A Consumption-Based Greenhouse Gas Inventory of San Francisco Bay Area Neighborhoods, Cities and Counties: Prioritizing Climate Action for Different Locations

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Abstract

This study develops a consumption-based greenhouse gas inventory of all San Francisco Bay Area census block groups, cities and counties. It is the first study to explore household carbon footprints at such fine geospatial resolution for any region. The methodology incorporates local consumption and emissions data wherever possible. In other cases, consumption is approximated using econometric analysis of national and statewide transportation and household consumption survey responses by S.F. Bay Area residents. The consumption-based method results in about 35% higher GHG emissions than the traditional territorial approach for the region, largely due to higher emissions from imported food and goods. Transportation is the largest source of emissions (33%), followed by food (19%), goods (18%), services (18%) heating fuels (5%), home construction (3%), electricity (2%) and 1% waste. Within the region there are large differences in the size of average household carbon footprints (HCF) between cities (>2.5x) and larger differences between neighborhoods within populous cities (~5x). These differences suggest large inequalities in climate responsibility within a single metropolitan area. The composition of household carbon footprints also varies considerably between different locations, with vehicle ownership, income, household size and home size contributing the most to differences. The study concludes with recommendations to prioritize policies and programs for different locations.

Keywords
Carbon footprint, consumption-based emission inventory, greenhouse gas inventory, climate change mitigation, input-output, life cycle assessment, San Francisco Bay Area

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Introduction

This study develops a consumption-based greenhouse gas (GHG) inventory of all populated census block groups, cities and counties in the San Francisco Bay Area. It is the first study to estimate carbon footprints at such fine geospatial resolution of any region, essentially at the neighborhood scale in urbanized areas of the S.F. Bay Area. Average household carbon footprints are developed for each census block group and then multiplied by the total number of households to obtain a consumption-based emissions inventory (CBEI) of each location, and the S.F. Bay Area as a whole.

Household carbon footprints include all direct and indirect greenhouse gas emissions resulting from the life cycle of energy, transportation, water, waste, food, goods and services consumed by households in a calendar year, in this case 2013. Consumption-based GHG inventories allocate all emissions to consumers, regardless of where emissions are released to the atmosphere in supply chains. For example, if a business in China produces a computer that is purchased by a California household, then all emissions related to the production of that computer are allocated to the California. household, not the Chinese company. Similarly, emissions originating from materials extraction, processing, manufacturing, transport and trade of goods, regardless of where those emissions occur, are all allocated to consumers, not to the businesses that produce the emissions.

A consumption-based method can be considered the *flip side of the coin* to production-based methods. Both are fully comprehensive; if all countries and regions of the planet accounted emissions using both approaches, the sum of all emissions globally would be the same using both methodologies. Locations with heavy industry or agriculture would have higher emissions under the production-based approach, while locations with high populations would have higher emissions from a consumption-based approach. A consumption-based approach lends itself to emission inventories of cities and urbanized areas by capturing more emissions than a traditional geographic approach.

The differences between the two methods are clear when considering transportation. A fully geographic-based approach would only consider emissions from vehicles operating within the geographic boundaries of the location. This would include vehicles that enter and pass through a community, as well as vehicles that only operate within the boundaries. A consumption-based approach, on the other hand, considers emissions from household travel regardless of where residents go (whether inside or outside of the location's boundary). The approach also considers the full life cycle emission of travel, including direct emissions from the fuel, indirect emissions from to the production of the fuel (well-to-pump), vehicle manufacturing and repairs. Similarly, emissions from air travel and public transit are also allocated to households, regardless of where residents travel.

Consumption-based emissions inventories compliment traditional production-based (or geographic-based) inventories by providing information on the carbon footprint of food, goods and services consumed by residents, as well as the transportation of residents, regardless of where the gases are released to the atmosphere. This approach provides an additional lens by which to view the responsibility of communities, and consequently, suggests a different set of GHG mitigation opportunities. For example, in urbanized areas, emissions from food and air travel are important sources of emissions in consumption-based inventories, but not in production-based approaches. At the same time, emissions from local businesses are more accurately addressed with a production-based approach.

An earlier study (Jones and Kammen 2014) calculated carbon footprints for all populated U.S. zip codes, cities, counties and states, and incorporated the results into an online carbon management tool (coolclimate.berkeley.edu/calculator) and map (coolclimate.berkeley.edu/maps). This work demonstrated that household carbon footprints, and corresponding GHG mitigation opportunities, vary dramatically by location within the United States and between populations within. For example, electricity accounts for only 6% of household carbon footprints on average in California, but over 30% in many parts of the United States. This heterogeneity between locations suggests that localizing climate action requires a nuanced, place-based application of planning, policy and behavioral approaches that consider the unique greenhouse gas mitigation opportunities of each population.

The current study develops higher geospatial resolution results and uses local data where available in a hybrid approach. Results for neighborhoods, cities and counties are analyzed, with a particular focus on differences in the size and composition of carbon footprints for different locations. The study concludes with climate mitigation recommendations tailored to the unique characteristics of the San Francisco Bay area overall, and for different sub-populations within. It is hoped that this information will lead to more highly tailored intervention strategies and additional work to prioritize the most promising GHG reduction opportunities for different populations.

Methods

The basic approach to calculate a household carbon footprint is to multiply annual consumption of goods and services by appropriate greenhouse gas emission factors. Multiplying average household carbon footprints by the total number of households in each location produces a consumption-based greenhouse gas inventory of each location. Additional emissions from local government activities may be added, but these are typically less than <5% of a city's total carbon footprints (Jones, Kammen, and Onsrud 2013) and are not included in these results.

Where possible we have obtained local consumption data, including electricity and natural gas consumption (by zip code), average fuel economy of vehicles (by county), local price adjustments, and energy consumption by public transit authorities. In other cases, we have estimated consumption based on factors that strongly correlate with each category of emissions. We develop econometric models of household consumption using local subsamples of large household consumption surveys (National Household Travel Survey, the Residential Appliance Saturation Survey, and the Consumer Expenditures Survey). Model variables for motor vehicle miles include vehicle ownership, household size, income, number of workers, population density, and household size. Air travel estimated as a function of income. Public Transit is from the National Transit Database, by county. Electricity and natural gas consumption is disaggregated from zip codes to census block groups using demographic information, physical characteristics of homes, and geographic data. Household consumption of goods and services is approximated by income and household size, which are the two variables with the most explanatory power in the Consumer Expenditures Survey. Diets of typical S.F. Bay Area residents are obtained from analysis of several data sources, including USDA (2015), the CEX and the and the Cost of Living Index (C2ER 2014). Other source of consumption include water, waste and home construction. See Appendix A for further details.

Each category of household consumption is then multiplied by greenhouse gas emission factors to determine the carbon footprint of average households in each location. Emission factors for fossil fuels (gasoline, aviation fuel and home heating fuels) are from the U.S. Office of Air Quality Planning and Standards (2013). Indirect life cycle emission from the production of fuels are from the California Air Resources Board (2015). Emission factors for electricity were provided by each electric utility. See Appendix A for emission factors for public transit, air travel indirect emissions, waste, water, recycling, composting, motor vehicle manufacturing, and home construction. Emission factors for food, goods and services are from the Comprehensive Environmental Data Archive, CEDA (Suh 2009). CEDA is an environmentally-extended input output life cycle assessment model of the U.S. economy. It considers all inputs to production resulting from supply chains, including the extraction of materials, processing, manufacturing, transport and trade of goods services.

See Appendix A for a detailed description of all methods used in this study. Further reading is also available in two published academic papers (Jones and Kammen, 2010 and 2014).

Results

Overview

The carbon footprint of the average S.F. Bay Area household (Figure 1) is 44.3 metric tons of CO_2 equivalent gases per year (16.3 tons tCO_2e per person). This compares to about 50 metric tons for the average U.S. household. The total includes 14.6 tons (33%) from transportation (vehicle fuels, motor vehicle manufacturing / repairs, air travel and public transportation), 5.8 tons (13%) from housing (energy, waste, water and construction), 8.5 tons (19%) from food, 8.0 tons (18%) from goods, and 7.9 tons (18%) from services. Composting decreases the carbon footprint by 0.4 tons (1%). Recycling also reduces 3 tons, but this is already theoretically included in emissions from manufactured goods so is not further subtracted from the total carbon footprint.

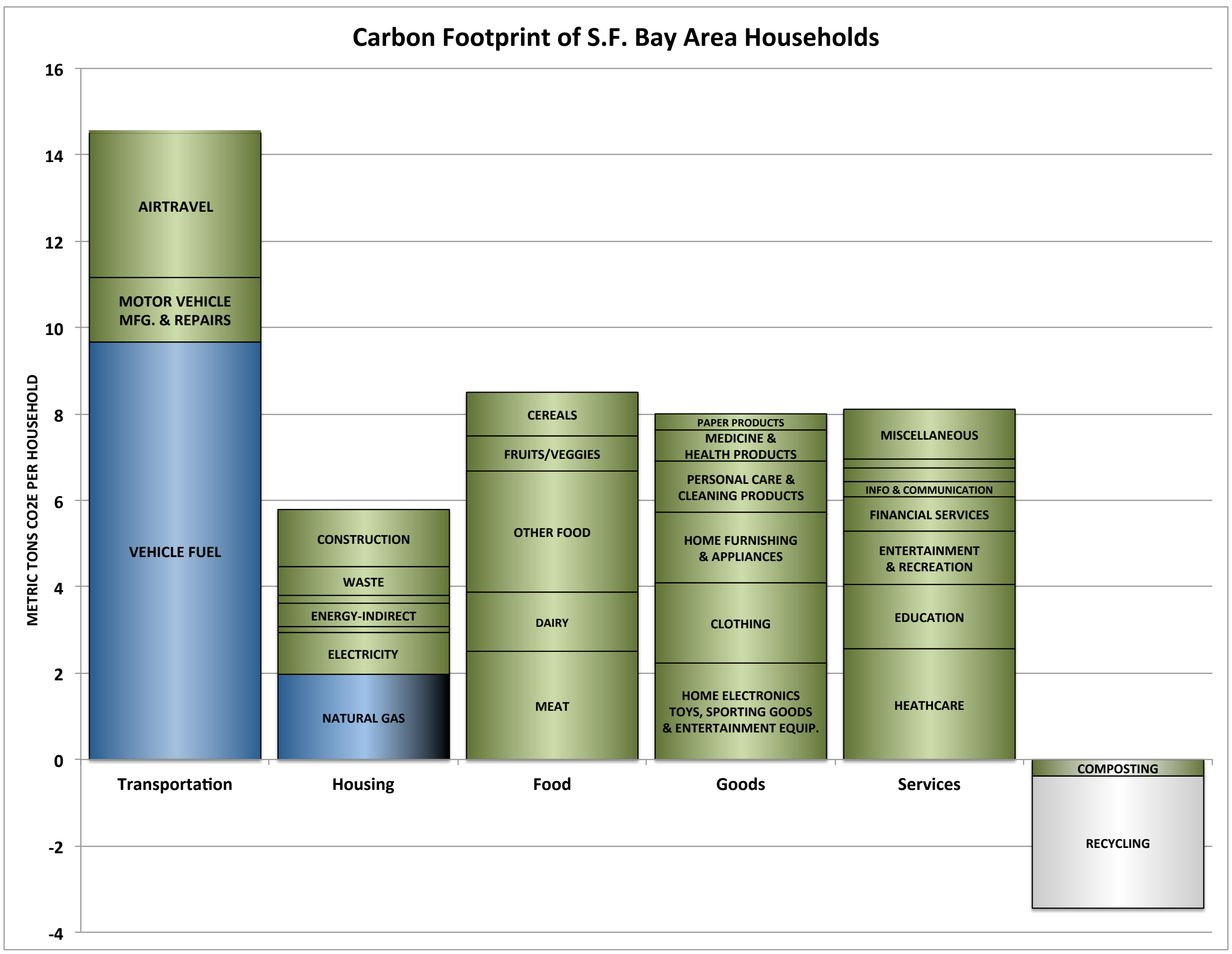

Figure 1. Carbon footprint of typical San Francisco Bay Area household

Multiplying total 44.3 tCO_2e per household by the 2,612,609 households in the SF Bay Area (defined as homes in the BAAQMD jurisdiction), the consumption-based carbon footprint of the SF Bay Area for 2013 was 115.2 million metric tons of CO_2 equivalent (MMTCO2e) in 2013. Table 1 compares this consumption-based approach with the traditional territorial GHG inventory conducted by the San Francisco Bay Area Air Quality Management District (BAAQMD 2015). Using a territorial approach, total GHG emissions in 2013 were 86.6 MMTCO2e. Thus, a consumption-based approach increases total GHG emissions by about 35%. This difference is due largely to goods, food and services purchased by SF Bay Area households that was produced outside of the region. For example, agriculture accounts for only 1.3 MMTCO2e using the territorial approach, while food accounts for 22 MMTCO2e using a consumption-based approach. Emissions from all products purchased from commercial and industrial sectors (goods, services, waste, water, home construction, and indirect emissions from energy) were roughly 60% higher than the industrial and commercial sectors in the territorial approach. Another large difference is emissions from electricity, which are only 2% in the consumption-based approach but 14% in the territorial approach. The difference is that the territorial approach includes all electricity production for all commercial, industrial and residential end-users, while the consumption-based approach only includes residential electricity (commercial and industrial electricity is included in goods and services consumed by households). The contribution from transportation is quite similar (within 5%) despite very different definitions; emissions from motor vehicles in the territorial approach include all GHG emissions emitted by motor vehicles within the territorial boundary of the region, while the consumption-based approach includes only emissions from household vehicles regardless of where they travel (even if outside of the region).

