project Directory and USGBC's online credit database. LEED-EBOM is a voluntary green construction standard that has become the industry standard definition for high-performance buildings. To achieve certification, a building must demonstrate attainment of certain pre-requisites, plus a given number of voluntary credits that add up to the desired certification threshold (standard, silver, gold or platinum).

The research team first identified the LEED-EBOM credits relevant to this study from within the LEED-EBOM 2008 and 2009 submittal data only. The prior version of the rating system (known as LEED-EBOM 2.0) was based on credits that were not performance-based, and hence would not have the measured data needed. LEED-EBOM v4, which strengthened some of the standards relevant to this study (including making water metering and waste audits mandatory pre-requisites), was launched too recently for there to be sufficient submittal data collected.

The LEED-EBOM 2008 and 2009 credits[2] relevant to the co-benefits study included the following:

- Sustainable Sites credit 4 (SSc4) – Alternative Transportation Commuting
- Water Efficiency credits 1.1 and 1.2 (WEc1.1 and 1.2) – Water Performance Measurement
- Water Efficiency credit 2 (WEc2) – Indoor Water Efficiency
- Water Efficiency credit 3 (WEc3) – Landscape Irrigation Efficiency
- Material & Resources credit 6 (MRc6)– Solid Waste Management – Waste Stream Audit
- Material & Resources credit 7 (MRc7) – Solid Waste Management – Ongoing consumables

[2] The labeling, description and point distribution of these credits varies slightly between versions 2008 and 2009, but because this analysis is based on the actual reported performance data and not the points received under LEED-EBOM, these differences are largely ignored in this study.

The USGBC Project Directory provided readily available information on each non-confidential LEED-certified building's location, certification type (i.e. what rating system it is certified under), project type, owners, square footage and date of certification.[3] The research team used this information as input data for the search fields in the online credit database in order to gather information on the specific credits achieved by each building of interest. Because one of the research team members also served as a USGBC Research Program intern, she was able to collaborate with USGBC staff and obtain access to portions of the online credit database that are not publicly accessible. Access to the data was accompanied by a responsibility to respect and enforce USGBC policies with respect to data aggregation and privacy, with which the research team complied.

The research team first gathered data on all California buildings labeled as "commercial" by the LEED database, then discarded from the dataset all commercial buildings that are not predominantly office buildings. This narrowing was done in order to ensure that the building uses were similar enough to support direct comparative analysis of their water, waste and transportation usage patterns. The commercial real estate database Loopnet.com was used to assist in distinguishing between office buildings and non-office commercial buildings.

In addition, inclusion in the Project Directory database does not guarantee that credit information will be available in the online credit database; buildings for which this was true were also discarded from the database. The team then assigned building identification numbers to each remaining record and categorized all records into one of five California regions for analytical purposes (Bay Area, LA region, Sacramento region, San Diego region, and Rest-of-State). Not every building that sought certification achieved all relevant credits. For instance, there are several buildings that achieved MRc6 and SSc4 but not WEc1. For this reason, the research team analyzed data samples by credit, isolating building performance data by resource area (transportation, water or waste), as opposed to analyzing buildings in their entirety (see Table 2).

Table 2. Qualifying LEED-EBOM buildings with data in each resource area, by region

	Transportation	Water	Waste
SF Bay Area	99	89	105
LA metro	54	63	74
Sacramento metro	21	22	31
San Diego metro	16	11	14
Rest of CA	6	6	9
Total	**196**	**191**	**233**

WEc1.1 and 1.2 (water) submittals report water consumption data from building water meter readings. This potentially includes sub-metering for indoor use, irrigation, cooling towers, domestic hot water heaters and process water if the applicant so chooses. All water consumption data, including irrigation data, was converted into a unit of gallons per

[3] Some LEED certifications are kept confidential upon agreement by the building owner and the USGBC; these buildings were not available for analysis in this study.

building square foot to adjust for building size and ensure comparability. WEc 1.2 submittals reported on total building usage for those building seeking to earn extra points for reducing their water usage up to 30% below the calculated LEED baseline. There were 71 such submittals included in the analysis, after the cleaning of the dataset described in the section on methods of calculating measured water use.

MRc6 (waste) submittals report on a waste stream audit during a performance period ranging from one day to several months. This waste data can be reported by volume or by weight. Volumetric data was converted to weight using standard reference sources (see subsection on waste methods below) to ensure comparability. The submittals included information on amounts disposed to landfills and amounts diverted to recycling or composting facilities, enabling the research team to calculate disposal and diversion percentages for each building. The data also included measurement of the composition of the waste stream broken down into standard categories (paper, plastics, wet waste, etc). MRc7 submittals included the same data for buildings seeking to earn extra points for achieving at least 50% diversion of their waste streams. There were 144 such submittals, included in the analysis, after the cleaning of the dataset described in the section on methods of calculating measured waste.

The SSc4 (transportation) records contained data on the percentage reduction in conventional commuting trips using a metric known as Average Vehicle Ridership (AVR). AVR is essentially the ratio of the number of building occupants to the number of automobiles used to deliver them to the building each day, averaged over a period of recording (usually one week). If every occupant drives a single-occupancy automobile to the building, the AVR will equal 1.0. The more non-automobile modes (e.g. bus, rail, bicycle, walking) and carpooling are used to deliver occupants to the building, the higher the AVR will be.

The research team also attempted to collect measured data from commercial office buildings certified under other LEED rating systems, including LEED for New Construction (LEED-NC), LEED for Core and Shell (LEED-CS) and LEED for Commercial Interiors (LEED-CI), by issuing a survey to owners, operators and managers of buildings certified under these systems throughout California. Unlike LEED-EBOM, these are point-of-construction rating systems for which there are not yet any performance data at the time of certification. Obtaining operational data for these buildings would have enabled analysis of the performance of LEED-certified commercial office buildings relative to the performance predicted or implied by the rating systems and the GHG estimation methods for building strategies promulgated by CAPCOA.

The research team developed surveys of building operators (for water and waste performance data) and building occupants (for transportation performance data) and invested considerable effort in developing contacts among the operators of these LEED-certified buildings (i.e. the prospective respondents). The research team also developed contacts among key staff at large associations of building owners and operators, such as the Building Owners and Managers Association (BOMA) and United States Green Building Council (USGBC) chapters within California, to assist with distribution of the survey from August to October 2013. Despite these efforts, the number of returned and fully completed surveys was insufficient to support useful findings, due to the reluctance of most commercial building operators to record and/or disclose performance data on their buildings.

Water

Baseline water use

To determine the baseline for water use, we identified two existing studies that examined water use in commercial office buildings with a focus on California. These studies, Dziegielewski (2000) and Gleick et al (2003), provided a total of three potential baselines, shown in Table 3. Each baseline was normalized to units of annual gallons per 1000 square feet.

Table 3. Water baselines considered for use in analysis
(gallons/sf/yr)

	Dziegielewski (AWWA survey)	Gleick 1 (Pacific Inst from MWD survey)	Gleick 2 (Pacific Inst modeled)
Indoor	73.0	74.4	42.1
Irrigation	365.2	72.5	31.1
Cooling	66.1	43.9	34.9
Total	**504.3**	**190.8**	**108.1**

Sources: Derived from Dziegielewski (2000), Gleick et al (2003)

The Dziegielewski (2000) baseline was generated by a survey of commercial office buildings in Los Angeles, San Diego, Santa Monica, Irvine, and Phoenix. The two baselines in the Gleick et al (2003) report were generated in different ways. The first baseline is derived from data about water use in various employment sectors (in this case, commercial office buildings), modified by empirical data from a survey of office buildings conducted by the Metropolitan Water District of Southern California (MWD) that calculated the typical proportion of total water use devoted to indoor use, irrigation, and cooling tower use in office buildings in southern California. The second baseline was calculated by estimating typical water flow from indoor fixtures and fittings, irrigation needs, and cooling towers, then adding these together.

The research team elected to use the second Gleick et al (2003) baseline, i.e. the modeled approach, for this study. The Dziegielewski (2000) baselines, though based on empirical data, resulted in very high irrigation estimates that may be inappropriate for this analysis. The estimates reported in that survey were characterized by very large standard deviations (often twice the size of the mean), suggesting that the reported estimates were pulled upwards by outliers on the high-usage end of the distribution. In addition, the survey only covered cities in southern California and included Phoenix, AZ, possibly biasing the sample toward locations with particularly high irrigation demand relative to the conditions in California as a whole. Finally, given the specific locations under study in that survey, the sampled buildings may have been disproportionately situated on large parcels in suburban settings (hence with high irrigation demand per building square foot) relative to the population of California office buildings as a whole.

The Gleick et al (2003) baselines, though not as directly based on empirical data, lack these shortcomings and are based on estimates pertinent to the entire state. The second baseline ultimately was selected because it uses the same method that this study uses to generate a predicted value for office building water use (see below), meaning that discrepancies between the two due to methodological differences would be minimized. This baseline also has the lowest estimates of the three options, enabling this study to err on the side of conservatism in comparisons between baseline, predicted and measured values for water use.

Predicted water use

Values for predicted water use were derived from the 2010 California Green Building Standards Code (the "CalGreen" code in Title 24, Part 11) and the 2010 California Plumbing Code. These codes were selected because at the time most of the buildings under study were certified under LEED-EBOM, these codes represented the state's official standard of how a new green building in California should perform. Because the LEED-EBOM data on green building performance available to the research team did not include information on precisely what actions building designers and managers took to achieve water use performance, it was not possible to directly predict the water usage expected from those actions. Instead, the research team could only compare the water use expected from compliance with the state's green building code for new construction – reflecting the prevailing expectations of how a state-of-the-art green building should perform – with the actual performance of these existing buildings being certified as green, but not subject to the official state green building standards in question.

The CalGreen code contains standards for the indoor fixtures and fittings to be used in new green commercial office buildings, as well as information on the flow rates, durations of usage, and frequency of usage for each. When combined with plumbing code standards for occupant load factors (i.e. employees per square foot), these were used to generate estimates of anticipated water use per square foot for indoor usage, as shown in Table 4.

Table 4. Predicted indoor water use from 2010 CalGreen and CA Plumbing Codes
(Relevant fixtures and characteristics only)

Fixture	Flow rate			Duration		Daily uses			Fixture water use	Occupant load	Fixture water use	
	gal/min	gal/cycle	gal/flush	min	flush	all	male	female	gal/occupant/workday	(sf/occupant)	gal/tsf/workday	gal/sf/yr
Lavatory faucets	0.5			0.25		3			0.4	200	1.88	0.5
Kitchen faucets	2.2			4		1			8.8	200	44.00	11.4
Metering faucets		0.25		0.25		3			0.2	200	0.94	0.2
Water closets			1.6		1		1	3	6.4	200	32.00	8.3
Urinals			1		1		2		2.0	200	10.00	2.6
Total indoor											88.81	**23.1**

CalGreen also contains information that enables a prediction of irrigation water usage when combined with the California Department of Water Resources' (DWR 2010) data on evapotranspiration rates for various municipalities around the state (see Table 5). For each of the major metropolitan regions used in this study, the selected evapotranspiration rate was that of the largest city within the region, except in the Bay Area where Oakland was used because it represents a reasonable climatic average between the Bay Area's two major office cores in San Francisco and San Jose/Silicon Valley. The evapotranspiration rate for Redding was selected to represent the rest-of-California region since most coastal areas are within one of the other regions, and yet the largest cities in the Central Valley (e.g. Fresno, Bakersfield) are too hot and dry to reflect any averaging from the northern and mountain regions of the state.

The research team then used the method in DWR (2010) to calculate Estimated Total Water Use (ETWU) per square foot for landscaping for each of these five cities, assuming an average plant factor of 0.6 (in the middle of the possible range), the default irrigation efficiency (71%), and no "special landscape area" such as vegetable gardens or areas irrigated with recycled water. The ETWU was initially calculated per square foot of *irrigated* area. The research team then converted this to be expressed per square foot of *building* area (to ensure comparability with other results) using the ratio of average irrigated area to average building area (0.34) found among the 72 commercial office buildings surveyed by Dziegielewski (2000).

