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Residential Energy Use and GHG Emissions Impact of Compact Land Use Types

FINAL REPORT

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Disclaimer

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ABSTRACT

This research project created a spreadsheet-based calculator to allow local land use planners to estimate the greenhouse gas emissions expected to result by 2035 from residential energy use under different local land use scenarios. The calculator allows users to input simple land use data available in general planning processes, as opposed to the parcel-level data required by advanced tools like CalEEMod, and is based upon the relationship between land use types and GHG emissions. Establishing that relationship involved analysis of the relationship between land use type and the median size of dwelling units within each land use type in a major metropolitan region in California (Fresno); the development of two statistical models explaining electricity and natural gas use observed in the 2005 Residential Energy Consumption Survey (RECS) dataset as a function of dwelling unit size and heating/cooling degree-days in a given location; and identification of the anticipated GHG intensity of the electricity and natural gas provided by every utility serving residential customers in California from 2012 to 2035. The calculator allows users to choose between using average or marginal GHG intensities of electricity for a given utility, to choose between using the CREC statistical model of recent usage or a blended model that incorporates CalEEMod projections of future usage into the model, and to choose whether a given utility will meet renewable generation targets as required in the Renewable Portfolio Standard. The calculator was evaluated through four separate methods: preliminary validation against the 2009 Residential Appliance Saturation Survey (RASS) dataset, field-testing with municipal planners, validation against actual electricity use data obtained from the Sacramento Municipal Utility District (SMUD) for the period between 2001 and 2011, and comparison with CalEEMod assumptions and results. Results of the evaluation collectively show that the calculator does a good job of producing estimates that closely match recent historical data, and is regarded as useful and accessible by the target audience of professional planners.

EXECUTIVE SUMMARY

The State of California, through AB 32 and Gov. Schwarzenegger's E.O. S-3-05, has committed to reducing its greenhouse gas (GHG) emissions to 1990 levels by 2020, and to 80 percent below 1990 levels by 2050. Attainment of these goals will require concerted action not only by the State of California but also the local governments throughout the state that retain exclusive authority to make land use decisions. These decisions are outlined in municipal general plans and expressed in specific physical terms within zoning codes. Other documents, such as specific plans and climate action plans, can also be adopted into general plans and thereby take on the force of law. Collectively, these local plans shape the physical development of California's communities and therefore have far-reaching consequences for greenhouse gas emissions.

Building energy use produces almost a quarter of all GHG emissions in California, and residential structures are responsible for about two-thirds of these building-related emissions. Yet despite several influential state laws and policies devoted to building energy efficiency, including the long-standing California Building Standards Energy Code (a.k.a. Title 24, Part 6), there is no state policy structure devoted to addressing building energy consumption and GHG emissions as a function of land use. The State established such a structure with respect to transportation, the leading source of GHG emissions at about 38 percent of the state total, when it passed SB 375 in 2008. Achieving the deep emissions reductions sought by 2050 may require a similar initiative for the buildings sector.

There are few tools available to assist local governments in assessing the GHG consequences of different land use patterns at the critical general planning stage when basic land use alternatives are being considered. Valuable tools such as CalEEMod, iPLACE^{3}S, and the Subdivision Energy Analysis Tool (SEAT) are only useful at a later stage of the development process, when specific projects are being proposed and detailed information pertaining to the projects' characteristics is available. By that time, basic decisions about the location, density, and form of residential growth in the municipality have long since been made.

This research project created a spreadsheet-based calculator to calculate the greenhouse gas emissions resulting from residential energy use under different land use scenarios. Unlike tools such as CalEEMod, this calculator requires users to input data that is available in general planning processes, as opposed to the parcel-level data more typical of specific development proposals. General plans program the overall density and form of growth across an entire municipality, and only coarsely characterize that growth according to broad land use categories and density classes. The CREC calculator is therefore designed to produce estimates of energy use and GHG emissions from the housing built within commonly used land use types.

Methods

The research proceeded in three major phases:

1. Interviews with local planners and designers of other similar tools (including CalEEMod) to determine which potential input variables local governments have available when creating the land use elements of their general plans and climate action plans, and to get additional input on desirable characteristics of a planning-level screening tool;

2. The design of the spreadsheet calculator, based upon the relationship between land use types (functionally defined as non-overlapping density classes) and GHG emissions attributable to residential energy use up to 2035. Establishing that relationship involved analysis of the relationship between land use type and the median size of dwelling units within each land use type/density class in a major metropolitan region in California (Fresno); the development of two statistical models explaining electricity and natural gas use observed in the 2005 Residential Energy Consumption Survey (RECS) dataset as a function of dwelling unit size and heating/cooling degree-days in a given location; and the identification of the anticipated GHG intensity of the electricity and natural gas provided by every utility serving residential customers in California from 2012 to 2035. The spreadsheet calculator was then designed within Microsoft Excel to allow the direct comparison of the GHG emissions consequences of up to three land use scenarios.

3. The evaluation of the calculator through four separate methods: preliminary validation against the 2009 Residential Appliance Saturation Survey (RASS) dataset, field-testing with the same planners and tool designers previously interviewed, validation against actual energy use data obtained from the Sacramento Municipal Utility District (SMUD) for the period between 2001 and 2011, and comparison with CalEEMod assumptions and results.

Results and conclusions

The primary result of the research is the creation of the spreadsheet calculator itself. The calculator allows users to create estimates of future GHG emissions to 2035 instantly by inputting the amount of development (expressed either as housing units or as acreage) anticipated within each of eight commonly used density classes, as well as the city, county, and utility service area within which the growth will occur. Users can also input either default values or user-defined, locally appropriate estimates of the median size of housing units within each density class, and can incorporate the effects, if any, of certain locally specific conditions. The calculator allows users to choose between using average or marginal GHG intensities of electricity for a given utility, to choose between using the CREC statistical model of recent usage or a blended model that incorporates CalEEMod projections of future usage into the model, and to choose whether to assume that a given utility will meet renewable generation targets as required in the Renewable Portfolio Standard. Results of the evaluation collectively show that the calculator does a good job of producing estimates that closely match recent historical data in both the RASS and SMUD datasets, and on balance is regarded as useful and accessible by the target audience of planners and consultants.

As additional relevant datasets become available in the future, including the next edition of the RASS survey, additional regional housing and land use datasets to complement the Fresno one used here, and potentially a natural gas usage dataset for validation of the natural gas model, the calculator can be improved in its predictive accuracy and therefore in its range of applicability. The calculator can be incorporated into the ARB-sponsored Cool California Local Government Toolkit website, and could be expanded in the future to include transportation and other major sources of GHG emissions connected to local land use decisions.

I. INTRODUCTION

Through the 2008 Global Warming Solutions Act, commonly known as AB 32, and the Governor Schwarzenegger's Executive Order S-3-05, California has committed to reducing its greenhouse gas (GHG) emissions to 1990 levels by 2020, and to 80 percent below 1990 levels by 2050. The Air Resources Board (ARB) is the state agency in charge of creating and implementing plans to meet these ambitious goals. ARB's AB 32 Scoping Plan makes it clear that the agency views local governments as an "essential partner"[i] in reducing GHG emissions. To date, well over 100 municipalities in California have adopted specific policies or programs (including climate action plans)[ii] to reduce GHG emissions, and hundreds more are in the process of development. ARB has developed tools to help local governments calculate GHG emissions and promoted best practices in local climate action.

California's local governments have exclusive authority to make decisions over how land is developed. According to ARB, these decisions "have large impacts on the greenhouse gas emissions that will result from the transportation, housing, industry, forestry, water, agriculture, electricity, and natural gas sectors,"[iii] These land use decisions are guided by the land use element of a local government's general plan, which outlines "the ultimate pattern of development for the city or county at build-out"[iv] and guides decisions on individual development projects. Other documents, such as specific plans and climate action plans, also have the force of law if adopted into the general plan. Together, these plans provide a framework for approving and shaping new development projects.

Senate Bill 375 has specified a set of analytical tools that regional agencies must use to examine the impacts of land use decisions on GHG emissions in the transportation sector, which accounts for the largest share of California's emissions, as well as a set of policy tools to translate regional plans into local actions. There is no comparable state policy structure devoted to governing GHG emissions from building energy use, which is the second-largest source of energy-related GHG emissions. Residential buildings produce about two-thirds of the building sector's emissions, and since the majority of California's growth over the next several decades is projected to take place in inland climate zones with more extreme temperatures where more energy is needed to cool and heat homes, the proportion of GHG emissions from the residential sector may increase in the near future.

Few tools are available to help local governments assess the GHG impacts of land use decisions *at the general plan or climate plan level*, where a local government broadly outlines the location and form of its long-term growth. The South Coast Air Quality Management District (SCAQMD) and other California air districts sponsored the development of CalEEMod, which since its introduction in 2011 has become the industry standard tool for estimating future GHG emissions from proposed development, and which is widely used to document such projected emissions in Environmental Impact Reports (EIRs) throughout the state. However, CalEEMod requires a wide range of inputs, is intended as an estimator of emissions at the project level more than the plan level, and relies upon characterization of building types as an input, rather than the land use and density classes that planners use.

The California Energy Commission has also created tools to help local governments assess the energy impacts of specific land use decisions, such as its Internet Planning for Community Energy, Economic, and Environmental Sustainability (I-PLACE^{3}S)[v] and

Subdivision Energy Analysis Tool (SEAT) software programs, which require maps of land use at the parcel level or precise street layouts. While these tools provide users with in-depth energy use estimates, general plans and climate action plans are typically not detailed enough for local governments to use either program to evaluate the land use policies contained in these plans. In addition, the SEAT tool does not calculate greenhouse gas emissions.

Rapid Fire and Urban Footprint are scenario modeling tools developed by Calthorpe Associates in conjunction with several state agencies as part of the Vision California statewide planning effort.[vi] They are designed primarily to produce and evaluate regional and state-level development scenarios across several key indicators, including residential energy use. Both calculate residential energy use based on the proportion of new development that takes place in pre-defined Land Development Categories (LDCs). Each LDC is defined by a different mixture of housing types, which in turn are associated with different levels of residential energy consumption.[vii] But the LDCs do not correspond to the land use categories and density classes typical of general planning processes, and hence their direct utility in these processes is limited.

Only a small handful of academic papers to date have directly examined the relationship between urban form and residential energy use and GHG emissions in North America. Ewing and Rong used data from the American Housing Survey and the U.S. Census Public Use Microdata Sample to link urban form and land use controls to housing type and house size, and then used data from the U.S. Residential Energy Consumption Survey (RECS) to examine the effect of building size and type on energy use.[viii] They then calculated the total energy use of hypothetical compact and sprawling counties and found that the average household in a compact county would consume 20 percent less energy than in a sprawling one. Ewing and Nelson subsequently applied this analysis to California and found that, taking into account forecasted population growth and market demand, a statewide shift to compact development would reduce GHG emissions due to residential energy use by between 3 and 3.6 percent.[ix] Meanwhile, a similar analysis conducted in Canada using neighborhoods in Toronto as a case study concluded that residents of high-density neighborhoods use emit 45 percent fewer GHG emissions due to building operations than residents of low-density neighborhoods.[x]

This project aimed to create a tool that calculates GHG emissions due to residential energy use at the general plan level, and thereby both fits the needs of the growing number of local planners that are investigating the GHG impacts of long-term plans, and supplements the limited existing body of research. Given that hundreds of local governments are in the process of creating such plans, providing guidance at this level will be an important step in helping local governments craft land use policies that help meet California's GHG reduction targets. Once these plans are in place, planners can use CalEEMod, I-PLACE^{3}S, SEAT, and other such tools to evaluate how well individual projects meet policy goals.

The project consisted of three major phases:

1. Interviews with local planners and designers of other similar tools (including CalEEMod) to determine which variables local governments examine when creating the land use elements of their general plans and climate action plans, and to gain insight into tool design;

2. The design of an easy-to-use spreadsheet calculator that relies upon the variables identified as inputs, and then uses these inputs, statistical modeling of observed energy usage, and utility-level GHG intensity data to perform a policy-level estimation of the residential sector GHG emissions associated with up to three land use scenarios;

3. The evaluation of the calculator through preliminary validation against the 2009 Residential Appliance Saturation Survey (RASS) dataset, field-testing with the same planners interviewed in phase one, validation against actual energy use data obtained from the Sacramento Municipal Utility District (SMUD), and comparison with CalEEMod assumptions and results.

This report describes the methods, results, and conclusions of each of these three major phases in the construction of the calculator. The main result of the research is the creation of the CREC Greenhouse Gas Calculator for Residential Development, which allows municipal planners and their consultants to:

- Estimate the residential energy use and associated GHG emissions from any amount of future residential development;
- Select a base year (no earlier than 2012) that growth is anticipated to occur and calculate cumulative GHG emissions out to 2035
- Create those estimates instantly by inputting the amount of development (either as housing units or acreage) in each of eight common density classes, as well as the city, county, and utility service area within which the growth will occur;
- Decide whether to use the average GHG intensity factors for a specific utility's electricity portfolio or whether to use an assumption of the GHG intensity of a typical utility's marginal electricity (i.e. the last electricity generation source added or subtracted from a utility's portfolio when demand changes);
- Decide whether to rely solely upon the CREC statistical model of the recent past or to use a blended model that includes both CREC statistical modeling and projections of future use from CalEEMod that incorporate assumptions about future building energy codes (i.e. Title 24, Part 6);
- Decide whether to use GHG intensity factors based on a utility's current-day performance or ones based on the assumption that the utility in question will meet the Renewable Portfolio Standard by 2020;
- Use either default values or user-defined, locally appropriate estimates of the median size of housing units within each density class, at the user's discretion;
- Incorporate the effects, if any, of certain locally specific conditions that may exist: "reach codes" that go beyond Title 24, Part 6 building energy efficiency standards; local lighting efficiency standards that exceed state standards, and anticipated presence of renewable generating capacity;

- Examine the interim calculations of electricity and natural gas use, including both Title-24 and non-Title-24 components, that produce the GHG estimates;

- Directly compare up to three growth scenarios within the same output display, or any number of scenarios through multiple output displays.

The evaluations collectively suggest that the calculator is meeting its primary design goals of creating a simple, quick, and transparent calculator to screen alternative land use scenarios in a general planning or climate action planning process. The report closes with discussion of these results, and a series of recommendations for future research that could enhance the capabilities and applicability of the spreadsheet calculator.

II. MATERIALS AND METHODS

To develop the spreadsheet calculator, CREC evaluated and/or utilized a variety of materials and methods. These are described below for each of the three project phases: interviews, calculator creation and calculator evaluation. Because the interviews were a preparatory step to the main objectives of the research, the results of the interviews are discussed in this section to contextualize certain methodological choices made in the creation of the spreadsheet calculator.

1. Interviews

In order to make sure that this project produces results that are useful to planners working in local government in California, the research team interviewed 26 professional planners and seven designers of other GHG estimation tools, for a total of 33 interviewees. We focused on obtaining an even distribution of planners that represented different geographic areas of the state, a variety of planning agencies and organizations, and the main specialties within planning that touch on GHG impacts—climate action planning, environmental review under the California Environmental Quality Act (CEQA), and long-range land use planning. The tool designers included individuals associated with the design of CalEEMod, the Climate and Air Pollution Planning Model (CAPPA) of ICLEI Local Governments for Sustainability, the Southern California Association of Governments (SCAG) Sustainability Tool, Calthorpe Associates' RapidFire/Urban Footprint, and Arup's Integrated Resources Management Tool.

Due to confidentiality considerations mandated by UC-Berkeley's human subjects protocols, these individuals cannot be identified publicly. Tables 1 and 2 identify the types of organizations for which the interviewees work and their planning specialty (some interviewees have more than one specialty).

Table 1. Interviewees by organization type

City	13
County	6
Region	6
Private	4
NGO	4
Total	*33*

Table 2. Interviewees by specialty

Climate action plans	17
CEQA	7
Land use	13
Tool design	7

(several interviewees have multiple specialties)

The research team asked each interviewee about their current use of GHG analysis tools, the needs that they have for such tools, and about key factors shaping the design of the tool that the current project intends to produce. The rough script used in each interview is reproduced in Appendix A.

There are two different cases in which local governments in California typically analyze GHG emissions: when creating climate action plans and when analyzing GHG impacts of land use plans and projects under CEQA. Each case requires different analytical tools.

A climate action plan (CAP) typically consists of three elements: an inventory of current GHG emissions, a projection of future "business as usual" emissions, and a plan containing mitigation measures to reduce GHG emissions to a target level in the future. The community-wide inventories of GHG emissions generally involve collecting data on vehicle travel, energy and resource consumption, and waste production and applying GHG emissions coefficients to estimate GHG emissions. Many local governments use ICLEI's Clean Air Climate Protection (CACP) software for this purpose. Planners then use a separate set of tools to estimate the impact of community-wide GHG reduction measures, including ICLEI's Climate and Air Pollution Planning Assistant (CAPPA).

Planners who were involved in creating climate action plans voiced concerns with the "proliferation of tools in the marketplace" for conducting GHG inventories and examining the GHG impacts of mitigation measures, especially since "different models produce different results." In particular, some planners felt that the tools that cities use to conduct community-wide GHG inventories are not very useful for distinguishing the impacts of different policies from one another. As a result, "there's a disconnect between emissions inventories and policy control" and cities cannot always "count the impact [of mitigation measures] in a way that's congruent with our overall inventory."

ICLEI's tools and methods dominate GHG inventories, but according to one municipal planner, some of his colleagues "roll their eyes" at CAPPA (though he was referring to a version now being updated). In spite of the fact that land use planning can be a key lever for local governments in reducing GHG emissions, most tools emphasize energy efficiency measures instead, since it is easier to calculate the benefit of such measures and because they are often less politically sensitive. Several interviewees mentioned that since inventory tools are not based on land use inputs, they offer no direct means of analyzing how land use plans and policies affect GHG emissions levels. Some municipal planners have responded by cobbling together climate action plans from a variety of resources; these planners generally prize ease of use and responsiveness of a tool. Other local governments focus more on maximizing accuracy and generally hire consultants to create a CAP. ICLEI is currently updating its tools, and it is possible that the updated versions will create a framework for assessing the indirect, cross-sector emissions that result from land use activities.

As lead agencies under CEQA, local governments are responsible for analyzing the GHG impacts of long-term plans and specific development proposals. The South Coast AQMD has developed an emissions estimator tool, CalEEMod, which incorporates recent research on CEQA-defensible mitigation measures conducted by the California Air Pollution Control Officers' Association (CAPCOA) and calculates new categories of emissions, including operational emissions due to building energy use. Several consultants and local governments are now using CalEEMod, but users have complained that the tool runs slowly.

CalEEMod and its predecessor URBEMIS are both designed for project-level analysis and require substantial amounts of specific project-level data that is not available in the context of a long-term plan, which limits applicability at the plan level. Nonetheless, since most land use decisions are subject to CEQA decisions, local planners reported using these tools for plan-level analysis. Many reported that CEQA, and the tools associated with it, often drive their land use planning efforts, so using URBEMIS or CalEEMod for plan-level analyses may help to ensure that these analyses are consistent with subsequent analyses of the individual projects that implement these plans. Several planners reported that these tools are so data-intensive that they can only be used when a plan is fully developed, and as a result local governments seldom conduct GHG analyses of alternatives in the early stages of the planning process.