Table 1. Comparison of territorial and consumption-based methods

A. Territorial			B. Consumption-Based			B / A
Sector	% of total	MMTCO2e	Sector	% of total	MMTCO2e	
Transportation & off-road equipment	39%	34.8	Transportation	33%	37.8	1.09
Residential fuel usage	8%	6.7	Natural Gas & other heating fuels	5%	5.5	0.82
Electricity / Co-generation	15%	13.0	Electricity	2%	2.5	0.19
Industrial / Commercial	35%	30.9	Goods, Services, water, construction, indirect energy	40%	46.5	1.50
Agriculture	1%	1.3	Food	19%	22.1	17.40
Recycling & Waste	2%	1.5	Waste & Composting	1%	0.7	0.47
Total	100%	88.2	Total	100%	115.2	1.31

Range and Composition of Carbon Footprints of Block Groups

Table 2 provides summary data for census block groups within the SF Bay Area, and for the Bay Area as a whole. The lowest carbon footprint of any census block is 15 tons of tCO_2e while the highest is 104 (a 7x difference). Comparing just the 5th percentile (29 tCO_2e) and the 95% percentile (68 tCO_2e) the range is 2.4x. In other words, the highest carbon footprint neighborhoods have between 2 – 7 times more emissions than the lowest carbon footprint neighborhoods.

Table 2. Summary data of average household carbon footprint of census block groups in S.F. Bay Area

	Min	5th percentile	mean	percentile	Max	95/05	Max/Min	Mean %
Motor Vehicle Fuel	0.2	5.1	9.7	15.9	27.9	3.1	127.2	22%
Motor Vehicle Mfg.	0.0	0.9	1.5	2.4	4.1	2.8	121.9	3%
Air Travel (direct + indirect)	0.1	1.3	3.3	6.4	10.7	4.9	141.0	8%
Public Transit	0.0	0.0	0.0	0.1	0.1	6.7	71.4	0%
Electricity	-	0.6	1.0	1.6	3.9	2.9	N/A	2%
Natural Gas	-	0.4	2.0	4.8	13.0	13.4	N/A	4%
Other Fuel	-	-	0.1	0.6	4.1	N/A	N/A	0%
Energy Lifecycle	0.0	0.2	0.5	1.0	2.7	4.2	215.4	1%
Home Construction	0.0	1.2	1.3	1.6	2.4	1.4	80.4	3%
Water	0.0	0.1	0.2	0.3	0.4	2.3	108.8	0%
Waste Disposal	0.0	0.4	0.7	1.0	1.6	2.3	108.5	2%
Composting	(5.0)	(2.8)	(0.4)	(1.1)	(0.0)	0.4	0.0	-1%
Food	0.2	5.5	8.5	12.6	21.0	2.3	108.8	19%
Goods	0.2	4.4	7.8	12.9	20.3	2.9	114.9	18%
Services	0.2	4.3	7.8	13.1	20.7	3.1	116.9	18%
TOTAL	14.3	28.1	44.1	67.5	103.7	2.4	7.3	100%

Roughly one third of carbon footprints are from transportation, with motor vehicles accounting for 11.2 tCO_2e (33%), including 9.7 metric tons from fuels (direct & indirect) and 0.5 metric tons from motor vehicle manufacturing and repairs. Air travel ranges between 1.3 and 6.4 metric tons for the 5th and 95th percentiles, with a mean of 3.3 tCO_2e (8%), including direct and indirect effects. This 5x difference in air travel emissions between the 5% and 95% percentiles demonstrates highly unequal distribution of air travel between households with different income levels.

In contrast, only 1 tCO_2e (2%) is from electricity production. This compares to roughly 2 metric tons for the typical California household. Electricity emissions are some of the lowest in the country due mostly to the relatively low carbon-intensity of electricity and low cooling, but also, no doubt, from energy efficiency and conservation measures by residents. Natural gas accounts for twice the emissions as electricity at 2 tons CO_2e (5%). An additional 0.5 tCO_2e (1%) is from the upstream life cycle of energy production (e.g., power plant construction). Emissions from fuel oil or other heating fuels are only 0.1 tCO_2e for the Bay Area overall, but larger in rural locations with no natural gas connections (e.g., Sonoma County coastal communities). Home construction accounts for 1.3 tCO_2e (3%) on average, while water is only 0.2 tCO_2e (<1%), and waste is 0.7 tCO_2e (2%). Composting reduces household carbon footprints by 0.4 tCO_2e (1%).

Recycling also reduces global greenhouse gas emissions by an estimated 1.8 tCO_2e but these reductions are theoretically already included in goods and services and not deducted from the total. In total, "housing" (not including recycling) accounts for 5.8 tCO_2e (13%).

The production, processing, transport and commercialization of food are large sources of emissions when considered on a consumption basis. For the average SF Bay Area household, food contributes 8.5 tCO_2e (19%), roughly three times more emissions than all household energy (gas, electricity and heating fuels) combined. We estimate that the average SF Bay Area resident consumes about 10% fewer calories, and therefore GHG emissions, than the average U.S. resident. These emission are applied on a per capita basis since we find no correlation between income and total caloric consumption of food. The range of emissions from food (6.1 tCO_2e for the 5^{th} percentile and 14.1 tCO_2e for the 95^{th} percentile) is solely a function of household size.

Goods and services each contribute about contribute 8.0 tCO_2e (18%) from supply chains. In total, indirect lifecycle emissions from food, goods, services, home construction, water and energy are 67% of total carbon footprints, while residential emissions typically included in GHG inventories (natural gas, electricity, waste, transportation fuels) account for only one third of total household carbon footprints. There is a 3x difference in GHG emissions between the 5% and 95% percentile of census block groups.

Indirect emissions account for about two-thirds of total consumption-based greenhouse gas emissions. Only transportation fuels (primarily gasoline) and heating fuels are direct.

Geographic Distribution

The spatial distribution of household carbon footprints is clear when viewed in map form. Figure 2 is a map of average household carbon footprints by census block group for all SF Bay Area communities (locations served by the SF Bay Area Air Quality Management District). Carbon footprints tend to be lower in population-dense urban core areas and lower in surrounding suburban areas. San Francisco and the East Bay have the highest concentration of low carbon footprint neighborhoods. Other urban centers throughout the Bay Area mimic this pattern, with low carbon footprint downtown areas clearly visible for each medium to large-sized city.

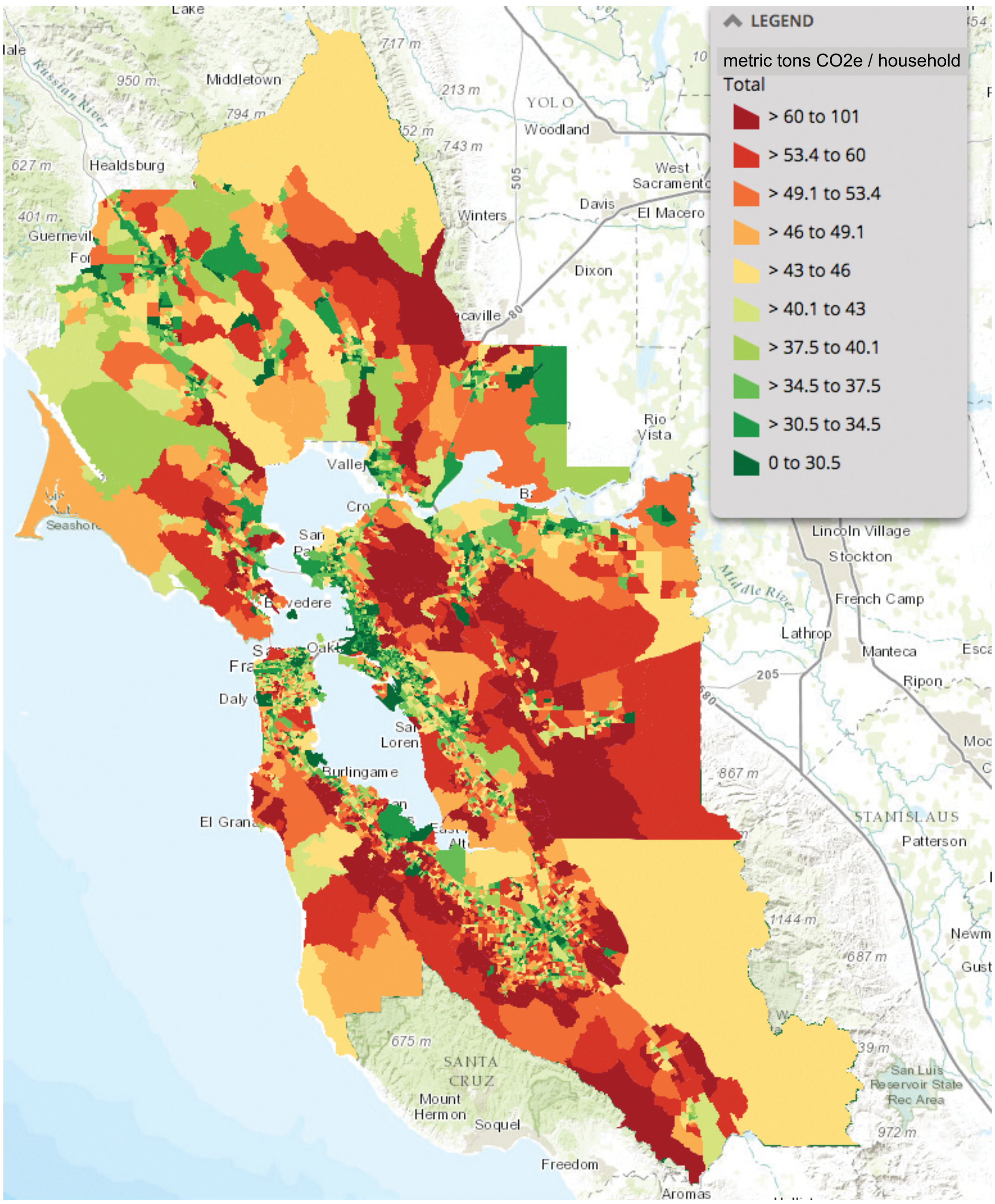

Figure 2. Map of average household carbon footprints (tCO2e per household) in S.F. Bay Area census block groups

While San Francisco and Oakland have very low carbon footprint cores, as well as low emissions overall, they also contain a few of the highest carbon footprint locations in the San Francisco Bay Area. These neighborhoods are characterized by high vehicle ownership, large homes and high income, all of which correlate strongly with larger carbon footprints. Air travel, for example, is particularly high in these locations. Larger cities tend to have the most inequality. The highest carbon footprint neighborhoods in San Francisco and Oakland are more than 5 times larger than the lowest carbon footprint neighborhoods. The difference is roughly 4x in San Jose and Berkeley.

Closer inspection of locations reveals variation within cities and between locations. For example, San Francisco and the East Bay have low emissions from motor vehicles compared to more inland communities to the east (Figure 3). There is a striking factor of 10 difference between motor vehicle emissions in the highest and lowest deciles. San Francisco and the East Bay have low vehicle emissions overall, but there are still pockets of high vehicle ownership and related emissions. The University of California, Berkeley and surrounding neighborhoods, has very lower transportation emissions (from students), but high-income neighborhoods in the Berkeley and Oakland hills have some of the highest transportation-related emission in the SF Bay Area. Neighborhoods surrounding Stanford University (not shown) also have some of the lowest vehicle emissions in the SF Bay Area.