Table 5. Predicted irrigation usage from CalGreen code

	Sac metro (Sacramento)	Bay Area (Oakland)	LA metro (LA)	SD metro (SD)	Rest of CA (Redding)
Evapotranspiration rate (in/yr)	51.9	41.8	50.1	46.5	48.8
Estimated Total Water Use (gal/irrigated sf/yr)*	27.2	21.9	26.2	24.4	25.6
Estimated Total Water Use (gal/building sf/yr)**	9.2	7.4	8.9	8.3	8.7

Sources: 2010 California Green Building Standards Code, Section 5.304.1
DWR, 2010, Water Budget Workbook, Beta Version 1.01

CalGreen does not contain any standards for cooling towers, so the baseline value for cooling tower usage was used as the predicted value as well. Predicted whole-building water use is simply the sum of indoor, irrigation and cooling tower usage.[4]

Measured water use

The 2008 and 2009 LEED-EBOM rating systems enable applicants to seek optional credits for metering water use (WEc1.1), for sub-metering at least one sub-system (WEc1.2), and for achieving performance standards for indoor usage (WEc2) and/or irrigation usage (WEc3). The research team used the information on total building water usage and building square footage to express all usage on a per-square-foot basis. Buildings with water usages

[4] Process water (i.e. water used to create products or run mechanical processes) is negligible in office buildings.

above 1000 gallons per square foot were excluded from the subsequent analysis because this is an implausibly high usage rate that suggests an error in reporting on the part of the LEED applicant (such as reporting in gallons instead of the requested kilogallons, for example). In addition, any building record in which the reported usage for any sub-metered system was larger than the total building usage was also excluded from the analysis, since this also suggests a reporting error.

Buildings seeking the sub-metering credit are not required to sub-meter all of the sub-systems in the building to earn the credit, and no building did so. Thus, even among the sub-metered buildings, the dataset does not include direct measurement of indoor, irrigation and cooling tower usage in the same buildings. In addition, virtually no applicants chose to sub-meter indoor usage, but approximately half chose to sub-meter irrigation and more than half (not necessarily the same half) chose to sub-meter cooling tower usage. The calculation of measured water usage values therefore proceeded in the following steps:

1. Calculate the average total building usage for all buildings not excluded for reporting errors,
2. Calculate the average irrigation usage for buildings sub-metering irrigation usage,
3. Calculate the average cooling tower usage for buildings sub-metering cooling tower usage,
4. Impute the average indoor usage by subtracting the irrigation average and the cooling tower average from the whole-building average, and
5. Break these results down by region.

Step 5 revealed that for three of the regions (Sacramento, San Diego, and Rest-of-California), there were not enough records to enable reporting of reliable results. Hence, only data for the state as a whole, and for the Bay Area and Los Angeles regions, is reported.

LEED-EBOM also includes two optional credits for achieving specified water use efficiency levels (compared to the LEED baseline) for indoor usage and for irrigation usage. Only five buildings in the dataset earned the credit for irrigation efficiency, too small a number to form the basis for any analysis. The 71 buildings that earned the indoor efficiency credit, however, allow for an interesting supplemental analysis on the effectiveness of this performance credit in incentivizing water use efficiency. The research team therefore compared the indoor, irrigation and cooling tower water usage for these high-performing buildings (derived by the same five steps described immediately above) with that of the 115 buildings in the dataset that metered water usage but did not seek either of the performance credits.

Greenhouse gas intensity of water

The final component of the analysis was to estimate the GHG intensity of the water used (or not used) by these buildings. This involved estimating the energy intensity of the water in question and then estimating the GHG intensity of that energy. The energy intensity of the water varies significantly across the state, requiring the research team to estimate these values for each of the five regions separately.

Estimating the energy intensity of water requires making assumptions about the exact source of the water in question. While all of the major regions of the state draw from a variety of water sources, this study followed previous precedent for water-energy studies

(CEC 2006) and used a marginal-water approach to analyzing the energy intensity of avoided water use. In other words, it assumes that as water is conserved, the energy expenditures avoided will be those associated with the last water added to the supply, as opposed to the average water in the supply. This distinction is significant since the last water added is often the most energy-intense.

For the LA and San Diego regions, the marginal water is assumed to be State Water Project imports from the East Branch, among the most energy-intense water supplies in the state. The Sacramento region is water-rich and relies almost exclusively on localized surface water supplies. The Bay Area water portfolio is more complicated, with the major cities relying on water of very different origins (San Francisco's Hetch Hetchy system, the East Bay Municipal Utility District's Mokelumne Aqueduct system, and the State Water Project for San Jose and much of Silicon Valley). A regional weighted average of the energy intensity of these sources was created to represent the marginal water for the Bay Area. For the rest of the state, energy intensity typical of Central Coast and San Joaquin Valley groundwater extraction was used, since these are the major population areas of the state not included in the other regions, and groundwater pumping in these areas is likely to be cut back before any reductions in use of surface supplies.

The energy intensities associated with these marginal water supplies, presented in Table 6, are drawn from information in CAPCOA (2010) and a more recent study of the energy intensity of water in the LA region by Blanco et al (2012). These sources include estimates of the energy used to deliver water to the building for use, and for indoor use include the energy cost of wastewater treatment, but do not include any estimate of the energy involved in heating the water for use inside the building. To incorporate this factor, the research team applied the energy intensity of water heating identified by NRDC (2004) in an in-depth analysis of San Diego's water supply (20,562 kWh/MG), and assumed that 25% of indoor water use in office buildings is subject to heating.

Estimation of the GHG intensity of energy also took a marginal (as opposed to average) approach, assuming that the GHG intensity of the energy consumption avoided would be that of the "last electrons" added to the electricity supply, not the average of the entire supply. In previous research described in Mozingo and Arens (2013), ARB recommended the use of a statewide GHG intensity for marginal electricity of 0.000270 MT/kWh. For the Sacramento region, the average GHG intensity of the entire electricity supply is used because it is lower than the statewide marginal electricity estimate (E3 2010).

Table 6. Energy and GHG intensities for regional marginal water supplies

Region	Assumed origin	Quantity	Energy intensity of water		GHG intens. of energy	GHG intensity of water	
			Outdoor	Indoor		Outdoor	Indoor
		(TAF)	(kWh/MG)	(kWh/MG)	(MT/kWh)	(MT/gal)	(MT/gal)
Bay Area	State Water Project	188	2,817	9,869	0.000270	0.000000761	0.00000266
	Hetch Hetchy	265	1,383	8,435	0.000270	0.000000373	0.00000228
	Mokelumne	365	1,543	8,595	0.000270	0.000000417	0.00000232
	Weighted average		1,784	8,835	0.000270	0.000000482	0.00000239
Sac metro	Local/intrabasin		1,503	8,555	0.000233	0.000000350	0.00000199
SD metro	State Water Project (East)		3,459	10,511	0.000270	0.000000934	0.00000284
LA metro	State Water Project (East)		3,459	10,511	0.000270	0.000000934	0.00000284
Rest of state	Groundwater		2,279	9,331	0.000270	0.000000615	0.00000252

Source for water energy intensities: CAPCOA (2010), Table WSW-3.1, p. 345; Blanco et al (2012) for State Water Project
Source for marginal GHG intensities of energy: ARB personal communication; Sacramento marginal intensity from E3 (2010)
Source for Hetch Hetchy and Mokelumne diversion quantity: http://www.aquafornia.com
Source for water heating energy intensity incorporated in indoor estimate: NRDC (2004)

These GHG intensities for water were then applied to all baseline, predicted and measured water use for the buildings in each of the regions to generate the findings discussed in the Results chapter.

Waste

The two-step process for calculating the GHG co-benefits of waste reduction efforts in office buildings includes a determination of baseline, predicted and measured waste diversion rates and the GHG emissions associated with landfilled waste. The former relied on data collected by CalRecycle and the USGBC, while the latter involves the equations at the heart of ARB's Landfill Emissions Model tool.

Baseline waste diversion rates

CalRecycle has collected solid waste data over the past two decades, but the focus of this data has been on diversion and disposal rates for entire jurisdictions, and the landfills within them. After 2007, CalRecycle started to measure per-capita disposal rates as a means to measure program implementation by jurisdiction, but this data blends waste generation from all sources within the jurisdiction and does not distinguish between waste generation rates from different building types.

CalRecycle published Waste Characterizations Reports in 1999, 2004, 2006 and 2008 that look beyond waste streams in jurisdictions, at statewide practices. The reports from 1999, 2004 and 2008 all characterize the materials disposed at waste facilities throughout the State, derived from commercial, residential and self-haul waste streams. The 2006 Statewide Waste Characterization Report, however, examines diversion and disposal practices by key industry groups. After consultation with multiple experts at CalRecycle and elsewhere, the research team determined that this report contained the best available data for establishment of baseline values. Regional studies conducted in Los Angeles and

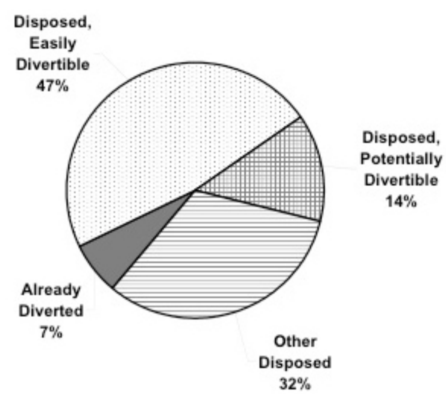
Alameda County report data by Standard Industrial Classification (SIC) codes and not by building types.

The 2006 Statewide Waste Characterization study categorizes industry groups by building types, and contains a specific category for large office buildings. The regional samples from this category for the statewide study were not large enough to form the basis for regionally specific baseline values, so the research team relied instead upon one statewide baseline value derived from the following data points:

- Waste generated by large office buildings: 1,998 pounds/1,000 square feet
- Waste diverted by large office buildings: 132 pounds/1,000 square feet

Hence, the baseline diversion rate for commercial office buildings in California is 7% (see Figure 1) and the generation rate is rounded to one ton per 1,000 square feet.

Figure 1. Diverted and divertible waste material in CA large office buildings, 2005 (From CalRecycle 2006).



Predicted waste diversion rates

CAPCOA (2010) provides a method for calculating emissions associated with building waste generation and utilizes CalRecycle's 2006 Statewide Waste Characterization Study for annual diversion rates, but it does not provide any additional waste diversion rate to serve as the basis for a predicted value. Furthermore, it acknowledges the complications involved with determining default waste diversion values, stating that "no literature references exist which provide default values for percent of waste diverted" (CAPCOA 2010, 392). CalGreen also makes no mention of any anticipated waste diversion rate for non-residential buildings during operation.

In the absence of an established prediction methodology, the research team used the policy goals embodied in state law. At the time that the buildings in our dataset were applying for LEED-EBOM certification, the leading solid waste management law in the state (AB 341) mandated a 50% solid waste diversion rate on a jurisdictional basis, with a goal of 75%

waste diversion statewide by 2020. AB 341 was subsequently updated in July 2012, shortly after the date of LEED certification of most of the buildings in the dataset, to extend the 50% target to commercial solid waste. Hence, at the time these buildings were applying for LEED certification, 50% was considered an appropriate goal for green buildings to achieve, but had not yet been mandated in state law (which would make it a new baseline). In addition, the 2006 Waste Characterization Study found that while only seven percent of office building waste was being diverted at that time, another 47% was "easily divertible" (see Figure 1). For these reasons, a 50% diversion rate was adopted as a reasonable predicted value for the operations of certified green buildings.

Measured waste diversion rates

Over 200 measured values for building waste diversion rates were collected from the LEED-EBOM buildings. The MRc6 credit requires an audit of the building's entire ongoing consumables waste stream, conducted during a performance period selected by the applicant. The data can be collected and reported in weight (pounds or tons) or volume (gallons) and are reported as such. Waste data reported by volume instead of weight was converted using the material-specific conversion factors found at a standard online conversion calculator (http://www.aqua-calc.com/calculate/volume-to-weight).

The total quantities of waste measured could have been used to determine a waste generation rate in addition to a diversion rate, except that there was no information in the records on how long the waste had been accumulating at the measurement point before the period of measurement. For this reason, it became apparent upon examination of the data that the most meaningful data from the samples would come from the diversion *percentages*, as opposed to quantities. The overall measured value diversion rate was therefore determined by taking the simple average of every building's waste diversion rate.