Consultants and regional governments have created a third category of tools, scenario-planning tools, to assist local and regional governments in analyzing long-term land use scenarios. Three prominent examples in California are iPLACE^{3}S, developed by the California Energy Commission, and Rapid Fire and Urban Footprint, both developed by Calthorpe Associates. Regional agencies in Sacramento and Greater Los Angeles have used these tools or developed similar tools that are available for use by local governments as part of outreach efforts surrounding regional "blueprint" plans. However, few local planners expressed awareness of these tools, and the one local planner who was familiar with Sacramento's regional iPLACE^{3}S model expressed suspicion of it, labeling it a "black box" and complaining that it "takes all night to run." Furthermore, even proponents of scenario planning tools admitted that they do not quantify impacts specifically enough to be used in the context of environmental review, which poses an obstacle to their deployment in the CEQA-driven world of local general planning and climate action planning.

Treatment of land uses and other input variables

One of the critical aspects of CREC's spreadsheet calculator is that it is focused on analyzing and informing land use plans at the policy level, when planners and decision-makers are making decisions over the general form of new development, not making the detailed decisions that are necessary to provide the data inputs that are required by environmental analysis tools such as CalEEMod. CREC therefore sought in the interviews to clarify what factors city planners consider when making long-term land use decisions.

Urban planning has traditionally focused on designating allowable densities, land uses, and building dimensions (via height limits, lot coverage limits, and floor area ratios). Therefore, many planners mentioned that it would be useful to understand the difference between "density ranges" that correspond to different types of buildings, such as "the difference [in energy use] between townhouses and condos… form-based codes specify between 17-35 DU/ac (dwelling units per acre) for townhouses and 35-55 DU/ac for condos." Cities generally use broader categories for high-density construction, and particularly need a tool that can distinguish between different types of low- and moderate-density construction. Planners told us that "fifteen versus twenty DU/ac is a big difference" and that "two versus five is bigger difference than 18 vs. 30 [DU/acre]." Though every local government's method of categorizing density is different, planners mentioned several rules of thumb that proved useful to CREC in building our calculator.

Urban form is not only the product of land use planning, but also of the market. Zoning only produces the intended results where the market supports the land uses that are zoned for. Some interviewees acknowledged that "the land uses that we've designated are really only guesses… we have such a poor record building up community centers that it's difficult to predict." Nonetheless, when CREC asked whether we should include market variables, such as the cost of land or the average area income, most planners said that this would not be useful, because though these variables make a difference, they rarely get considered in the planning process. According to one, "spatial variables are more interesting than demographics," while another mentioned that to truly consider market feasibility is "too expensive to be justifiable."

These discussions with planners suggested that it would be best to include default assumptions about which building types will result in different zoning categories in CREC's calculator, but also to allow planners to modify the building characteristics. That way, the calculator will be approachable for planners that still use zoning as the primary land use variable, but will also allow planners working in cities with form-based codes to modify building types to fit the specific requirements and assumptions of their zoning code.

Treatment of land uses in current GHG impact assessment tools

Several interviewees have created tools that allow for some consideration of the effect of land use on GHG emissions. Some of these, such as ICLEI's Climate and Air Pollution Planning Assistant (CAPPA) tool and CalEEMod, include land use issues but are not explicitly focused on land use. For example, CAPPA estimates the potential for local governments to reduce GHG emissions by pursuing transit-oriented development (TOD), but does not allow users to change actual land use variables. ICLEI staff mentioned that this is because ICLEI serves a variety of local governments across the nation, including many in states that lack policies linking land use decisions and GHG emissions. The political nature of land use decisions makes land use a "touchy subject," so ICLEI's tools focus more on behavioral outreach and technological changes.

Though CalEEMod does analyze the impact of land use decisions, it is not structured to explicitly consider compact land use as a GHG mitigation strategy. Though CalEEMod does adjust trip estimates and building energy use based on the density, mix of uses, and building types that users input into the tool, these factors are considered to be intrinsic aspects of project design, not mitigating factors for GHG emissions. In theory, users could compare land use alternatives by creating a different file for each alternative and comparing the base-case GHG emissions for each, but in practice this rarely happens. Planners rarely develop land use alternatives to the level of detail required by CalEEMod. Interviewees also reported two additional obstacles to using CalEEMod to analyze land use impacts. First, "there can be a lot of confusion" about how to treat land use variables like density in CalEEMod; specifically whether to calculate density based on the project area or based on the wider area surrounding the project. Second, CalEEMod runs slowly, which has been "a major concern for all users" and discourages planners from using the tool to explore alternatives.

Other GHG impact tools were designed with the explicit goal of weighing land use alternatives, and interviewees report that it can be difficult to create a single tool that meets the needs of a wide variety of local governments. For example, Arup's Integrated Resource Management (IRM) tool is a spreadsheet-based tool that takes into account several variables related to planning, site design, and building type and analyzes GHG, water, and energy impacts. While IRM is based on up-to-date research, interviewees reported that it was often necessary to adjust the coefficients and inputs in the tool in different applications based on differences between local governments. Furthermore, local governments are sometimes reluctant to accept the results produced by IRM because it is a proprietary tool that is not acknowledged by many public agencies and therefore its legal defensibility for use in CEQA-related documents is not guaranteed.

SCAG's Sustainability Tool is a map-based tool that estimates GHG emissions based on local land use plans. The agency uses the Sustainability Tool in public workshops surrounding its regional plans, and has made the tool available to local planners through its GIS servers. However, local planners in the SCAG region have pointed out several obstacles to using the tool. First, it requires GIS software, and SCAG staff estimate that only 35 percent of local governments in the region use GIS. Second, the tool inputs land uses in 5.5-acre grid cells, which is too large of a scale for many local governments considering small-site redevelopment. Finally, the 24 development types used by the Sustainability Tool do not conform to the wide variety of zoning types used by the many local governments in the SCAG region.

Potential uses of CREC's calculator

Interviewees mentioned several factors that would make local governments more receptive to using CREC's calculator:

- Growth –jurisdictions that are rapidly growing would be the most likely to need a calculator such as the one CREC is developing. Interviewees frequently mentioned this in light of the recent downturn in the real estate market.
- Political support – in the absence of strong state and regional GHG thresholds for new development, public and political concern over climate change are the primary drivers for cities to consider GHG emissions as a driving concern behind development decisions.
- ARB approval – several interviewees mentioned the importance of having a tool that is developed and approved by ARB, since ARB and the AQMDs ultimately determine what tools are acceptable to use in environmental analyses. This was particularly true in Southern California, where several local governments have recently gotten letters from the Attorney General's office for inadequately considering GHG impacts of land use decisions. (Though the research to create the CREC calculator is sponsored by ARB, that does not necessarily imply ARB approval.)

Generally speaking, interviewees suggested two areas in which CREC's calculator may potentially be useful:

- In larger, more urban cities, which are generally more progressive and have the capacity to engage in scenario planning. These areas are generally more likely to already be built out, but may see opportunities to analyze GHG impacts of land use scenarios in the context of major infill projects.
- In rapidly-urbanizing rural areas, where there are ample opportunities for growth, and local governments may not have the capacity to engage in scenario planning using the tools that are currently available.

Generally, interviewees felt that this project would be most useful if it produced a simple scenario planning tool for analyzing plan alternatives. Local governments typically identify several land use alternatives in the context of a general or large-site specific plan, but planners reported that they "do not run CalEEMod on alternatives" nor "do an environmental analysis for the alternatives." Instead, planners only develop the preferred alternative to the point where it can be analyzed using a data-intensive tool like CalEEMod. CREC's calculator could serve as a basis for conducting preliminary environmental analysis of alternative scenarios, so that decision-makers and the public would be able to consider GHG impacts when weighing these alternatives. This is important, because "the idea of illustrating different scenarios for outreach is very effective in informing the conversation and pushing to go beyond the easy solutions." Some planners suggested that this approach could also help cities develop land-use related mitigations for a climate action plan, and to establish a basis for allowing infill development projects to streamline environmental analysis off of that plan.

Another idea that emerged through many of our interviews is that it is important to analyze transportation emissions, especially from passenger vehicles and heavy-duty vehicles. CEQA analysis traditionally focuses on traffic, both because it is responsible for a majority of GHG and criteria pollutant emissions, particularly from residential projects, and because congestion is a primary cause for public concern. However, it is very difficult for individual local governments to calculate the passenger vehicle and heavy-duty vehicle GHG emissions occurring within their jurisdictions because vehicle trips routinely cross municipal boundaries. While transportation emissions are not within the scope of this current project, it may be worth incorporating them into future versions of the calculator.

Summary of key interview findings

- There are few tools available with which to conduct a high-level analysis of the GHG impacts of land use decisions. Climate action planning tools do not often deal with land use, while project-level environmental assessment tools such as CalEEMod and URBEMIS are too data-intensive to use in the early stages of the planning process.
- Many cities still use density as the primary variable in land use planning, while some are switching to form-based codes that focus more on building form.
- Planners tend to use a greater number of categories with smaller density ranges to characterize medium- and low-density areas, and use fewer categories with wider ranges for high-density areas. This reflects the fact that the majority of residential areas in California are low-to-mid density.
- It would be useful if the calculator produced by this project includes default assumptions about what building types occur in different zoning categories, but also allows planners who have more information about building-level variables (e.g. planners working in cities with form-based codes or cities with infill development opportunities) to modify these assumptions.
- The main use that planners saw for a tool that analyzes the energy impacts of different land use types would be to compare the GHG impacts of plan alternatives, and to include land use-related strategies in climate action plans.
- This calculator will likely be most useful to local governments in large central cities and fast-growing areas.
- Several interviewees mentioned that the basis for making assumptions needs to be transparent in order to build trust among local planners, and planners need to be able to change default assumptions in order to fit local circumstances.
- It's important to allow planners to make simple comparisons based on limited data. Though allowing planners to modify assumptions based on local circumstances is an important way of tailoring a tool to account for the different circumstances that

different local agencies face, it is equally important to allow users a simple means of conducting high-level comparisons.
- The calculator should work within the technical and political constraint of local governments. Key constraints include the lack of GIS capability, lack of time to devote to a tool with slow processing speeds, and often the need for CEQA consistency. While the latter concern may be difficult for this project to meet completely given the relative lack of research on the relationship between building size and energy use, consistency with the assumptions behind CalEEMod, URBEMIS, and other tools that are commonly used in the CEQA process is important.

2. Creation of the spreadsheet calculator

With these interview findings in mind, the research team identified five steps to creating the spreadsheet calculator:

1. Compiling existing datasets on household energy use in California
2. Designing the structure of the spreadsheet calculator
3. Converting planning inputs into building size and type
4. Conducting analysis of household energy use as a function of building type, size and location
5. Researching GHG emissions factors for major utilities' energy supply mix

The methods involved in each step are described below.

Compiling existing datasets on household energy use in California

The goal of this task was to gather all available existing data on household energy use and building characteristics in California. Originally the project team proposed to collect three datasets:

a. The 2009 Residential Appliance Saturation Survey (RASS), administered by the California Energy Commission (CEC).
b. The 1999-2007 American Household Surveys (AHS), administered by the U.S. Census Bureau.
c. The 2005 Residential Energy Consumption Survey (RECS), administered by the U.S. Energy Information Administration.

After collecting data, researchers originally intended to clean and format each dataset in a common, comma delineated database format, with variables that appear across multiple datasets labeled and formatted consistently. For reasons the sections below describe, this only occurred with the RECS dataset.

a. Residential Appliance Saturation Survey (RASS) data

The RASS is a survey of residential energy and appliance use conducted by the CEC in collaboration with California's largest investor-owned utilities. Researchers identified the RASS as the preferred dataset to use during this analysis because it is the largest dataset on energy use in California, with records from over 25,000 households. Since the investor-owned utilities that provide the RASS data prevent the CEC from releasing disaggregate data for confidentiality reasons, the research team decided to gather aggregate data on energy use from the RASS Reporting Center website[xi] for each combination of building type, climate zone, and square footage contained in the RASS. After investigating the website, the researchers created a standard procedure for collecting RASS data, which is detailed in Appendix B.

Researchers collected data on physical characteristics of housing units, household energy use, and socio-economic characteristics for new (post-1993) housing units for 144 records. These records represented each possible combination of climate zone, building type, and housing unit size. However, due to the extensive need to subdivide the RASS sample in order to get the data of interest, 28 records contained no data, and 52 records were based on a sample of less than five housing units.

In the course of this effort, researchers identified a critical issue with the RASS data. Several records returned abnormally high values for natural gas consumption in multi-family buildings, some of which were on the order of ten times the consumption of single-family homes in the same climate zone. Researchers surmised that these errors are due to the RASS collecting the whole building's natural gas usage for certain apartments rather than the individual unit's consumption. However, since only aggregate RASS data is available, there was no way for researchers to exclude the erroneously entered data from the analysis.

This issue effectively prohibited the research team from using the RASS data as intended for this project since accurate data on apartment buildings is critical to an analysis of energy use in more compact neighborhoods. In the course of interviewing creators of other energy-use assessment tools we heard about two other tools, CalEEMod and Calthorpe Associates' Urban Footprint model, that ran into this issue with the 2009 RASS, and elected to use the 2003 RASS instead. However, the research team was concerned that using the 2003 survey would require more extensive assumptions in order to ensure that the analysis is relevant to new buildings, as well as make the analysis more challenging due to the smaller sample size of the 2003 RASS.

The research team therefore identified three potential alternative approaches to obtaining and analyzing the RASS data:

- Obtain disaggregate 2009 RASS data from the CEC.
- Contract with KEMA, the consultants who partnered with the CEC on the 2009 RASS, to conduct an analysis of energy use.
- Conduct an analysis based on the unit energy consumption (UEC) values that were calculated as part of the 2009 RASS.

The first approach failed after the research team, in collaboration with ARB, made multiple inquiries to the CEC regarding disaggregate 2009 RASS data. The CEC informed us that the RASS data was unavailable, even under the terms of existing confidentiality agreements between ARB and the CEC. The second approach failed due to uncertainty on KEMA's part about whether they could regain access to the RASS data, as well as to whether they could complete the work within the project budget. Finally, the research team determined that the UECs were not appropriate data on which to base an analysis of residential energy use for two reasons. First, UECs are calculated using some of the same variables, such as square footage, that we intended to use as explanatory variables in our analysis of energy use, which means that an analysis based on UECs would be circular.[xii] Second, UECs do not include lighting,[xiii] which is the largest spatially dependent end use of electricity in California homes.[xiv]

Having exhausted the alternatives, the research team elected to base its analysis of residential energy usage on other data sources, though we continued to use the RASS to inform other aspects of this project.

b. American Housing Survey (AHS)

The AHS is a survey of housing characteristics in major metropolitan areas conducted by the U.S. Department of Housing and Urban Development.[xv] Surveys are conducted in select metropolitan areas every two years, such that any given area is surveyed once every four to six years. A member of the research team, Chris Jones, worked extensively with AHS data on energy usage in a separate ARB-funded project to create a consumption-based model of household energy use. In the end, Mr. Jones and his team elected not to use AHS data due to the difficulties of creating a standardized national dataset from multiple AHS surveys of individual cities, which are conducted in different years using slightly different techniques for each survey. Instead, Mr. Jones' team used RECS data for their analysis of residential energy use, and after discussing the AHS data in more depth with Mr. Jones, the research team elected to do the same.

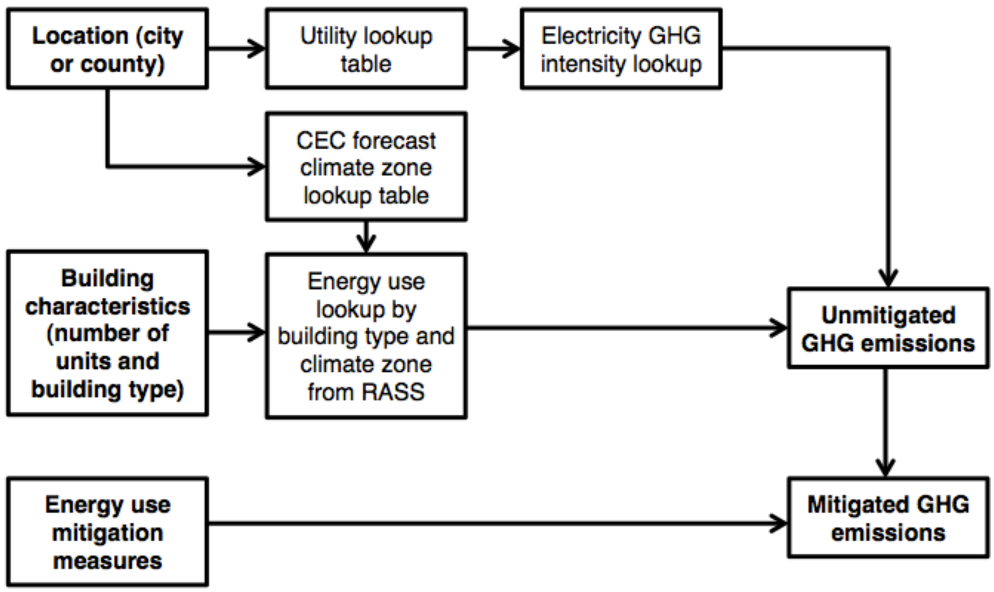
c. Residential Energy Consumption Survey (RECS)

The RECS is a national survey of residential energy use conducted by the Energy Information Agency. The most recent RECS for which disaggregate micro-level data is available was completed in 2005. The 2005 RECS surveyed 4,382 households in housing units statistically selected to represent the 111.1 million housing units in the U.S., including 468 California records selected to be representative of California's housing stock.[xvi] Though this is a smaller sample of California homes than was available from the other two datasets, the research team identified the RECS as the preferred data source given the issues with the RASS and AHS discussed above. Researchers downloaded data from the RECS website and cleaned it, keeping only variables of interest, dropping records from mobile homes, which are not a predominant form of housing in urban areas, and eliminating records with energy use values that varied from the median by more than three standard deviations. We discuss our process for working with the RECS data in more depth in our description of the preliminary analysis of residential energy use, below.

Designing the structure of the spreadsheet calculator

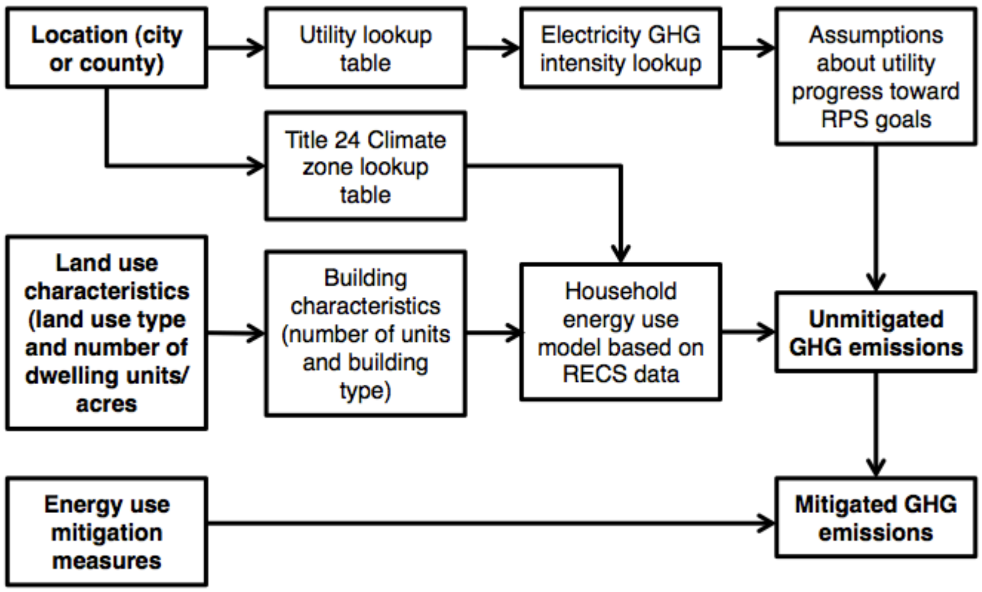
During our interviews, many planners expressed familiarity with CalEEMod and its predecessor URBEMIS, which is not surprising given that environmental review is a very important activity in the local land use planning process. We therefore decided to model the basic structure of the spreadsheet-based calculator around CalEEMod for three reasons. First, though the intent of this project—to enable plan-level comparison of the GHG impacts of different land use scenarios—differs from the project-level focus of CalEEMod, the lookup tables underlying CalEEMod contain much of the background information that we need to inform our calculator, such as a table of cities by climate zone and information on the GHG intensity of different electricity sources throughout the state. Second, making our calculator similar in structure to already-popular tools like CalEEMod and URBEMIS will help planners familiarize themselves with the calculator. Third, CalEEMod includes information about vehicle trips and related GHG impacts. While these impacts are outside the scope of this current project, our interviews with planners suggested that transportation impacts are an important consideration in local planning, so structuring the spreadsheet around CalEEMod may make it easier to incorporate these impacts in the future. Figure 1 shows the process by which CalEEMod calculates GHG emissions due to residential energy use.