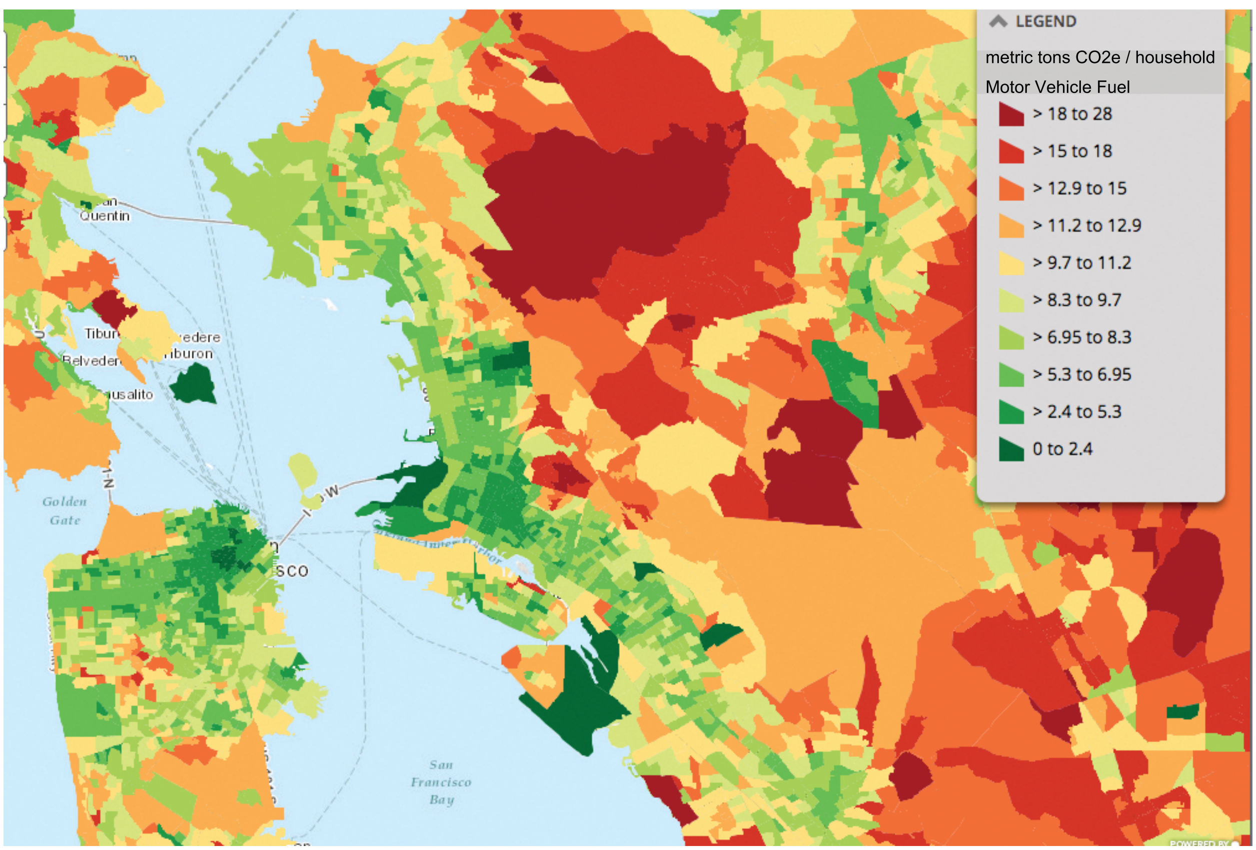

Figure 3. Map of average motor vehicle fuel emissions by census block group

As should be expected, hotter inland communities to the east have higher electricity demand and emissions than cooler communities closer to the ocean (Figure 4A) San Francisco and the East Bay west of the Berkeley Hills consistently have less than 1 ton of tCO_2e from electricity, compared to over 1 ton for much of eastern Contra Costa County. Emissions from natural gas, on the other hand, are roughly three times larger than electricity, and also fairly evenly dispersed throughout the SF Bay Area (Figure 4B). This has important implications for climate policy, as discussed below.

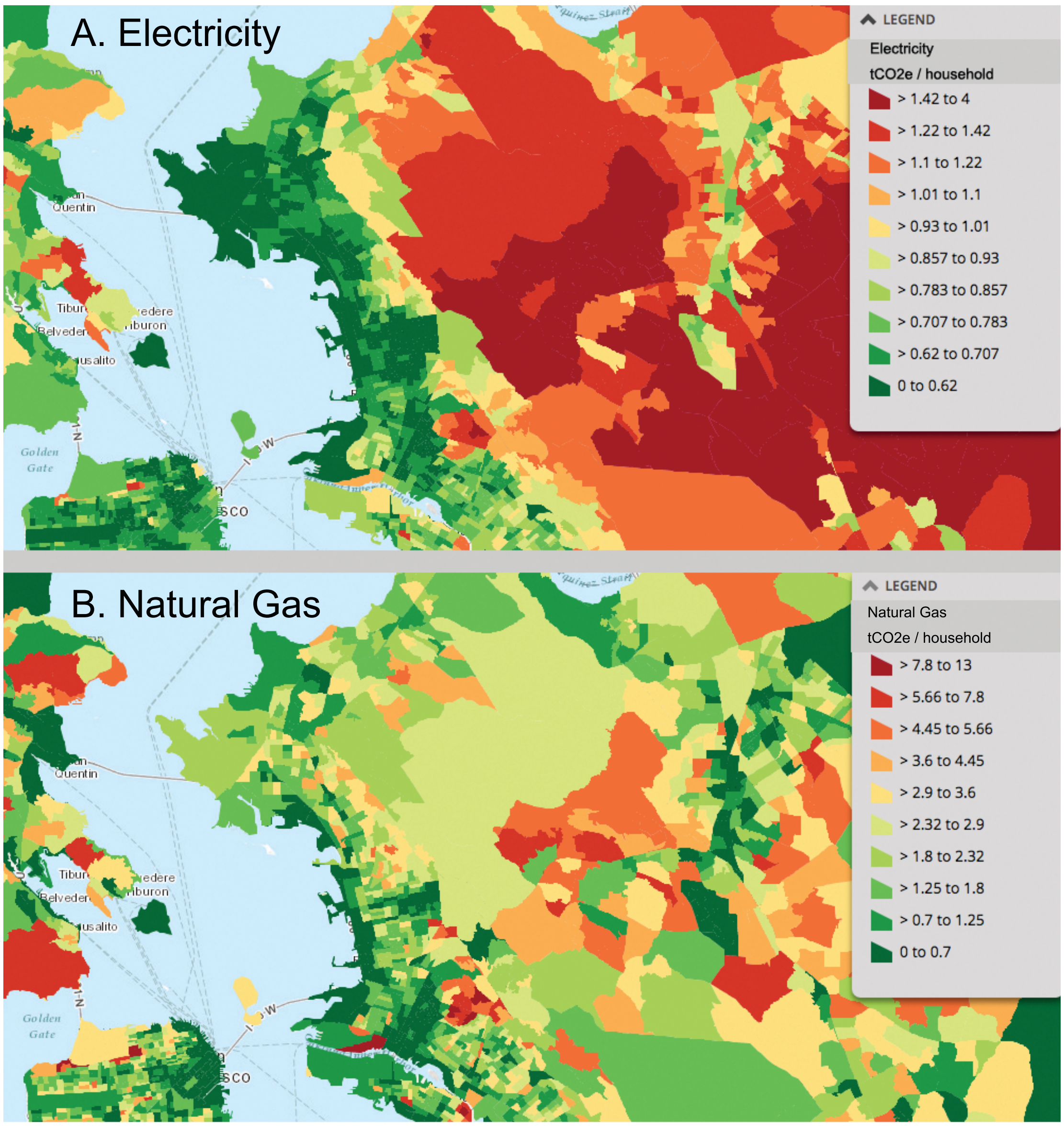

Figure 4. Average household carbon footprints from electricity (map A) and natural gas (map B) for S.F. Bay Area census block groups

Carbon Footprints of SF Bay Area Cities

East Bay Cities in Alameda and Contract Costa Counties

The East Bay has some of the highest and lowest carbon footprint neighborhoods in the SF Bay Area, ranging from 31 tCO_2e in Emeryville to 76 tCO_2e in Piedmont. Emissions from transportation range from 9 to 28 tCO_2e between East Bay cities, a 3x difference. Higher transportation footprints tend to be found in the outlying and wealthier suburbs of Alamo, Orinda, Danville, Lafayette and Moraga, with the exception of Piedmont, which is bordered by entirely by Oakland. Emissions from housing also range nearly 3x, from 4 to 11 tCO_2e, while goods and services range from 12 to 27 tCO_2e. Contra Costa has 9 cities with carbon footprints of 50 tCO_2e or more compared with only 5 in Alameda County. Oakland is an excellent example of urban infill, with low household carbon footprints and high population. Several outlying cities have both high carbon footprints and high population, including Fremont, Danville, San Ramon, Livermore and Pleasanton.

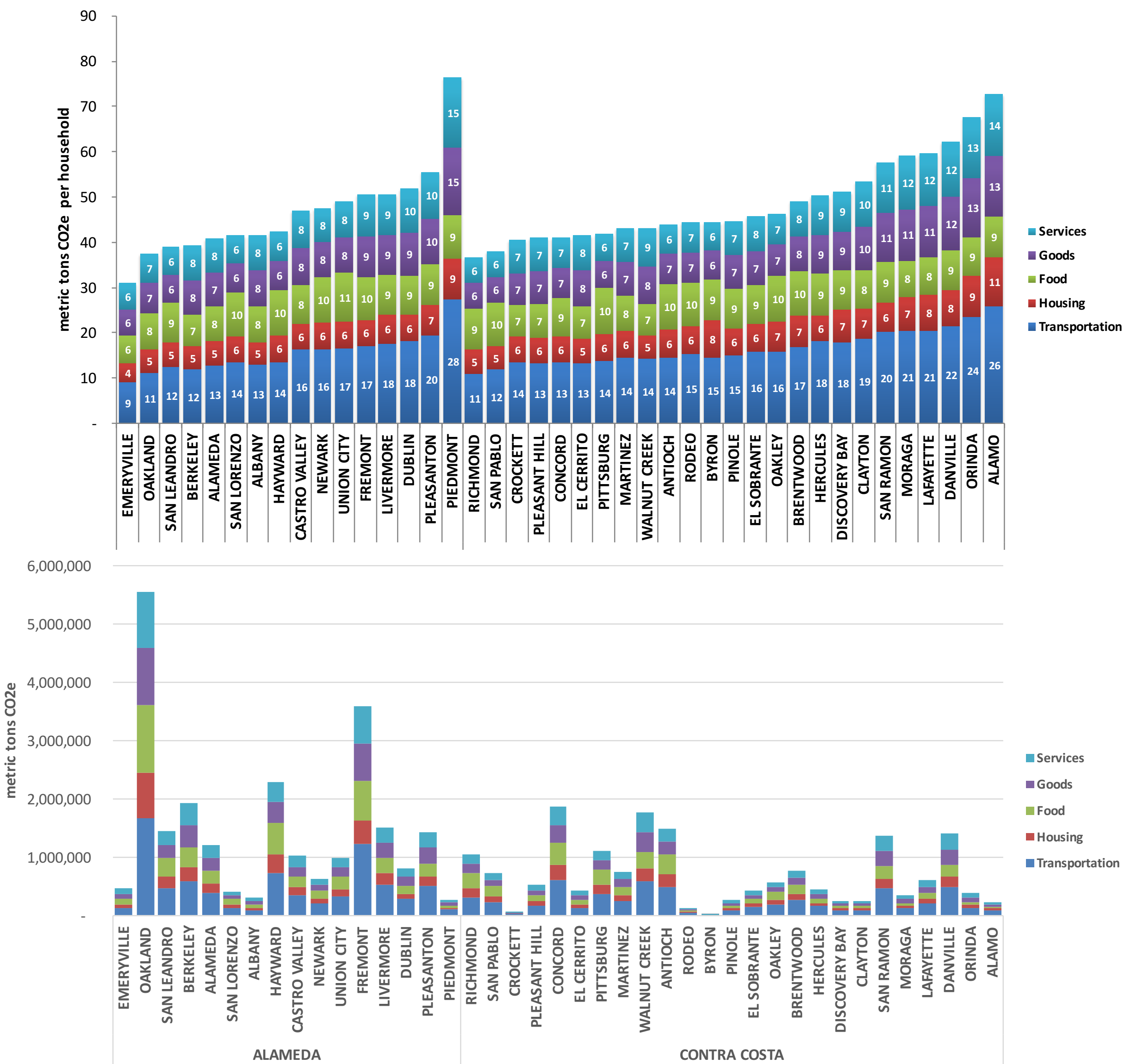

Figure 5. Average household carbon footprint (top figure) and total consumption-based GHG emissions (bottom figure) of S.F. East Bay cities

North Bay Cities in Marin, Napa, Solano and Sonoma Counties

Cities in the North Bay tend to have lower carbon footprints than in the East Bay and South Bay. No cities in Napa, Solano or Sonoma counties have carbon footprints higher than 50 tCO_2e, although several cities are above the SF Bay Area average of 44 tCO_2e. A few upper income cities in Marin have average household carbon footprints above 50 tCO_2e; however, these communities all have relatively low populations and total net emissions. A few cities have both higher than average carbon footprints and total emissions, including Petaluma, Vacaville and Fairfield. Santa Rosa, the largest city, has lower than average household carbon footprints of about 40 tCO_2e. The range of carbon footprints is also less than between East Bay cities, with less than 2x difference between the lowest and highest footprints by category of emissions, and in total.