GHG intensity of landfilled waste

The leading tool with which to quantify the GHG emissions associated with waste diversion in California is the Landfill Emissions Tool Version 1.3, which implements the mathematically exact first-order decay model of the 2006 IPCC guidelines for landfills. In consultation with subject experts at ARB, the research team adapted the calculations underlying the landfill model for use on office building waste streams, especially the following formula (shown in expanded form here for clarity of explanation) for use at landfills that have methane collection systems:

$MTCO_2e$ / MT of waste = (ANDOC% x 0.5 x 1.33 x 25) x ((0.75 x 0.01) + (0.25 x 0.9))

Where:

- ANDOC% = the percentage of waste material that is anaerobically degradable carbon
- 0.5 = the proportion of ANDOC that converts to methane (CH4)
- 1.33 = the ratio of methane to carbon (C)
- 25 = the conversion factor to convert methane quantity into CO2-equivalent
- 0.75 = the proportion of methane captured by the collection system
- 0.01 = the proportion of captured methane that escapes from the collection system
- 0.25 = the proportion of uncaptured methane that escapes through the soil
- 0.9 = the proportion of the uncaptured methane that is not oxidized in the soil

This involved selecting values for the proportion of Anaerobically Degradable Carbon (ANDOC) in the office building waste stream. From the trends displayed in the measured waste values (see Figure 4), it was determined that the majority of waste being sent to landfill (disposed) from office buildings is on average comprised of 70% wet waste (largely food) and 30% paper. Using these percentages, the research team was able to calculate a unique weighted ANDOC percentage applicable to all office building waste streams in California. That ANDOC value was then used in the above formula that determines the amount of methane (CH_4) emissions per metric ton of waste for landfills with gas collection systems. Though gas collection systems are not universally employed by landfills in California, they are present in the large majority of landfills servicing the metropolitan areas where green building are concentrated (CalRecycle 2013), so their presence was assumed for purposes of these calculations. Landfills also emit carbon dioxide, but these emissions are not considered by ARB to be an anthropogenic emissions source subject to emissions control efforts and are therefore ignored here.

Transportation

The analysis of transportation usage centered on the metric known as average vehicle ridership (AVR), essentially the ratio between the number of office building occupants and the number of cars it takes to bring them to the building on a typical day. Because the measured transportation data available from the USGBC reports on building AVR, the research team developed original methods for calculating baseline and predicted AVR for the five regions being analyzed.

Baseline transportation usage

The main data source for the transportation baselines is the American Community Survey (ACS), conducted annually by the U.S. Census Bureau, which gathers data on means of transportation to work (Table B08301) and compiles those data on a county-by-county basis and on a one-year, three-year or five-year time span. Given that the LEED-EBOM green buildings in our dataset were certified between 2008 and 2012, we chose to examine five-year county transportation data compiled over those years for each county within our metropolitan regions.

The boundaries of our four metropolitan regions follow those of the respective Metropolitan Planning Organizations (MPOs), the Southern California Association of Governments (SCAG), the Bay Area Metropolitan Transportation Commission and Association of Bay Area Governments (MTC/ABAG), the Sacramento Area Council of Governments (SACOG), and the San Diego Association of Governments (SANDAG). Each of these MPOs contains only whole counties, and because they form geographical units used for regional transportation planning, are sufficiently representative of the actual commute-sheds of buildings in our dataset. The counties involved are named in Table 7. The values for the "rest-of-state" region were derived by removing the effects of the four major regions from the statewide totals reported in the ACS through a simple algebraic equation.

Table 7. Counties included in major CA metropolitan planning organizations

MTC (Bay Area)	SCAG (LA)	SACOG (Sacramento)	SANDAG (SD)
Alameda	Imperial	El Dorado	San Diego
Contra Costa	Los Angeles	Placer	
Marin	Orange	Sacramento	
Napa	Riverside	Sutter	
San Francisco	San Bernardino	Yolo	
San Mateo	Ventura	Yuba	
Santa Clara			
Solano			
Sonoma			

The ACS data estimate the total number of commuters for drive-alone, 2-person carpools, 3-person carpools, 4-person carpools, 5 or 6-person carpools, 7-person or more carpools, public transportation, bus or trolley bus, streetcar or trolley car, subway or elevated, railroad, ferryboat, taxicab, motorcycle, bicycle, walking, other means, and "worked at home" for every county. A sample of this data for Alameda County, California is shown in Table 8.

Table 8. Sample American Community Survey commute data for Alameda County, 2008-2012
(# of commuters using each mode)

Total:	693,960
Car, truck, or van:	527,826
Drove alone	454,660
Carpooled:	73,166
In 2-person carpool	54,162
In 3-person carpool	13,176
In 4-person carpool	3,583
In 5- or 6-person carpool	1,155
In 7-or-more-person carpool	1,090
Public transportation (excluding taxicab):	82,417
Bus or trolley bus	31,062
Streetcar or trolley car (carro publico in Puerto Rico)	1,056
Subway or elevated	42,900
Railroad	6,412
Ferryboat	987
Taxicab	301
Motorcycle	2,050
Bicycle	11,945
Walked	26,202
Other means	6,872
Worked at home	36,347

To calculate the baseline AVR for each region, the categorical totals were summed together across the different counties in order to find:

- The total number of commuters in the region (N_{total})
- The total number of vehicle users (car, truck or van) driving alone (V_{DA})
- The estimated number of vehicles (car, truck or van) used for carpooling (V_{CP})

The estimated number of vehicles used for carpooling, V_{CP}, is calculation by simply dividing the number of commuters who carpooled by the size of the carpool (e.g. the number of carpoolers in two-person carpools divided by two, the number of carpoolers in three-person carpools divided by three, etc.), then summing the estimated number of vehicles across the carpool category. The "5 or 6-person" carpool category was assumed to carry 5.5 people per carpool, and the "7-or-more-person carpool" category was assumed to carry 7.5 people per carpool.

The regional AVR is defined as the adjusted total number of vehicles divided by the total of all commuters for a region. For each region, we calculated the baseline AVR as follows:

$$\frac{Number\ of\ commuters}{Number\ of\ vehicles} = \frac{N_{total}}{(V_{DA} + V_{CP})}$$

Table 9 shows the baseline AVRs for the five major regions.

Table 9. Baseline average vehicle ridership (AVR) for major CA regions

	Commuters	Vehicles	AVR
Bay Area	3,400,199	2,444,789	1.39
LA metro	7,886,161	6,271,379	1.26
Sacramento metro	984,449	792,260	1.24
SD metro	1,431,134	1,152,142	1.24
Rest of state	11,810,893	9,116,305	1.29

Predicted transportation usage

Prediction of transportation usage was performed based upon the location of the buildings in the study dataset. LEED-EBOM does not require the reporting of any other building characteristics or management strategies, such as the amount and allocation of parking spaces, that might influence commute AVRs and therefore GHG emissions.

AVR is fundamentally a measure of mode share, i.e. the proportion of commuters using various transportation modes, and not of vehicle miles traveled (VMT). Fortunately, CAPCOA (2010) provides an equation, shown in Figure 2, for predicting rail transit mode share based upon the proximity of buildings to rail stations, and this equation can be used to adjust regional baseline AVRs to reflect the AVR that this particular set of buildings, based on their locations, "should" be achieving. This process makes no adjustment for bus transit, bicycling, walking or other non-automobile modes. For this reason, the predicted AVRs resulting from this method can be thought of as conservative, i.e. closer to the regional baseline than would be expected if all non-automobile modes were included in the analysis.

Figure 2. Equations for calculating transit mode share as a function of distance of destination to transit.

Distance to transit	Transit mode share calculation equation (where x = distance of project to transit)
0 – 0.5 miles	-50*x + 38
0.5 to 3 miles	-4.4*x + 15.2
> 3 miles	no impact

The research team identified the distance of each building in the study dataset to the nearest rail station using Google Maps. The distance between the building and the rail station was defined as the walking distance over the street network, and was determined by activating Google Maps' pedestrian walking directions function, which indicates the total walking distance between two identified points. The predicted rail transit mode share was then calculated for each building using the appropriate component of the CAPCOA equation, and the predicted rail transit mode shares for all buildings in a given region were then averaged.

For each region, the averaged predicted rail mode share was then used to modify the baseline regional AVR. For purposes of calculating AVR, all non-automobile trips are equivalent because they deliver a building occupant to the site without the use of a car. The three components that matter for the calculation of AVR, therefore, are the use of single-occupancy automobiles, the use of carpools, and the use of all other modes combined. The third of these components was modified to reflect the additional rail trips predicted for this set of buildings, and the other two categories reduced proportionally, to create a new AVR. This method assumes that the additional rail commute trips will displace carpool trips at the same rate that they displace single-occupancy vehicle trips. The mathematical process by which this AVR adjustment was performed, using the Sacramento region as an example, is illustrated in Figure 3. The predicted AVRs are incorporated into Table 17.

Figure 3. Process for calculating predicted regional AVR (Sacramento example).

Method	labels	values	Notes and formula
Census data	Drove alone	0.752	P_{DA}, *portion of employees driving alone*
	Carpooled	0.049	P_{CP}, *portion of employees doing carpooling*
	All other	0.200	P_{other}, *portion of person using other means of transportation*
	Rail (all forms)	0.007	$P_{light\ rail}$, *portion of person using rail* *Included in* P_{other} *Sum of Census "street car or trolley car", "subway or elevated" and "railroad" categories*
	Carpool size	2.41	$carpool\ size = \frac{\sum_k \frac{P_{CPk}}{k}}{P_{CP}}$ *Where* *k is the number of person in a k − person carpool* P_{CPk} *is the portion of emplyees in a k − person carpool* P_{CP} *is the portion of employees doing carpooling*
CAPCOA	Predicted rail	0.197	*Derived from dataset using formulas in Figure 2*
	Increase in rail	0.190	*Difference between "predicted rail" and "rail" categories*
	All other (predicted)	0.321	P_{other} *predicted*, *predicted portion of person using other means of transportation* Sum of "all other" accounted with the "rail" increased number
	Drove alone (predicted)	0.587	P_{DA} *predicted*, *predicted portion of employees driving alone* Ratio of "drove alone" relative to "carpooled" accounted with "all other (predicted)" increased value $= (1 - P_{other}\ predicted) * \frac{P_{DA}}{(P_{DA} + P_{CP})}$
	Carpooled (predicted)	0.092	P_{CP} *predicted*, *predicted portion of employees doing carpooling* Ratio of "carpooled" relative to "drove alone" accounted with "all other (predicted)" increased value $= (1 - P_{other}\ predicted) * \frac{P_{CP}}{(P_{DA} + P_{CP})}$
	Predicted AVR	1.599	$\frac{(P_{other}\ predicted +\ P_{DA}\ predicted + P_{CP}\ predicted)}{\left(P_{DA}\ predicted + \frac{P_{CP}\ predicted}{carpool\ average\ size}\right)}$

Measured transportation usage

The measured data for this research are based on the LEED-EBOM 2008 and 2009 submittal data for the Sustainable Sites credit 4 (SSc4) credit. For each of the buildings considered, the database provides the points for the SSc4 credit which is associated with a percentage of reduction in conventional trips. Tables 10 and 11 provide the scales for the 2008 and 2009 versions, respectively, of LEED-EBOM.

Tables 10 and 11. Distribution of points for the SSc4 credit in LEED-EBOM versions 2008 and 2009.

Demonstrated % reduction in conventional commuting trips	Points
10	1
25	2
50	3
75	4

Table 10 LEED EBOM v 2008

Demonstrated % reduction in conventional commuting trips	Points
10	3
13.75	4
17.50	5
21.25	6
25	7
31.25	8
37.5	9
43.75	10
50	11
56.25	12
62.50	13
68.75	14
75	15

Table 11 LEED EBOM v 2009

The "demonstrated percentage reduction in conventional commuting" used in the LEED reporting is equivalent to the improvement in the reported AVR value compared to the LEED baseline of 1.0 (i.e. everyone commutes by single-occupancy automobiles). As a result, the percentage reductions can be directly converted to AVR values, i.e. a 10% reduction of conventional trips will results in an AVR of 1.1, a 20% reduction will result in an AVR of 1.2, and so on.

