Using Scenario Analysis to Forecast Long-Term Residential Electric Energy Consumption in California

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ABSTRACT

This paper presents results from a long-term forecast of electricity consumption in California's residential sector to the year 2050. The model developed for our projections builds upon the California Energy Commission's (CEC) forecast results and historic input data for the period 1970 to 2015. These data are expanded upon using other sources including long-term demographic forecasts, short-term bottom up energy-efficiency potential studies, econometric forecasts, and interviews with technologists on long-term emerging technology prospects. The focus of our work is on the interaction among key drivers of future electricity use, which includes population, energy efficiency, and end use service demands. We use scenario analysis to address the major uncertainties associated with our long-term forecasting horizon.

Our results show that even if energy efficiency improvements continue to provide significant reductions in electricity consumption through 2050, aggregate consumption also continues to increase due to increasing population and energy service demands. Under one extremely aggressive and optimistic scenario, residential electricity consumption is reduced by 2050 to today's level; however, this scenario requires reducing per capita consumption by almost 40 percent, which would be an unprecedented accomplishment, given historic efficiency achievements. Continuation of existing efficiency programs and standards, along with new, more much more aggressive policies, and a change in consumer adoption behavior would likely be necessary to achieve these reductions.

Introduction

The objectives of the study summarized in this paper are to develop long-term estimates of electric energy-efficiency potential for California's residential sector, as well as a methodological and modeling framework that can be expanded to address the state's other buildings sectors and fuels. This work was carried out for the California Energy Commission's (CEC) Public Interest Energy Research (PIER) program and is part of a larger effort addressing economic analyses of climate change impacts and greenhouse gas (GHG) mitigation led by the University of California at Berkeley. In designing this study we sought to address several questions:

- What methods would be most appropriate for long-term forecasting of residential electricity consumption?
- What factors explain historic trends in residential electricity use in California?
- What are the major drivers that will contribute to long-term residential electric energy consumption in California?
- What are realistic expectations for the role of electric energy-efficiency improvements in reducing long-term residential electricity consumption in California through the year 2050?

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- What types of broad policy initiatives would be required to accomplish alternative levels of residential electric energy reduction?

Methodology and Modeling Considerations

Prediction is very difficult, especially about the future.
Niels Bohr

There is no foolproof methodology for looking far into the future. In preparation for this study, we considered a variety of approaches ranging from top-down econometric to fully bottom-up, technology adoption modeling approaches. Ultimately, we rejected deterministic approaches and developed instead a hybrid approach that relies on a combination of trend analysis (of both consumption as well as technology characteristics and holdings), regression techniques, structured expert opinion, end use and sub-sector segmentation, scenario development, and scenario simulation. This approach adapts well to the challenges presented by the limited availability of electric decomposition data, associated consistencies among the data that do exist, and immutable uncertainties about the future (e.g., that past trends, though critical and informative to long-term forecasting, can not, in the end, provide a reliable roadmap for the future).

We set out as our tasks to analyze the major factors that contributed to changes in California's residential electric energy consumptions from 1970 to the present, to model the relationship among these factors and overall consumption, to forecast end points for each of the contributing factors, and, lastly, to estimate total usage under a set of alternative futures. At each stage of data development and for each component of the analysis, we assessed the validity of the historic and exogenous forecast data, calibrated our short-term models to known values that were available, and examined the results in the context of long-term trends to ensure their plausibility.

A Bottom-Up, End-Use Level Analysis

The approaches we used for this study are drawn from both retrospective energy decomposition methods (see, for example, Schipper, et al., 2003) and prospective technology adoption models (Rufo 2003, Rufo and Coito 2002, Rogers 2003). However, in a departure from fully bottom-up technology adoption approaches, which model adoption decisions about individual technologies and practices, our model operates at the end-use level.

Technology-rich bottom-up analyses typically assume a prototypical base case technology and apply prototypical efficient technologies to these base case technologies as alternative decisions faced by end users. However, the base and energy efficient technology characteristics are usually static. The results of these analyses often provide a snapshot of technical and economic potential at a given point in time. In some studies, customer adoption is also explicitly modeled. In practice, this method can be very powerful for forecasting adoption in the short term (under 5 years) and reasonable for forecasting within a 10-year time frame. However, the validity and accuracy of this approach diminishes quickly the longer the forecasting horizon since, by definition, decision making and usage are tied to a discrete set of technology specific characteristics known well in advance of the forecast year of interest.