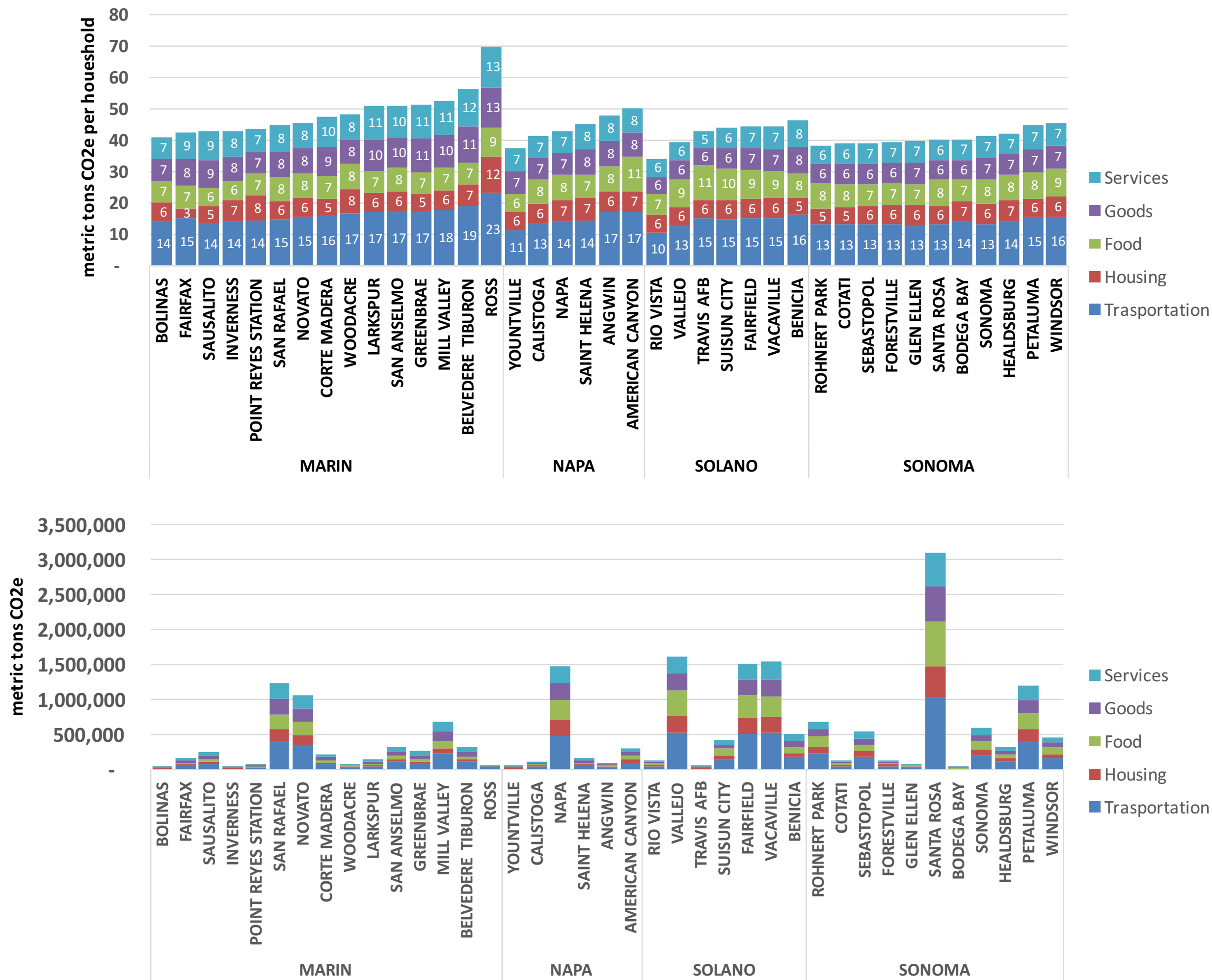

Figure 6. Average household carbon footprint (top figure) and total consumption-based GHG emissions (bottom figure) of S.F. North Bay cities

San Francisco and South Bay Cities in San Francisco, San Mateo, and Santa Clara Counties

Emissions in the South Bay are dominated by the city of San Jose, which has higher than average carbon footprints (48 tCO_2e), and a large population. San Jose has about 10% higher total consumption-based GHG emissions compared to San Francisco, despite having 10% fewer households; however, San Jose has a lower average per capita carbon footprint (15.5 compared to 16.75 metric tons per household). The average carbon footprint of San Francisco households is 38.7 tCO_2e, which is 13% below the Bay Area Average, despite relatively high incomes ($118k/yr). Stanford University is classified as a city in our analysis and has the lowest carbon footprint of all cities at 31.5 tCO_2e. By contrast, Atherton has the highest carbon footprint of any city in the SF Bay Area at 86 tCO_2e, or nearly 3x the carbon footprint of Stanford (and over 2.5x higher than Emeryville). All other cities in the South Bay are over 40 tCO_2e, and most are over average.

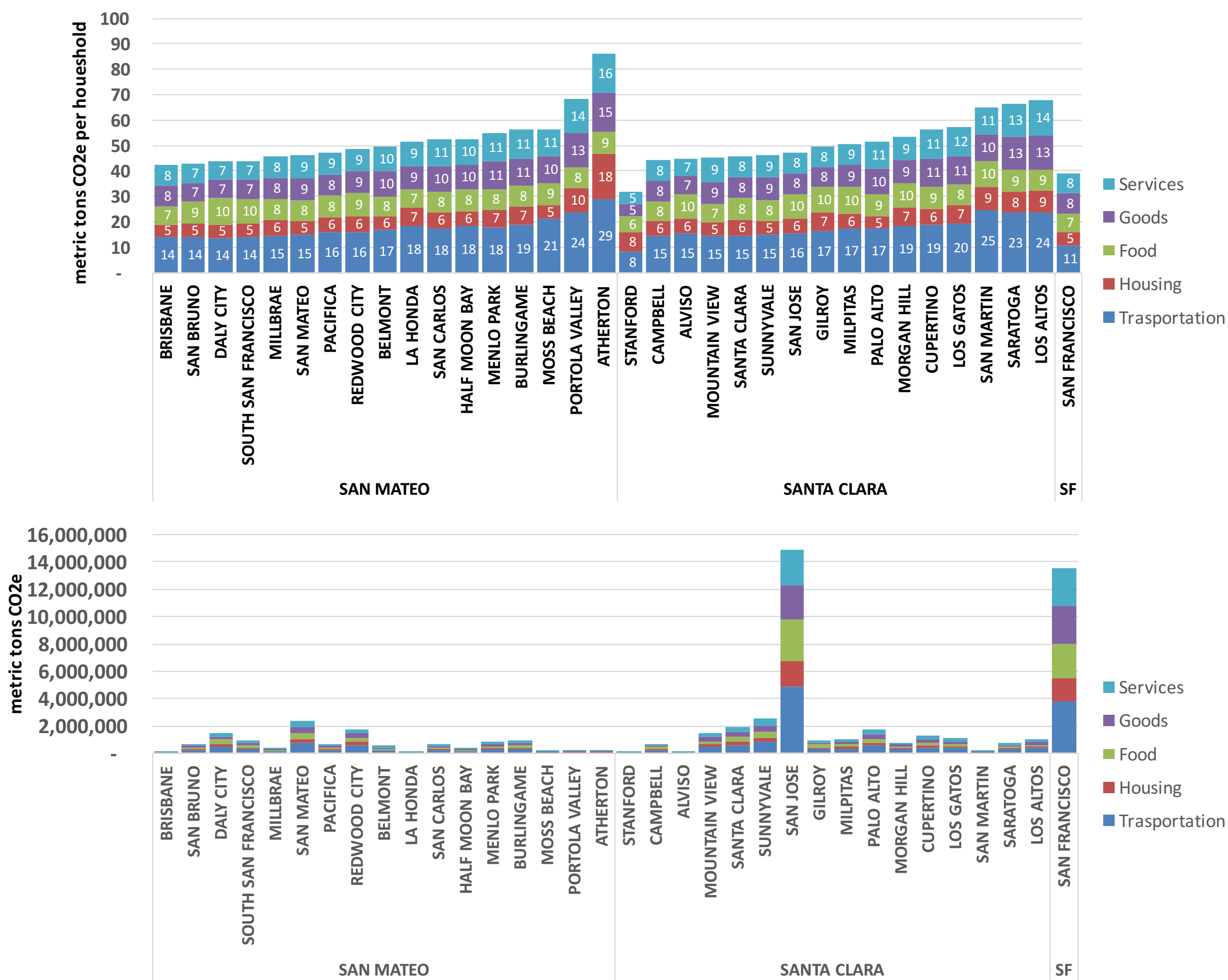

Figure 7. Average household carbon footprint (top figure) and total consumption-based GHG emissions (bottom figure) of San Francisco and S.F. South Bay cities

Discussion

High geospatial resolution consumption-based GHG inventories have a number of potential policy applications. First, considering the full range of GHG emissions may help prioritize a different set of behaviors and technologies for mitigation in communities as a whole, and for specific neighborhoods. For example, food contributes roughly 20% to SF Bay Area GHG emissions when considered on a consumption-basis, roughly 8 times more than the contribution of electricity. Community-based programs to promote healthy and low-carbon diets should be an essential part of community-based climate action planning. Strategies to promote more sustainable consumption should also start to gain in prominence under a consumption-based perspective. For example, local services and entertainment results 2-3 fewer emissions per dollar than typical consumer goods, while generating more money for local economies.

Differences in the size and composition of carbon footprints between different neighborhoods and cities are particularly relevant for the development of climate action plans. For example, high technology solutions, such as combining all-electric homes with solar photovoltaic systems and electric vehicles, are ideally tailored for suburban areas with large roof space, high fuel costs, higher incomes and moderate commuting distances. Lower-carbon urban areas are better candidates for campaigns and policies to promote healthy diets, sustainable consumption and alternatives to flying. In short, solutions should be tailored to the GHG reduction potential of each location.

Neighborhood comparisons may also be more salient to households than comparisons at larger geographic scales. Home energy reports, comparing household consumption with neighbors, have demonstrated electricity savings of 1-2%, on average (Allcott 2011; Ayres, Raseman, and Shih 2012). Neighbors are used for comparison because normative information is thought to be more impactful when individuals are compared to people most like themselves (Cialdini 2003). Neighborhood comparisons of entire household carbon footprints (not just energy) may be particularly useful for community-based initiatives targeting different sub-populations within cities, e.g., carbon footprint reduction competitions (Vine and Jones) or other community-based programs (Abrahamse 2005, 2007).

While GHG reduction opportunities vary widely from one location to another, there are still some clear policy recommendations that seem ideally tailored for the Bay Area.

1. Vehicle Electrification: Carbon footprints from motor vehicles are over ten times larger than carbon footprints from electricity in the SF Bay Area. Low-carbon electricity production, as well as compact design, presents an ideal opportunity for massive electric vehicle adoption in the area.

2. Heating Electrification: While much has been done to reduce emissions from electricity,

natural gas emissions are consistently high in all areas served by natural gas. The Bay Area's moderate climate is ideal for electric heat pumps, providing both heating and air-conditioning. While somewhat costlier, electric heating equipment installed today will last decades and will increasingly provide GHG benefits as the electric grid becomes cleaner.

3. Electricity should be 100% renewable. Home solar photovoltaic systems are now cost-effective for many consumers. Utilities should also offer customers the option to purchase 100% renewable electricity. This strategy has worked well for Palo Alto, which now has 100% renewable electricity, and for community choice aggregation in Sonoma and Marin counties. Zero carbon electricity, combined with vehicle and heating electrification, is a critical pathway to meet California's GHG reduction target of 80% by 2050 (Wei et al. 2013; Williams et al. 2012).