Because only binned data are available, the team assumed that each building actually demonstrated a percentage reduction on average 25% above the lower threshold of the bin provided by the LEED rating system (see Table 12). A possible alternative would be to assume that the actual AVRs are clustered around the midpoint of the range (i.e. 50% above the lower threshold), but the research team elected not to assume this for two reasons. First, given the point-based incentives to reach each threshold, it seemed more likely that the AVRs are not evenly distributed throughout each bin range but are instead likely clustered in the lower half of each bin range. Second, given the high GHG-intensity of transportation, the research team felt it important to be conservative in any assumptions about building performance relative to baseline and predicted values, since small differences in assumptions could result in estimates of large, but potentially illusory, GHG savings.

Table 12. Assumed measured AVRs for each LEED-EBOM point bin's lower threshold

Demonstrated % reduction in conventional commuting trips	Assumed measured AVR
10	1.125
13.75	1.171875
17.50	1.21875
21.25	1.265625
25	1.3125
31.25	1.390625
37.5	1.46875
43.75	1.546875
50	1.625
56.25	1.703125
62.50	1.78125
68.75	1.859375
75	1.9375

These measured AVR values were then averaged across buildings within each region to create a measured AVR value for the LEED-EBOM buildings within each region that can be compared to the baseline and predicted AVRs.

GHG intensity of transportation

The GHG intensity of each mode of travel, expressed as pounds of CO_2e emitted per passenger mile traveled, was obtained from the individual emissions calculator at travelmatters.org, developed by the Center for Neighborhood Technology for the Federal Transit Administration (Feigon et al 2003). This tool enables users to determine the per-mile emissions resulting from travel by various modes in locations around the country, including California. Though they are state-specific, the coefficients are now over ten years old and therefore do not reflect the gradual de-carbonization of fuel stocks resulting from the state's Low Carbon Fuel Standard and Renewable Portfolio Standard.

For baseline values, the GHG intensity of each region's AVR was determined by creating an average of the GHG intensities of the modes used, weighted by the proportion that each mode was used in that region. This yielded a GHG intensity for each AVR expressed in pounds of CO_2e per mile commuted. This was then converted into metric tons of CO_2e per 1000 square feet per year of office building by assuming a typical occupant loading of 5 occupants per 1000 square feet (drawn from the 2010 California Plumbing Code), a typical commuting distance of 12 miles each way, or 24 miles per occupant per day (drawn from findings on average commute distance in ARB 2012a and 2012b), and a typical workyear of 260 days. The same method was used for predicted AVRs, except that the GHG intensity of the extra predicted rail trips was represented by the arithmetic average of the GHG intensities of the various rail modes (streetcar or trolley car, subway or elevated, and railroad) denominated in the ACS data.

For measured AVR data, the method was somewhat different because the measured data does not contain any breakdown of the means of transportation to work for each building. All non-automobile trips are equivalent with respect to AVR but do not have the same GHG footprint, so it is necessary to assume something about the proportion of non-automobile trips taken by various modes (rail, bus, bicycling, walking, etc.). Because the measured AVRs are fairly similar to the baseline AVRs and there is no other reason to assume dramatic differences in the selection of travel modes, the research team assumed that the proportional distribution of non-automobile trips in the measured AVR was the same as the ACS data that formed the basis for the baseline AVR. With respect to car drivers, the research team also assumed that the relative proportions of people driving alone and carpooling are the same for the measured AVR as for the baseline AVRs.

After adjusting the number of employees driving alone or carpooling and keeping the distribution for the other means of transportations identical to the baseline AVR, the GHG emissions in metric tons of CO_2e per 1000 square feet per year was calculated with the same method used for the baseline and predicted AVRs.

Results

The results of our analysis are shown in Tables 13 to 19. The results for all three resource areas are expressed in units of metric tons of carbon dioxide-equivalent per 1000 square feet of commercial office space per year ($MTCO_2e$/1000sf/yr). This normalization enables comparison of the three resource areas to one another, and also facilitates expression of the results in terms of the emissions savings achievable per office building types, or per the entire commercial office building stock of California.

Water

Table 13 shows water results for indoor usage, irrigation usage, and cooling tower usage independently, as well as whole-building usage (which is the sum of these). Two regions, the Bay Area and Los Angeles, have enough buildings in the sample to enable them to be examined independently of the set as a whole. The 191 LEED-EBOM buildings in the dataset in general show noteworthy reductions of water usage from both baseline and predicted values. Total building usage for the entire dataset was measured at 48.5 gal/sf/yr, about 55% below the baseline of 108.2 gal/sf/yr and about 27% below the predicted value of 66.6 gal/sf/yr. The GHG emissions improvements vary from the usage improvements because the GHG intensity of water varies both regionally and depending on the use of the water (indoor usage includes energy expenditure for heating and sewage treatment, whereas outdoor usage does not). The GHG emissions reductions for total building water usage are 50% compared to baseline, and 13% compared to prediction. Notably, these values are substantially better for 63 buildings in the LA region than for the 89 buildings in the Bay Area, where water-related GHG emissions are actually 16% higher for the measured values than the predicted values.

For indoor use, measured values for Bay Area LEED-EBOM buildings (29.5 gal/sf/yr) exceed the predicted value of 23.1 gal/sf/yr, and as a result pull the statewide result up to 23.5 gal/sf/yr, also above the predicted value. Indoor usage in the LA EBOM buildings, by contrast, is considerably lower, at only 14.2 gal/sf/yr.

Irrigation usage for both predicted and measured values is considerably lower than the baseline of 31.1 gal/sf/yr. (Irrigation values are expressed per square foot of building, rather than per square foot of irrigated area, to maintain comparability with indoor and cooling tower usage). Measured irrigation usage among Los Angeles EBOM buildings exceeds the predicted value of 8.9 gal/sf/yr, while both Bay Area EBOM buildings and the dataset as a whole used 10.6 gal/sf/yr, for irrigation, as compared to predicted values of 8.1 and 8.6 gal/sf/yr, respectively.

Cooling tower usage in both regions, and statewide, is also considerably lower than the baseline and predicted value of 34.9 gal/sf/yr. The 43 LA-region buildings in the dataset measuring cooling tower use reported only 5.4 gal/sf/yr, 85% below baseline and prediction, while Bay Area EBOM buildings were at 23.3 gal/sf/yr, still 33% below baseline and prediction. This over-performance in cooling tower usage relative to prediction outweighs the under-performance in indoor and irrigation usage to yield total building measured values that are better than prediction.

The water results also include analysis of the effect of the EBOM performance credit for extra-efficient indoor water usage (see Table 14). The 71 buildings achieving this credit

Table 13. Water Usage and Associated GHG Emissions in CA Certified Green Office Buildings

	N	Baseline		Predicted		Measured		Usage improvements		GHG improvements	
		Water use gal/sf/yr	GHG emissions MT CO2e/1000sf/yr	Water use gal/sf/yr	GHG emissions MT CO2e/1000sf/yr	Water use gal/sf/yr	GHG emissions MT CO2e/1000sf/yr	Base-Measure	Pred-Measure	Base-Measure	Pred-Measure
Indoor usage	191	42.1	0.106	23.1	0.058	23.5	0.060	44%	-2%	43%	-3%
Bay Area	*89*	*42.1*	*0.100*	*23.1*	*0.055*	*29.5*	*0.070*	*30%*	*-28%*	*30%*	*-27%*
LA region	*63*	*42.1*	*0.119*	*23.1*	*0.066*	*14.2*	*0.040*	*66%*	*39%*	*66%*	*39%*
Irrigation usage	95	31.1	0.021	8.6	0.006	10.6	0.008	66%	-23%	62%	-33%
Bay Area	*35*	*31.1*	*0.015*	*8.1*	*0.004*	*10.6*	*0.005*	*66%*	*-31%*	*67%*	*-25%*
LA region	*37*	*31.1*	*0.029*	*8.9*	*0.008*	*13.1*	*0.012*	*58%*	*-47%*	*59%*	*-50%*
Cooling tower usage	117	34.9	0.023	34.9	0.023	14.4	0.008	59%	59%	-	65%
Bay Area	*61*	*34.9*	*0.017*	*34.9*	*0.017*	*23.3*	*0.011*	*33%*	*33%*	-	*35%*
LA region	*43*	*34.9*	*0.033*	*34.9*	*0.033*	*5.4*	*0.005*	*85%*	*85%*	-	*85%*
Total building usage	**191**	**108.2**	**0.149**	**66.6**	**0.086**	**48.5**	**0.075**	**55%**	**27%**	**50%**	**13%**
Bay Area	*89*	*108.2*	*0.132*	*66.1*	*0.075*	*63.4*	*0.087*	*41%*	*4%*	***34%***	*-16%*
LA region	*63*	*108.2*	*0.181*	*66.9*	*0.106*	*32.7*	*0.058*	*70%*	*51%*	***68%***	*45%*

Table 14. Analysis of Buildings Earning LEED-EBOM Water Performance Credit

	Indoor Perf Credit (W2) Bldgs			Non-Perf Credit Bldgs			Usage Improvements		GHG Improvements	
	N	Water use gal/sf/yr	GHG emissions MT CO2e/1000sf/yr	N	Water use gal/sf/yr	GHG emissions MT CO2e/1000sf/yr	Nonperf-Perf	Pred-Perf	Nonperf-Perf	Pred-Perf
Indoor usage	71	12.3	0.019	115	30.4	0.048	60%	47%	60%	67%
Irrigation usage	35	7.4	0.012	55	12.5	0.020	41%	14%	40%	40%
Cooling tower usage	39	11.5	0.018	75	16.3	0.025	29%	67%	28%	22%
Total building usage	**71**	**31.2**	**0.046**	**115**	**59.2**	**0.092**	**47%**	**53%**	50%	53%
Bay Area	*34*	*36.3*	*0.050*	*55*	*80.2*	*0.110*	*55%*	*45%*	*55%*	*33%*
Los Angeles	*20*	*16.2*	*0.029*	*41*	*40.6*	*0.071*	*60%*	*76%*	*59%*	*80%*

Table 15. Solid Waste Disposal Rates and Associated GHG Emissions in CA Certified Green Office Buildings

	N	Baseline			Predicted			Measured			Usage improvements		GHG improvements	
		Diversion	Disposal	GHG emissions MT CO2e/1000sf/yr	Diversion	Disposal	GHG emissions MT CO2e/1000sf/yr	Diversion	Disposal	GHG emissions MT CO2e/1000sf/yr	Base-Measure	Pred-Measure	Base-Measure	Pred-Measure
Total building usage	**233**	**7%**	**93%**	**0.079**	**50%**	**50%**	**0.043**	**52%**	**48%**	**0.041**	**48%**	**4%**	**48%**	**4%**
Bay Area	*105*	*7%*	*93%*	*0.079*	*50%*	*50%*	*0.043*	*53%*	*47%*	*0.040*	*49%*	*6%*	*49%*	*6%*
LA region	*74*	*7%*	*93%*	*0.079*	*50%*	*50%*	*0.043*	*53%*	*47%*	*0.040*	*49%*	*6%*	*49%*	*6%*

Table 16. Analysis of Buildings Earning LEED-EBOM Solid Waste Performance Credit

	Waste Perf (MRc7) Buildings				Non-Perf Credit Bldgs				Usage Improvements		GHG Improvements	
	N	Diversion	Disposal	GHG emissions MT CO2e/1000sf/yr	N	Diversion	Disposal	GHG emissions MT CO2e/1000sf/yr	Nonperf-Perf	Pred-Perf	Nonperf-Perf	Pred-Perf
Total building usage	**144**	**65%**	**35%**	**0.030**	**84**	**39%**	**61%**	**0.052**	**43%**	**30%**	**43%**	**30%**

used 31.2 gal/sf/yr, an improvement of 47% over the 115 EBOM buildings that did not earn the credit. As would be expected, these improvements were most pronounced for indoor usage (60%), but are also sizable for irrigation and cooling tower usage (41% and 29%, respectively). Notably, the EBOM rating systems of 2008 and 2009 only awarded points for reductions of up to 30% for indoor usage compared to the minimum level that all certified EBOM buildings are required to achieve. Hence, the observed performance gap between buildings earning the indoor efficiency credit and those not earning it is considerably larger than one would expect from the EBOM rating system itself.