Figure 1: Process of calculating GHG emissions due to residential energy use using CalEEMod (inputs and outputs in bold)



In order to create the draft spreadsheet calculator, we created a single spreadsheet that includes a main page where users enter inputs and see outputs, as well as several lookup tables on separate worksheets that convert the inputs into the information needed to calculate GHG emissions. Figure 2 shows the structure of the spreadsheet calculator.

Figure 2: Process of calculating GHG emissions due to residential energy use using CREC spreadsheet calculator (inputs and outputs in bold)



The process by which our spreadsheet estimates GHG impacts of residential development is similar to the process that CalEEMod uses, but with a few key differences. First, CREC's draft spreadsheet allows users to input development in land use types in order to enable planners to use it to evaluate long-term, large-scale planning scenarios. Second, CREC's calculator primarily relies on Title 24 climate zones instead of CEC forecast zones, since the former conform more closely to actual weather conditions. Third, instead of looking up the average electricity usage of a given building type in a given climate zone, as CalEEMod does, our spreadsheet models energy usage based on an analysis of RECS data and, if selected by the user, incorporation of CalEEMod-based expectations of how future energy use will be shaped by future updates of Title 24, Part 6. Fourth, the calculator allows users to choose between whether to use the average GHG intensity of a specifically selected utility's electricity generation sources in the GHG emissions calculation, or to use the GHG intensity of "marginal electricity" (i.e. the electricity generation source most likely to be added and subtracted based on demand changes) for a typical California utility. Finally, the CREC calculator incorporates assumptions about how emissions factors will change over time as utilities progress toward the goals of the Renewables Portfolio Standard (RPS), which requires utilities to use renewables to generate 33 percent of their electricity by 2020.

Converting planning inputs into building size and type

A key goal of the spreadsheet-based calculator is to allow users to input information in a way that is intuitive to planners and reflective of the type of choices that planners are likely to consider when creating long-term plans. These land use choices also must be related to building size. These are challenging tasks for two reasons. First, as many of the local planners that we interviewed mentioned, planners determine what type of buildings *can* be built, but the market determines what *will* be built, and there is often a loose relationship between land use designations and the building characteristics that determine land uses. Second, local systems of planning and designating land uses vary widely, which makes it challenging to identify a uniform set of land use categories that will work statewide.

Local governments typically designate land uses through two separate documents:

- General plans: in a large city or county with a diversity of land uses, general plans typically designate a set of eight to ten residential land use categories, distinguished broadly in terms of ranges of allowable densities, maximum lot size, and/or allowable building types. Smaller or less diverse communities will often use fewer categories.
- Zoning ordinances: zoning ordinances specify in detail the physical limits on development in each general plan land use category using factors such as lot coverage, building heights, setbacks, and floor-area ratios. Zoning ordinances sometimes subdivide general plan land uses into subcategories for the purposes of making finer distinctions between different neighborhoods.

After interviewing planners and reviewing select local general plans and zoning ordinances, we determined that general plan land uses would be more valuable for the purposes of this project, since they are less detailed and therefore more likely to be consistent between cities. Though a number of factors mentioned above can be used to categorize growth, planners mentioned density more frequently than any other variable used to categorize growth, so we decided to focus on density as a descriptive variable to distinguish between land uses.

In order to identify a preliminary set of land use categories, we conducted a review of academic and professional literature for systems of categorizing land uses. We found relatively recent systems in the following trade literature sources:

- *The Guide to California Planning* by William Fulton and Paul Shigley[xvii]
- *Planning and Urban Design Standards* by the American Planning Association[xviii]
- *Smart Code Version 9 and Manual* by Andres Duany, Sandy Sorlien, and William Wright[xix]
- *Trip Generation: An ITE Informational Report* by the Institute of Transportation Engineers[xx]
- *Planner's Estimating Guide* by Arthur C. Nelson[xxi]
- *Residential Development Handbook* by the Urban Land Institute[xxii]

We compared land use categories used in each source to create a list of eleven commonly used residential development types and their physical characteristics. We focused on variables with a direct effect on the physical characteristics of homes, which in turn influence energy use. Sources occasionally assigned different values for land use variables to the same development category. For example, according to one source the density of townhome development ranged from eight to twelve DU/ac (dwelling units per acre), while according to another source the range was ten to fiftenn DU/ac. We assigned ranges for each variable based on the lowest and highest limit across all sources, so in the case above, we assigned townhomes a density range of eight to fifteen DU/ac. Appendix C contains a detailed table describing the physical characteristics and references for each land use category, and table 3 summarizes the results of the literature review.

Table 3: List of physical characteristics of zoning categories from literature review

Land use category	Density (DU/ac)	Height (stories)	Lot size (ac)
Rural or Very Low Density	<2	1-2	>.5
Low Density Suburban	3-5	1-2	0.2-0.33
Mid Density Detached	6-8	2-3	0.13-0.17
Duplex, Quadruplex	4-24	1-3	
Conventional Townhomes	8-15	2-3	0.08
High-Rise Townhomes	15-30	3-4	0.03
Garden/Low-Rise Apartments	15-25	1-2	
Low-Rise Apartments	20-40	2-3	0.5-4
Low-Rise Apartments 2	30-50	3-4	0.5-4
Mid-Rise Apartments	40-80	5-12	0.5-4
High-Rise Apartments	80+	12+	0.5-4

We then conducted a preliminary test of the land use categories from our literature review against actual data by identifying examples from cities across California of the different development types listed in Table 3. We began by searching zoning ordinances from cities across California in order to identify case studies where cities used zoning categories that conformed closely to the categories we identified during our literature review. We then selected a different case study city to represent each land use category in order to avoid geographical bias. We identified development projects within each category using real estate listing sites such as Zillow.com, and took data from these sites on projects' building type and unit square footage. We used Google Earth to calculate the density of the area surrounding each project, and then compared the actual density with the maximum allowable density from the zoning ordinance with the range of densities for each category that we identified through our literature review. The results of this are summarized in Table 4.

Table 4: Land uses, locations, building characteristics, and densities of sample developments for each land use category

Lit review land use category	City zoning designation	City	Building type	Unit floor area (sq. ft.)	Density (DU/ac) Actual	Zoned Max.	Range from lit review
Rural/Low Density							<2
Low Density Suburban	Res. Suburban (RS)	Arroyo Grande	Single family	3,350	4.3	2.5	3-5
Mid Density Detached	Downtown Res. District (DR)	Healdsburg	Single family	1,280	6.3		6-8
Duplex	Res. Development (medium density)	Cerritos	Town-home	1,824	21.8	17	4-24
Conventional Townhomes	Waterfront Commercial (CW)	Benicia	Town-home	1,442	50.0		8-15
High-Rise Townhouse							15-30
Garden/Low-Rise Apartments	Low Density Multiple Family Res. District (R-2)	Fresno	Apt. (5+ units)	720-1,238	12.5	16	15-25
Low-Rise Apartments 1	Multi-family Res. (R3)	El Centro	Apt. (2-4 units)	3,600	25.8	12	20-40
Low-Rise Apartments 2	Planned Development (PD)	San Ramon	Apt. (5+ units)	598-1,072	n/a	30	30-50
Mid-Rise Apartments	High-Density Res. (R-4)	San Bruno	Apt. (5+ units)	1300	45.5	30	40-80
High-Rise Apartments	Multiple Dwelling Zone (R5)	Los Angeles	Apt. (5+ units)	1,210	259.2	218	80+

This analysis revealed potential issues with several categories:

- We were unable to find examples for Rural/Low Density development in the cities examined. Counties are more likely to contain this land use type.
- The Duplex category was problematic because it covers too wide a range of densities. Furthermore, our subsequent analysis of RECS data showed that duplexes are not a prevalent building type for new construction.
- We were unable to find examples of High-Rise Townhomes in any city. Since this category was not cited in a large number of sources in our literature review, it was dropped from the analysis.
- It was difficult to distinguish between the multiple overlapping categories for Low-Rise Apartments, and these categories were therefore consolidated.

- High-Rise Apartments frequently exceeded the zoned maximum. This is likely because these buildings are typically located in urban environments with higher land values, where developers are more likely to apply for variances to the land use code in order to maximize return on investment.

Based on these observations, we consolidated our density categories as shown in Table 5, and expanded the density ranges of some categories so that there are no gaps between categories.

Table 5: Consolidated list of land use categories, with density ranges for each category

Land use category	Category density (DU/ac)
Rural or Very Low Density	<2
Low Density Suburban	2-5
Mid Density Detached	5-8
Conventional Townhomes	8-15
Garden/Low-Rise Apartments	15-20
Low-Rise Apartments	20-40
Mid-Rise Apartments	40-80
High-Rise Apartments	80+

This preliminary analysis did not depict the straightforward inverse relationship between density and unit size that we might expect, necessitating statistical analysis. In order to estimate the average housing unit size associated with each zoning category, we conducted an analysis of data from Fresno County. We selected Fresno County as a study area because it is located in the Central Valley, which is the fastest-growing area of California, and one in which residential energy use is of particular concern due to high cooling loads in the summertime. Also, Fresno County includes the city of Fresno, which is the most populous city in the Central Valley, so it represents a larger range of land use types, particularly for more compact urban development, than many other counties in the Valley. Though typical dwelling unit sizes in a given density class may be larger in Fresno than in many municipalities in the more expensive, coastal regions of the state, the unit size-density relationship is likely representative of the inland areas of the state (especially the Central Valley and Inland Empire) where most future growth will occur.

We compiled data for this analysis from three separate sources:

1. Fresno County Tax Assessor's data, compiled and cleaned by the UC Davis Information Center for the Environment, which contains information on the number of units, building type (single-family or multi-family), and square footage of buildings for each parcel.
2. Land use maps for the county's two largest cities, Fresno[xxiii] and Clovis,[xxiv] and for the unincorporated areas of Fresno County.[xxv] Together these areas contain roughly 715,000 people, which is 75 percent of the county's total population.
3. Historical maps of urban development from the Department of Conservation's Farmland Mapping and Monitoring Program (FMMP).[xxvi]

We began by dividing the total square footage of buildings on each parcel by the number of units in order to calculate the average square footage of housing units. Since the Tax Assessor's data allows a maximum value of 99 units per parcel, this may lead us to a slight overestimation of the floor area for very large multi-family apartment buildings. We then used ArcMap GIS software to assign centerpoints to each parcel, and did a spatial join to identify which zoning category parcels were located in. The zoning data expresses density in terms of minimum lot size (or minimum parcel area per unit for multi-family units), so we divided the area of an acre by the minimum lot size in order to calculate the maximum allowable density for each zoning category. Finally, in order to focus on new construction, we also did a spatial join of parcel midpoints and land designated as "urban and built-up land" by the 2000 FMMP. Parcels that were outside of urbanized areas in 2000 were considered to be new construction. We then calculated the mean housing unit area for each density category, both for all housing units and for new construction. Table 6 summarizes the results.

Table 6: Average housing unit area and sample size by density category

		All housing units		**New construction**		
Land use category	**Category density** (DU/ac)	Mean unit area (sq. ft.)	Sample size	Mean unit area (sq. ft.)	Median unit area (sq. ft.)	Sample size
Rural or very low density	<2	1,835	1,501	1,853	1,729	115
Low density suburban	2-5	2,221	19,348	2,142	1,948	1,190
Mid density detached	5-8	1,615	106,530	2,262	2,145	14,339
High density detached	8-15	1,547	1,355	1,668	1,601	1,012
Townhomes	15-20	1,144	4,886	1,560	1,559	280
Low-rise apartments/ townhomes	20-40	942	2,414	684		1
Mid-rise apartments	40-80	861	366			
High-rise apartments	80+					

It is useful to differentiate new construction because studies generally suggest that new housing units, particularly single-family homes, are larger than older units. However, our method of determining which housing units are new construction does not necessarily capture all new construction, because it only distinguishes units that are built on newly developed land, and many new homes—particularly higher-density apartments—are more likely to be built on infill properties. Thus, the means shown for new construction in Table 6 are probably not valid for low-rise apartments, because the sample of these units is so small.

The difference between new and old construction is particularly interesting in the case of mid-density detached homes, which account for the majority of post-2000 construction in Fresno County, and have grown substantially in size according to our analysis. This is likely because newer single-family developments tend to consist of larger homes with larger lot coverages, which produces larger buildings at higher densities. We calculated the median housing unit size for the new construction in order to guard against the possibility that the means are being pulled upward by a few abnormally large housing units, especially in the categories with smaller sample sizes. It is important to note that the maximum density allowed by any of the jurisdictions included in our analysis is below 80 DU/ac, so high-rise apartments are not represented at all by this sample.

We had hoped to use this analysis to also examine whether building types conformed to the assumptions implicit in our land use categories—for example, to determine whether the "conventional townhomes category" actually consists entirely of townhomes, or rather of a mix of townhomes, high density single-family detached homes, and low-density apartments. However, we were unable to conduct such an analysis in the depth that we would like because the tax assessor's data only includes information on whether units are single- or multi-family, but does not contain any information that would allow us to distinguish between single-family homes. The data appeared to contain additional errors in that it showed some parcels that were zoned for one unit per lot contained multiple units according to the assessor's data. This is probably due to subdivisions that are not recorded as multiple parcels, and this uncertainty prevents us from assuming that parcels with multiple single-family buildings contain townhomes.

In spite of these issues, we used our Fresno dataset to examine the breakdown of single- and multi-family housing in the different zoning categories. We assumed that parcels were either single- or multifamily only if they contained one type of housing; we categorized parcels that contained both single- and multi-family units as "other" and did not include them in the results shown in Table 7 below. We differentiated between the two different types of apartment buildings based on how many units the tax assessor's data reported for the parcel. Since our method of differentiating new housing does not capture new multi-family development in infill areas, as discussed above, we did not attempt to base this analysis on new construction.

Table 7: Building type by land use category

Land use category	Category density (DU/ac)	All housing units: % single-family	% apts 2-4 units	% apts 5+ units
Rural or Very Low Density	<2	100%	0%	0%
Low Density Suburban	2-5	100%	0%	0%
Mid Density Detached	5-8	100%	0%	0%
Conventional Townhomes	8-15	81%	16%	3%
Garden/Low-Rise Apartments	15-20	64%	31%	5%
Low-Rise Apartments	20-40	31%	42%	26%
Mid-Rise Apartments	40-80	31%	31%	37%
High-Rise Apartments	80+	-	-	-
All records		97%	2%	1%

Table 7 shows that development in the Fresno area is often less intensive than our land use category names would suggest. For example, the "Garden/Low-Rise Apartments" is predominantly single-family buildings—presumably townhomes, since several of the planners that we interviewed mentioned a rule of thumb that townhomes become the dominant housing type above 15 DU/acre. And though the zoning codes for homes in the "conventional townhomes" category allow multi-family units, few are actually constructed. This observation, in conjunction with the rule of thumb noted above, led us to believe that this category contains primarily single-family detached buildings.

We summarized the results of our analysis of Fresno-area housing data in Table 8, which shows final square footage estimates and dominant building types for each land use category. For categories up to 20 DU/ac, we based our square footage estimates on the median size of new construction, while for categories between 20 and 80 DU/ac we based our estimates the mean for all records due to lack of data for new construction in these categories. Since there are no examples of high-rise apartments in the data that we analyzed, we assumed that these units are similar to mid-rise apartments. We assigned dominant building types based on Table 7 and in some cases altered category names to reflect our observations about building type in each category.

Table 8: Final square footage estimates and building type assumptions by land use category

Land use category	Category density (DU/ac)	Median unit area (sq. ft.)	Dominant building type
Rural or Very Low Density	<2	1,729	Single-family detached
Low Density Suburban	2-5	1,948	Single-family detached
Mid Density Detached	5-8	2,145	Single-family detached
High Density Detached	8-15	1,601	Single-family detached
Townhomes	15-20	1,559	Townhomes
Low-Rise Apartments/Townhomes	20-40	942	Apartments 2-4 units
Mid-Rise Apartments	40-80	861	Apartments 5+ units
High-Rise Apartments	80+	861	Apartments 5+ units

Table 8 is the basis for the assumptions in our spreadsheet calculator that relate land use categories to building types and square footages. However, this analysis also highlights the fact that housing units of different types and sizes can occur within the same designation, so we determined that it would be important to allow users to modify these assumptions in the spreadsheet calculator.

Conducting analysis of household energy use as a function of community design variables

Creating the spreadsheet calculator requires us to analyze the effect that spatial variables such as building type and square footage have on energy use. In order to ensure that this analysis is accurate, we needed to build a model that controls for the many other factors that may influence residential energy use. For example, larger houses may consume more energy because they have more interior space to light, heat, and cool, or because they are generally owned by wealthier people with more money to spend on energy-consuming appliances. Though we are primarily interested in square footage, our model must be comprehensive, and to include variables such as income and household size to better isolate the effects of square footage on energy use.

Data used in our analysis came from the 2005 Residential Energy Consumption Survey (RECS),[xxvii] which is a national sample survey of housing units conducted by the Energy Information Agency of the Department of Energy (DOE) that collects information on the energy consumption and the factors that influence energy consumption, such as the physical characteristics of housing units, socio-economic characteristics of housing occupants, and appliances used within the household. The 2005 RECS contains data on

4,382 homes. This sample formed the basis for our analysis. Table 9 shows the variables that we used in our analysis.

Table 9: Variables used from the 2005 RECS

Variable name	Description
DOEID	DOE-assigned ID number
TOTSQFT	Total square footage of the housing unit
HHINCOME	Household income
BEDROOMS	Number of bedrooms in the housing unit
TYPEHUQ	Building type
YEARMADE	Gives ranges for when the housing unit was built
NHSLDMEM	Number of people that live in the household
CD65	Number of cooling degree-days (base temperature of 65º F)
HD65	Number of heating degree-days (base temperature of 65º F)
LRGSTATE	Indicates whether a home is located in one of the four largest states, and if so, identifies the state
ELFOOD	Indicates whether a housing unit uses electricity for cooking
ELWARM	Indicates whether a housing unit uses electricity for space heating
ELCOOL	Indicates whether a housing unit uses electricity for air conditioning
ELWATER	Indicates whether a housing unit uses electricity for water heating
UGCOOK	Indicates whether a housing unit uses natural gas for cooking
UGWARM	Indicates whether a housing unit uses natural gas for space heating
UGWATER	Indicates whether a housing unit uses natural gas for water heating
KWH	Total annual electricity usage in kilowatt-hours
CUFEETNG	Total annual natural gas usage in 100s of cubic feet

We used these variables to create additional dummy variables, listed in Table 10.