4. Urban infill: downtown core areas of Bay Area cities have considerably lower carbon footprints than surrounding neighborhoods. Efforts should be made to increase housing density in lower-carbon locations and decrease housing in high carbon footprint locations. This has generally been the strategy of regional climate action planning to meet requirements under SB 375, but there is little enforcement and high carbon footprint communities continue to expand. Care should be taken to limit home construction in high carbon footprint locations unless population and employment densities can be increased to comparable levels of urban cores.

5. Home Size Efficiency: Larger homes correlate with increased demand for energy, goods, construction and maintenance. Smaller homes could receive tax incentives, while larger homes could be taxed at higher rates above a threshold. The state of Oregon is exploring such policies.

6. Diet: California Cuisine has its roots in the San Francisco Bay Area and vegetarianism has long been an established norm. However, when considering all 2.6 million households, SF Bay Area residents do not appear to have substantially different diets than other cities in the western United States. More effort should be placed on promoting low-carbon diets. The largest opportunities to reduce emissions are reduce the amount of food consumed, reduce waste and reduce consumption of meat and dairy.

7. Promoting sustainable consumption. Local services produce 2-3 times fewer emissions per dollar than consumer goods. Efforts to promote gift cards to local services could reduce life cycle GHG emissions embodied in imported consumer goods, while improving local economies. Vibrant urban core areas filled with services, entertainment and social activities help promote more sustainable consumption, while urban centers filled with big box shopping malls foster a consumer culture. Local goods may alsobe lower carbon, particular if made in California, where electricity is relative low carbon, and shipping distances are shorter.

The authors hope that this study will result in increased awareness of the greenhouse gas mitigation opportunities available to cities and communities throughout the San Francisco Bay Area. To the extent that the data and tools tell people something they did not already know about greenhouse emissions (and indeed there may be many surprises), free access to this information (see next section below) may help generate new creative solutions to reducing the consumption-based carbon footprint of San Francisco Bay Area neighborhoods, cities and counties.

Supporting Online Tools and Materials

Supporting tools and data are available for free access on the project website (http://coolclimate.berkeley.edu/inventory), including:

- A results spreadsheet tool that displays carbon footprints, plus key input and output data, for all SF Bay Area cities and counties

- An image slide deck allowing for easy comparison of carbon footprints of all SF Bay Area cities and counties

- Link to an interactive online map that allows users too zoom in and see results for any neighborhood

- Access to the CoolClimate Calculator, an online tool allowing users to compare their carbon footprints to similar households and create customized climate action plans

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Appendix A: Supplementary Methods

Travel

Motor Vehicle Fuel

Motor vehicle miles traveled (VMT) are approximated using SF Bay Area respondents in the National Household Travel Survey (Oak Ridge National Laboratory 2013) (n=7,362; r2=0.441). Model variables (with standardized β coefficients), entered stepwise, include: number of motor vehicles (β=.319), natural log of household size (β=.504), income (β=.119), number of workers (β=.156), population density (β=.-.074), and household size (β=.038).[1] A stepwise analysis enters the variables with the most influence on the dependent variable first, controlling for all other variables previously entered. Therefore, the number of vehicles owned by households has the most influence on VMT, followed by household size, log of income, etc.

The weighted fuel economy of light duty vehicles in the SF Bay Area counties is estimated using Emfac2014 (California Air Resources Board 2014). Emfac2014 calculates the fuel economy for California counties based on the vehicle models as well as the driving conditions in each county. The average fuel economy for the San Francisco Bay Area is 22.4 miles per gallon (mpg), which is roughly 1 mpg higher than the national average (source). For San Francisco County (which is also a dense, congested city), we assume 50% of driving is outside the city using the average SF Bay Area fuel economy, for an average of 21.6 mpg.

We use the California Low Carbon Fuel Standard emissions rate of 11,406 gCO_2e per gallon (98.47 gCO_2e/MJ * 115.83 MJ/gallon) (California Air Resources Board 2015), which includes all direct and indirect emissions of California reformulated gasoline. GHG emissions from diesel fuel are somewhat higher, while emissions from natural gas and biofuels are lower. Since we do not have weighted fuel economy for each county by fuel type, or the fraction of vehicles of each fuel type by county, we assume all vehicles are gasoline.

Motor Vehicle Manufacturing and Repairs

Based on a previous review of life cycle assessment studies (Jones and Kammen 2011) manufacturing an average motor vehicle produces 9 metric tons of CO_2. We allocate emissions over the average of 160,000 mile life span for an average of 58 grams CO_2e per mile. Additional emissions from motor vehicle repairs, including parts and services, are included using the CEDA database (Suh 2009) (see description under goods and services below). We do not include emissions from road construction, road maintenance and related emissions (Chester and Horvath 2009) that are not otherwise included in CA-GREET 2.0.

[1] A model including all 14,475 NHTS California respondents, and more variables (e.g., employment density, home ownership and race) was also run for locations outside of the SF Bay Area, but these locations are not included in the current report.

Air Travel

Economic expenditures on air travel for each location are approximated using the Consumer Expenditures Survey (CEX) (Bureau of Labor Statistics 2013) with the household income as the independent variable. Household income is the largest factor contributing to air travel in the United States, with other variables, such as population density, trip distance and the presence of low-cost airlines having mixed and often complex relationships (Bhadra 2003). Figure A1 presents data from the 2005 Consumer Expenditures Survey (Bureau of Labor Statistics 2006) and demonstrates that income is highly correlated with expenditures on air travel, but not other modes of public transportation. To obtain S.F. Bay Area estimates of air travel expenditures we multiple average S.F. Bay Area expenditures on Public Transit in the 2013 CEX ($1,116) by the fraction of public transit expenditures spent on air travel in each income bracket in 2005. These values were then multiplied by the average cost of air travel in 2013, 5.83 miles per $, (Bureau of Transportation Statistics 2013) to obtain average miles of air travel for each income bracket (Figure A2).

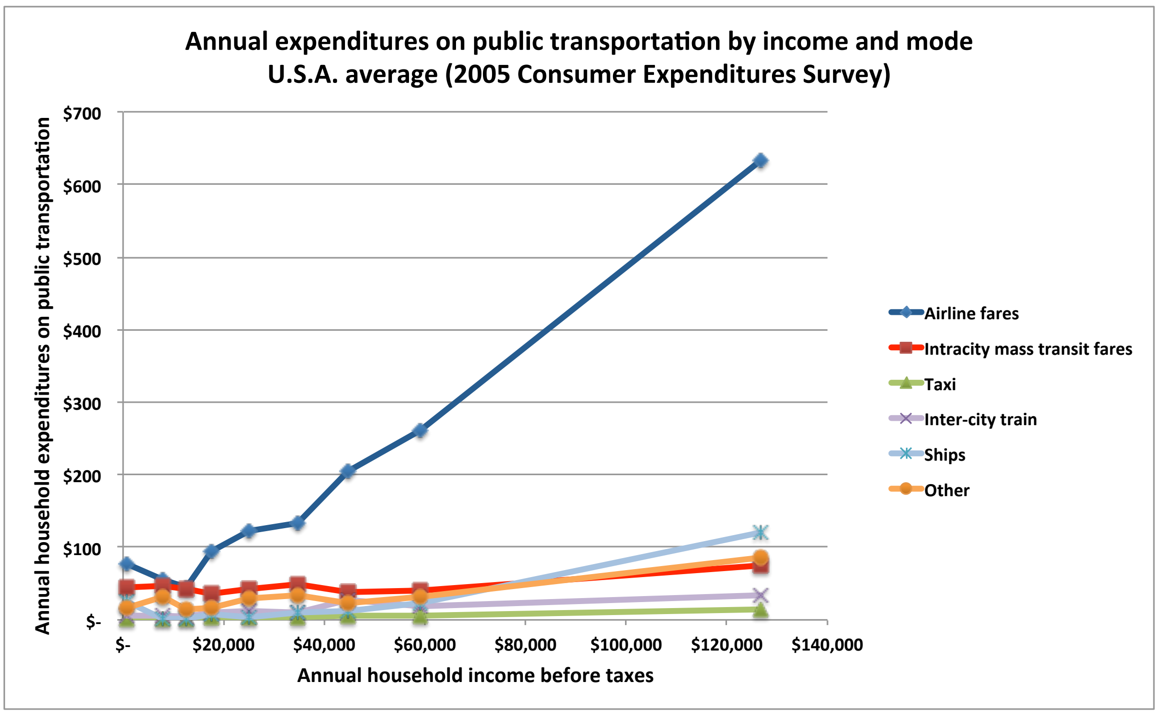

Figure A1. Public transportation expenditures by household income. Each mark is the mean value for each income bracket

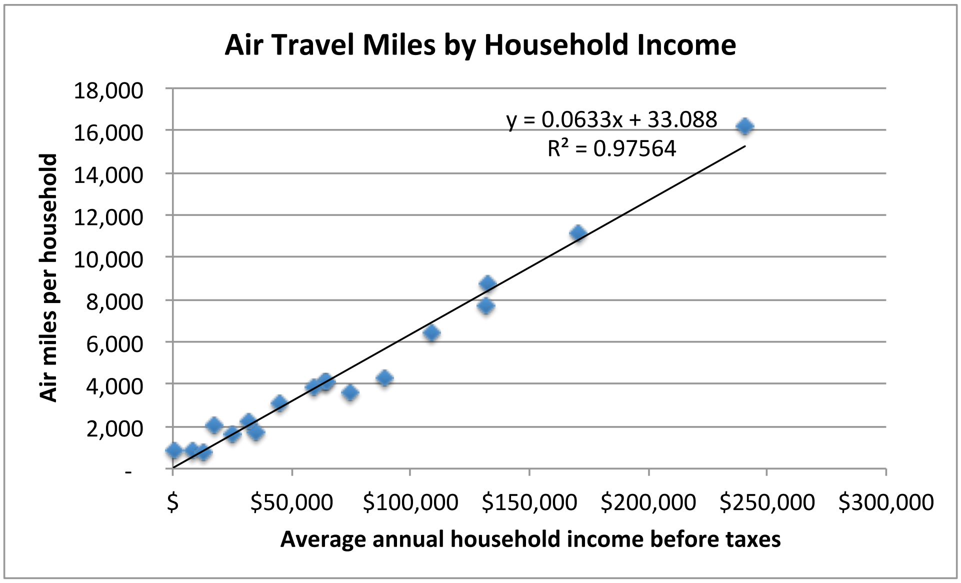

Figure A2. Linear regression of air miles by average annual household income. Each mark represents the mean value for each income bracket

A typical flight produces direct emissions of 223 grams of CO_2 per passenger mile (Ranganathan et al. 2004), plus a roughly equivalent amount of atmospheric warming due to high altitude water vapor and effects on high altitude atmospheric chemistry (Sausen et al. 2005). While there is considerable amount of variation in both direct and indirect emission for individual flights, these differences should be moderated when considering average values for multiple flights by multiple households in each location.

Public Mass Transportation

Greenhouse gas emissions from S.F. Bay Area public transit systems are roughly approximated using the National Transit Database. S.F. Bay Area public transit systems reporting fuel consumption are reported in Table A1. Some public transit vehicles appear to be missing from in database, e.g., buses operated by S.F. Municipal Transit Agency. Electricity is assumed to be procured from PG&E. Direct diesel and gasoline emission factors are from EPA (Office of Air Quality Planning and Standards 2013). Indirect GHG emission from gasoline and diesel are from the GREET model (Wang 2008). GHG emission from other fuels are assumed to be 50% of diesel, considered on a life cycle basis. As shown in Table 1, total GHG emissions are 149,524 for all public transit systems. We allocated emissions to households in counties served by each public transit system.