Comparing Tables 14 and 13, it is noteworthy that the EBOM buildings *not* earning the indoor performance credit underperform the predicted value for indoor usage (30.4 gal/sf/yr compared to 23.1 gal/sf/yr) but still outperform the baseline value of 42.1 gal/sf/yr. They also underperform the predicted irrigation usage (12.5 gal/sf/yr compared to 8.6 gal/sf/yr), but because they substantially outperform the predicted value for cooling tower usage, the total building usage for these buildings is still better than prediction (59.2 gal/sf/yr compared to 66.6 gal/sf/yr), and significantly better than the baseline of 108.2 gal/sf/yr.

Waste

Table 15 shows detailed results for waste diversion rates for the statewide EBOM dataset, as well as the Bay Area and LA regions. As noted in the methods section, the baseline, predicted and measured values in question are the diversion rates for solid waste (i.e. the percentage of solid waste sent to landfill as opposed to recycling or compost), assuming a given rate of generation of solid waste (1,998 pounds/1000sf/yr). Hence, higher diversion rates are better from the point of view of GHG emissions.

Statewide, the EBOM buildings achieve a diversion rate of 52%, compared to the baseline rate of 7% and predicted rate of 50%. Because the GHG impact is calculated from the disposal rate (the inverse of the diversion rate), these figures represent a 48% and 4% improvement over baseline and prediction, respectively. The EBOM buildings of the Bay Area and LA regions happen to achieve the same diversion rate of 53%, approximately the same as the state as a whole.

The LEED-EBOM rating system also contains a performance credit for improved waste diversion rates that requires, among other things, that 50% of "ongoing consumables" (as opposed to construction waste or other forms of solid waste) be reused, recycled or composted, equivalent to a diversion rate of 50%. The buildings earning this credit actually achieved diversion rates of 65%, compared to 39% for the EBOM buildings not earning the credit (see Table 16). As with the performance credit for water, the observed performance of buildings achieving this credit exceeds what one would expect from the EBOM rating system itself. In addition, even the buildings not seeking the performance credit significantly outperform the baseline diversion rate of 7%.

Transportation

The detailed results of the transportation analysis are shown in Table 17. As noted previously, the unit of analysis is Average Vehicle Rideship (AVR), essentially a ratio of the number of employees in a given office building and the number of cars it takes to bring

Table 17. Transportation Rates and Associated GHG Emissions in CA Certified Green Office Buildings

	N	Baseline		Predicted		Measured		Usage Improvements		GHG Improvements	
		AVR	GHG emissions MT CO2e/1000sf/yr	AVR	GHG emissions MT CO2e/1000sf/yr	AVR	GHG emissions MT CO2e/1000sf/yr	Base-Measure	Pred-Measure	Base-Measure	Pred-Measure
Total building usage	**196**	**1.32**	**13.60**	**1.54**	**12.20**	**1.40**	**12.99**	**5%**	**-11%**	**5%**	**-6%**
Bay Area	*99*	*1.39*	*13.17*	*1.60*	*11.92*	*1.51*	*12.17*	*8%*	*-6%*	*8%*	*-2%*
LA region	*54*	*1.26*	*14.11*	*1.41*	*12.88*	*1.28*	*13.86*	*2%*	*-10%*	*2%*	*-8%*

Table 18. Summary of GHG Emissions Rates from Water, Waste and Transportation in CA Certified Green Office Buildings

	N	Baseline	Predicted	Measured	Hi-Performance	GHG Improvements		
		GHG emissions MT CO2e/1000sf/yr	GHG emissions MT CO2e/1000sf/yr	GHG emissions MT CO2e/1000sf/yr	GHG emissions MT CO2e/1000sf/yr	Base-Measure	Pred-Measure	Base-Hi Perf
Water	191	0.149	0.086	0.075	0.046	50%	13%	69%
Waste	233	0.079	0.043	0.041	0.030	48%	4%	62%
Transportation	196	13.605	12.204	12.988		5%	-6%	
Operational energy (for comparison)		5.289						

them to work on a given workday. A higher AVR indicates a higher employee–to-car ratio with lower GHG impacts.

The measured AVR value for the EBOM dataset as a whole is 1.40, a 5% improvement over the baseline of 1.32, but 11% below (worse than) the predicted AVR of 1.54 generated by observing the distance to rail transit for each building and applying the CAPCOA formula for mode share (see methods section for detail). The GHG emissions impacts of these buildings' transportation patterns were only 6% below (worse than) prediction, however, given the regional distribution of the mode shifts.

The measured AVR value for Bay Area EBOM buildings is 1.51, 8% above the baseline and 6% below prediction (2% below for GHGs). For the LA region, measured AVR for the EBOM buildings was 2% above baseline but 10% below prediction (8% below for GHGs). There is no additional credit in LEED-EBOM for transportation behavior beyond the one from which this AVR data was drawn, so no supplementary analysis akin to that performed for water and waste performance credits was possible.

Table 18 shows a summary of the statewide results from all three resource areas. A baseline values for operational energy, derived from the California Commercial End-Use Study (CEUS), is shown for the sake of comparison (Itron 2006). This figure was derived by applying the same estimate of the statewide marginal GHG intensity of electricity described in the water methods section, as well as the EPA (2014) estimate for the GHG intensity of natural gas, to the per-square-foot energy consumption data compiled by CEUS for California office buildings.

Total emissions comparisons

Table 19 shows the levels of GHG emissions and potential emissions savings that might be expected from typical commercial office buildings of various sizes, and California's office building stock as a whole, from these three resource areas. These comparisons rely on an implicit assumption that all commercial office buildings, as a whole, could attain performance comparable to the LEED-EBOM buildings studied here. While not all existing buildings could meet such standards individually, others could significantly exceed them under the right code requirements. This extrapolation is meant simply to illustrate the approximate potential of the commercial office building sector to avoid GHG emissions from these three resource areas, and to offer insight into the role that commercial office buildings could play in GHG control efforts in California. (See the discussion section below for more detail).

The 2006 CEUS study sample, selected to be statistically representative of California's office building stock, had an average building size of 12,968 sf. A building that size using typical construction could be expected to trigger emissions of 1.93 $MTCO_2e$/yr from water use, 1.03 $MTCO_2e$ /yr from solid waste, 176.42 $MTCO_2e$/yr from transportation. A LEED-EBOM building of that size, however, would reap emissions savings of 0.96 $MTCO_2e$ /yr from water use efficiency, 0.50 $MTCO_2e$ /yr from solid waste, and 8.00 $MTCO_2e$ /yr from transportation compared to that typical construction.

The emissions levels expected from office buildings of various sizes scale upward linearly. Potential savings from a large urban high-rise office building of 500,000 sf (about 32 stories) would be 37.00 $MTCO_2e$ /yr from water, 19.13 $MTCO_2e$ /yr from solid waste, and

Table 19. Summary of GHG Emissions Co-Benefits from Water, Waste and Transportation in CA Office Buildings

All figures in MT CO2e/yr

	Baseline Emissions	Predicted Emissions	Measured Emissions	Hi-Performance Emissions	Potential GHG Improvements		
					Base-Measure	Pred-Measure	Base-Hi Perf
Average office building (12,968 sf)							
Water	1.93	1.12	0.97	0.60	0.96	0.14	1.34
Waste	1.03	0.55	0.53	0.39	0.50	0.02	0.64
Transportation	176.42	158.26	168.43		8.00	(10.17)	
Large office building (100,000 sf)							
Water	14.90	8.60	7.50	4.60	7.40	1.10	10.30
Waste	7.91	4.25	4.08	2.98	3.83	0.17	4.93
Transportation	1,360.45	1,220.38	1,298.78		61.67	(78.41)	
High-rise office building (500,000 sf, ~32 stories)							
Water	74.50	43.00	37.50	23.00	37.00	5.50	51.50
Waste	39.53	21.25	20.40	14.88	19.13	0.85	24.65
Transportation	6,802.26	6,101.89	6,493.92		308.35	(392.03)	
All CA office buildings (1.14 billion sf)							
Water	169,860.00	98,040.00	85,500.00	52,440.00	84,360.00	12,540.00	117,420.00
Waste	90,117.00	48,450.00	46,512.00	33,915.00	43,605.00	1,938.00	56,202.00
Transportation	15,509,159.25	13,912,303.64	14,806,132.50		703,026.75	(893,828.86)	
Total	**15,769,136.25**	**14,058,793.64**	**14,938,144.50**	**14,892,487.50**	**830,991.75**	**(879,350.86)**	**876,648.75**

308.35 $MTCO_2e$ /yr from transportation when comparing LEED-EBOM certification to typical construction.

The area of California covered by the CEUS survey contains about 1.02 billion sf of commercial office space (Itron 2006). The survey covered electric utility service areas that contain all of the important office markets in the state with the notable exception of the service area of the LA Department of Water and Power – essentially the City of Los Angeles plus portions of a few neighboring cities. Drawing upon economic reports prepared by the commercial real estate company CBRE (2014), the City of Los Angeles is estimated to contain about 120 million sf of office space. Thus, the state of California as a whole is estimated to contain approximately 1.14 billion sf of office space.

Typical construction of that square footage triggers about 0.170 million megatons (MMT) of CO2e/year from water use, 0.090 $MMTCO_2e$/year from solid waste, and 15.509 $MMTCO_2e$ /yr from transportation. Savings relative to baseline from LEED-EBOM certification of the entire California office building stock, if it performed identically to the buildings studied here, would be about 0.084 $MMTCO_2e$ /yr from water use, 0.044 $MMTCO_2e$ /yr from solid waste, and 0.703 $MMTCO_2e$ /yr from transportation, for a total of about 0.831 $MMTCO_2e$ /yr. Stock-wide achievement of the water use and solid waste diversion rates of the buildings earning additional performance credits under LEED-EBOM would boost the total potential emissions savings to about 0.877 $MMTCO_2e$ /yr.

Discussion

These results show that green building certification with respect to water, waste and transportation does indeed produce important GHG co-benefits relative to baseline levels reflecting typical office construction. Water usage and waste diversion performance, in particular, is significantly improved by green building certification relative to baseline, even among buildings that do not seek additional performance-based credits within the EBOM rating system. In general, the certified green buildings approximately match the performance predicted for them for waste and indoor water usage (on a statewide basis), but fall short of predicted performance for irrigation water usage and transportation.

Water

In general, EBOM buildings are achieving very significant water savings relative to baseline, and this is true even though the research team selected the most conservative of three possible baselines (see methods section). Bay Area LEED-EBOM buildings are significantly underperforming the predicted values for both indoor (-28%) and irrigation (-31%) usage, while LA region buildings are underperforming for irrigation (-47%). The LEED-EBOM buildings are shown to be saving considerable water (27% overall) relative to predicted values, but this is entirely due to dramatic over-performance in cooling tower usage, where there was no basis upon which to create a predicted value that differed from baseline.

The LA region buildings perform much more efficiently than the Bay Area buildings with respect to indoor usage but less efficiently with respect to irrigation usage. This finding is consistent with the general observation that Southern California water districts and municipalities have invested heavily in indoor water use efficiency due to water supply reliability challenges, but as yet have not made comparable investments in outdoor water use efficiency.

Cooling tower performance in the LEED-EBOM buildings is dramatically better than both baseline and predicted values (the same in this case), especially in the LA region. It is possible that this reflects a geographical bias in the LEED-EBOM building sample, which is disproportionately composed of buildings located in the most temperate parts of the inner Bay Area and coastal southern California, where cooling demand is lower than in inland parts of the state. It may also mean that these buildings have identified some way of avoiding major cooling tower water use that future LEED-EBOM and CalGreen versions could seek to incentivize. The buildings in this sample received no credit in LEED-EBOM for any level of cooling tower performance, only for sub-metering this usage.