Table10: Dummy variables generated

Variable Name	Description
CASTATE	Indicates whether a housing unit is located in California (CASTATE = 1 if LRGSTATE = 2)
SFDETACH	Indicates whether a housing unit is a single-family detached housing unit (SFDETACH = 1 if TYPEHUQ = 2)
SFTOWN	Indicates whether a housing unit is a single-family attached housing unit (SFDETACH = 1 if TYPEHUQ = 3)
APT24	Indicates whether a housing unit is an apartment in a building with 2-4 units (SFDETACH = 1 if TYPEHUQ = 4)
APT5	Indicates whether a housing unit is an apartment in a building with 5+ units (SFDETACH = 1 if TYPEHUQ = 5)
APT	Indicates whether a housing unit is an apartment (SFDETACH = 1 if TYPEHUQ = 4 or 5)
POST80	Indicated whether a housing unit was built in 1980 or later (POST80 = 1 if YEARMADE >= 6)
POST90	Indicated whether a housing unit was built in 1990 or later (POST80 = 1 if YEARMADE >= 8)
POST95	Indicated whether a housing unit was built in 1995 or later (POST80 = 1 if YEARMADE >= 9)
POST00	Indicated whether a housing unit was built in 2000 or later (POST80 = 1 if YEARMADE >= 10)

After generating dummy variables, we filtered and cleaned the RECS data as follows:

- *Dropping all mobile homes:* Mobile homes are not a prevalent housing type in California general plans and often have different energy use characteristics than other housing types. We therefore eliminate all mobile homes from our sample by dropping all records where TYPEHUQ equals 1.

- *Eliminating outliers:* In order to create an analysis that accurately applies to the majority of new construction, we needed to ensure that our sample population does not include outliers, in this case buildings with unusually high energy use. We therefore dropped all records where either electricity or natural gas usage differed from mean usage by ±3 standard deviations. This effectively meant filtering out records with excessive energy use, since the minimum possible usage value (zero) was within 3 standard deviations of the mean.

Applying these two filters leaves us with 3,971 remaining records on which to base our analyses.

Seventy-eight percent of new California homes built between 2001 and 2008 use natural gas as their primary fuel heating source, and no alternative heat source dominates under those homes that do not use natural gas.[xxviii] We therefore stated in our scope our intention to filter all buildings that do not use natural gas for heating fuel. However, less than half of new large apartment buildings use natural gas for heat, and these buildings are an important focus of our analysis with a relatively small sample size. Therefore, we determined to keep these buildings in the sample in order to allow for a larger sample size in the analysis of energy usage. We strove to ensure that these records do not distort our analysis of natural gas usage by recoding CUFEETNG (total annual natural gas usage) to 0 if CUFEETNG is "not applicable" (e.g. where a home is not hooked up to a natural gas line) and then filtering our analysis of natural gas to only include records where CUFEETNG > 0. We can then account for the effect of space heating, which typically accounts for the majority of natural gas usage, by including the dummy variable UGWARM (usage of natural gas for space heating) in our analysis of natural gas usage.

Regression analysis modeling approach

Broadly speaking, there are two different approaches to modeling residential energy use. The *consumption-based* approach treats energy use primarily as a function of the different appliances used within a house and of their usage rates,[xxix] while the *demographic* approach treats energy use as a function of characteristics such as household income and number of occupants. The former approach is more accurate, because it focuses on the actual determinants of energy use. However, a strict consumption-based approach requires extensive data, and in practice most research ends up using a hybrid of the two approaches, using demographic data as a proxy for data on appliances and usage rates that are otherwise unavailable.

We initially used a consumption-based approach to build a model of residential energy use that included variables for the presence and number of several different appliances within a household. However, the large number of variables in the consumption-based models and the wide variation within the sample population led to models with counterintuitive results, such as negative coefficients for electricity use associated with certain appliances. We therefore adopted a simplified approach based on a recent analysis of California's electricity use conducted by the U.S. Department of Energy,[xxx] which analyzed energy use as a function of building characteristics, household income, and whether a housing unit uses the fuel in question for various purposes (through dummy variables such as ELWARM, usage of electricity for space heating, and UGCOOK, usage of natural gas for cooking). This approach assumes that household income is a proxy for the presence, number, and usage rate of various appliances. Though there were differences between our initial approach and the approach that we finally adopted, the coefficients for the major spatial variables of interest to this project—particularly square footage—were not very different under these two approaches.

After cleaning and filtering data, we were left with four housing types to examine. Ideally, we should base our model on California data, because California has some of the most energy-efficient building codes in the nation. However, we also wanted to focus on new construction and differentiate between building types in our model. Though our total sample, which has nearly 4,000 records, can support a robust statistical analysis, the sample of some of the subgroups that are of special interest to our analysis—for example, newly built townhomes located in California—is quite small. As Table 11 shows, building types other than single-family homes, particularly townhomes and apartments with 2-4 units, have a small number of records built after 1980. 1980 is an important cutoff year for our analysis, because it roughly corresponds to 1978, which is to the year that California's Title 24 energy standards first went into effect.

Table 11: Tabulation of housing units built after 1980 by building type and by whether or not they are located in California (RECS dataset)

	Located in California?		
Building type	**No**	**Yes**	**Total**
Single-family detached	908	83	991
	68.2%	58.9%	67.3%
Townhome	123	14	137
	9.2%	9.9%	9.3%
Apartment 2-4 units	64	16	80
	4.8%	11.4%	5.4%
Apartment 5+ units	236	28	264
	17.7%	19.9%	17.9%
Total	1,331	141	1,472
	100%	100%	100%

Instead of creating separate models for new California buildings of each type, we therefore chose to base our models on the larger sample and use dummy variables and interaction terms to account for the differential effect of California building standards and different building types. Table 12 shows the interaction terms generated for this analysis.

Table 12: Interaction terms generated

Variable Name	Description
CASF	CASTATE * TOTSQFT
THSF	TOWNSF * TOTSQFT
APT24SF	APT24 * TOTSQFT
APT5SF	APT5 * TOTSQFT
APTSF	APT * TOTSQFT
CACD65	CASTATE * CD65
CAHD65	CASTATE * HD65

Factors such as energy standards and building types could have two different effects on energy use, and this approach enables us to capture them both. For example, households in California may on average consume less total energy than average U.S. households due to the state's mild climate and energy efficient building standards. This difference will be captured in the coefficient on the dummy variable CASTATE, which describes whether or not a record is located in California. However, since California's energy standards do not regulate overall energy use, but rather energy consumption per square foot (also known as energy intensity), it is also reasonable to expect that California buildings will have a different coefficient for the variable TOTSQFT, total square footage, than average buildings. This difference will be captured in the coefficient for the interaction term CASF. The same is true for different building types: apartments may use less total energy on average than single-family homes because they are typically smaller and contain fewer appliances, but they may also be less energy-intense because it is more efficient to heat units with shared walls.

We created two models, one for electricity usage and one for natural gas usage, since each of these types of energy have different end uses and therefore are correlated with different explanatory variables. For example, space heating accounts for a large percentage of natural gas usage, so it is reasonable to expect that the variable HD65 (heating degree days) will have a strong effect in the natural gas model. Meanwhile, nearly all air conditioners use electricity, so we would expect CD65 (cooling degree days) to be more influential in the electricity model.

The key assumptions of ordinary least squares regression, our statistical analysis method of choice, is that variables are normally distributed and that the data observations are independent. To ensure normality of distribution, after examining the distribution of our dependent variables KWH (total annual electricity usage) and CUFEETNG (total annual natural gas usage), we transformed them by taking the square root of each. The resulting variables, SQRTKWH and SQRTNG, have a more normal distribution, and using them as the dependent variables avoids heteroscedasticity in the final model results. Independence of the data observations is achieved by the randomized selection process that the RECS survey uses to generate its cross-sectional dataset.

We began by running single-variable tests to determine which variables had a significant effect on either natural gas or energy use. We then ran a regression analysis using all variables that these tests had shown to be relevant. Variables were dropped if they:

- Had a counterintuitive sign on their coefficient and were not significant at the 0.05 level (for example, we would expect buildings that use natural gas for water heating to use more natural gas, all other factors being equal, so we would drop UGWATER, usage of natural gas for water heating, if it had a negative sign and was not statistically significant)

- Were highly insignificant ($p>|t| > 0.8$)
- Were interaction terms that were not significant at the 0.05 level and had coefficients that, when added to the coefficient on the term that they were interacting with, had a counterintuitive sign (For example, if the coefficient on TOTSQFT is 0.2, and the coefficient on CASF is -0.4, we would drop CASF, because 0.2 + -0.4 = -0.2, which implies that larger apartments use less energy than smaller ones).

We repeated this process while filtering the sample for progressively more recent construction, and selected a preferred model that that was based on the most recent construction possible without compromising the statistical significance of results.

We ran diagnostic tests on all models to test whether preferred models met the following assumptions of ordinary least squares regression analysis. Below we list the assumptions tested for, with the diagnostic tests that we used in parentheses:

- Model specification – model includes relevant explanatory variables (link test for model specification, Ramsey RESET test)
- Normality of residuals – residuals have a normal distribution (skewness/kurtosis test for normality)
- Heteroscedasticity – residuals have a constant variance (Breusch-Pagan/Cook-Weinberg test)
- Multicollinearity – explanatory variables are not independently correlated (variance inflation factors)

The preferred models, described in the results section, passed all diagnostic tests unless otherwise noted.

Incorporating optional recognition of future building energy code updates

The statistical modeling just described is based upon observation of past behavior and implicitly assumes that future behavior will mirror the recent past. This approach has the strength of being based upon empirically observed human behavior rather than models or assumptions about future actions. However, it has the drawback of being unable to take into account the fact that future residential energy use will take place under updated building energy codes (i.e. Title 24, Part 6) that will be more stringent than those of the recent past, and that therefore GHG emissions from future residential energy use may be lower than one would necessarily conclude from studying only the recent past.

To recognize the fact that both approaches have different strengths and weaknesses, the calculator is designed to allow the user to elect to use the CREC statistical model only as the basis for assumptions about future residential energy usage and GHG emissions, or a blended model that combines estimates of residential energy usage patterns under future Title 24, Part 6 updates with portions of the CREC statistical model. Title 24, Part 6 governs only part of a given residence's energy usage; important sectors such as lighting and plug loads (appliances, electronic devices, etc) are not subject to Title 24, Part 6. Hence, reliance on observation of the recent past in these sectors is less likely to diverge substantially from probable future behavior.

The blended model option therefore uses projections from CalEEMod for Title 24, Part 6-related residential energy use and combines those with projections for non-Title 24, Part 6-related residential energy use derived from the CREC statistical model. In order to do this, CREC researchers determined the proportion of energy use in Title 24, Part 6-related sectors within the CREC statistical model and substituted for that portion of the results the projections for future Title 24, Part 6-related energy use from CalEEMod. CalEEMod distinguishes between four different building types and expresses the expected future energy use on a per-unit basis for each of the 15 climate zones that CalEEMod uses (which are not the same as the Title 24 climate zones). CalEEMod assumes that detached dwelling units are 1800 square feet in size, while attached dwelling units are 1000 square feet in size. In order to adapt these building types to the building typologies and sizes used in the calculator, CREC researchers simply matched the CREC building types to the closest equivalent in CalEEMod, then normalized the future energy use projection in CalEEMod to the median building sizes used in the CREC calculator. In addition, the calculator matches the location of the municipality with the CalEEMod climate zones in order to ensure that the correct estimate is being used for a given location.

Researching GHG emissions factors for major utilities' energy supply mix

This task was simplified by the fact that the Air Resources Board (ARB) and the California Public Utilities Commission (CPUC) previously funded a study by Energy and Environmental Economics (E3) that looked at the economic feasibility of meeting Renewable Portfolio Standard goals and estimated GHG emissions factors for major utilities through 2020 accordingly.[xxxi] To extend these emissions factors to 2035, CREC researchers used the utility-specific emissions factor multipliers for the post-2020 period distributed by the Statewide Energy Efficiency Collaborative (SEEC).[xxxii] These multipliers are expressed as a proportion of 2008 base year emissions factors, the same base year as the E3 study used. Because there is only one multiplier per utility for the entire period from 2021 to 2035, CREC researchers assumed that it applied evenly across all years in the period (i.e. utilities were assumed to achieve that emission factor in 2021 and sustain it until 2035). For several utilities, the E3 study anticipates an emissions level for 2020 that is lower than that resulting from SEEC's emissions factor for the post-2020 period. In these cases, the lower 2020 level was simply maintained out to 2035.

CREC researchers considered whether to attempt to extrapolate the progress scheduled to be made by utilities under the RPS beyond its sunset date of 2020. But given the absence to date of any specific legislation or regulation requiring continued progress beyond 2020, and the use of a constant post-2020 emission factor by SEEC, the research team became concerned that assumptions about continued post-2020 progress would introduce too much subjectivity into long-range GHG estimates.

It is important to note that some utilities are behind schedule in meeting RPS goals, and that as a result many local governments may wish to use more conservative assumptions about the future GHG intensity of their energy sources. The research team therefore decided that the spreadsheet calculator should allow users the option of assuming "on-schedule" progress toward the RPS or using static present-day GHG intensity figures.

In addition, CREC researchers designed the calculator to permit users to elect to use a "marginal electricity" approach to estimating future GHG emissions. Rather than using the GHG intensities for specific utilities described above, this approach allows users to rely upon a statewide estimate for the GHG intensity of the electricity source most likely to be added or subtracted by a typical utility as demand changes. Based on guidance from ARB staff, this value was assumed to be 0.27 MT/MWH. For some utilities, this is a lower GHG intensity than the average of the portfolio as a whole, especially for those such as the Los Angeles Department of Water and Power that obtain electricity from coal-fired power plants to meet baseloads. However, other utilities, such as the Sacramento Municipal Utility District, have an average portfolio-wide GHG intensity that is already lower than 0.27 MT/MWH because of relatively heavy reliance on hydropower and renewable energy. In these cases, it seems likely that marginal electricity sources are actually of lower GHG intensity than the 0.27 MT/MWH statewide estimate. To account for these realities, the calculator is designed to select the *lesser* of the two GHG intensities (i.e. average versus marginal) if the user elects to use the marginal source estimation approach.

3. Evaluation of the spreadsheet

We used four methods for evaluating the performance of the spreadsheet calculator:

- A preliminary validation of the statistical models using 2009 RASS data
- A field test of the calculator by the interviewees
- A validation of the spreadsheet calculator using recent historical data from the Sacramento Municipal Utility District (SMUD)
- A model comparison with CalEEMod

The methods involved in each of these evaluation techniques are described below.

Preliminary validation using 2009 RASS data

In order to test whether these models yield reasonable estimates, we took data from the 2009 RASS[xxxiii] on the average square footage, electricity consumption, and natural gas consumption of housing units units constructed after 1978 for single-family homes and apartments with 5+ units, the two most common building types, in each Title 24 Climate Zone from the 2009 RASS (we used data from the 2003 RASS for apartment buildings due to the errors in the 2009 RASS). We also gathered data on the average number of heating- and cooling-degree days in each climate zone.[xxxiv] We used the data on climate and square footage to calculate energy use according to the statistical models described above, and compared our calculated values with the actual values.

Field test of the spreadsheet calculator

A second evaluation process involved sending the preliminary draft calculator to the same set of individuals (both professional planners and tool designers) interviewed at the outset of the research. These individuals were selected originally either because of their familiarity with CalEEMod and other existing tools of a similar nature, or because they are doing the kind of planning work that the spreadsheet calculator is intended to support. These same characteristics qualified them to effectively evaluate the calculator itself once developed.

The preliminary draft of the spreadsheet calculator, and a one-page evaluation questionnaire, were sent to these 25 individuals by email in July 2012. The questionnaire is reproduced in Appendix D. Respondents were requested to "field test" the calculator – i.e. enter in real or hypothetical data and exercise the various choices and capabilities within the calculator – before responding to the questionnaire. After the initial request, researchers followed up within five working days by phone. A month after the initial request, those who had not yet responded were solicited again by email. Five working days after this second solicitation, those who had not responded were again contacted by phone.

The questionnaire was designed to gather both general and specific feedback about the following issues:

- User-friendliness of the calculator
- Clarity of the calculator's purpose and instructions
- The applicability of the calculator to the respondents' professional planning activities
- The likelihood that requested input data would be readily available to the user
- The likelihood that the user would choose default or user-defined assumptions
- The usefulness of the calculator in a specified list of common planning processes
- The usefulness of the calculator in a specified list of common planning activities
- The likelihood that the respondent will actually use the final version of the calculator

The results of the questionnaire, discussed in the results section, were then used to inform subsequent revisions of the spreadsheet calculator.

Validation of the spreadsheet calculator using SMUD data

The third, and most rigorous, form of evaluation involved using electricity use data from the Sacramento Municipal Utility District (SMUD) to validate the spreadsheet calculator's statistical model for electricity. SMUD makes its use data much more available to researchers than others utilities around the state, partly because it is publicly owned. SMUD data is also appropriate for this task because the SMUD service area in and around Sacramento has a more variable climate (and hence greater heating and cooling needs) than most other large population centers in the state.

SMUD was willing to release usage data aggregated by zip code without requiring lengthy review to ensure data security and confidentiality. Because the spreadsheet calculator is designed to estimate the energy usage and GHG emissions from residential energy consumption over relatively large areas, we concluded that zip code-level data was sufficient for the validation task.

The research team also looked for a suitable utility dataset of natural gas usage but was unable to find one. The vast majority of residential natural gas in California is supplied by three large investor-owned utilities that do not make usage data available to researchers. Researchers also approached the two municipal gas utilities in the state – Palo Alto and Long Beach – about sharing data, but these utilities declined to share data in a form that could be useful for model validation. Hence, full validation of the natural gas model remains for future research.

Any use data is a measure of past activity, while the spreadsheet calculator seeks to estimate future usage. The validation method was designed to mitigate this problem by:

- Assuming that the spreadsheet calculator was being used at the *beginning* of a recent historical period for which usage data is available;
- Programming into the calculator the actual amount of growth that in fact occurred over the ensuing period; and
- Comparing the calculator's projections for electricity usage resulting from that new construction over the ensuing period with the actual amounts used by the buildings newly constructed in that period.

This involved a number of specific steps, detailed below.

1. Identification of the appropriate time period – SMUD indicated that usage data quality was much better in the post-2001 period (inclusive), and was available up until the end of 2011. Hence the decade from 2001 from 2011 was selected as the period of analysis. Indeed, this validation method is only possible because the earliest base year of the spreadsheet calculator (2012) almost matches the final year of the period of analysis. Hence observations of energy use at the end of this decade of growth can be compared to the modeled results for the year 2012.

2. Identification of high-growth zip codes in the SMUD service area – Using data derived from the 2000 and 2010 federal census, we identified four zip codes within the SMUD service area that had experienced a significant amount of new housing growth from 2000 to 2010, a close proxy for the period of analysis. They were also selected to fall within only two jurisdictions (the City of Sacramento and the City of Elk Grove) to minimize a potential source of variability and to minimize the amount of research into local zoning designations necessary to characterize the growth. The selected zip codes and their estimated 2000-2010 population growth are shown in Table 13.

3. Sorting of SMUD data – The monthly SMUD usage data were sorted and selected along the following fields in the database:

   - Zip code
   - Year (2011)
   - House type (single-family and multi-family)
   - Space heat energy source (gas only)
   - Service type (standard only)

   Homes that used electricity for space heat were excluded from the dataset because the statistical model assumes that new construction will use gas space heating (see results section for further discussion). Additionally, only the "standard" service type was selected in order to exclude homes that have wells, an unusual and significant usage of electricity not accounted for in the models.