Table A1. Revenues, fuel consumption and GHG emissions of SF Bay Area public transit systems. Fuel consumption and revenues from the National Transit Database

Agency	Fare Revenues	kWh electricity	Gallons of Fuel	Metric tons CO2	gCO2 per $
San Francisco Bay Area Rapid Transit District	$ 406,889,588	294,344,664	-	52,393	129
San Francisco Municipal Railway	$ 220,093,193	3,835,961	-	683	3
Peninsula Corridor Joint Powers Board dba: Caltrain	$ 64,216,475	-	4,394,988	54,885	855
Alameda-Contra Costa Transit District	$ 61,499,891	-	844,123	6,172	100
Golden Gate Bridge, Highway and Transportation District	$ 32,129,337	-	164,323	919	29
San Mateo County Transit District	$ 19,427,746	-	271,913	2,516	129
San Francisco Bay Area Water Emergency Transportation Authority	$ 10,501,989	-	2,026,809	25,311	2,410
Solano County Transit	$ 3,945,585	-	236,740	2,956	749
The Eastern Contra Costa Transit Authority	$ 3,439,725	-	139,678	781	227
Sonoma County Transit	$ 2,193,485	-	68,011	380	173
City of Santa Rosa	$ 2,158,609	-	41,739	302	140
Western Contra Costa Transit Authority	$ 2,034,280	-	78,967	986	485
Napa County Transportation Planning Agency	$ 926,661	-	54,462	612	661
City of Petaluma	$ 240,671	-	13,345	75	310
TOTAL SF Bay Area		**298,180,625**	**8,335,098**	**148,972**	

The following is how emissions from public transit systems were allocated to locations

- San Francisco Bay Area Rapid Transit District - SF, SM, Alameda, Contra Costa counties
- San Francisco Municipal Railway – SF
- Peninsula Corridor Joint Powers Board dba: Caltrain – SF, SM, SCL counties
- Alameda-Contra Costa Transit District – Cities of Alameda, Albany, Berkeley, El Cerrito, El Sobrante, Emeryville, Fremont, Hayward, Kensington, Newark, Oakland, Piedmont, Richmond, San Leandro, San Pablo, and Unity City. Also unincorporated areas including San Lorenzo, Ashland, Cherryland, Castro Valley, Fairview.
- Golden Gate Bridge, Highway and Transportation District – Marin & Sonoma
- San Mateo County Transit District – San Mateo County
- San Francisco Bay Area Water Emergency Transportation Authority – Alameda & Solano counties
- Solano County Transit - Solano
- Victor Valley Transit Authority delete this one, it's in Southern Cal
- The Eastern Contra Costa Transit Authority - cities of Antioch, Pittsburg, Brentwood, Oakley, Bay Point, Discovery Bay and Concord
- Sonoma County Transit – Sonoma
- City of Santa Rosa – City Santa Rosa
- Western Contra Costa Transit Authority - WCCTA service area comprises just over 20 square miles of West Contra Costa County, including the cities of Pinole and Hercules and the unincorporated areas of Montalvin Manor, Bayview, Tara Hills, Rodeo, Crockett, and Port Costa.
- Napa County Transportation Planning Agency – Napa County
- City of Petaluma –City of Petaluma

<u>Household Energy</u>

Electricity and natural gas consumption were provided by the following local utilities at the level of zip codes:

- Alameda Power: electricity only
- Pacific Gas & Electric Company: electricity and natural gas
- City of Palo Alto: electricity and natural gas
- Silicon Valley Power (City of Santa Clara): electricity only

GHG emission factors for electricity are provided by each electric utility (Table A2). Pacific Gas & Electric Company (PG&E) provides detailed information on their company website. Marin Clean Energy's website claims its electricity is, on average, 20% lower than PG&E. Customers may also choose 50% renewable or 100% renewable options. We assume the same 20% lower rate for Sonoma Clean Power. In the case of Santa Clara, net generation for the year 2007 was available via form EIA-861 filing (U.S. Energy Information Administration 2015); purchases were assumed to the California grid average (U.S. E.P.A. 2013).

Table 2. GHG emission factors for electric utilities

Electric Utility	Rate	Units	Notes	Source
PG&E	178	gCO2/kWh		PG&E
Palo Alto	-	gCO2/kWh	100% renewable	Palo Alto
Santa Clara	340	gCO2/kWh	EIA-861 filing (2007)	EIA, eGRID
Marin Clean Energy	142	gCO2/kWh	Maring Clean Energy	80% of PGE
Alameda	186	gCO2/kWh	33% renewable / 67% CA avg.	Alameda Power
Sonoma Clean Power	142	gCO2/kWh	80% of PG&E	Sonoma Clean Power

In order to provide higher geospatial resolution to the level of census block groups we developed econometric models for electricity and natural gas based on average home characteristics. The modeled results provided a scaling factor for each census block group such that the weighted mean consumption of all households in zip codes matched the mean consumption provided by utilities. In cases where zip codes are served by more than one utility, we create customer-weighted average.

Modeled results are used to predict expected consumption based on characteristics of homes in each census block group, provided by the U.S. Census. Two additional data sources were only available at the level of US zip codes: square feet of homes (provided by agreement with CoreLogic) and heating and cooling degree days (interpolated from NOAA weather stations) (NOAA 2015). The US Census provides a concordance table that matches Census Tracts to zip code tabulation areas (ZCTA). For tracts that intersect more than one ZCTA the tract segment with the highest population was mapped to the corresponding ZCTA such that each census tract corresponds to only one zip code.

The following section describes methods for modeled results.

Modeled electricity

Electricity consumption (natural log of kWh per household) is approximated using San Francisco Bay Area respondents in the Residential Energy Saturation Survey (California Energy Commission 2015) (r2=0.440 ; n=3,520; mean =5,909 kWh per year). The variables, entered stepwise and presented in order below, are cooling degree days (CCD) (**β**=.254), natural log of income (**β**=.125), square feet (**β**=.294), CCD * square feet (**β**=.-.195), natural log of CCD * square feet (**β**=.0.61), persons per household (**β**=-.158), natural log of persons per household (**β**=.379), % single-detached homes (**β**=.0.74), % homes owned (**β**=.099), number of rooms (**β**=.158), % with graduate degrees (**β**=-.078), % heat with natural gas (**β**=.128), % Asian, (**β**=-.084), % black / African American (**β**=.049), % White / Caucasian (**β**=.059). The purpose of our model is to have the strongest predictive power, not to explain the contribution of different factors to electricity demand. Due to multicollinearity between variables it is not possible to directly interpret the relative impact of individual independent variables on the dependent variable considering the standardized coefficient (**β**) alone.

The modeled results are strongly correlated with actual results. Figure A3 (left-hand figure) presents modeled electricity results by zip code (x-axis) vs. actual electricity consumption (y-axis), as provided by electric utilities. As should be expected, the goodness of fit (R^2 = 0.615) is stronger in this case when hundreds or thousands of households are averaged together than in the original econometric model (R^2=0.440) in which modeled results are compared with individual households in RASS. Since our goal is to produce the most accurate results for census block groups, we scaled modeled results such that the population-weighted mean of census all block groups within zip codes matches actual electricity consumption in that zip code. The results of this adjustment for all census block groups are shown in the right-hand Figure 3. The width of each row of data represents the range of annual average electricity consumption of census block groups with the same actual kWh at the scale of zip codes.

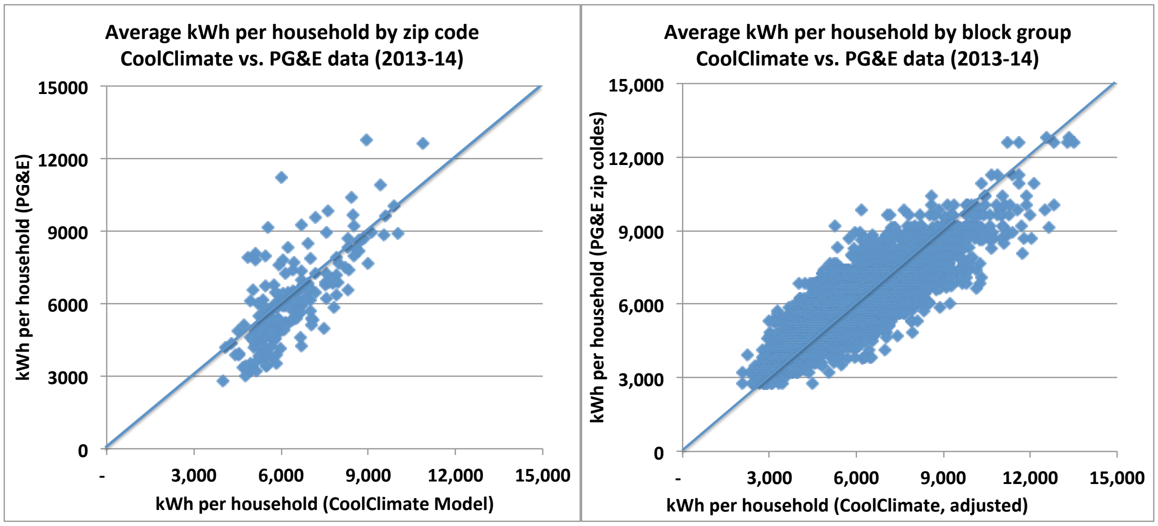

Figure A3. Left-hand figure: CoolClimate modeled electricity (x-axis) vs. actual electricity (y-axis) by zip code; Right-hand figure: CoolClimate modeled electricity, adjusted to mean of actual by zip code (x-axis) vs. actual electricity (y-axis) by census block group

Modeled Natural Gas

Natural gas consumption is modeled from S.F. Bay Area respondents in the Residential Appliance Saturation Survey 2009 (r^2=.503; n=3,540 , mean = 411 therms/year) and the following variables (entered stepwise and presented in order): percentage of homes that heat with gas (β=0.551), number of rooms (β=-.183), age of homes (β=.0.84), % Asian householders (β= -0.096), natural log of persons per household (β= 0.058), % Latino households (β=-0.054), % of householders with graduate degrees (β= -0.050), square feet of living area (β= 0.062), % home owners (β=-0.056), % single detached homes (β=.0.052).

Natural gas produces 5,470 gCO_2 per therm (EPA). There is a high degree of uncertainty for indirect emissions from natural gas. System-wide leaks from extraction, transmission and distribution vary considerably by location. We assume an indirect rate of 13.6% of direct emissions (Jaramillo, Griffin, and Matthews 2007).

Unlike electricity, which is essentially used by all Bay Area homes, not all homes have natural gas connections, and of those home that do, not all have heating equipment or appliances that use gas. This makes it difficult to compare actual usage with modeled results since data are only available for customers who use natural gas, and we are interested in the "average" home. Figure 4 compares CoolClimate modeled average therms of natural gas per household (a-axis) with average therms of gas reported by PG&E multiplied by a correction factor (y-axis) for Bay Area zip codes. The correction factor is the number of customers reported by PG&E divided by the number of homes in the zip code estimated by the U.S. Census in 2013. Thus, our "average home" will have a fraction of heating that is from natural gas, and other fuels, depending on the prevalence of the heating fuel in the block group. The right-hand figure in Figure A4 shows the effect of adjusting the CoolClimate results such that the weighted mean of all census block groups in the CoolClimate model matches the mean estimate by utilities (correcting for number of homes using gas). The width of each row of data represents the range of annual average natural gas consumption of census block groups with the same actual gas consumption at the scale of zip codes.

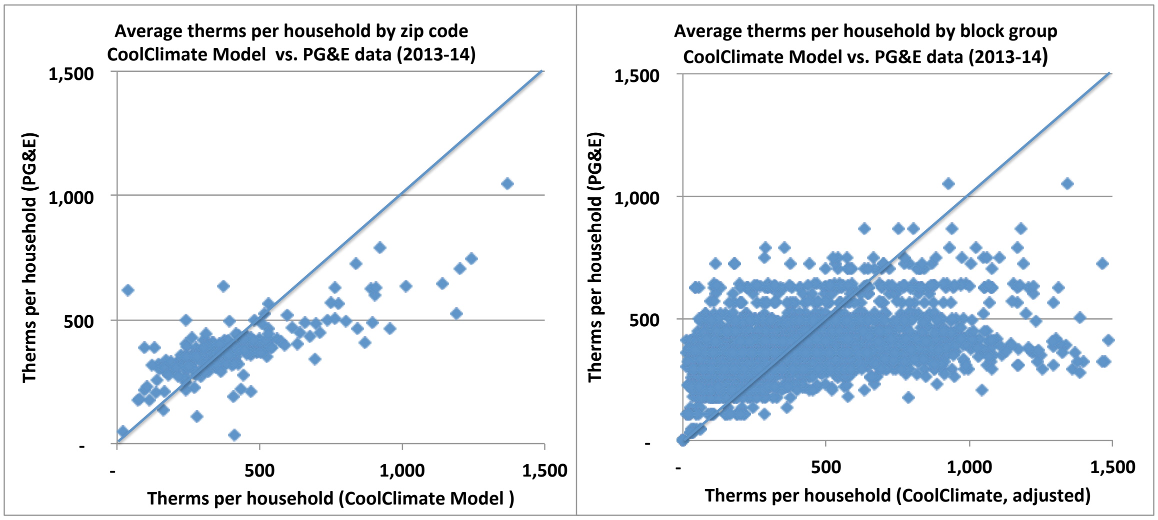

Figure A4. Left-hand figure: CoolClimate modeled natural gas (x-axis) vs. actual PG&E data (y-axis) by zip code; Right-hand figure: CoolClimate modeled natural gas, adjusted to the mean of actual by zip code (x-axis) vs. actual natural gas (y-axis) by census block group

Other fuels

Other heating fuels are approximated in the Residential Energy Consumption Survey (U.S. Energy Information Administration 2005)(n=2,693; R^2 = .019) based on number of rooms (β=0.434) census region (β=0.118), home ownership (β=-0.187), and the age of householder (β=0.134) and race of primary household is white (β=-0.099). Consumption (in gallons) is multiplied by the fraction of homes that heat with fuel oil or other fuels. Fuel oil produces 10,153 gCO_2 per gallon (Office of Air Quality Planning and Standards 2013), plus indirect life cycle emissions of 23%, or 2,335 gCO_2 per gallon (GREET 2.8).