As noted above, irrigation usage is expressed per *building* square foot, not per square foot of irrigated area. One consequence of this is that the measured values of irrigation usage may be influenced by the fact that LEED-EBOM buildings are likely disproportionately located in denser urban settings, where parcels are smaller and therefore overall irrigation needs lower, than the typical California office building. Nonetheless, they still fall short of the usage predicted by modeling of the CalGreen irrigation standards, though both represent substantial water and GHG savings compared to baseline. Unlike indoor and cooling tower usage, irrigation usage could theoretically be brought to near zero through a combination of xeriscaping, siting of buildings in urban settings where there is very little landscaped space, and the use of captured stormwater or other highly localized alternative supplies. Hence, the more than 20% of total water use that irrigation still represents, even for the EBOM buildings, could be an area of significant future water and GHG savings.

The indoor performance credit available in EBOM (W2) appears to be having a disproportionately large effect on water usage for those buildings that chose to obtain it. The difference between the measured usage of the credited buildings versus the non-credited is much larger than the EBOM credit itself rewards, and the gap is by far the largest in the indoor usage imputed from the overall building usage, as it should be if the credit is indeed the motivating factor for these improvements. But there are also major improvements in irrigation and cooling tower usage compared to non-credited buildings as well as to predicted values, suggesting that buildings committed to efficiency find ways to save everywhere. This across-the-board over-performance due to a single performance credit suggests that embedding rewards for extra efficiency within buildings may be a worthwhile policy initiative. Both predicted indoor and irrigation usage are derived from CalGreen 2010. The water usage rates measured for the buildings seeking the extra performance credit, compared to predicted values, suggest that there is significant latitude for further improvement in future editions of CalGreen.

From the point of view of per-gallon GHG savings, indoor usage is the best place for codes and standards to focus since this water use is more GHG-intense than other uses due to water heating and wastewater treatment requirements. In addition, this water is harder to displace with reclaimed water or captured stormwater, each of which are potentially applicable to irrigation and cooling towers and may be significantly less GHG-intense than utility-delivered water treated to potable standards.

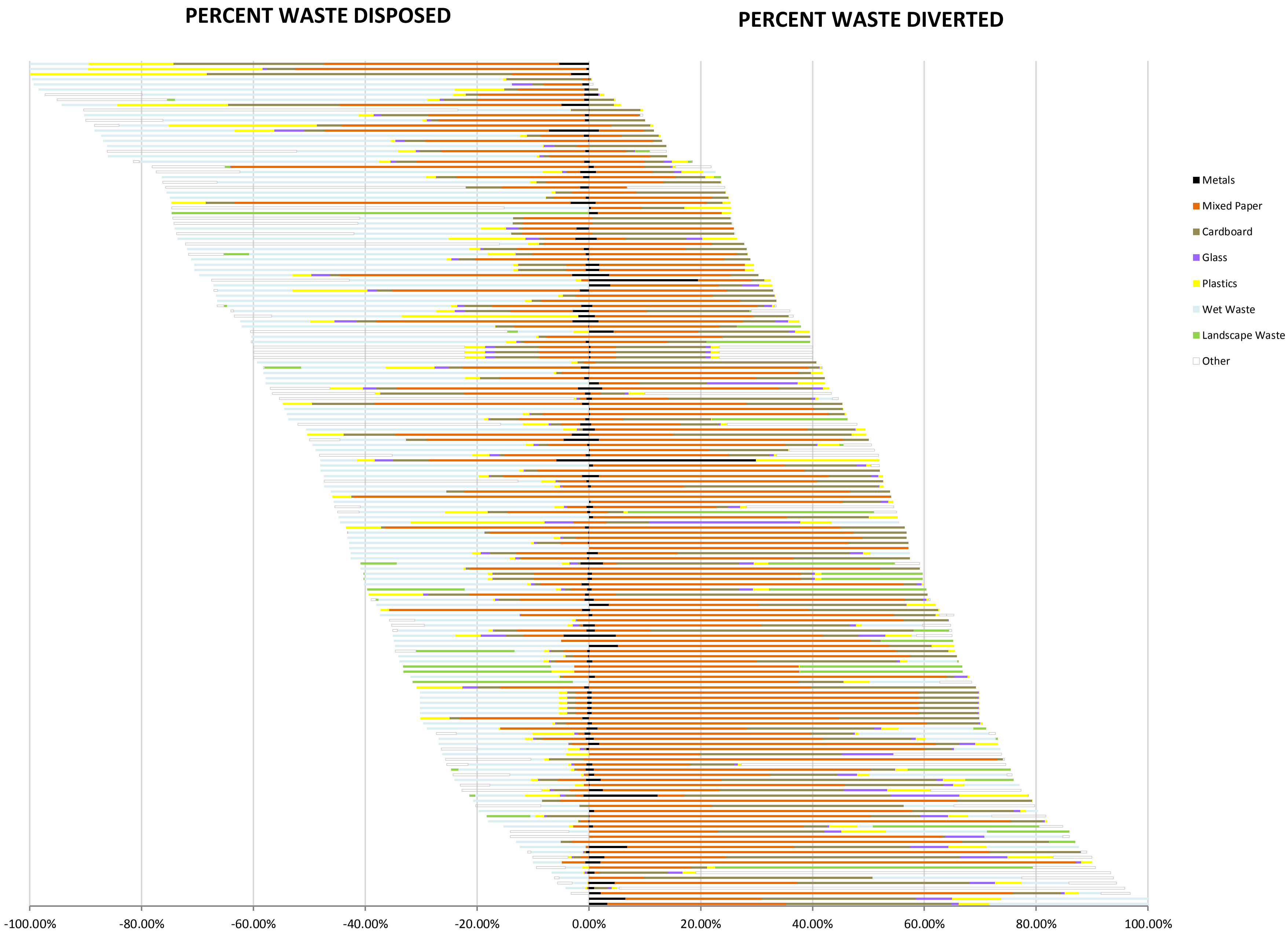
Waste

Solid waste diversion performance by the EBOM buildings only marginally exceeds predicted levels (52% compared to a 50% prediction), but significantly exceeds the much lower diversion rates of baseline buildings. The GHG intensity of solid waste is significantly lower than that of water or transportation, however, so even this large percentage improvement relative to baseline is resulting in comparatively little emissions reduction benefit.

As with water usage, the performance credit available in the LEED-EBOM rating system appears to be effective in stimulating disproportionately large performance improvement. The buildings earning that credit are required by EBOM to achieve a 50% diversion rate, but instead are achieving a 65% diversion rate (as compared to 39% for the buildings not seeking the credit). Both the water and waste performance credit results suggest that once building operators begin a conscious effort to reduce resource use, they are able to exceed the stated goals on a routine basis. The waste results may be even more significant in this regard, given that recycling and other waste diversion require ongoing effort by building managers and potentially occupants, whereas water use efficiency gains may be "hard-wired" into the building by one-time decisions about plumbing fixtures and fittings, landscaping patterns, and cooling tower design.

Data on the composition of the waste streams (see Figure 4) shows that a large amount of the undiverted waste is wet waste. This suggests that additional composting capacity will

Figure 4. Percentage of waste disposed and diverted, by material



be important to further improving diversion rates. This is doubly so since wet waste generates more methane than other types of waste once disposed in landfills. Though building occupant behavior is critical to any effort to reduce disposal to landfills, building codes could stimulate additional improvements by requiring office buildings to install three-bin systems (recycling, composting, and landfill streams) and contract with the relevant waste-hauling services. Measures of this kind may be necessary for the state to meet its current goal of 75% diversion (25% disposal) at the municipal level. Notably, even the EBOM buildings earning the extra performance credit are currently falling short of that goal, with 65% diversion (35% disposal).

Transportation

The GHG intensity of transportation to and from office buildings greatly exceeds that of water and waste, so improved performance in this area is essential to significantly reducing associated GHG emissions. Indeed, even though the EBOM buildings report only a 5% improvement over baseline in their transportation performance, the associated GHG savings are far larger than that of the water and waste sectors combined. It is worth noting that this finding likely would be significantly different for some other kinds of commercial buildings, such as warehouses, which have many fewer occupants (and hence less transportation need) but may have proportionally higher water usage and solid waste generation per building.

The character of the data is important to its interpretation. The baseline values represent the average vehicle ridership (AVR) of the region as a whole, with the implication being that a "typical" office building would have the same AVR. The prediction formula is based solely upon the location of the building, specifically the effect that its distance to a rail stop is predicted to have on the proportion of occupants using rail (including subway, light rail, commuter rail, and heavy rail) to travel to work. The EBOM rating system, for its part, requires nothing other than the measurement of a building's AVR; hence, there is no information on what, if any, additional strategies to improve transportation sustainability these buildings may be employing.

In that sense, it is perhaps unsurprising that the measured values do not deviate dramatically from the predicted values. The prediction formula appears to be over-predicting non-automobile usage, especially outside of the Bay Area, which has the most mature commuter rail systems in California and the most transit-supportive land use context. The dramatic expansion of the LA Metro system notwithstanding, the necessity of, and perhaps cultural disposition toward, automobile usage in southern California appears still to be a powerful force shaping transportation behavior. These conclusions are true even though the prediction method used here likely understates the proportion of non-automobile commute travel in transit-friendly locations (since it is based entirely on predictions of rail mode share).

Other green building rating systems, such as LEED for New Construction, include specific strategies that building designers and managers can undertake to reduce transportation energy use and GHGs, such as parking policies, pre-tax transit fare withholdings from paychecks, and shuttle bus programs. Evaluation of the GHG co-benefits of these strategies will have to await another study, but it is worth noting that the literature on commuting behavior strongly supports the assertion that the proximity of the trip destination (in this case, the office building) to transit is a very important factor shaping the likelihood to use non-automobile modes (Ewing et al 2008).

It is also worth noting that the GHG emissions consequences of commutes to office buildings are more directly dependent upon average vehicle miles traveled (VMT) per occupant than they are on the AVR. Previous research by the USGBC (Pyke et al 2014) has found that office districts with similar land use and transportation sustainability characteristics, such as the Pleasanton Office Parks and East Palo Alto Office Park in the Bay Area, may nonetheless have quite different average commute distances for office workers and hence quite different GHG impacts from commuting even if the mode splits are identical. That study also presents evidence that the occupants of LEED-EBOM buildings may be more willing to use transit for long-distance commutes than other commuters. These dynamics are not captured by an AVR-based approach or by the prediction methods employed in this study, and subsequent research should explore this issue in greater depth.

To a large extent, sustainable transportation is synonymous with compact land use patterns that cluster both origins and destinations around transit (or so close to one another that walking and bicycling become viable options). In that sense, the finding that the location of EBOM buildings alone can generate transportation GHG savings of approximately 5% relative to baseline is useful confirmation of the value of compact development, especially given the very high GHG intensity of transportation for office buildings. Perhaps not coincidentally, these GHG savings are similar to those sought on a regional level by SB 375, which seeks to reduce transportation-related GHG emissions by enabling more non-automobile travel within California's eighteen urban regions.

There is also evidence that people generally commute longer distances for high-wage jobs of the sort often found in LEED-EBOM buildings, and that these long commutes may be more difficult to carry out through transit (Pyke 2014). If so, this would introduce an extra impediment to LEED-EBOM buildings relative to both the baseline and prediction estimation methods used here.

As noted above, transportation is so GHG-intense that even these seemingly marginal percentage gains mean a much larger absolute reduction in GHG emissions for the state. Just the 5% improvement over baseline statewide would translate to about 0.7 MMT of CO_2e avoided, whereas a 55% improvement in water use translates to barely one-tenth the GHG savings (about 0.08 $MMTCO_2e$ avoided).

General

In interpreting these results, it is important to recall the characteristics of the EBOM dataset that is the basis of the measured values. Because it is focused on improving the operations of already-existing buildings rather than the design characteristics of new construction (as other LEED rating systems and much of CalGreen are), these results have direct implications for the retrofit of the existing California office building stock – over one billion square feet of space. These findings support the idea that green building rating systems such as LEED-EBOM can perform effectively in meeting the expectations of state policy makers for GHG emissions reductions.