4. Calculation of 2011 annual electricity consumption – For each zip code, the monthly records indicating the average kilowatt-hour usage per household, the number of

total accounts, and the number of billing days per month were aggregated across both house types (single-family and multi-family) to calculate a weighted average consumption per household per year. This became the number against which model results were compared.

5. Identification of housing units built within the 2001 – 2011 time period – SMUD also provided linked Sacramento County Assessor's data for the four zip codes under examination. These datasets included every building within the zip code (identified only by an ID number, not an address), and each data record included the SMUD data fields identified above, allowing these property records to be sorted in precisely the same way as the SMUD usage data. Crucially, the assessor's data fields included information on the zoning classification within which the property stands, and on the year the structure was built, allowing the research team to a) exclude properties built before the period of interest, and b) identify how each zoning classification would fit within the density classes used to characterize growth in the spreadsheet calculator.

6. Classification of the housing units built within the 2001-2011 time period – Using the local zoning codes and aerial photographs, the research team classified each house or building constructed in the four zip codes within the selected time period into one of the eight density classes used in the spreadsheet calculator. In most cases, the descriptions of permissible development written into the zoning code made clear which density class was appropriate. In a few cases, mainly special zoning classes such as Planned Unit Developments or other special development zones, inspection of aerial photographs was necessary to determine the approximate density of a group of buildings.

7. Running the spreadsheet calculator on the actually occurring growth between 2001 and 2011 for each of the four zip codes – Using the classifications developed in the previous step, the research team created a scenario for each zip code within the spreadsheet calculator assuming that all of the actually ensuing growth was being planned in 2001 as it would subsequently occur, and recorded the estimated electricity use to compare to the SMUD data covering the same dwelling units. The spreadsheet calculator was run using both the default setting for median housing unit size, and the user-defined setting that allows the user to input the actual median housing size for the areas in question. The medians were calculated from the property tax assessor records linked to the SMUD data.

Table 13. Zip codes selected for validation analysis

Zip code	City	Pop. in 2000	Pop. in 2010[xxxv]	Pop. growth	% growth
95834	Sacramento	8,392	14,116	5,724	68.2%
95835	Sacramento	834	8,363	7,529	902.8%
95758	Elk Grove	47,063	76,762	29,699	63.1%
95624	Elk Grove	38,521	53,771	15,250	39.6%

Model comparison with CalEEMod

The fourth form of evaluation involved simply comparing the spreadsheet calculator's results from the validation exercise (i.e. the results from the four high-growth zip codes) with the electricity and natural gas usage estimates programmed into CalEEMod. As noted, CalEEMod assumes an average (not median) dwelling unit size within each of five building types, and assumes that future usage is in comformity with updated Title 24, Part 6 standards. These building types roughly correspond to the types ultimately used in the CREC spreadsheet calculator, but in order to perform the model comparison, it was necessary to normalize the CalEEMod energy use estimates to the size of dwelling units used in the CREC spreadsheet calculator validation runs. For purposes of this normalization, it was assumed that energy use scaled proportionally to the size of the dwelling unit.

This is not a validation method in the traditional sense, since the spreadsheet calculator's statistical model is based on actual past behavior and CalEEMod is based on assumed future usage levels. This is an especially important distinction given that the State of California frequently updates the Title 24 standards for building energy efficiency. CalEEMod assumes that the current Title 24 standards will be achieved by future development, while the spreadsheet calculator's statistical model is based on usage patterns observed in development that was subject to older (and less stringent) editions of Title 24.

Moreover, not all energy usage within residences is subject to Title 24. Efficiency improvements in non-Title 24 energy usage are likely harder to predict with any assurance. CalEEMod relies upon model-based assumptions to project this future energy use, whereas the spreadsheet calculator relies upon the actually observed usage patterns of the recent past that form the basis of our statistical model. Discrepancies between CalEEMod and the spreadsheet calculator are therefore not necessarily evidence of error in either one, but instead simply two methods of estimating for the future. The blended model option described above was also compared with CalEEMod results to determine the extent to which it reduces discrepancy between the two projection methods.

III. RESULTS

The results achieved in the creation of the spreadsheet calculator, and the use of the four evaluation methods, are presented below.

1. Creation of the spreadsheet calculator

The results of this phase of the research include the results of the statistical modeling and the actual creation of the spreadsheet calculator itself in Microsoft Excel. Each is described below.

Results of the statistical modeling

As described in the methods chapter, we created separate ordinary least-squares regression models to describe the relationship between land use types (functionally defined as density ranges) and electricity and natural gas usage, respectively. For the electricity model, the dependent variable is SQRTKWH (the square root of total annual electricity usage), and the independent variables included in the initial analysis were TOTSQFT (total square footage), HD65 (heating-degree days), CD65 (cooling-degree days), NHSLDMEM (number of people living in the household), CASTATE (location in California), HHINCOME (household income), ELWATER (use of electricity to heat water), ELFOOD (use of electricity for cooking), ELWARM (usage of electricity for space heating), and ELCOOL (use of electricity for air conditioning), as well as all of the dummy variables and interaction terms described in the methods chapter. After dropping variables that were insignificant or had counterintuitive sings, we arrived at the model shown in Table 14, which is based on a sample of post-1990 homes.

Table 14: Electricity usage model

Source	SS	df	MS		
Model	447056.31	12	37254.69	**Number of obs**	849
Residual	353251.70	836	422.55	**F(12, 836)**	88.17
				Prob > F	0.00
				R^2	0.56
Total	800308.01	848	943.76	**Adjusted R^2**	0.55
				Root MSE	20.56

Variable	Coefficient	Standard Error	t	P>|t|
totsqft	0.00199	0.00046	4.29	0.00
nhsldmem	5.26980	0.49161	10.72	0.00
hhincome	0.00012	0.00002	5.15	0.00
elwater	16.60331	1.95267	8.50	0.00
elfood	4.48769	1.72930	2.60	0.01
elwarm	7.83763	1.82097	4.30	0.00
elcool	13.89020	1.95790	7.09	0.00
cd65	0.00466	0.00075	6.18	0.00
sftown	-18.58629	5.84204	-3.18	0.00
thsf	0.00325	0.00214	1.52	0.13
apt	-19.18836	2.16132	-8.88	0.00
castate	-13.02057	3.02074	-4.31	0.00
_constant	54.99790	3.01584	18.24	0.00

This model passed all diagnostic tests except for the test for normality of residuals and the Ramsey-Reset test for model specification. However, none of the models we arrived at using the RECS data passed the test for normality of residuals, and since this model passed the link test and the value for the Ramsey-Reset was close to the significance value we elected to use it.

For the natural gas model, the dependent variable is SQRTNG (the square root of total annual natural gas usage), and the independent variables included in the initial analysis were TOTSQFT (total square footage), HD65 (heating degree days), NHSLDMEM (number of members of the household), CASTATE (location in California), HHINCOME (household income), UGWATER (use of natural gas to heat water), UGCOOK (use of natural gas to cook), and UGWARM (use of natural gas for space heating), as well as of the dummy variables and interaction terms described in the methods chapter. After dropping variables that were insignificant or had counterintuitive sings on their coefficients, we arrived at the model shown in Table 15, which is based on a sample of post-1980 homes. As described in the methods chapter, we confined this analysis to homes that use natural gas, i.e. records where CUFEETNG > 0, and this filter reduced the sample size such that we needed to include older homes in order to ensure a statistically valid model.

Table 15: Natural gas usage model

Source	SS	df	MS		
Model	21626.23	12	1802.19	**Number of obs**	845
				F(12, 836)	64.62
Residual	23203.93	832	27.89	**Prob > F**	0.00
				R^2	0.48
Total	44830.16	844	53.12	**Adjusted R^2**	0.47
				Root MSE	5.28

Variable	Coefficient	Standard Error	t	P>|t|
totsqft	0.00065	0.00013	5.07	0.00
nhsldmem	0.53885	0.12343	4.37	0.00
hhincome	0.00002	0.00001	3.35	0.00
ugwater	3.79398	0.60601	6.26	0.00
ugcook	1.25100	0.37572	3.33	0.00
ugwarm	5.47828	0.59273	9.24	0.00
hd65	0.00133	0.00010	13.26	0.00
sftown	-0.80334	0.61246	-1.31	0.19
apt	-3.26424	0.93573	-3.49	0.00
aptsf	-0.00028	0.00067	-0.43	0.67
castate	0.61826	1.04354	0.59	0.55
casf	-0.00023	0.00039	-0.59	0.56
constant	5.81852	0.97613	5.96	0.00

This model passed all model diagnostics except the test for normality of residuals.

Based on the model results shown above, we created equations for use in the preliminary spreadsheet-based calculator:

KWH = (0.00199 * TOTSQFT + 5.26980 * NHSLDMEM + 0.00012 * HHINCOME + 16.60331 * ELWATER + 4.48769 * ELFOOD + 7.83763 * ELWARM + 13.89020 * ELCOOL + 0.00466 * CD65 + -18.58629 * SFTOWN + 0.00325 * THSF + -19.18836 * APT + -13.02057 * CASTATE +54.9979)^2

CUFEETNG = 000056 * TOTSQFT + 0.53885 * NHSLDMEM + 0.00002 * HHINCOME + 3.79398 * UGWATER + 1.251 * UGCOOK + 5.47828 * UGWARM + 0.00133 * HD65 + 0.80334 + -3.26424 * APT + -0.00028 * APTSF + 0.61826 * CASTATE + 0.00023 * CASF + 5.81852)^2

However, planners using the calculators will not likely be able to enter values for all of the independent variables. They will likely only enter information on square footage and building type (based on the zoning category assumptions discussed previously) and cooling or heating degree-days (based on the climate zone in which they are located). Therefore, we used assumptions to estimate standard values for the other factors, and based these assumptions on the 2009 RASS[xxxvi] except where noted. For dummy variables, we assumed a value of one if over 75% of housing units used a given fuel type for a given use (and a value of zero for the other fuel for the use in question). If fewer than 75% of housing units used a given fuel for a given use, we assigned a value of 0.5 for the dummy variables in question. Table 16 summarizes those assumptions:

Table 16: Assumptions for variables that are not inputs in the spreadsheet-based calculator

Variable name	Description	Assumed Value
NHSLDMEM	Number of occupants	3.2 (single-family) 2.7 (townhome) 2.7 (apt 2-4 units) 2.2 (apt 5+ units)
HHINCOME	Household income	$60,883[xxxvii]
CASTATE	Indicates whether a housing unit is located in California	1[xxxviii]
ELFOOD	Indicates whether a housing unit uses electricity for cooking	0 (single-family) 0.5 (apartments)
ELWARM	Indicates whether a housing unit uses electricity for space heating	0
ELCOOL	Indicates whether a housing unit uses electricity for air conditioning	1
ELWATER	Indicates whether a housing unit uses electricity for water heating	0
UGCOOK	Indicates whether a housing unit uses natural gas for cooking	1 (single-family) 0.5 (apartments)
UGWARM	Indicates whether a housing unit uses natural gas for space heating	1
UGWATER	Indicates whether a housing unit uses natural gas for water heating	1

Based on the equations and assumptions shown above, we created the equations for estimating energy use in each building type. Plugging the assumptions in Table 16 into the equations shown above enabled us to combine several of the variables in each equation into a single constant, leaving us with equations that have only two independent variables requiring input: TOTSQFT and either CD65 (in electricity equations) or HD65 (in natural gas equations). The coefficients for CD65 and HD65 remain unchanged between models for different building types, while the coefficient for TOTSQFT in a given building type is the sum of the coefficient for TOTSQFT and any interaction terms (e.g. APTSF or THSF) that apply to that building type. The final equations are shown below:

Table 17: Electricity usage equations

Single-family detached homes	$KWH = (0.0020 * TOTSQFT + 0.0047 * CD65 + 80.10)^2$
Townhomes	$KWH = (0.0052 * TOTSQFT + 0.0047 * CD65 + 58.88)^2$
Apartments 2-4 units	$KWH = (0.0020 * TOTSQFT + 0.0047 * CD65 + 60.52)^2$
Apartments 5+ units	$KWH = (0.0020 * TOTSQFT + 0.0047 * CD65 + 57.89)^2$

Table 18: Natural gas usage equations

Single-family detached homes	$CUFEETNG = (0.00042 * TOTSQFT + 0.0013 * HD65 + 19.88)^2$
Townhomes	$CUFEETNG = (0.00042 * TOTSQFT + 0.0013 * HD65 + 18.80)^2$
Apartments 2-4 units	$CUFEETNG = (0.00013 * TOTSQFT + 0.0013 * HD65 + 15.72)^2$
Apartments 5+ units	$CUFEETNG = (0.00013 * TOTSQFT + 0.0013 * HD65 + 15.44)^2$

In order to convert the results of these equations into estimated GHG emissions, we identified the GHG intensity factors of electricity for all utilities serving California residences (see Methods chapter). These findings are presented below in Table 19.

Table 19: GHG intensity factors in MT/MWh 2012-2035 for electric utilities serving CA residences
(sources: CPUC for pre-2020, see http://www.ethree.com/public_projects/cpuc2.php; SEEC CAPA Reference Tables for post-2020)

Utility	2008	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021-35
Pacific Gas & Electric Company	0.2438	0.2053	0.1956	0.1870	0.1774	0.1678	0.1582	0.1487	0.1391	0.1315	0.1315
Southern California Edison	0.3054	0.2734	0.2652	0.2582	0.2501	0.2419	0.2338	0.2257	0.2177	0.2118	0.2107
San Diego Gas & Electric	0.3273	0.2800	0.2682	0.2392	0.2278	0.2164	0.2051	0.1940	0.1829	0.1737	0.1735
Sacramento Municipal Utility District	0.2693	0.2332	0.2242	0.2159	0.2069	0.1980	0.1890	0.1800	0.1711	0.1633	0.1633
LA Department of Water & Power	0.5540	0.5056	0.4934	0.4817	0.4694	0.4571	0.4446	0.4321	0.4193	0.3210	0.3210
Anaheim Public Utilities	0.4695	0.4139	0.4023	0.3921	0.3806	0.3692	0.3579	0.3466	0.3353	0.3263	0.3263
Austin Energy	0.4695	0.4139	0.4023	0.3921	0.3806	0.3692	0.3579	0.3466	0.3353	0.3263	0.3263
City and County of San Francisco	0.4291	0.3860	0.3764	0.3600	0.3511	0.3425	0.3343	0.3263	0.3185	0.3140	0.3133
City of Palo Alto Public Utilities	0.4291	0.3860	0.3764	0.3600	0.3511	0.3425	0.3343	0.3263	0.3185	0.3140	0.3133
Glendale Water & Power	0.4695	0.4139	0.4023	0.3921	0.3806	0.3692	0.3579	0.3466	0.3353	0.3263	0.3240
Imperial Irrigation District	0.4695	0.4139	0.4023	0.3921	0.3806	0.3692	0.3579	0.3466	0.3353	0.3263	0.3263
Modesto Irrigation District	0.4291	0.3860	0.3764	0.3600	0.3511	0.3425	0.3343	0.3263	0.3185	0.3140	0.3140
PacifiCorp	0.4291	0.3860	0.3764	0.3600	0.3511	0.3425	0.3343	0.3263	0.3185	0.3140	0.3133
Pasadena Water & Power	0.4695	0.4139	0.4023	0.3921	0.3806	0.3692	0.3579	0.3466	0.3353	0.3263	0.3240
Platte River Power Authority	0.4695	0.4139	0.4023	0.3921	0.3806	0.3692	0.3579	0.3466	0.3353	0.3263	0.3263
Riverside Public Utilities	0.4695	0.4139	0.4023	0.3921	0.3806	0.3692	0.3579	0.3466	0.3353	0.3263	0.3240
Roseville Electric	0.4291	0.3860	0.3764	0.3600	0.3511	0.3425	0.3343	0.3263	0.3185	0.3140	0.2961
Salt River Project	0.4695	0.4139	0.4023	0.3921	0.3806	0.3692	0.3579	0.3466	0.3353	0.3263	0.3263
Seattle City Light	0.4291	0.3860	0.3764	0.3600	0.3511	0.3425	0.3343	0.3263	0.3185	0.3140	0.3140
Sierra Pacific Resources	0.4291	0.3860	0.3764	0.3600	0.3511	0.3425	0.3343	0.3263	0.3185	0.3140	0.3133
Turlock Irrigation District	0.4291	0.3860	0.3764	0.3600	0.3511	0.3425	0.3343	0.3263	0.3185	0.3140	0.2961

In addition, we used a GHG intensity figure of 0.0053 MT CO_2/therm for natural gas, based on guidance from U.S. EPA.[xxxix]

Features of the spreadsheet calculator

The final result of this stage of the project was the creation of the spreadsheet calculator itself in Microsoft Excel (see Appendix E, a digital file containing the spreadsheet calculator). The calculator was designed so that all of the input data entry and results displays would fit onto a single Excel worksheet entitled "CREC GHG CALCULATOR." Users can also view a worksheet entitled "BACKGROUND" that provides a brief description of the context and process of calculator development, and a worksheet entitled "DETAIL TABLE" that displays the results of the interim calculations used to generate the overall energy use and GHG emissions estimates, as well as the breakdown of the energy usage estimates into "Title 24" and "non-Title 24" sectors according to the typical proportions for each in existing California buildings. In addition, a series of worksheets containing look-up tables and other reference information necessary for the calculations were programmed but hidden from the view of users.

The GHG Calculator sheet guides users through a series of simple steps, as follows:

Step 1: General Information. Users are prompted to select their county, city, energy utility, and base year (i.e. the year beginning from which GHG emissions estimates are desired). With this information, the calculator automatically identifies which Title 24 climate zone the municipality is in, and the number of heating and cooling degree-days in that zone (which are needed as inputs to the statistical models). In addition, users are asked to decide whether to:

- assume that future energy use should be projected based solely on the recent past (i.e. the CREC statistical model) or (b) assume that future projections should attempt to anticipate future updates of Title 24, Part 6 (i.e. the CREC/CalEEMod blended model)
- assume that GHG emissions should be estimated using the average GHG intensity of a specific utility's electricity generation portfolio, or (b) assume that GHG emissions should be estimated using a statewide estimate of the GHG intensity of a typical California utility
- assume that the GHG intensity factor of electricity decreases over time as utilities meet the requirements of the state's Renewable Portfolio Standard by 2020, or (b) assume that the GHG intensity factor of electricity remains constant at the most recent observed level (drawn from the California Climate Action Registry).

Figure 3. Screenshot of CREC calculator Step 1 (hypothetical data)

STEP 1: GENERAL INFORMATION

Instructions: Select your county, city, utility, and desired base year using the arrow tabs that appear when you click on each GREEN cell. (If you are planning for an unincorporated area, select the nearest incorporated city.) Then use the drop-down bars in lines 30, 33 and 36 to select your desired residential energy use and GHG emission factor assumptions.

Note: Information in BLUE cells is generated automatically

COUNTY	Sacramento
CITY	Elk Grove
Title 24 Climate Zone	12
CalEEMod Climate Zone	6
Heating degree-days	2,702
Cooling degree-days	1,470
UTILITY	Sacramento Municipal Utility District
START YEAR	2013

(A) Project future residential energy use based on usage patterns of recent past

(A) Project future GHG emissions based on average GHG intensity of utility's electricity portfolio

(A) Assume that GHG intensity of electricity decreases as utilities meet the 2020 Renewable Portfolio Standard

Step 2: Plan Information – Scenario One. Users are prompted to enter the amount of housing anticipated in each of the eight land use types (which are non-overlapping density ranges) described in the methods chapter. They can use a pull-down menu to choose between dwelling units and acreage as the units for the quantity of growth in each land use type. In addition, users must choose between (a) using default assumptions within the calculator for the typical building type and median building square footage within each land use type, and (b) creating their own customized inputs for these based on past experience or reasonable expectations in their community.