WATER

Given the difficulty of collecting residential water consumption for all locations, and that total GHG emissions are less than 0.5%, we have estimated water consumption on a per capita basis. Statewide about 30% of water is for indoor purposes (~70 gallons per day per capita) and 70% is for outdoor purposes (~165 gallons per day per capita). Given that much of the SF Bay Area is built in high urban density with relatively cool temperatures, it is likely that outdoor uses are less than average. We assume total average usage of 130 gallons per day per person for outdoor purposes.

The GreenPoint Rated Calculator (Jones, et al. 2012) developed a 10-region carbon-intensity model of water withdrawals: The indoor energy intensity for the SF Bay Area is 4260 kWh per million gallons; the outdoor intensity is 2340 kWh per million gallons. The assumed carbon intensity of electricity is 303 gCOe/kWh.

Thus for the average home, annual GHG emissions from indoor and outdoor water are: (70 gallons per person-day * 2.5 persons per household * 365 days * 4260 kWh/ M gallon + 130,000 gallons per person-day * 2.5 persons per household * 365 days * 2340 kWh per million gallons) * 303 gCO2 per gallon = (255.6 + 234) * 303 grams CO2 per kWh = 167 $kgCO_2$ (66 $kgCO_2$ per person).

WASTE

Residential waste disposal and diversion rates for each county were obtained from CalRecycle's 2008 Waste Characterization Study (CalRecycle 2015) (Table A3). There is surprising uniformity of waste disposal rates between counties, with each resident disposing of about 0.43 tons of material per year. Diversion rates vary between 53% of 73% of waste streams, with the remainder sent to landfills.

Table A3. Residential waste disposal and diversion rates in SF Bay Area counties. Source: CalRecycle, 2008 Waste Characterization Study"

Example CA County	Total MSW (tons/resident/year)	Annual Disposal Rate (tons/resident/year)	Annual Diversion (tons/resident/year)	Annual Diversion Rate %
Alameda	1.14	0.42	0.72	63
Contra Costa	0.91	0.42	0.49	54
Marin	1.50	0.42	1.08	72
Napa	0.89	0.42	0.47	53
San Francisco	1.40	0.42	0.98	70
Solano	1.08	0.42	0.66	61
Sonoma	1.22	0.44	0.78	64
San Mateo	1.17	0.42	0.75	64
Santa Clara	1.00	0.42	0.58	58

On average each standard ton of mixed municipal solid waste (MSW) sent to landfills generates 0.58 metric tons of CO_2 equivalent gases (U.S. E.P.A. 2015). Recycling and composting, in contrast, result in net negative emissions due to reduction of upstream manufacturing and land use emissions. The GHG savings of recycling depend largely on the composition of recycled materials. California does not have mandatory reporting of recycling materials. Nonetheless, a recent study by CalRecycle (CalRecycle 2015) published an estimate of the composition of the total recycling stream, including commercial and residential sectors (first two columns of Table 4). To estimate the composition of residential recycling streams we have made a few adjustments (column 3, Table A4). First, we assume the total recycling waste stream is reflective of the residential waste stream, with the exception of construction and demolition (which is included in principle in the home construction emissions). Additionally, we assume 50% of “other recycling and source reduction” is mixed recycling and the other 50% is source reduction. Since source reduction reduces the carbon intensity of manufacturing consumer goods, we assume those emission reductions are already accounted for properly in the goods portion of model (see below). Based on these adjustments, organics comprises nearly 50% of the recycling waste stream by weight, most of which is yard trimmings; paper is roughly 25% and other mixed recycling is another 25%. We apply GHG emission factors for organics composting from the California Air Resources Board (California Air Resources Board 2011) and GHG emission factors for plastic, tires, and mixed recycling (including beverage containers) from EPA’s Warm Model (U.S. E.P.A. 2015). The weighted GHG reduction factor is 1.83 metric tons of CO_2e per short ton of diverted waste.

Table A4. Estimate of composition of CA recycled materials (CalRecycle) and GHG emission factors

Materials in Recycling Stream (CalRecycle)	%	Adjusted % (assumed)	metric ton CO2e/short ton recycled	Source/notes
C&D	37%	0%		
Plastic	0.5%	1.0%	-1.52	EPA
Paper stock	13%	25.2%	-3.54	EPA
Organics	25%	48.5%	-0.42	ARB
Tires	0.50%	1.0%	-1.84	EPA
Beverage containers	1%	1.9%	-2.88	EPA/Mixed recyclables
Other recycling	11.5%	22.3%	-2.88	EPA/50% of "other"
Resource reduction	11.5%	0.0%	0	50% of "other"
Total	100%	100%	(1.83)	

Home Construction

A recent study conducted for the Oregon Department of Environmental Quality concluded that emissions associated with the manufacturing of new and replacement building materials, materials transport and the construction and demolition of homes accounts for over 100 metric tons of CO_2e over a 70 year expected lifetime for an average 2,262 square foot home. Emissions are not perfectly linearly correlated with home size, since there are efficiencies of scale for building larger homes. Following Jones and Kammen (2014) we apply the following formula to account for GHG emissions for homes of different sizes:

Climate impact = $0.0097X^2 - 10.012x + 80256$,

where Climate Impact is the total greenhouse gas emissions (kg CO_2e) resulting from the manufacturing of new and replacement materials over a 70 year expected lifetime of homes, and x is the floor area in square feet of the home. We divide total lifetime emissions by 70 to account for an annualized emissions rate. This methodology will overestimate emission if homes are over 70 years old; however, roughly half of emissions are for materials the need regular replacement (carpet, flooring, cabinets, windows, etc.) and the methodology will underestimate when homes have undergone considerable remodeling. Here we include only emissions from home construction, construction materials and maintenance of the structure; furniture and goods are included under the "goods" category.

Food

The average American adult consumes over 2,700 calories per day, roughly 25% more calories than is recommended for healthy diets (USDA 2015). California has among the lowest rates of obesity in the United States (Centers for Disease Control and Prevention 2015) so presumably Californian's eat less food with lower food-related GHG emissions. According to the Consumer Expenditures Survey (Bureau of Labor Statistics 2013) SF Bay Area residents spend about 6% more on food than the U.S. average with roughly the same fraction of food spent on meat, dairy, cereals, and other food as other U.S. cities. The cost of groceries is 24% higher in the Bay Area(C2ER 2014). Bay Area residents also spend about 30% more on food away from home, so a larger fraction of food is eaten outside of the home. Combining this information, our best estimate is that Bay Area residents consume about 10% less food than the U.S. average. The composition of average diets is shown in Table A5. We reduce the total diet of all food categories by 10%. Due to lack of evidence of diets at finer geographic scale the SF Bay area we assume all diets are the same on a per capita basis, thus our estimates for food-related emissions are solely based on the average household size of each location.

GHG emission factors are from the Comprehensive Environmental Data Archive (CEDA) (Suh 2009) Version 4.0. CEDA is an environmentally-extended input-output life cycle assessment model of U.S. consumption. It considers all inputs to production resulting from supply chains. Emissions in CEDA are expressed per dollar of sector output. We convert emissions of all food, goods and services to retail prices (a.k.a., "purchaser prices"), accounting for emissions from transportation (air, truck, rail, water), wholesale trade and retail trade (C. M. Jones and Kammen 2011).

Table A5. Caloric consumption and carbon footprint of average California household with 2.74 people

	Adults	children	Total		
number of people	2.00	0.74	2.74		
	Calories/day-adult	Calories/day-child	Calories/day-household	gCO2/calorie	tCO2/year-household
Meat, fish, eggs	487	365	1,242	5.53	2.506
Beef, pork, lamb	241	181	615	6.09	1.365
Poultry & eggs	130	98	332	4.27	0.518
Other (processed meat, nuts....)	100	75	256	2.24	0.209
Fish & seafood	16	12	40	5.71	0.084
Dairy	232	174	592	4.00	0.865
Grains & baked goods	584	438	1,489	1.45	0.791
Fruits & vegetables	304	228	777	3.35	0.948
Other (snacks, drinks, etc.)	1,170	877	2,985	2.24	2.438
Total	2,776	2,082	7,085	3.26	7.218

Goods and Services

Methods for the development of goods and services are explained in detail elsewhere (Jones and Kammen 2014; 2011). The basic steps involved are: 1) develop econometric models of household consumption for category of goods and services in the Consumer Expenditures Survey (Bureau of Labor Statistics 2013), using household size and income as the dependent variables; 2) use these models to estimate household consumption profiles for each census block group; 3) adjust consumption by the Consumer Price Index and the Cost of Living Index (C2ER 2014) for the S.F. Bay Area; 4) multiple by GHG emission factors derived from CEDA Version 4 in purchaser prices, and weighted by average annual U.S. spending on each of over 250 subcategories of goods and services.

The current version of the CEDA model assumes that U.S. imports from other countries are produced with the same GHG emissions intensity as U.S. products. This assumption is thought to underestimate consumption-based GHG emissions by between 10-15% (Weber and Matthews 2008). Table A6 shows the weighted GHG-intensity factors for each of the categories of goods and services in our model. We have increased the emissions shown by 10% to account for higher carbon-intensity of imported goods.

Table A6. Goods and Services categories and weighted GHG-intensity from CEDA Version 4

Consumption Category	Value	Units
Clothing	750	gCO2e/$(2005)
Furnishings, appliances, other household items	614	gCO2e/$(2005)
Other goods (sum of below)	971	gCO2e/$(2005)
Healthcare products	696	gCO2e/$(2005)
Electronics & entertainment equipment	1,279	gCO2e/$(2005)
Paper products	2,100	gCO2e/$(2005)
Personal care & cleaning	954	gCO2e/$(2005)
Auto parts	558	gCO2e/$(2005)
Services (sum of below)	507	gCO2e/$(2005)
Vehicle repair	433	gCO2e/$(2005)
Household maintenance and repair	134	gCO2e/$(2005)
Education	1,065	gCO2e/$(2005)
Health care	1,151	gCO2e/$(2005)
Personal business and finances	197	gCO2e/$(2005)
Entertainment & recreation	711	gCO2e/$(2005)
Information and communication	291	gCO2e/$(2005)
Organizations and charity	122	gCO2e/$(2005)
Miscellaneous services	720	gCO2e/$(2005)

A summary of household consumption for the typical San Francisco Bay Area household is provided in Table A7. These factors vary considerably from one location to another.

Table A7. Summary of major categories of consumption estimated in this study

Consumption category	Value		Units
Motor vehicles		19,057	miles per year
Air tavel		7,472	miles per year
Electricity		5,631	kWh per year
Natural Gas		359	therms per year
Other fuel		15	gallons per year
Waste		1.15	short tons per yea
Recycling / composting		1.88	short tons per yea
Clothing	$	2,514	$ per year
Furnishings	$	2,762	$ per year
Other Goods	$	6,073	$ per year
Services	$	19,110	$ per year