It is worth bearing in mind that the LEED-EBOM office buildings included in this dataset are relatively early adopters that differ in important ways from the office building stock as a whole. LEED-EBOM office buildings, as a group, are more concentrated in central cities than others, which has particular implications for the extrapolation of transportation findings. Central-city office space offers access to more alternative transportation modes than does suburban space, but average commute distances – which have large effects on transportation-related GHG emissions – can vary significantly from one office core to another (Pyke et al 2014), and there is no guarantee that central-city locations necessarily play host to shorter commutes. For water, on the other hand, more suburban office buildings will generally be sited on larger parcels requiring more irrigation even if standards for indoor use are the same. While this may lead one to conclude that suburban office buildings would not perform as well as urban ones even if certified as green under LEED-EBOM, it also suggests that there may be even more potential room for improvement than these findings suggest.

Adherence to CalGreen became mandatory for new construction (not existing buildings) in California on January 1, 2014. CalGreen contains requirements to install water fixtures and fittings that meet certain performance standards, but it does not contain any mandatory provisions requiring achievement of a given level of water consumption or waste diversion, and provisions encouraging building location within short distances of transit stops are voluntary in the 2013 version of the code. As CalGreen takes effect and is updated in the future, it will gradually improve the baseline performance of the commercial building stock in California to which green retrofits of existing buildings (what LEED-EBOM certifies) are compared, but this transformation of the building stock will be slow and should not affect short-range expectations for the emissions avoidance available from retrofit of existing buildings.

The AB 32 Scoping Plan (ARB 2008) includes a green building strategy that identifies a GHG reduction potential of 26 $MMTCO_2e$/yr from green buildings as a whole, 7.5 $MMTCO_2e$/yr of which is attributed to existing commercial buildings (not just office buildings). This total was derived from projections that one-third of an anticipated 7.05 billion square feet of California commercial building space could be retrofitted to LEED-EBOM standards by 2020 (CAT 2008). The results of the present study cannot be directly related to this estimated total for the following reasons:

- ARB's avoided emissions estimates include potential savings from operational energy efficiency improvements, but do not include transportation
- ARB's avoided emissions estimates for solid waste involve construction and demolition waste, not the solid waste generated from building operations as assessed here
- ARB's avoided emissions estimates encompass all commercial buildings – including very disparate uses such as hotels, educational buildings, restaurant and warehouses – not only office buildings.

Nonetheless, there are points of comparison that allow us to assess whether the two estimates are generally consistent with one another. The only directly comparable estimates are in water, where CAT (2008) identified from then-current research a GHG emissions factor of 3.85 $MTCO_2e$ per million gallons, substantially higher than the GHG intensities of water derived from more recent sources for this report (see Table 20).

Table 20. Comparative GHG Intensities of Water

MTCO2e/million gal

		n	Outdoor	Indoor	Whole building avg
CAT (2008)	Statewide				3.850
Present study	Bay Area	89	0.482	2.386	1.368
	Los Angeles	63	0.934	2.838	1.761
	Sacramento	22	0.350	1.993	1.494
	San Diego	11	0.934	2.838	1.832
	Rest-of-state	6	0.615	2.520	2.449

The assumed baseline water usage in the CAT (2008) report is 202.95 gal/sf/yr, almost double the baseline of 108.2 gal/sf/yr used in this report, but the CAT baseline applies to all commercial buildings, many of which (such as restaurants and hotels) have higher water demand per square foot than office buildings. Retrofits of existing non-residential buildings were predicted by CAT (2008) to save 40.59 gal/sf/yr, very close to the difference between baseline and predicted values in the present study (41.6 gal/sf/yr). Thus, despite the large difference in baseline values, the *predicted* savings are comparable in terms of water quantity per square foot. As noted, however, the LEED EBOM office buildings have in fact performed better than predicted – measured water usage is actually 59.7 gal/sf/yr below baseline.

The CAT (2008) study assumes that one-third of commercial space could be retrofitted to LEED-EBOM standards by 2020, or about 2.33 billion square feet. If this square footage of commercial space saved water at the same rates as the LEED-EBOM commercial *office* buildings in this study, it would result in avoidance of about 0.147 $MMTCO_2e$/yr. The CAT study does not explicitly state what proportion of the overall 7.5 $MMTCO_2e$/yr emissions savings is expected from water efficiency, as opposed to operational energy efficiency or construction and demolition waste reduction. However, the study presumes a 25% reduction in both water and energy use within commercial building.

Table 18 shows that typical commercial office space in California (the baseline values) triggers about 35 times more GHG emissions per square foot from operational energy use than from water use[5], so the vast majority of the anticipated 7.5 $MMTCO_2e$/yr from commercial buildings would have to come from operational energy, which is not analyzed in this report. Thus, while the two studies differ in too many ways to permit direct comparison, it can be said that the current study's results for potential water-related emissions reduction in office buildings, while they appear small, are not necessarily inconsistent with ARB's CAT-derived overall goals for GHG savings from the commercial building sector.

[5] This ratio likely varies considerably among other kinds of commercial buildings.

Notably, the GHG intensity of electricity assumed for the CAT study (0.442 $MTCO_2e$/MWh) is also higher than that used in this report (0.270 $MTCO_2e$/MWh). It is possible that some of this discrepancy is because the present study used a marginal-electricity approach, while the CAT study does not specify whether it used a marginal or portfolio-average approach. More importantly, however, GHG intensities of electricity have dropped throughout California since the CAT study was done in 2008, due to the implementation of the Renewable Portfolio Standard (RPS). This progress will continue at least through 2020 under the RPS, and likely beyond if the cap-and-trade system or successor legislation to AB 32 stimulates further de-carbonization of the electricity supply. As the electricity system is de-carbonized, however, building-level efficiency measures will avoid fewer GHG emissions than they would with a "dirtier" electricity supply. ARB's goal to reduce 26 $MMTCO_2e$/yr through green building measures and 7.5 $MMTCO_2e$/yr from existing commercial buildings, which are based on GHG intensity estimates dating from 2008, may therefore need to be revisited to account for the drop in GHG intensity of electricity (and by extension, water).[6] The current study also shows, however, that a 25% reduction in water use may be too modest a goal given the much larger usage reductions achieved by current LEED-EBOM buildings, especially those seeking the high-performance credit.

The apparent effectiveness of additional performance credits in stimulating over-performance in water and waste efficiency is instructive for the formulation of building codes for new construction, not just retrofits. In a sense, the buildings earning these credits over-performed the predictions of LEED-EBOM itself, suggesting that performance-based credits in codes and rating systems for new construction could do the same. LEED-EBOM was intentionally designed to try to stimulate improvements in underlying codes and standards, and these results suggest that continuing updates of LEED-EBOM could continue to drive market transformation, code updates, and over-performance by exemplary buildings (even relative to updated standards and codes). LEED v4, released too recently to produce data for this study, contains mandatory provisions for water metering and waste audits (as opposed to optional credits) and strengthens the standards in other ways. Previous research by USGBC (Pyke et al 2011) has shown that average credit achievement, and associated GHG co-benefits, under LEED for New Construction (not existing buildings) has risen even as the standard has been strengthened with periodic updates.

With respect to water use, LEED for New Construction (LEED-ND) and CalGreen both require the installation of plumbing fittings and fixtures that are expected to achieve a certain water usage rate. Indeed, this is all it is possible to require at the point of construction since actual usage will only occur after the certification (or code compliance) has been achieved. The question is, what actual usage rates could be expected from these plumbing installations? Though the character of our data prevented us from answering this question directly, the results from LEED-EBOM, which also requires minimum fixture and fitting standards (not identical to those of LEED-NC or CalGreen) but also awards credits for measurement of actual performance and achievement of specific performance rates, is at least encouraging to the conclusions that new construction could over-perform its plumbing "predictions."

It could be argued that there is a self-selection bias in these results. The buildings that chose to seek the water performance credit may have done so knowing that they were

[6] This is related to the reason why the green building targets were not included in the overall emissions reduction targets in AB 32 for fear of double-counting the same emissions reduction.

already performing very well and could therefore gain credit points easily with little or no extra effort. It seems unlikely, however, that that could fully explain such large over-performance across a set of 71 buildings.

With respect to solid waste, codes and rating systems for new construction are limited to requiring the provision of recycling and/or composting bins and waste handling facilities. LEED-EBOM office buildings that measured their waste diversion rates but did not earn the performance credit failed to meet the 50% diversion rate threshold derived from state law, instead achieving only a 39% diversion rate. If this performance is typical of buildings required to include recycling bins but not seeking any performance standard, it suggests that rating systems and codes for new construction will need to escalate their requirements in order to meet even a 50% threshold, much less the 75% diversion rates that are sought on a statewide level in the future.

For both water and waste, the prediction methods produced by the California Pollution Control Officers Association (CAPCOA 2010) provide methods for determining the GHG emissions from given levels of water and waste performance, but they do not provide methods for predicting the overall water and waste performance levels of a building based on the specific management strategies that they pursue. In that sense, prediction of water and waste performance levels of new construction based on the requirements of code and/or rating systems will have to be similar to those used in this study (i.e. modeling the water usage rates based on characteristics of plumbing fixtures and fittings, and identifying a rough diversion rate target derived from state law and/or CalGreen).

For transportation, there are more specific prediction methods available in CAPCOA (2010) that project the performance of buildings based on building characteristics, mostly having to do with parking, and also building location. This study used the CAPCOA prediction method that predicts rail mode share based on a building's distance to rail stations to create the predicted values for transportation AVR. Since LEED-EBOM does not require or request buildings to report upon the strategies that they are pursuing to achieve a given AVR level, but instead only to report on that AVR level, this study does not generate any insight, even indirectly, into the efficacy of parking management on transportation-related GHG emissions. However, the CAPCOA prediction method for rail transit use appears to be overly "optimistic" in predicting more transit-influenced AVR based on location when deployed using this study's method. The location of office buildings (and commercial buildings generally) is an issue that can only be addressed systematically through general plans and zoning codes, not through building codes, but it is highly important in shaping the transportation behavior of occupants.

Studying non-green-certified commercial buildings

Certified green office buildings are still a very small fraction of the overall commercial building stock, and state GHG control policies must concern themselves with all buildings, whether certified "green" or not. Many non-certified commercial buildings may also perform as well, or better than, certified green buildings, especially with respect to transportation, which is by far the most important source of GHG emissions in this context. A non-certified office building, if it is located near transit, may trigger fewer GHG emissions than a certified green office building farther from transit, even if the latter greatly outperforms it on water and waste management. Likewise, individual non-certified buildings could excel in water or waste management without adherence to any given rating system.

To set policies, codes and standards intended to reduce emissions from all commercial buildings, additional information on the performance of these non-certified buildings will therefore be necessary. Currently, information on building performance in general is scarce and there is very little transparency in the commercial office building sector in particular. LEED itself is a notable advance in this regard, and without improved transparency generally, it is difficult to imagine substantial improvement in building performance across the entire construction and building management industry.

Two major surveys of commercial buildings already exist and are conducted on a periodic basis: the federal Commercial Building Energy Consumption Survey (CBECS) and the California-wide Commercial End-Use Study (CEUS). These studies are focused on measuring operational energy consumption, but given their reach and the fact that they sample the commercial building population in ways that permit statistical inference to the entire building stock, they are likely the most effective vehicles for gathering information on water, waste and transportation performance.

The CBECS has already incorporated questions about water use. This was done in the survey's 2007 edition, but none of the survey's data was ever released due to errors in the sampling methodology. The 2013 edition, data from which are scheduled to be released in 2014, will contain information on total building water usage, building size and will distinguish between indoor, irrigation, and cooling tower, though not process water use (which is not a factor in the present study but is potentially important for other kinds of commercial buildings).

Neither survey currently contains any questions pertaining to solid waste management. To be of greatest use, measurements of solid waste output should be conducted over a specified reporting period (perhaps two weeks) and occur at a point in the year where building occupancy is expected to be typical (i.e. not summer or the holiday season). This would allow insight into rates of waste *generation*, not only the rates of disposal and diversion of the waste generated. LEED-EBOM's reporting format currently allows respondents to define the period of measurement themselves, limiting the ability to analyze waste generation rates. The surveys should also seek to acquire information on existence of recycling and/or composting facilities, both in the workspace and in the collection point in the building.