Figure 4. Screenshot of CREC calculator Step 2 (hypothetical data)

STEP 2: PLAN INFORMATION -- SCENARIO ONE

Instructions: Select Acres or Dwelling Units as your planning unit by clicking on cell B37 then using the arrows that appear. In the same manner, use cells A38-A45 to identify your general land use categories. Enter the number of dwelling units or acres for each land use type in cells B38-B45, grouping all planned development within a given density range as part of the indicated land use type. Then use the drop down bar in line 48 to determine whether you are using default assumptions or user-defined assumptions about the typical size of housing units within each land use category. Information in BLUE cells is generated automatically if you select "use default" in the drop down bar; otherwise, fill out the user-defined assumptions in GREEN in columns E and F. In column E, click on each cell, then select an anticipated building type for each land use type using the arrows that appear. In column F, fill in the anticipated median square footage for that building type.

		Default Assumptions		User-defined assumptions	
Land use types	Dwelling units	Building type	Median bldg square footage	Building type	Median bldg square footage
Rural or Very Low Density (<2 DU/ac)	100	Single-family detached	1,729	(none)	
Low Density Suburban (2-5 DU/ac)	100	Single-family detached	1,948	(none)	
Mid Density Detached (5-8 DU/ac)	100	Single-family detached	2,145	(none)	
High Density Detached (8-15 DU/ac)	100	Single-family detached	1,601	(none)	
Townhomes (15-20 DU/ac)	100	Townhomes	1,559	(none)	
Low-Rise Apartments/Townhomes (20-40 DU/ac)	100	Apartments 2-4 units	942	(none)	
Mid-Rise Apartments (40-80 DU/ac)	100	Apartments 5+ units	861	(none)	
High-Rise Apartments (80+ DU/ac)	100	Apartments 5+ units	861	(none)	
Total	800				

(A) Use default assumptions for building type and square footage

Step 3: Mitigation Measures – Scenario One. Users are prompted to check boxes indicating whether any of the following conditions apply locally and to fill in the corresponding implementation intensity:

- Standards requiring energy efficiency to exceed Title 24 (and by what percentage)
- Standards requiring use of high-efficiency lighting (and what percentage of efficiency improvement is expected)
- Existence of on-site renewable energy generation capacity (expressed in kWh).

These three conditions were selected because they are action items frequently identified in local climate action plans that have a substantial impact on the residential energy use and GHG emissions expected from new growth. With these inputs, the calculator then calculates the electricity usage, natural gas usage, and GHG emissions reductions resulting from these mitigation measures.

Figure 5. Screenshot of CREC calculator Step 3

STEP 3: MITIGATION MEASURES -- SCENARIO ONE

Instructions: In Column A, check the GHG mitigation measures (if any) that you anticipate for this scenario. Then adjust the percentage or amount of each selected measure in Column B.

Note: Information in BLUE cells is generated automatically

Mitigation Measure	Implementation	Implementation variable units	Total base year electricity reduction (kWh)	Total base year natural gas reduction (therms)	Total base year GHG reductions (metric tons)	Total GHG emissions reductions through 2035 (metric tons)
☐ Require energy efficiency to exceed Title 24		Percent improvement over Title 24*	-	-	-	-
☐ Require high-efficiency lighting		Percent improvement in lighting efficiency	-	-	-	-
☐ Generate renewable energy on site		kWh renewable energy generated on site per year	-	-	-	-
Total			-	-	-	-

* For example, some municipalities have "reach codes" that mandate building energy efficiency as much as 30% beyond Title 24 standards

Summary Statistics – Scenario One. Using all of the inputs provided in Steps 1-3, the spreadsheet calculator then calculates for Scenario One the average annual electricity usage, the average annual natural gas usage, the base year GHG emissions, and the cumulative GHG emissions through 2035. These are each calculated as a total for the entire amount of growth, per dwelling unit, and per capita. Each of those is also calculated on both an unmitigated and a mitigated basis (i.e. with or without consideration of the Step 3 inputs).

Figure 6. Screenshot of CREC calculator Summary Statistics (hypothetical data)

SUMMARY STATISTICS -- SCENARIO ONE

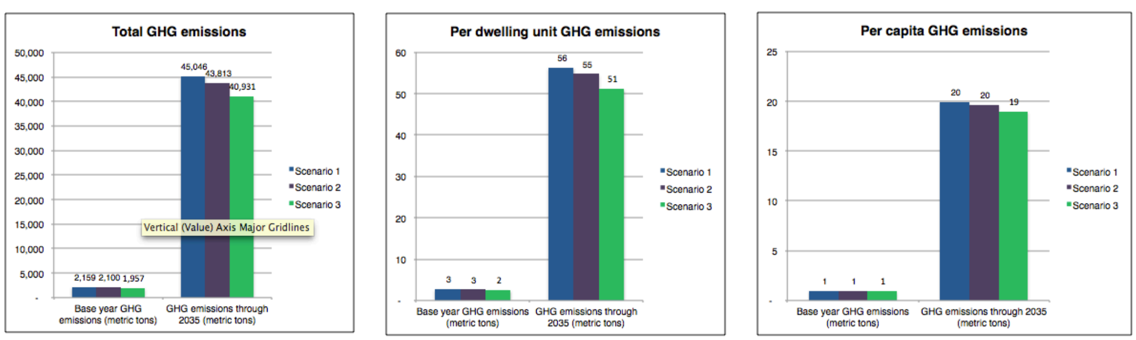
For details on how the values below are calculated, click on tab entitled "Detail Table" at bottom of screen

	UNMITIGATED ENERGY USE & GHG EMISSIONS			MITIGATED ENERGY USE & GHG EMISSIONS		
Indicator	Total	Per dwelling unit	Per capita	Total	Per DU	Per capita
Average annual electricity usage (kWh)	51,954	65	23	51,954	65	23
Average annual natural gas usage (therms)	4,045	5	2	4,045	5	2
Base year GHG emissions (metric tons)	2,159	3	1	2,159	3	1
GHG emissions through 2035 (metric tons)	45,046	56	20	45,046	56	20

Steps 4-7: Scenarios 2 and 3. These steps repeat Steps 2 and 3, and provide summary statistics, for Scenarios Two and Three. All three scenarios use the same locational information entered in Step 1.

Scenario Comparison. Finally, at the bottom of the worksheet, a table and three bar charts display the results of Scenarios One, Two and Three side by side. They display the mitigated energy use and GHG emissions only. The three bar charts display the GHG emissions on a total, per dwelling unit, and per capita basis, respectively, and for each of these show both the base year GHG emissions and the cumulative total through 2035. Thus, the calculator allows the user to discover the quantity of GHG emissions produced by the three land use scenarios, and by extension the amount of GHG emissions that can be avoided through more compact distribution of the same amount of housing units.

Figure 7. Screenshot of CREC calculator Scenario Comparison charts (hypothetical data)



The calculator was also graphically designed to make use as intuitive and flexible as possible, including limiting the width of the spreadsheet so that it displays correctly on a wide variety of computers. In addition, the spreadsheet uses green coloring to indicate cells requiring user input, and blue coloring to indicate cells providing output data generated by the calculator.

3. Evaluation of the spreadsheet calculator

Once the design of the spreadsheet calculator was complete, four methods were used to evaluate it:

- A preliminary validation of the standard (i.e. not blended) CREC electricity and natural gas statistical models using 2009 RASS data
- A field test of the calculator by the interviewees
- A validation of the calculator's standard model using recent historical data from the Sacramento Municipal Utility District (SMUD)
- A model comparison with CalEEMod, using both the standard and blended model options of the calculator

The results of each are presented below.

Preliminary validation of the statistical models

Table 20 and 21 show the results of our preliminary validation of the CREC statistical models, in which we compared the results of the statistical models to the electricity and natural gas consumption reported in the 2009 RASS dataset (see methods chapter for more detail).

Table 20: Preliminary model validation for single-family homes

Climate Zone	HD65	CD65	Average square footage	Actual KWH usage	Modeled KWH Usage	% diff.	# std. devs off	Actual NG usage (therms)	Modeled NG usage (therms)	% diff.	# std. devs off
1	4,496	-	2,058	5,388	7,089	32%	0.27	689	735	7%	0.10
2	2,844	456	2,157	7,349	7,485	2%	0.02	562	622	11%	0.12
3	2,909	128	2,364	7,473	7,294	-2%	-0.03	540	631	17%	0.19
4	2,335	574	2,357	7,827	7,650	-2%	-0.03	482	592	23%	0.23
5	2,844	456	2,078	6,197	7,458	20%	0.20	469	620	32%	0.31
6	1,458	727	2,653	8,749	7,880	-10%	-0.14	508	542	7%	0.07
7	1,256	984	2,365	7,342	7,991	9%	0.10	370	524	42%	0.32
8	1,430	1,201	2,318	8,725	8,156	-7%	-0.09	408	534	31%	0.26
9	1,154	1,537	2,528	10,381	8,518	-18%	-0.29	619	521	-16%	-0.20
10	1,678	1,456	2,205	8,916	8,331	-7%	-0.09	397	547	38%	0.31
11	2,688	1,904	2,165	9,271	8,701	-6%	-0.09	503	612	22%	0.23
12	2,702	1,470	2,248	9,176	8,358	-9%	-0.13	489	614	26%	0.26
13	2,702	1,470	1,968	9,824	8,257	-16%	-0.25	553	608	10%	0.12
14	1,581	4,239	1,961	8,328	10,765	29%	0.38	548	536	-2%	-0.02
15	1,106	6,565	2,465	13,070	13,362	2%	0.05	661	517	-22%	-0.30
16	4,313	1,037	2,140	6,695	7,955	19%	0.20	525	724	38%	0.41

Table 21: Preliminary model validation for apartments with 5+ units

Climate Zone	HD65	CD65	Average square footage	Actual KWH usage	Modeled KWH Usage	% diff.	# std. devs off	Actual NG usage (therms)	Modeled NG usage (therms)	% diff.	# std. devs off
1	4,496	-	758	2,110	3,528	67%	0.30	277	477	72%	0.64
2	2,844	456	1,019	3,847	3,849	0%	0.00	287	386	35%	0.02
3	2,909	128	1,156	3,529	3,695	5%	0.04	286	391	37%	0.02
4	2,335	574	1,013	3,691	3,916	6%	0.05	245	360	47%	0.02
5	2,844	456	1,375	1,838	3,937	114%	0.45	199	388	95%	0.04
6	1,458	727	1,173	3,372	4,046	20%	0.14	282	317	13%	0.01
7	1,256	984	1,092	2,930	4,179	43%	0.27	198	307	55%	0.02
8	1,430	1,201	1,040	3,986	4,297	8%	0.07	244	315	29%	0.02
9	1,154	1,537	1,152	4,273	4,535	6%	0.06	238	303	27%	0.01
10	1,678	1,456	1,036	4,615	4,453	-4%	-0.03	259	327	26%	0.01
11	2,688	1,904	858	5,087	4,688	-8%	-0.08	295	377	28%	0.02
12	2,702	1,470	823	3,595	4,406	23%	0.17	259	378	46%	0.03
13	2,702	1,470	830	3,763	4,408	17%	0.14	261	378	45%	0.02
14	1,581	4,239	825	3,423	6,285	84%	0.61	359	321	-10%	-0.01
15	1,106	6,565	1,300	5,559	8,292	49%	0.58	202	301	49%	0.02
16	4,313	1,037	962	3,102	4,178	35%	0.23	251	468	86%	0.05

These results show that models are relatively accurate, especially given the lack of accuracy in many industry-standard building energy use models and the standard deviations of the RASS data for electricity and natural gas usage. The models for electricity usage are more accurate than the natural gas models. Most modeled electricity usage falls within 15 percent or 0.2 standard deviations of actual results, while modeled natural gas usage typically fall within 35 percent or 0.3 standard deviations of actual results. There are very few large discrepancies (i.e. over 50 percent) between modeled and actual results. The model is less accurate for buildings with 5+ units; this could be because the sample size of these units in the RASS is smaller or because the research team had to use older RASS data for these units.

This is a preliminary test and should be taken with a grain of salt, particularly since the RASS results shown are based on a relatively small sample of housing units in many of the less populated climate zones. Still, the trend of CREC models overestimating energy use should be further examined.

Field test of the calculator by the interviewees

As noted, CREC researchers returned to the same set of planners and tool designers interviewed in the scoping phase of the project to conduct a field test of the preliminary version of the spreadsheet calculator. The questionnaire provided to professional planners to solicit their feedback is reproduced in Appendix D. We received ten completed questionnaires from the 25 planners and tool designers contacted for this field test, though not all questions were answered in all responses. Some respondents supplied supplemental comments in their email messages returning the questionnaires.

In general, the responses to the questionnaire are positive from the point of view of CREC's objectives for the calculator. Question 1 asks if the purpose and intended use of the calculator is immediately apparent to the user. Seven of the ten respondents answered yes. Additional comments included suggestions that "it might be a good idea to include additional language…that explains [the term] 'planned future growth'" and that "it is immediately apparent that you can use this tool for comparing different combinations of mitigation measures" but that "for many users it would not be apparent the power that this tool has for evaluating the difference between land use scenarios."

Question 2 asked if any specific instruction or aspect of the calculator is unclear. Among the text responses identifying an item, comments included that "it is unclear which guidelines this tool follows, and it would be necessary to tailor the methodology and approach to the Air District's guidelines," and that "use of the term 'base year" [was] somewhat confusing" and might better be referred to as an "implementation year" or a "development year." But when asked to rate the user-friendliness of the calculator on a ten-point scale in Question 3, six respondents gave it a "nine," three respondents gave it an "eight," and one respondent gave it a "five."

Question 4 asked whether the requested inputs to the calculator are readily available in a typical planning process, and nine of the ten respondents responded "yes." Seven of the nine respondents answering Question 5 indicated that the land use types in the calculator are appropriate "for planning processes you have worked on." Seven of the eight people providing a response to Question 6 indicated that they would be more likely to use user-defined assumptions for the typical housing unit size within each density class, not the default assumptions in the calculator.

Questions 7and 8 asked respondents to rate how useful the calculator is likely to be for various planning processes (Question 7) and various planning tasks (Question 8). These responses are summarized in Table 22 and 23, and are generally concentrated on the upper half of the ten-point scales. In general, respondents judged the calculator to be most useful for general planning and specific planning, as was intended in tool design. Among the specific tasks that a planner might undertake, the calculator was judged most useful for reporting to the state on GHG reduction efforts, formulating land use alternatives, completing or updating a local climate action plan, and preparing EIRs. Overall, most respondents indicated that they were likely to use the final version of the calculator (eight out of ten responses at five or higher on a ten-point scale).

Table 22. Responses to Question 7 "How useful is this tool for..."

Planning process	Average score (out of 10)	Total # of responses
General plan	6.5	8
Specific plan	6.8	9
Climate action plan	5.6	7
CEQA	5.8	6
Other AB 32 compliance	5.0	5

Table 23. Responses to Question 8 "How useful is this tool for the following tasks…"

Task	Average score (out of ten)	Total # of responses
Formulate land use alternatives	6.1	8
Decide between land use alternatives	5.4	9
Develop scenarios for use in modeling calculators such as RapidFire or iPLACE³S	4.0	5
Communicate land use alternatives to the public	5.1	9
Complete or update a local climate action plan	5.8	8
Report to the state on GHG reduction efforts	6.2	6
Prepare EIRs	5.8	5

Validation of the spreadsheet calculator using recent historical data from SMUD

As described in chapter 2 above, the validation process used four high-growth zip codes within the Sacramento Municipal Utility District (SMUD) service area to test the calculator's estimates of future electricity consumption against the actual consumption measured in SMUD billing records for those zip codes. These results are summarized in Table 24.

Table 24. Results of validation analysis using SMUD data for four high-growth zip codes

		Elk Grove		Sacramento	
		95624	**95758**	**95834**	**95835**
# DU	Rural or Very Low Density (<2 DU/ac)	6	647	1	7
	Low Density Suburban (2-5 DU/ac)	3979	789	0	0
	Mid Density Detached (5-8 DU/ac)	477	166	763	3449
	High Density Detached (8-15 DU/ac)	0	1	1828	4242
	Townhomes (15-20 DU/ac)	215	632	770	289
	Low-Rise Apartments/Townhomes (20-40 DU/ac)	0	462	1291	1611
	Mid-Rise Apartments (40-80 DU/ac)	0	0	0	450
	High-Rise Apartments (80+ DU/ac)	0	0	0	0
Median SF	Rural or Very Low Density (<2 DU/ac)	3473	2194	6326	2566
	Low Density Suburban (2-5 DU/ac)	2571	2494	N/A	N/A
	Mid Density Detached (5-8 DU/ac)	1942.5	2178	2758	2356
	High Density Detached (8-15 DU/ac)	N/A	1686	1842	1849
	Townhomes (15-20 DU/ac)	1344	1344	1562.5	1876
	Low-Rise Apartments/Townhomes (20-40 DU/ac)	N/A	942	1311	942
	Mid-Rise Apartments (40-80 DU/ac)	N/A	N/A	N/A	861
	High-Rise Apartments (80+ DU/ac)	N/A	N/A	N/A	N/A
Model Results	Default Model Predicted GHG/DU/year	8200	7092	7010	7524
	User-Defined Model Predicted GHG/DU/year	8307	6973	6860	7487
	Actual Observed GHG/DU/year	9819	6814	6205	7509
	% Difference (Default Model)	-16.5%	4.1%	13.0%	0.2%
	% Difference (User-Defined Model)	**-15.4%**	**2.3%**	**10.6%**	**-0.3%**

The error rates for calculator runs using the standard (i.e. non-blended) statistical model and the user-defined median building size vary within a range from -0.3% in the 95835 zip code in Sacramento and 2.3% in the 95758 zip code in Elk Grove on the low end, to 10.6% in the 95834 and -15.4% in the 95624 zip code in Elk Grove on the high end. In three of the four zip codes, the user-defined model run result is closer to the actual consumption amount than the default model run, as one would expect. (In the fourth case, the 95835 zip code in Sacramento, both results are extremely close to the actual consumption data). The error rates on the default version of the model are only marginally larger than the user-defined option.

Table 24 also shows that the zip codes vary in the composition of the housing stock developed in this ten-year period. A large majority of the housing developed in Elk Grove's 95624 is low-density suburban (2-5 dwelling units/acre), while the housing stock in the two Sacramento zip codes was more concentrated in the middle of the density classes (from five to 40 dwelling units per acre). Though firm conclusions are difficult to reach based on only four test cases, it appears that the model performs somewhat better for the denser zip codes than for lower-density development.

Model comparison with CalEEMod

The final method of evaluating the spreadsheet calculator was to compare the calculator's results with those of CalEEMod. As noted above, this is not a validation method, since CalEEMod is based upon modeled (not measured) data and assumes implementation of Title 24 updates that were not in force at the time that the residences used to develop the CREC statistical model were built. Both the original CREC statistical models, and the blended model option that incorporates CalEEMod assumptions for future Title-24, Part 6-related energy use, are tested Since CalEEMod contains only five housing types, the comparison is performed only for those types. The results of the comparison for the electricity and natural gas models, broken down by general consumption sectors, are shown in Tables 25 and 26.