Appendix B. Summary of carbon footprints by city

County	CITY	Households	Transportati	Housing	Food	Goods	Services	TOTAL	TOTAL tCO2
ALAMEDA	EMERYVILLE	15,010	9.16	4.04	6.37	5.53	5.61	30.41	456,405.01
ALAMEDA	OAKLAND	147,986	11.24	5.25	7.96	6.38	6.38	36.84	5,452,047.43
ALAMEDA	SAN LEANDRO	36,977	12.50	5.44	8.71	6.02	5.96	38.22	1,413,312.49
ALAMEDA	BERKELEY	48,877	11.87	5.15	7.07	7.38	7.49	38.63	1,888,161.58
ALAMEDA	ALAMEDA	29,796	12.89	5.27	7.72	7.28	7.34	40.13	1,195,607.64
ALAMEDA	SAN LORENZO	9,917	13.50	5.60	10.02	6.14	5.98	40.77	404,316.41
ALAMEDA	ALBANY	7,232	13.03	4.88	8.08	7.64	7.69	40.95	296,156.27
ALAMEDA	HAYWARD	53,982	13.66	5.85	10.05	6.35	6.20	41.64	2,248,052.77
ALAMEDA	CASTRO VALLEY	21,681	16.29	5.83	8.33	8.07	8.11	46.24	1,002,614.80
ALAMEDA	NEWARK	13,178	16.49	5.73	10.18	7.47	7.35	46.75	616,104.98
ALAMEDA	UNION CITY	20,188	16.57	5.95	10.75	7.73	7.58	48.07	970,518.10
ALAMEDA	FREMONT	71,055	17.26	5.68	9.50	8.85	8.84	49.69	3,530,716.73
ALAMEDA	LIVERMORE	29,941	17.77	6.32	8.77	8.65	8.69	49.78	1,490,506.51
ALAMEDA	DUBLIN	15,776	18.12	5.90	8.69	9.29	9.36	50.95	803,709.35
ALAMEDA	PLEASANTON	25,627	19.53	6.68	8.88	9.96	10.05	54.69	1,401,588.92
CONTRA COSTA	RICHMOND	28,726	11.07	5.19	9.17	5.50	5.38	36.02	1,034,615.06
CONTRA COSTA	SAN PABLO	19,002	11.89	5.28	9.57	5.56	5.41	37.41	710,808.54
CONTRA COSTA	CROCKETT	1,485	13.51	5.67	6.86	7.01	7.12	39.95	59,331.92
CONTRA COSTA	PLEASANT HILL	12,878	13.29	5.69	7.39	7.07	7.15	40.36	519,740.34
CONTRA COSTA	CONCORD	45,253	13.47	5.69	8.55	6.55	6.52	40.52	1,833,460.56
CONTRA COSTA	EL CERRITO	10,209	13.40	5.24	7.35	7.61	7.71	41.08	419,420.26
CONTRA COSTA	PITTSBURG	26,569	13.72	6.03	10.25	5.90	5.71	41.28	1,096,764.05
CONTRA COSTA	MARTINEZ	17,412	14.50	5.89	7.86	7.21	7.26	42.46	739,332.76
CONTRA COSTA	WALNUT CREEK	40,963	14.24	5.33	6.85	8.11	8.27	42.57	1,743,985.00
CONTRA COSTA	ANTIOCH	33,946	14.50	6.35	10.04	6.43	6.28	43.27	1,468,868.40
CONTRA COSTA	RODEO	2,939	15.39	6.17	9.55	6.55	6.45	43.81	128,752.45
CONTRA COSTA	BYRON	444	14.65	8.13	9.11	6.17	6.08	43.84	19,466.00
CONTRA COSTA	PINOLE	5,871	15.05	6.03	8.71	7.22	7.21	43.95	258,012.57
CONTRA COSTA	EL SOBRANTE	9,330	15.93	6.01	8.64	7.33	7.33	44.96	419,514.73
CONTRA COSTA	OAKLEY	12,276	15.91	6.64	9.99	6.74	6.61	45.58	559,564.87
CONTRA COSTA	BRENTWOOD	15,843	16.82	6.99	9.82	7.60	7.52	48.44	767,386.69
CONTRA COSTA	HERCULES	9,044	18.13	5.71	9.24	8.45	8.45	49.69	449,385.33
CONTRA COSTA	DISCOVERY BAY	4,957	17.86	7.27	8.71	8.47	8.51	50.53	250,487.15
CONTRA COSTA	CLAYTON	4,794	18.81	6.61	8.37	9.48	9.58	52.58	252,054.20
CONTRA COSTA	SAN RAMON	23,635	20.21	6.43	9.01	10.65	10.76	56.77	1,341,670.35
CONTRA COSTA	MORAGA	6,032	20.52	7.46	8.08	11.10	11.30	58.20	351,083.72
CONTRA COSTA	LAFAYETTE	10,346	20.54	7.93	8.23	11.06	11.24	58.74	607,702.31
CONTRA COSTA	DANVILLE	22,707	21.59	7.93	8.69	11.56	11.73	61.24	1,390,481.48
CONTRA COSTA	ORINDA	5,774	23.51	9.07	8.53	12.82	13.05	66.70	385,105.49
CONTRA COSTA	ALAMO	3,244	25.86	10.98	8.89	13.02	13.24	71.70	232,587.71
MARIN	BOLINAS	763	13.89	6.25	6.86	6.73	6.83	40.08	30,578.88
MARIN	FAIRFAX	3,658	15.04	3.27	7.03	8.19	8.34	41.38	151,375.94
MARIN	SAUSALITO	5,692	13.59	5.24	5.96	8.53	8.77	41.66	237,144.21
MARIN	INVERNESS	906	13.93	6.92	6.30	7.52	7.69	41.93	37,985.87
MARIN	POINT REYES STAT	1,386	14.27	7.92	6.90	7.00	7.11	42.71	59,200.11
MARIN	SAN RAFAEL	27,770	14.64	5.81	7.76	7.91	7.99	43.56	1,209,528.36
MARIN	NOVATO	23,280	15.42	5.99	7.89	7.86	7.93	44.53	1,036,741.49
MARIN	CORTE MADERA	4,681	15.66	5.48	7.19	9.19	9.37	46.39	217,158.64
MARIN	WOODACRE	1,600	16.62	7.80	7.92	7.56	7.62	46.96	75,135.51
MARIN	LARKSPUR	2,759	16.90	6.12	6.95	9.95	10.18	49.60	136,857.87
MARIN	SAN ANSELMO	6,177	17.33	6.21	7.52	9.47	9.64	49.64	306,613.08
MARIN	GREENBRAE	5,028	17.43	5.39	6.90	10.31	10.56	50.09	251,873.30
MARIN	MILL VALLEY	12,823	17.71	6.29	7.22	10.24	10.46	51.42	659,313.22
MARIN	BELVEDERE TIBUR(	5,671	18.82	6.88	7.21	11.19	11.45	55.04	312,128.42
MARIN	ROSS	718	23.06	11.79	8.99	12.54	12.74	68.49	49,176.42
NAPA	YOUNTVILLE	1,231	11.30	5.60	5.82	7.06	7.25	36.85	45,363.36
NAPA	CALISTOGA	2,589	13.47	6.17	7.64	6.66	6.70	40.41	104,612.62
NAPA	NAPA	34,522	13.81	6.84	8.28	6.74	6.74	42.15	1,454,981.44
NAPA	SAINT HELENA	3,472	14.32	7.35	7.31	7.79	7.90	44.44	154,302.56
NAPA	ANGWIN	1,732	17.11	6.47	7.94	7.88	7.95	47.10	81,573.49
NAPA	AMERICAN CANYON	5,837	17.15	6.56	10.82	7.58	7.43	49.20	287,162.14

SAN FRANCISCO	SAN FRANCISCO	345,344	10.88	5.13	7.21	7.71	7.82	38.29	13,223,928.51
SAN MATEO	BRISBANE	2,157	14.06	4.97	7.13	7.76	7.88	41.45	89,403.00
SAN MATEO	SAN BRUNO	14,886	14.08	5.18	8.64	7.24	7.23	41.95	624,430.28
SAN MATEO	DALY CITY	33,573	13.73	5.32	10.11	7.08	6.96	42.70	1,433,490.69
SAN MATEO	SOUTH SAN FRANC	20,881	14.13	5.38	9.53	7.24	7.17	43.00	897,821.99
SAN MATEO	MILLBRAE	8,038	14.68	6.01	8.35	8.04	8.08	44.74	359,604.29
SAN MATEO	SAN MATEO	51,569	14.89	5.45	8.00	8.56	8.65	45.15	2,328,326.83
SAN MATEO	PACIFICA	14,092	16.17	5.65	8.36	8.30	8.35	46.41	654,025.92
SAN MATEO	REDWOOD CITY	36,205	15.96	6.33	8.89	8.58	8.61	47.93	1,735,301.73
SAN MATEO	BELMONT	10,578	16.75	5.67	7.66	9.50	9.65	48.86	516,808.45
SAN MATEO	LA HONDA	1,527	18.33	7.07	7.45	9.00	9.15	50.65	77,340.27
SAN MATEO	SAN CARLOS	11,894	17.61	6.14	7.93	10.05	10.21	51.56	613,233.41
SAN MATEO	HALF MOON BAY	6,895	18.46	5.73	8.45	9.70	9.81	51.74	356,771.05
SAN MATEO	MENLO PARK	14,832	18.05	6.73	8.06	10.64	10.81	53.89	799,306.44
SAN MATEO	BURLINGAME	16,227	18.91	7.25	7.85	10.66	10.85	55.14	894,762.94
SAN MATEO	MOSS BEACH	2,095	21.16	5.35	8.87	10.25	10.35	55.56	116,390.25
SAN MATEO	PORTOLA VALLEY	2,617	23.52	9.81	7.98	13.06	13.34	67.32	176,184.29
SAN MATEO	ATHERTON	2,281	28.97	17.60	8.93	14.78	15.07	84.92	193,707.87
SANTA CLARA	STANFORD	2,018	8.31	7.53	6.30	4.64	4.69	31.23	63,014.22
SANTA CLARA	CAMPBELL	15,740	14.66	5.53	7.73	7.90	7.98	43.51	684,776.65
SANTA CLARA	ALVISO	540	15.26	5.72	9.95	6.87	6.75	44.19	23,860.77
SANTA CLARA	MOUNTAIN VIEW	32,417	14.53	5.02	7.30	8.83	8.98	44.37	1,438,491.48
SANTA CLARA	SANTA CLARA	41,712	14.50	6.32	8.42	8.08	8.13	45.14	1,882,711.45
SANTA CLARA	SUNNYVALE	54,442	14.98	5.26	8.22	8.70	8.79	45.63	2,484,351.77
SANTA CLARA	SAN JOSE	314,615	15.55	5.75	9.71	7.92	7.86	46.43	14,607,648.23
SANTA CLARA	GILROY	18,496	16.61	6.92	10.32	7.60	7.49	48.54	897,884.06
SANTA CLARA	MILPITAS	19,631	17.27	5.84	10.43	8.42	8.34	49.90	979,588.10
SANTA CLARA	PALO ALTO	34,180	17.16	4.81	8.70	10.09	10.20	50.60	1,729,609.39
SANTA CLARA	MORGAN HILL	14,393	18.55	6.98	9.53	8.88	8.88	52.46	754,999.56
SANTA CLARA	CUPERTINO	22,313	19.00	5.87	8.93	10.89	11.01	55.36	1,235,174.68
SANTA CLARA	LOS GATOS	18,868	19.50	7.15	7.85	10.99	11.20	56.39	1,063,963.16
SANTA CLARA	SAN MARTIN	1,569	24.81	8.85	10.28	10.27	10.27	64.10	100,566.22
SANTA CLARA	SARATOGA	11,002	23.42	8.30	8.60	12.67	12.90	65.57	721,353.32
SANTA CLARA	LOS ALTOS	14,997	23.51	8.60	8.50	13.10	13.35	66.73	1,000,775.40
SOLANO	RIO VISTA	3,971	10.41	5.73	6.58	5.45	5.51	33.39	132,603.04
SOLANO	VALLEJO	40,961	12.86	5.74	8.85	5.82	5.73	38.63	1,582,237.27
SOLANO	TRAVIS AFB	905	14.89	5.96	10.98	5.43	5.18	41.96	37,976.83
SOLANO	SUISUN CITY	9,621	14.81	6.19	9.95	6.28	6.14	42.94	413,126.10
SOLANO	FAIRFIELD	34,318	14.87	6.46	9.30	6.61	6.53	43.36	1,488,094.24
SOLANO	VACAVILLE	34,726	15.04	6.39	8.60	6.95	6.94	43.54	1,512,060.82
SOLANO	BENICIA	10,925	16.16	5.30	7.99	8.03	8.11	45.24	494,286.07
SONOMA	ROHNERT PARK	17,667	13.00	5.13	8.14	5.80	5.76	37.41	660,970.94
SONOMA	COTATI	3,478	12.95	5.46	7.56	6.19	6.21	37.98	132,086.38
SONOMA	SEBASTOPOL	13,804	13.19	5.63	6.94	6.34	6.41	38.16	526,734.97
SONOMA	FORESTVILLE	3,444	12.97	6.48	6.76	6.25	6.33	38.45	132,415.82
SONOMA	GLEN ELLEN	1,978	12.85	6.49	6.67	6.66	6.77	39.10	77,331.04
SONOMA	SANTA ROSA	77,711	13.09	5.87	8.24	6.20	6.18	39.16	3,043,132.06
SONOMA	BODEGA BAY	632	13.89	6.60	6.81	6.24	6.32	39.51	24,969.24
SONOMA	SONOMA	14,480	13.31	6.45	7.61	6.74	6.78	40.49	586,329.50
SONOMA	HEALDSBURG	7,624	13.76	7.17	7.89	6.42	6.43	41.25	314,509.47
SONOMA	PETALUMA	26,787	15.29	6.09	8.33	7.22	7.24	43.74	1,171,677.11
SONOMA	WINDSOR	10,091	15.61	6.23	9.13	7.14	7.09	44.74	451,477.79