Transportation measurement through surveys is more challenging and can take one of two paths: VMT-based or AVR-based reporting. This study used the latter for baseline and predicted values because the measured data used AVR, and it may be more appropriate for destination-side measurement since operators of *existing* buildings cannot be expected to influence the distance that occupants commute, only (to some degree) the transportation mode that they choose to commute. Studies of new construction, where building location is to some extent discretionary on the part of the builders, may differ in this regard. Importantly, using AVR as the study metric limits researchers to assuming average commute lengths rather than acquiring empirical building-specific data on commute lengths, which can vary in surprising ways from first-glance expectations (Pyke 2014). In addition, most of the existing transportation research literature does not use AVR, which reduces the ability to leverage other research findings in the analysis of the data.

AVR information could be obtained by either a survey of occupants (either for one day or preferably a period of days), or it could be estimated in most situations by counting cars in the parking garage/lot. Although the latter streamlines the survey process considerably and avoids the need to contact occupants, it will also be the least accurate in the cases where AVR is highest, i.e. dense urban cores where office buildings may not provide all their own parking and therefore counting cars could make AVR look even higher than it actually is. If reducing the data-gathering burden on the survey respondents is a high priority, then there could be a two-tier system where only buildings that do not provide all their own parking are required to survey the occupants (otherwise they can count cars in the parking lot).

Another downside is that car-counting does not capture people being dropped off by another driver who does not park at the building. The error this would introduce is fairly minimal because this practice rarely accounts for more than a very small percentage of commuters. AVR baseline and predicted values could be generated for virtually any location in the U.S. using the present study's method. Even for locations outside of the metropolitan regions for which the relevant census information is compiled routinely, baseline and predicted AVRs can be imputed from other geographical scales of census data, though areas without regionally compiled census information have small enough populations that transit usage for commuting is likely nearly negligible.

In VMT-based analysis, establishment of the baseline would also employ regional commuting information from the census, multiplied by average commute distance. To make use of CAPCOA prediction methods, the survey would have to generate detailed information on parking policies primarily (including bike parking), as well as policies pertaining to fleet vehicles (if any). Measured data would have to come from survey data that asks occupants directly about their commute modes and the distance of their automobile commutes, as well as usage of fleet vehicles (if any). This is inherently more difficult than a survey limited to asking questions of a single building manager. The advantages are that VMT is more directly related to GHG emissions than AVR, there would be improved analytical insight about the effect of building strategies on transportation behavior and related GHG emissions, and there would be much greater opportunity to leverage existing research findings on transportation behavior in the analysis.

Conclusion

This research quantifies, for the first time, the GHG co-benefits associated with water, waste and transportation aspects of certified green commercial office buildings in California. It finds that these buildings do in fact achieve significant GHG emissions reductions relative to typical non-green office buildings – about 38% for water, 48% for waste, and 5% for transportation. In terms of absolute emissions, however, savings in transportation dwarf those of the other sectors because transportation is more than 90 times as GHG-intense per square foot of building space as water use, and over 170 times as GHG-intense per square foot as solid waste, among baseline values. Overall, conversion of the entire stock of existing California office buildings to the performance standards achieved by the certified green office buildings would avoid emissions of about 0.831 $MMTCO_2e$ per year.

Furthermore, additional performance incentives for water and waste within the green rating systems were found to be effective in stimulating further resource use and emissions reductions. These performance improvements were actually larger than what is required to achieve the extra credits in the LEED-EBOM system, suggesting that such incentives may be worth more than "face value." This finding has particular significance for standards for new construction, and suggests that incentivizing higher efficiency standards could prompt a "virtuous loop" where builders seek additional efficiencies beyond code requirements.

The three resource areas differed significantly in their performance relative to predictions for green building performance. With respect to GHG emissions, the certified buildings performed better than predicted on water use (13%), slightly better than predicted on waste diversion (4%), and worse than predicted on transportation (-6%). The latter is a significant finding, given the GHG intensity of transportation, and suggests that the CAPCOA formula for calculating rail mode shares based on proximity to rail stations may over-estimate actual rail ridership outcomes. The wide divergence between predicted and measured values for water use likewise suggests that efforts should be made to improve water use prediction methods, especially with respect to cooling tower use.

Finally, additional insights into commercial office building performance could be gained by inserting basic questions on water, waste and transportation usage into the CEUS or CBECS surveys, which currently focus on operational energy use. Systematic collection of performance data of non-certified commercial office buildings would enable deeper analysis into the effectiveness of specific building design strategies, such as parking policies, placement of recycling and composting bins, and water-efficient landscaping, in securing GHG emissions reduction co-benefits. The findings of this report suggest that important additional efficiencies and GHG co-benefits are available in all three resource areas, as indeed they must be if the state is to meet its long-range GHG emissions goals.

Recommendations

The findings of this report imply a number of recommendations for future research future climate policy initiatives, and future updates to building standards.

Address transportation behavior through CalGreen and other building standards to the greatest possible extent. Transportation is so GHG-intense that even small percentage improvements over baseline, such as those reported here, can avoid substantial quantities of GHG emissions. Indeed, commercial office buildings stimulate more than twice as much GHG emission through induced transportation than they do through their own operational energy consumption (see Table 18), yet operational energy is the subject of detailed code requirements and standards while transportation is largely assumed to be beyond the reach of building standards. Locating buildings in transit-accessible areas, in particular, is so impactful to GHG emissions and so fundamental to facilitating non-automobile transportation that it may be worth more to GHG control efforts (from commercial office buildings) than all other foreseeable improvements to green building standards combined. It should be given an emphasis within CalGreen and other building standards related to commercial construction commensurate with that importance.

Improve prediction methods for future analysis of green building performance. CAPCOA guidance on the quantification of GHG emissions should be revised and expanded to include more direct methods for assessing the GHG emissions expected from specific water and waste-related building strategies (as opposed to usage levels), especially those related to irrigation and cooling towers. In addition, the formula for estimating rail mode shares from the distance to rail stations should be updated with further research when feasible, and ultimately expanded to include bus, bicycle, walking, and other non-automobile modes.

Improve the information base for assessing regional transportation baselines. The method for identifying transportation baselines used in this study relied on regional-scale data that likely oversimplifies the commuting dynamics of particular office cores. Recent work by USGBC (Pyke et al 2014) draws upon aggregated cellular data to establish more fine-grained characterizations of typical commuting patterns in specific neighborhoods of office buildings. Future research in this vein could establish much more accurate, neighborhood-scale baselines against which the transportation behavior of green office building occupants could be compared. Such research might also enable the incorporation of other demographic factors that influence commuting behavior and may co-vary with green building occupancy, and enable greater insight into commute distances (and by extension, vehicle miles traveled).

Future CalGreen updates should significantly strengthen plumbing standards. The predictions for green building water use were derived from the fixture and fitting standards in the 2010 edition of the CalGreen code. Given that the LEED-EBOM buildings outperformed these predictions by 27%, it appears that significant additional strengthening of these standards is feasible and justifiable.

Future CalGreen updates should require placement of composting collection facilities within commercial office buildings. According to the date shown in Figure 4, a large proportion of the un-diverted waste leaving commercial office buildings and entering landfills is "wet waste" – i.e. food and other organic waste that is high in carbon content and therefore a relatively potent source of methane in landfills. Introduction of compost collection facilities would enable this waste to be diverted from landfills far more effectively, improving diversion rates, avoiding unnecessary GHG emissions, and creating compost for re-use or resale. The current CalGreen requirement (Section 5.410.1) requires provision of "readily accessible areas" for the "depositing, storage, and collection" of recyclables, but does not explicitly include any such requirement for compostable materials.

Include questions related to water, waste and transportation in the CBECS and/or CEUS surveys. As noted in the discussion, insertion of a small number of simple questions in these surveys would greatly expand the information base for analysis of GHG co-benefits in non-certified commercial buildings. CBECS has already incorporated water questions in its 2013 edition. Collection of high-quality transportation data may involve requiring building managers to issue surveys to occupants, but given the importance of transportation to the overall GHG emissions footprint of commercial office buildings and the general paucity of destination-side commuting data, it is worth the extra effort.

Encourage information-sharing on operational performance of buildings. This research was made possible by USGBC's unilateral commitment to share information about project performance as part of LEED's stated goal of market transformation. Even if CBECS and CEUS are revised as recommended above, there will still be a need for much more information on the operational performance of commercial buildings, whether certified as "green" or not. Data sharing and collection should be institutionalized, particularly for any performance domain that is claimed to produce public benefit or is cited as evidence of compliance with laws and regulations such as AB 32. Building codes, including CalGreen, could require public operational data-sharing as part of a post-occupancy inspection process. Local building permits, whether for green or non-green buildings, could also be made conditional on commitment to share post-occupancy data, subject to later inspection by local building officials.

Expand emphasis on existing buildings in state and local climate planning efforts. Building energy efficiency and GHG control efforts have historically tended to emphasize creation of standards for new construction as a means of saving energy and GHGs. While this is gradually changing with the passage of AB 758 and other efforts to establish standards for renovations, the existing building sector remains under-emphasized in climate planning generally. More than one billion square feet of commercial office space already exists in California, and bringing this space up to performance standards typical of certified green building would save over 0.83 $MMTCO_2e$ per year. Considerably larger improvements beyond that are possible given the water and waste performance levels achieved by the high-performance buildings in this dataset, and given the very large latent potential for reduction of transportation-related emissions through transit-friendly building siting decisions. It should also be borne in mind that the figures reported in this study are for office buildings only; additional large savings can be expected from efforts to reduce water, waste and transportation usage associated with other types of commercial buildings.

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Glossary of Abbreviations

AB 32	Assembly Bill 32, a.k.a. The Global Warming Solutions Act of 2006
ACS	American Community Survey
ANDOC	Anaerobically degradable carbon
ARB	California Air Resource Board
AVR	Average vehicle ridership
CalGreen	California Green Building Standards Code
CAPCOA	California Air Pollution Control Officers Association
CBECS	Commercial Building Energy Consumption Survey
CEC	California Energy Commission
CEUS	California Commercial End Use Survey
CO2e	Carbon dioxide equivalent
DWR	California Department of Water Resources
EBMUD	East Bay Municipal Utility District
GHG	Greenhouse gas
LA DWP	Los Angeles Department of Water and Power
LEED	Leadership in Energy and Environmental Design green building rating systems
LEED-EBOM	Leadership in Energy and Environmental Design for Existing Buildings Operation and Maintenances green building rating system
LEED-CI	Leadership in Energy and Environmental Design for Commercial Interiors green building rating system
LEED-CS	Leadership in Energy and Environmental Design for Core and Shell green building rating system
LEED-MC	Leadership in Energy and Environmental Design for New Construction green building rating system
$MTCO_2e$	Metric tons of carbon dioxide equivalent
$MMTCO_2e$	Million metric tons of carbon dioxide equivalent
MPOs	Metropolitan Planning Organizations
MRc6	Materials & Resources credit 6 in LEED-EBOM v 2008 and 2009 requiring a waste stream audit
MRc7	Materials & Resources credit 6 in LEED-EBOM v 2008 and 2009 requiring a 50% waste diversion rate
MTC/ABAG	Metropolitan Transportation Commission and Association of Bay Area Governments (Bay Area)
MWD	Metropolitan Water District of Southern California
PG&E	Pacific Gas and Electric
SACOG	Sacramento Area Council of Governments
SANDAG	San Diego Association of Governments
SCAG	Southern California Association of Governments
SDG&E	San Diego Gas and Electric
SF PUC	San Francisco Public Utilities Commission
SIC	Standard Industrial Classification code
SMUD	Sacramento Municipal Utility District
SSc4	Sustainable Sites credit 4 in LEED-EBOM v 2008 and 2009

SWP	State Water Project
USGBC	United States Green Building Council
VMT	Vehicle miles traveled
WEc1.1	Water Efficiency credits 1.1 in LEED-EBOM v 2008 requiring a water consumption audit (referred to as WEc1 option 1 in LEED-EBOM 2009)
WEc1.2	Water Efficiency credits 1.2 in LEED-EBOM v 2008 requiring submetering of water systems (referred to as WEc1 option 2 in LEED-EBOM 2009)
WEc2	Water Efficiency credit 2 in LEED-EBOM v 2008 and 2009 requiring additional plumbing fixture and fitting efficiency for indoor use
WEc3	Water Efficiency credit 3 in LEED-EBOM v 2008 and 2009 requiring water efficient landscape irrigation