Table 25. Electricity model comparison with CalEEMod

Land use subtype	Title-24 Electricity Energy Intensity kWhr/size/yr	Non-Title-24 Electricity Energy Intensity kWhr/size/yr	Lighting Energy Intensity kWhr/size/yr	Total Electricity Energy Intensity kWhr/size/yr
*CalEEMod **				
Single family housing	900	4,476	1,478	6,855
Condo/townhouse	321	2,943	1,016	4,280
Apartments Low-Rise	550	2,399	876	3,825
Apartments Mid-Rise	465	2,392	806	3,663
Apartments High-Rise	465	2,392	806	3,663
*CREC energy use model ***				
Single family housing	2,830	3,605	1,815	8,250
Condo/townhouse	1,874	2,386	1,202	5,462
Apartments Low-Rise	1,578	2,162	1,055	4,795
Apartments Mid-Rise	1,453	1,992	971	4,416
Apartments High-Rise	1,453	1,992	971	4,416
Percentage CREC over CalEEMod				
Single family housing	214.5%	-19.5%	22.8%	20.4%
Condo/townhouse	484.3%	-18.9%	18.3%	27.6%
Apartments Low-Rise	187.0%	-9.9%	20.4%	25.3%
Apartments Mid-Rise	212.6%	-16.7%	20.5%	20.6%
Apartments High-Rise	212.6%	-16.7%	20.5%	20.6%

* CalEEMod energy use assumptions for buildings built 2011 onwards, normalized to median size in CREC model
Sacramento County, CEC Climate Zone 6, Urban Setting, Operational Year 2012

** CREC model based on buildings built between 1990 and 2005
Elk Grove, Sacramento County, Title 24 Climate Zone 12, Base Year 2012

Table 26. Natural gas model comparison with CalEEMod

Land use subtype	Title-24 Natural Gas Energy Intensity KBTU/size/yr	Non-Title-24 Natural Gas Energy Intensity KBTU/size/yr	Total Natural Gas Energy Intensity KBTU/size/yr	Total Natural Gas Energy Intensity therms/size/yr
*CalEEMod **				
Single family housing	30,391	5,958	36,350	363
Condo/townhouse	15,280	3,381	18,661	187
Apartments Low-Rise	11,552	2,756	14,308	143
Apartments Mid-Rise	11,423	1,971	13,394	134
Apartments High-Rise	11,423	1,971	13,394	134
*CREC energy use model ***				
Single family housing	50,800	8,900	59,700	597
Condo/townhouse	45,800	8,000	53,800	538
Apartments Low-Rise	30,000	8,200	38,200	382
Apartments Mid-Rise	32,100	5,000	37,100	371
Apartments High-Rise	32,100	5,000	37,100	371
Percentage CREC over CalEEMod				
Single family housing	67.2%	49.4%	64.2%	64.2%
Condo/townhouse	199.7%	136.6%	188.3%	188.3%
Apartments Low-Rise	159.7%	197.5%	167.0%	167.0%
Apartments Mid-Rise	181.0%	153.7%	177.0%	177.0%
Apartments High-Rise	181.0%	153.7%	177.0%	177.0%

* CalEEMod energy use assumptions for buildings built 2011 onwards, normalized to median size in CREC model
Sacramento County, CEC Climate Zone 6, Urban Setting, Operational Year 2012

** CREC model based on buildings built between 1980 and 2005
Elk Grove, Sacramento County, Title 24 Climate Zone 12, Base Year 2012

The results show that the CREC model produces significantly higher results than CalEEMod, perhaps unsurprisingly given the respective analytical bases for the two models. On the electricity side, the discrepancies are very large for electricity use subject to Title 24 (as would be expected), but despite this are on the order of only 20-25% for total electricity consumption. For natural gas, the CREC model's estimates are up to 200% higher than those of CalEEMod for both Title-24 and Non-Title-24 usage sectors.

The results of the comparison of the blended electricity and natural gas models with CalEEMod are shown in Table 27 and 28.

Table 27. Blended electric model comparison with CalEEMod

Land use subtype	Title-24 Electricity Energy Intensity kWhr/size/yr	Non-Title-24 Electricity Energy Intensity kWhr/size/yr	Lighting Energy Intensity kWhr/size/yr	Total Electricity Energy Intensity kWhr/size/yr
*CalEEMod **				
Single family housing	900	4,476	1,478	6,855
Condo/townhouse	321	2,943	1,016	4,280
Apartments Low-Rise	550	2,399	876	3,825
Apartments Mid-Rise	465	2,392	806	3,663
Apartments High-Rise	465	2,392	806	3,663
*CREC blended model ***				
Single family housing	900	3,605	1,815	6,320
Condo/townhouse	321	2,386	1,202	3,909
Apartments Low-Rise	550	2,162	1,055	3,767
Apartments Mid-Rise	465	1,992	971	3,428
Apartments High-Rise	465	1,992	971	3,428
Percentage CREC blended over CalEEMod				
Single family housing	0.0%	-19.5%	22.8%	-7.8%
Condo/townhouse	0.0%	-18.9%	18.3%	-8.7%
Apartments Low-Rise	0.0%	-9.9%	20.4%	-1.5%
Apartments Mid-Rise	0.0%	-16.7%	20.5%	-6.4%
Apartments High-Rise	0.0%	-16.7%	20.5%	-6.4%

* CalEEMod energy use assumptions for buildings built 2011 onwards, normalized to median size in CREC model
Sacramento County, CEC Climate Zone 6, Urban Setting, Operational Year 2012

** CREC blended model uses CalEEMod projections for Title 24-related energy use
Elk Grove, Sacramento County, Title 24 Climate Zone 12, Base Year 2012

Table 28. Blended natural gas model comparison with CalEEMod

Land use subtype	Title-24 Natural Gas Energy Intensity KBTU/size/yr	Non-Title-24 Natural Gas Energy Intensity KBTU/size/yr	Total Natural Gas Energy Intensity KBTU/size/yr	Total Natural Gas Energy Intensity therms/size/yr
*CalEEMod **				
Single family housing	30,391	5,958	36,350	363
Condo/townhouse	15,280	3,381	18,661	187
Apartments Low-Rise	11,552	2,756	14,308	143
Apartments Mid-Rise	11,423	1,971	13,394	134
Apartments High-Rise	11,423	1,971	13,394	134
*CREC blended model ***				
Single family housing	30,391	8,900	39,291	393
Condo/townhouse	15,280	8,000	23,280	233
Apartments Low-Rise	11,552	8,200	19,752	198
Apartments Mid-Rise	11,423	5,000	16,423	164
Apartments High-Rise	11,423	5,000	16,423	164
Percentage CREC blended over CalEEMod				
Single family housing	0.0%	49.4%	8.1%	8.1%
Condo/townhouse	0.0%	136.6%	24.8%	24.8%
Apartments Low-Rise	0.0%	197.5%	38.0%	38.0%
Apartments Mid-Rise	0.0%	153.7%	22.6%	22.6%
Apartments High-Rise	0.0%	153.7%	22.6%	22.6%

* CalEEMod energy use assumptions for buildings built 2011 onwards, normalized to median size in CREC model
Sacramento County, CEC Climate Zone 6, Urban Setting, Operational Year 2012

** CREC blended model uses CalEEMod projections for Title 24-related energy use
Elk Grove, Sacramento County, Title 24 Climate Zone 12, Base Year 2012

Tables 27 and 28 show that the blended model approach substantially reduces the divergence between the calculator outputs and CalEEMod outputs. For the electricity model, in particular, the percentage difference between the two modeling alternatives is in the single digits for all five building types. Table 28 shows that the blended model approach diverges from CalEEMod's results by 8-38%, depending upon the building type. This divergence is dramatically lower than that of the non-blended CREC model, indicating that most of the divergence between CREC's model and CalEEMod is concentrated in the Title 24, Part 6-related energy use.

IV. DISCUSSION

The primary purpose of this project was to create a tool that provides professional planners in California with a statistically robust spreadsheet calculator useful for screening land use alternatives at the general-planning or climate-action-planning level. As noted, the land use alternatives available in these processes are coarse characterizations of broad land use patterns that specify little beyond the density and general classification of development (residential, commercial, etc) across entire neighborhoods or sub-sections of the city. For tools like CalEEMod, iPLACE³S and SEAT, this input information is not nearly specific enough.

To fill this gap successfully, the tool needed to be not only accurate, but also easily accessible and intuitive for working planners, requesting input information that is readily available in ordinary planning processes. It is worth recalling as well that many local governments in California have faced severe budgetary pressures in recent years, in some cases outsourcing many planning functions to consulting firms. For these municipalities with minimal staff resources, ease of use is more than a matter of convenience – it is probably a necessity if a tool is to be adopted.

The feedback obtained from local planners as part of the evaluation process indicates that this objective was largely achieved. The calculator scored highly on questions having to do with the design, intuitiveness, and required input information. Most comments from field testers indicated that they found the instructions clear, the design visually intuitive, and the input information requirements to be reasonable.

More generally, the calculator's design and functionality also respond to the needs identified by the interview subjects for a tool that:

- Uses density as the primary input variable (since that is the primary variable used in land use planning);
- Makes finer distinctions between density classes at lower densities than at higher densities;
- Includes default assumptions about what building types occur in different zoning categories, but also allows user-defined customization to fit particular local circumstances;
- Makes calculations transparent to the user;
- Allows simple comparisons based on limited data;
- Allows direct comparison of multiple scenarios.

Given these needs and the calculator's characteristics, there should be few barriers to incorporation of the calculator into local planning processes.

The portions of the calculator that could be directly validated against real-world energy consumption data (i.e. electricity usage for the Sacramento region) performed very well. The calculator achieved very low error rates in comparison to many other energy modeling exercises, including iPLACE³S, which was found to have error rates ranging from 13-38% for four neighborhoods in Sacramento[xl]. The two *worst* error rate among the four zip codes tested (95624 at -15.4%, and 95834 at 10.6%) would still compete well against the error rates achieved by iPLACE³S and many other energy models. In the two best of the zip codes tested, the calculator achieved near-perfect accuracy (-0.3% in 95835 and 2.3% in 95758).

Due to data limitations, it was not possible to validate the calculator in its entirety. Electricity data from outside the SMUD service area was not available, and attempts to obtain consumption data to validate the natural gas estimations were unsuccessful. There is reason to believe that the calculator's errors in natural gas estimation are considerably larger than in electricity. The preliminary validation of the calculator against the consumption data reported in the 2009 RASS dataset showed larger errors on average for natural gas than for electricity (13 of 16 climate zones had double-digit error rates for natural gas, while only 7 of 16 did for electricity). The comparison with CalEEMod likewise shows larger deviation between the two estimation methods for natural gas than for electricity.

One possible explanation for the larger divergence for natural gas is that data limitations forced the CREC calculator to draw from older housing in the RECS dataset for natural gas than for electricity. The research team based the electricity model upon residences in the RECS dataset built after 1990, while the natural gas model had to stretch back to residences built after 1980. Because building energy standards have improved over time in California due to periodic updates of Title 24, Part 6, these data limitations meant that more poorer-performing older residences were incorporated into the statistical model for natural gas than for the electricity model. This is likely leading to greater divergence from CalEEMod's expectations for future usage. (The CREC calculator and CalEEMod rely on the same basic information about the GHG intensity of utility's energy portfolios, but because of the way CalEEMod functions and presents results, it is not possible to directly compare their respective GHG estimations from residential energy use specifically.)

The model comparison with CalEEMod reveals important complexities involved in anticipating future consumption. As noted previously, the CREC calculator and CalEEMod use differing approaches to estimating future usage. The CREC calculator is based upon observations of *past* energy consumption, whereas CalEEMod relies heavily upon projections of the energy consumption likely to result from *future* Title 24 updates. For that reason, it is unsurprising that the model comparison yields wide divergences in energy estimation. CREC's calculator implicitly assumes that future development will perform similarly to past development, while CalEEMod implicitly assumes that future development will perform in accordance with future standards.

The truth is likely somewhere in between. While future Title 24 updates (and other regulatory measures implemented by local governments) will undoubtedly improve energy performance among new buildings, adherence to these future standards will not be perfect. Local governments are required to incorporate Title 24 standards into their local building codes, but do not always have robust plan-check functions to ensure compliance. In addition, actual building construction often diverges from what is indicated on plans and blueprints, often at a cost to energy efficiency. Unless there are diligent post-construction inspections, which do not occur in many municipalities, deviations from Title 24 standards in actual construction won't be noticed. For natural gas applications, in particular, construction practices often compromise the energy efficiency of new structures relative to the blueprints for those buildings that are reviewed for energy code compliance. Failure to seal windows and vents carefully, for instance, can lead to dramatic wastage of heating energy and therefore significantly higher natural gas consumption than would be anticipated based on an assumption of strict compliance with Title 24, Part 6. The effects of noncompliance of this sort, whether intentional or unintentional, would more likely be (roughly) captured in the CREC models that are based on actually observed usage than by the future projections of CalEEMod.

As a result, energy performance in new construction will typically lag somewhat behind building efficiency standards. A realistic projection of future usage will take this into account. Moreover, both the CREC model and CalEEMod include non-Title 24 energy usage, such as lighting and plug loads. While these too have typically improved in efficiency over time due to state standards, periodically the popularization of new devices (such as flat-screen TVs) will drive a temporary upward spike in these usage sectors. As with the Title 24 sectors, a model based on actual measurements of usage (as the CREC model is) may be reflective of these sorts of demand spikes more than one based on idealized future standards.

Because of these differences in modeling approach, the standard CREC model will generate higher estimates for future energy consumption than CalEEMod, and therefore might also implicitly suggest that larger absolute energy and GHG emissions savings are possible from compact growth (relative to low-density growth). But because the CREC calculator is meant as a screening tool to inform choices between alternatives, what matters most is that its findings are internally consistent and allow planners to make basic distinctions between the energy- and GHG-intensity of different land use alternatives. Once plans reach a degree of specificity where an environmental impact report or rigorous GHG accounting become necessary, the CREC calculator's findings can be supplemented through the use of other tools, including CalEEMod.

Given the foregoing, it is possible to view the CREC standard model as a "worst-case scenario" for potential future residential energy use and related GHG emissions, i.e. a scenario that implicitly assumes minimal compliance with expected future improvements in building energy codes, though the blended model will predict lower energy use and emissions. That sort of pessimism is not necessarily a drawback for a screening tool given the existence of tools to conduct more detailed project-level analysis. Moreover, the blended model offers users the alternative of splitting the difference between these two estimation approaches. By combining CalEEMod's expectations of Title 24, Part 6-related energy use with the CREC model's results for the remainder of residential energy use, it likely mitigates the possibilities for substantial error in projecting future energy use by reducing the largest sources of divergence between the two estimation approaches. This may be especially helpful in local climate action planning processes, where relatively accurate quantification of GHG emissions and avoided emissions is important. But because there is no single "right answer" to the question of how best to anticipate the future, it is important to allow users the flexibility to examine the results of alternative approaches, as the calculator does.

Interestingly, the blended CREC model actually produces lower estimates for total future residential electricity use than CalEEMod, driven by a substantially lower estimate of non-Title 24-related sectors. This could be resulting from an expectation on the part of CalEEMod's designers that plug loads may rise in the future relative to the recent past, given continued proliferation of flat-screen TVs, handheld computing devices, and other small electronics. CREC's standard and blended models both anticipate about 20% more electricity use in the lighting sector than CalEEMod. This could represent a failure to anticipate future lighting efficiency standards, but it also could be evidence that building occupants have historically used more lighting energy than energy planners have assumed and that this trend may continue into the future.

A major contribution of the CREC model is the connection between land use types, density ranges, and typical building sizes. This connection is what enables the CREC calculator to utilize the type of input data available in general planning and climate action planning, as opposed to the parcel-level input data required by other tools. The robustness of this connection is therefore important to the calculator's overall performance. The research team carefully assessed a wide range of land use classification systems, both from standard secondary sources and from California municipalities, and ultimately relied upon the Fresno metro area as the source of data upon which to establish the connection between density classes, building types, and median dwelling unit size.

Fresno was chosen because it is a large enough region to contain the full range of housing types under examination, and also contains enough recent construction to reflect likely future trends in housing type and size. Furthermore, it is located in the Central Valley, where the bulk of California's future growth is anticipated to occur. The research team therefore concluded that the Fresno region was a sufficiently representative sample of California development to warrant extrapolating conclusions from it to the rest of the state. Nonetheless, basing a statewide model on examination of a single region is bound to introduce error into modeling results. In particular, there is less very high density housing in the Fresno region than in some other parts of the state, and this could be introducing error into the modeling results for the highest density classes. These potential errors are mitigated, however, by the calculator's ability to accept user-defined parameters for median building size rather than the default assumptions drawn from the Fresno data. Judging by the results of the field test, planners seem inclined to exercise that capability instead of relying on the default settings in the calculator.

Finally, the CREC spreadsheet calculator also produces cumulative GHG emissions estimates out to 2035, a relatively long horizon that was selected to recognize the long-lasting nature of major land use decisions, but one that also introduces potential error into the estimates. It could be argued that projections should go even further into the future, given that housing created today is likely to stand for many decades, making land use decisions especially significant for both medium- and long-term emissions control efforts. Projection of GHG intensity factors for electricity beyond 2020 is difficult and fraught with potential error, however, because the 2020 sunset dates of the Renewable Portfolio Standard and AB 32 provide the last firm anchor point for estimation of these intensity factors. The GHG intensity factor estimates for electricity generation produced by SEEC are the only utility-specific, post-2020 GHG intensity factors known to the research team. Extrapolating these any further than 2035 would be little more than guesswork, and would also implicitly introduce additional error into the model by the inevitable failure to anticipate long-term technological evolution and other transformations in the energy, construction and consumer electronics industries. The 2035 horizon should therefore suffice to usefully inform general planning and climate action planning processes undertaken in the coming years.

V. SUMMARY AND CONCLUSIONS

The State of California, through AB 32 and E.O. S-3-05, has committed to reducing its greenhouse gas emissions to 1990 levels by 2020, and to 80 percent below 1990 levels by 2050. Attainment of these goals will require an intensive, economy-wide emissions control effort, which ARB has initiated with the AB 32 Scoping Plan and the creation of a cap-and-trade system.

Nonetheless, the authority to make necessary changes to achieve these far-reaching goals lies in many hands beyond only those of the State. In particular, local governments retain exclusive authority to make land use decisions that have far-reaching climate-related consequences. These decisions are outlined in municipal general plans and expressed in specific physical terms within zoning codes. Other documents, such as specific plans and climate action plans, can also be adopted into general plans and thereby take on the force of law.

Building energy use is the second-largest energy-related source of GHG emissions in California, behind only transportation. Despite this fact, there is no SB 375-like state policy structure devoted to addressing the link between land use decisions and emissions from residential buildings, which generate two-thirds of the building-related emissions. There are also few tools available to assist local governments in assessing the GHG consequences of different land use patterns at the critical general planning stage when basic land use alternatives are being considered. Valuable tools such as CalEEMod, iPLACE^{3}S, and the Subdivision Energy Analysis Tool (SEAT) were developed for later stages of the development process, when specific projects are being proposed and detailed information pertaining to the projects' characteristics is available. By that time, basic decisions about the location, density, and form of residential growth in the municipality have long since been made.

The spreadsheet calculator described in this report fills this analytical gap in the planning process. The CREC Greenhouse Gas Calculator for Residential Development allows municipal planners and their consultants to:

- Estimate the residential energy use and associated GHG emissions from any amount of future residential development;

- Select a base year (no earlier than 2012) that growth is anticipated to occur and choose to calculate cumulative GHG emissions out to 2035

- Create those estimates instantly by inputting the amount of development (expressed either as housing units or as acreage) anticipated within each of eight commonly used density classes, as well as the city, county, and utility service area within which the growth will occur;

- Decide whether to use the average GHG intensity factors for a specific utility's electricity portfolio or whether to use an assumption of the GHG intensity of a typical utility's marginal electricity (i.e. the last electricity generation source added or subtracted from a utility's portfolio when demand changes);

- Decide whether to rely solely upon the CREC statistical model of the recent past or to use a blended model that includes both CREC statistical modeling and projections of future use from CalEEMod that incorporate assumptions about future building energy codes (i.e. Title 24, Part 6);

- Decide whether to use GHG intensity factors based on a utility's current-day performance or ones based on the assumption that the utility in question will meet the Renewable Portfolio Standard by 2020;

- Use either default values or user-defined, locally appropriate estimates of the median size of housing units within each density class, at the user's discretion;

- Incorporate the effects, if any, of certain locally specific conditions that may exist: "reach codes" that go beyond Title 24 building energy efficiency standards; local lighting efficiency standards that exceed state standards, and anticipated presence of renewable generating capacity;

- Examine the interim calculations of electricity and natural gas use, including both Title-24 and non-Title-24 components, that produce the GHG estimates;

- Directly compare up to three growth scenarios within the same output display, and any number of scenarios through multiple output displays.

This calculator was constructed based on three main components of primary research:

- Interviewing 33 municipal planners and designers of related tools (including CalEEMod) to determine which variables local governments examine when creating land use elements of their general plans and climate action plans, and to gain insight into tool design;

- Documenting a relationship between land use categories (i.e. density classes) and building types, based on industry literature, review of prevailing patterns throughout the state, and detailed analysis of Fresno County's building stock and zoning classifications;

- Creating statistical models of electricity and natural gas usage based on the 2005 Residential Energy Consumption Survey (RECS);

These energy models were then combined with the best available information on the GHG intensity of energy from every utility servicing residential customers in the state from 2012 to 2035 in order to create both base year and cumulative emissions estimates.

The completed spreadsheet calculator was then subjected to four forms of performance evaluation:

- A preliminary validation of the statistical models using 2009 Residential Appliance Saturation Survey (RASS) data;
- A field test of the calculator, including a survey questionnaire distributed to 25 of the same planners and tool designers interviewed earlier in the project;

- A validation of the spreadsheet calculator using recent historical data from the Sacramento Municipal Utility District (SMUD);
- A model comparison with CalEEMod.

These evaluation methods show that the calculator does a good job of producing estimates that closely match recent historical data (particularly in the SMUD dataset), and is regarded as useful and accessible by the target audience of planners and consultants. When used to retroactively estimate the electricity use from growth occurring in four zip codes in the SMUD service region between 2000 and 2010, the calculator achieved error rates of -0.3%, 2.3%, 10.6% and -15.4%. Though no comparable dataset with which to conduct natural gas validation was available, it is apparent from the preliminary validation against RASS and the model comparison with CalEEMod that the error rates for the natural gas model are likely higher than those of the electricity model.

Comparison with CalEEMod also shows that the CREC statistical model's reliance on recent historical energy performance may lead to overestimation of future energy use (and therefore GHG emissions) due to continuing updates of Title 24 building energy standards. CalEEMod relies on assumptions about future compliance with updated Title 24 standards, which may or may not actually occur to the extent assumed. It is likely, therefore, that actual future energy use will lie somewhere in between the two models' estimates. A blended model option created to account for this divergence substantially reduces the divergence between the calculator's results and those of CalEEMod, especially for electricity use.

In that sense, the CREC standard model may be seen as offering a pessimistic view of future energy use and GHG emissions resulting from development compared to other estimation methods. But because the primary intent of the calculator is to screen alternatives at the general planning or climate action plan level, rather than produce project-level GHG emissions estimates for an environmental impact report (a primary purpose of CalEEMod), it is more important that the calculator be internally consistent in comparing various land use alternatives, that there be a defensible connection between land use types and building types, and that the calculator be user-friendly with few input data demands.

Available evidence suggests that the calculator is generally meeting these goals. As additional relevant datasets become available in the future, including the next edition of the RASS survey, additional regional housing and land use datasets to complement the Fresno data used here, and potentially a natural gas usage dataset for validation of the natural gas model, the calculator can be improved in its predictive accuracy and therefore in its range of applicability.

VI. RECOMMENDATIONS

The CREC calculator is designed to be easily modified and expanded as new data, capabilities and potential applications become apparent. The simple Excel-based spreadsheet structure is highly flexible; improvements in many cases may be as simple as reprogramming a single cel or adding a new worksheet of supporting calculations. CREC anticipates that the calculator can continue to grow and improve over time, both as a result of feedback from users, and as a result of CREC's continuing research into land use – energy – GHG relationships.

The following recommendations are therefore meant to identify ways to disseminate and improve the existing calculator, as well as chart a path toward a next-generation calculator with greater capabilities.

Use established outreach venues to disseminate the calculator to local land use planners. In addition to CREC's existing relationships with professional planners throughout the state, outreach venues such as the Governor's Office of Planning and Research's Local Government Roundtable, the Local Government Commission, and the California League of Cities should be used to publicize the availability of the calculator. In addition, CREC is a founding partner of the California Center for Sustainable Communities Research, which may provide a venue for distribution of the calculator.

Find a dataset with which to validate the natural gas portion of the calculator. CREC was unable to find a natural gas usage dataset that was sufficiently disaggregated and available within the timeframe needed for this initial calculator development project. If one of the natural gas utilities in California (Pacific Gas and Electric, San Diego Gas and Electric, Southern California Edison, the City of Palo Alto, and the City of Long Beach) change their policies regarding sharing of data for research purposes, CREC could perform needed validation of the natural gas usage model embedded in the calculator.

Update statistical model based on next RASS. CREC was unable to use the most recent RASS dataset to create the statistical models of energy usage due to critical errors in the multi-family building observations. Assuming the next RASS does not contain these errors, it would be possible for CREC to update the statistical models using RASS, which is significantly larger and more robust (for California residences) than the RECS dataset. The accuracy and explanatory power of the statistical models should improve accordingly.

Integrate into the Cool California Local Government Toolkit website. ARB has created the Cool California Local Government Toolkit to provide a range of decision support tools to local governments engaged in climate action planning, AB 32 compliance, and other GHG-reduction efforts. The toolkit includes the Cool California website, partly developed by colleagues at UC-Berkeley who have already indicated interest in incorporating the CREC calculator into the toolkit to expand its capabilities in modeling residential energy consumption.

Put in "smart defaults" related to household income and demographics. In the current version of the CREC calculator, users select the county and city in which they are working, and the calculator automatically calculates the heating and cooling degree-days associated with that location for incorporation into the statistical model of residential energy use. There are other variables pertinent to energy use that vary with geography, however, including household income and certain demographic characteristics (such as the average number of people living in households). Future versions of the calculator could incorporate these factors into the energy consumption modeling to enhance local accuracy.

Investigate the feasibility of creating a transportation module that would allow quicker screening of alternatives than CalEEMod. CREC researchers will consider expanding the calculator to include other major sources of energy use and GHG emissions that are related to local land use decisions. In particular, surface transportation is the largest single source of GHG emissions in the state. Though personal transportation choices are to a large extent a byproduct of regional land use patterns beyond the control of any single municipality, local land use alternatives nonetheless may carry significant GHG emissions consequences related to transportation. With significant additional research, it may be possible to expand the calculator to estimate transportation-related GHG impacts from alternative land use (i.e. density) configurations. As with the current calculator, this would be intended for use at the level of screening alternatives, not as a substitute for the more robust project-specific modeling that CalEEMod can perform. Preserving the simplicity and flexibility of the spreadsheet calculator, while defensibly modeling transportation impacts of land use decisions, would be a significant challenge, but also potentially very useful to local governments and state agencies concerned with reducing GHG emissions.

VII. REFERENCES

[i] California Air Resources Board (ARB). 2008. Climate Change Scoping Plan: A Framework for Change. December 2008. http://www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf, p. 26.
[ii] Governor's Office of Planning and Research. 2011. The Planner's Book of Lists. Sacramento, CA: OPR; Bedsworth, L.W. and E. Hanak. 2013. Climate policy at the local level: insights from California. Global Environmental Change 23: 664-677.
[iii] California Air Resources Board (ARB). 2008. Climate Change Scoping Plan: A Framework for Change. December 2008.
http://www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf, p. 27.
[iv] California Governor's Office of Planning and Research. 2010. 2003 General Plan Guidelines.
[v] Sacramento Area Council of Governments (SACOG). 2010. I-PLACE[3]S page.
http://www.sacog.org/services/I-PLACE3S/.
[vi] Vision California: Charting Our Future. http://www.visioncalifornia.org/.
[vii] Calthorpe Associates. 2010. Rapid Fire Model, Technical Summary, Model Version 1.5. June 17, 2010. www.visioncalifornia.org/Vision California - Charting Our Future - Rapid Fire Model Technical Summary.pdf.
[viii] Ewing, Reid, and Fang Rong. 2008. The Impact of U.S. Urban Form on Residential Energy Use. *Housing Policy Debate* 19(1): 1-30.
[ix] Ewing, Reid, and Arthur Nelson. 2008. CO_2 Reductions Attributable to Smart Growth in California. www.climateplanca.org/ewing_analysis.pdf.
[x] Norman, Jonathan, Heather L. MacLean, and Christopher A. Kennedy. 2006. Comparing High and Low Residential Density: Life-Cycle Analysis of Residential Energy Use and Greenhouse Gas Emissions. *Journal of Urban Planning and Development*, March 2006: pp. 10-21.
[xi] KEMA (2009), 2009 California Statewide Residential Appliance Saturation Survey Reporting Center, http://websafe.kemainc.com/rass2009/ (Accessed March 13, 2012).
[xii] KEMA (2010a), Chapter 5: Data Analysis Methodology, *2009 California Residential Appliance Saturation Survey*, *Volume 1—Methodology*, October 2010, available at
http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-V1.PDF (accessed March 14, 2012).
[xiii] Ibid.
[xiv] KEMA (2010b), *2009 California Residential Appliance Saturation Survey*, Executive Summary, October 2010, available at http://energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-ES.PDF (accessed March 14, 2012).
[xv] U.S. Census Bureau (2012), American Housing Survey Main Page,
http://www.census.gov/housing/ahs/ (Accessed March 15, 2012).
[xvi] U.S. Energy Information Agency (EIA) (2005), Residential Energy Consumption Survey, 2005 RECS Survey Data, http://205.254.135.7/consumption/residential/data/2005/ (Accessed March 9, 2012).
[xvii] Fulton, William and Paul Shigley (2005), *Guide to California Planning*, 3rd ed., Point Arena, CA: Solano Press Books, 2005: 133.
[xviii] American Planning Association (2006), *Planning and Urban Design Standards*, Hoboken, NJ: John Wiley and Sons, 2006: 185-193.
[xix] Duany, Andres, Sandy Sorlien, William Wright, et al (2008), *Smart Code Version 9 and Manual*. New Urban News Publications, 2008: SC53 and SC83.
[xx] Institute of Transportation Engineers (2008), *Trip Generation: An ITE Informational Report*, Volume 2 of 3, Washington, DC: Institute of Transportation Engineers, 2008.
[xxi] Nelson, Arthur C. (2004), *Planner's Estimating Guide: Protecting Land-Use and Facility Needs*, Washington, DC: Planners Process, American Planning Association, 2004: 21.
[xxii] Schmitz, Adrienne, et al. (2004), *Residential Development Handbook*, 3rd ed., Washington, DC: The Urban Land Institute, 2004: 99-104.
[xxiii] City of Fresno (2012), Geographic Information System (GIS) Downloadable Layers website, Zoning data, http://gis4u.fresno.gov/downloads/zoning.zip (accessed March 29, 2012).

[xxiv] City of Clovis (2012), Geographic Information System – Mapping Clovis website, Zoning data, http://www.ci.clovis.ca.us/SiteCollectionDocuments/EngineeringDivision/Zoning.zip (accessed March 29, 2012).
[xxv] Garcia, Anthony (2012), Staff Analyst, Fresno County, e-mail correspondence, March 19, 2012.
[xxvi] California Department of Conservation (2012), Farmland Mapping and Monitoring Program, Download GIS Data website, ftp://ftp.consrv.ca.gov/pub/dlrp/FMMP/ (accessed March 29, 2012).
[xxvii] EIA 2005.
[xxviii] KEMA 2009.
[xxix] For examples of approaches that are primarily consumption-based, see C.M. Jones and D. Kammen (2011), "Quantifying Carbon Footprint Reduction Opportunities for U.S. Households and Communities," *Environmental Science and Technology* 45 (2011): 4088-4095; and KEMA 2010a.
[xxx] National Energy Technology Laboratory (2009), *An Investigation into California's Residential Energy Consumption* (DOE/NETL-2009/1371), U.S. Department of Energy, July 29, 2009.
[xxxi] Energy + Environmental Economics (E3), Public Projects website, CPUC Projects and Proceedings, GHG Modeling, GHG calculator version 3c, October 2010, available at https://www.ethree.com/documents/GHG%20update/GHG%20Calculator%20version%203c_Oct2010.zip (accessed April 18, 2012)..
[xxxii] Statewide Energy Efficiency Collaborative (SEEC). CAPA Reference Tables – Renewable Portfolio Standard Adjustments for Future Year Emissions Factors.
[xxxiii] KEMA 2009.
[xxxiv] Pacific Gas and Electric Company (2006), Guide to California's Climate Zones and Bioclimatic Design, October 2006, available at http://www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/toolbox/arch/climate/california_climate_zones_01-16.pdf (accessed April 7, 2012).
[xxxv] http://www.city-data.com/forum/sacramento/1477371-sacramento-growth-trends-present-future.html
[xxxvi] KEMA 2009.
[xxxvii] U.S. Census Bureau (2011), 2006-2010 5-year Estimates, Table DP-03: Selected Economic Characteristics. Though the 2009 RASS does show some variance in average incomes among households in different building types, the local housing market will likely play a greater role in determining the income of occupants than building type. This contrasts with our treatment of other variables, notably occupancy, where we assumed that general differences in the spatial characteristics between building types do have an effect on occupancy.
[xxxviii] All records are assumed to be in California simply because the goal of this project is to examine energy use in California homes.
[xxxix] http://www.epa.gov/cleanenergy/energy-resources/refs.html
[xl] Alternative Energy Systems Consulting. 2010. iPLACE^{3}S Energy Module Validation Testing. CEC-500-2010-022. Sacramento, CA: California Energy Commission.

GLOSSARY

AB 32	Assembly Bill 32, the "Global Warming Solutions Act"
AHS	American Household Survey
APT	Dummy variable indicating whether a housing unit is an apartment (SFDETACH = 1 if TYPEHUQ = 4 or 5)
APTSF	Interaction term denoting APT*TOTSQFT
APT5	Dummy variable indicating whether a housing unit is an apartment in a building with 5+ units (SFDETACH = 1 if TYPEHUQ = 5)
APT5SF	Interaction term denoting APT5*TOTSQFT
APT24	Dummy variable indicating whether a housing unit is an apartment in a building with 2-4 units (SFDETACH = 1 if TYPEHUQ = 4)
APT24SF	Interaction term denoting TOWNSF*TOTSQFT
AQMDs	Air Quality Management Districts
ARB	California Air Resources Board
BEDROOMS	Variable indicating number of bedrooms in the housing unit
CACD65	Interaction term denoting CASTATE*CD65
CACP	Clean Air Climate Protection software
CAHD65	Interaction term denoting CASTATE*HD65
CalEEMod	California Emissions Estimator Model
CAP	Climate Action Plan
CAPCOA	California Air Pollution Control Officers Association
CAPPA	Climate and Air Pollution Planning Model
CASF	Interaction term denoting CASTATE*TOTSQFT
CASTATE	Dummy variable indicating whether a housing unit is located in California (CASTATE = 1 if LRGSTATE = 2)
CD65	Variable indicating number of cooling degree-days (base temperature of 65º F)
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CEUS	Commercial End-Use Survey
CPUC	California Public Utilities Commission
CREC	Center for Resource Efficient Communities (UC-Berkeley)
CUFEETNG	Variable indicating total annual natural gas usage in 100s of cubic feet
DOE	U.S. Department of Energy
DOEID	Variable indicating DOE-assigned ID number
DU	Dwelling unit
DU/ac	Dwelling unit per acre
EIR	Environmental impact report
ELFOOD	Variable indicating whether a housing unit uses electricity for cooking
ELWARM	Variable indicating whether a housing unit uses electricity for space heating
ELCOOL	Variable indicating whether a housing unit uses electricity for air conditioning
ELWATER	Variable indicating whether a housing unit uses electricity for water heating
E.O. S-3-05	Executive Order S-3-05 establishing an official state goal of reducing GHG emissions to 80% below 1990 levels by 2050
FMMP	Farmland Mapping and Monitoring Program

GHG	Greenhouse gases
GIS	Geographic information systems
HD65	Variable indicating number of heating degree-days (base temperature of 65º F)
HHINCOME	Variable indicating household income
ICLEI	International Council on Local Environmental Initiatives
iPLACE³S	Internet Planning for Community Energy, Economic and Environmental Sustainability
IRM	Integrated Resource Management tool (developed by Arup)
KBTU	Thousands of British thermal units
KWH	Kilowatt-hours
LGOP	Local Government Operations Protocol (created by ICLEI)
LRGSTATE	Variable indicating whether a home is located in one of the four largest states, and if so, identifies the state
NG	Natural gas
NHSLDMEM	Variable indicating number of people that live in a household
POST80	Dummy variable indicating whether a housing unit was built in 1980 or later (POST80 = 1 if YEARMADE >= 6)
POST90	Dummy variable indicating whether a housing unit was built in 1990 or later (POST80 = 1 if YEARMADE >= 8)
POST95	Dummy variable indicating whether a housing unit was built in 1995 or later (POST80 = 1 if YEARMADE >= 9)
POST00	Dummy variable indicating whether a housing unit was built in 2000 or later (POST80 = 1 if YEARMADE >= 10)
RASS	Residential Appliance Saturation Survey
RECS	Residential Energy Consumption Survey
RPS	Renewable Portfolio Standard
SB 375	Senate Bill 375 (requires partial integration of transportation and land use planning to achieve GHG reduction targets from transportation system)
SCAG	Southern California Association of Governments
SCAQMD	South Coast Air Quality Management District
SEAT	Subdivision Energy Analysis Tool
SEEC	Statewide Energy Efficiency Collaborative
SFDETACH	Dummy variable indicating whether a housing unit is a single-family detached housing unit (SFDETACH = 1 if TYPEHUQ = 2)
SFTOWN	Dummy variable Indicating whether a housing unit is a single-family attached housing unit (SFDETACH = 1 if TYPEHUQ = 3)
SMUD	Sacramento Municipal Utility District
Std devs	Standard deviations
Title 24	Shorthand for Title 24, Part 6, which establishes statewide building energy efficiency standards, primarily pertaining to space heating and cooling (lighting, plug loads and certain other energy uses are not covered)
TOD	Transit-oriented development
TOTSQFT	Variable indicating total square footage of the housing unit
TYPEHUQ	Variable indicating building type
UEC	Unit energy consumption
UGCOOK	Variable indicating whether a housing unit uses natural gas for cooking
UGWARM	Variable indicating whether a housing unit uses electricity for space heating
UGWATER	Variable indicating whether a housing unit uses electricity for water heating
URBEMIS	Urban Emissions model (the predecessor to CalEEMod)
YEARMADE	Variable indicating ranges for when the housing unit was built