Energy researchers and technologists have a strong understanding of the engineering and economic characteristics of technologies that are available to end users today, as well as of some of the technologies that are likely to be available in the next five to ten years. However, it is also clear that energy researchers and technologists have a limited ability to predict specific technologies and associated characteristics further out into the future (i.e., more than ten years). Note, however, that this is not the same as saying that researchers are equally limited at higher-level forecasting of efficiency gains over the longer term. Past projections of overall sectoral and end-use efficiency improvements have been able to capture longer-term efficiency gains at a more aggregate level. Of course, if trends are forecasted at too aggregate a level, important information can be lost on physical or other intuitively compelling characteristics that directly affect long-term opportunities and constraints. Thus, rather than forecast at a level we believe is too deterministic and difficult to defend (the technology level), or a level that is too divorced from physical and lifestyle factors (aggregate household usage), we elected to conduct our analysis at a decomposed end use level in which end use consumption is modeled as a function of demand for energy services (e.g., lumens) and the efficiency of the energy service delivered.

Basic Modeling Equation

The primary equation we used to forecast electricity consumption in any given year is defined as follows:

Total Annual California Residential Electric Consumption $= REC_y = \Sigma\, E_{esy,}$ where:

E_{esy} = Annual End Use Consumption = $UEC_{esy} * SAT_{esy} * HH_{sy}$

E_{esy} = total energy consumption for end-use (e) in market segment (s) in year (y)
UEC_{esy} = unit energy consumption for end-use (e) in market segment (s) in year (y)
SAT_{ys} = saturation for end-use (e) in market segment (s) in year (y)
HH_{ys} = number of households in market segment (s) in year (y)

Unit energy consumption is further disaggregated into the following relationship:

$UEC_{esy} = UEC_{es2006} * EffAdj_{esy} * UseAdj_{esy}$ where:

UECes2006 = unit energy consumption for end-use (e) in market segment (s) in year (2006)

$EffAdj_{esy}$ = efficiency adjustment = efficiency level in year (y)/efficiency level in 2006

$UseAdj_{esy}$ = usage adjustment = energy service demand in year (y)/energy service demand in 2006

Our model uses data from the CEC's end use forecasting model for all the above factors, except energy service demand and efficiency levels, for the period 1970 through 2004. It also uses the CEC's forecasts for all the above factors for the period 2005 through 2016. Our project analysis team then developed endpoint values for each of the factors for the year 2050. Different endpoint values were developed for different scenarios as discussed further below. These end point values were developed through interviews with technology experts, a literature review, and our team members' best judgment. The model then uses linear interpolation to calculate the factors from 2017 through 2049. The endpoint values and equations also take into consideration changes in efficiency and service levels associated with stock turnover.

Note that in this analysis we assume that there will be no significant amount of fuel switching. Most households in California that were capable of switching away from electricity to natural gas, for the purposes of heating, water heating and cooking, made those change prior to 1990. Almost all households that currently use electricity for those heating end-uses do not have a practical or cost effective alternative. Fuel switching will be explicitly addressed in a future phase of this work.

Forecasting Technology Change within Existing Paradigms

Technology change can occur over time in many ways. However, it is useful to consider two broad classes of technology change. The first type of change is through a continuation and improvement of the characteristics of an existing, known technology. Most efficiency improvements over the past twenty-five years fall within this category (e.g., improvements in air conditioner SEER levels). The second type of technology change requires a shift from a known technology to an entirely new technology (e.g., if LED lighting were to replace fluorescent and incandescent lighting in mainstream applications). This second type of technology change can be thought of as a paradigm shift and is, by definition, extremely difficult if not impossible to predict. While technology experts can make fairly good predictions about efficiency potentials within known technologies using engineering principles, it is nearly impossible to accurately predict technology paradigm shifts and their effects on energy use. For this reason, the efficiency potentials and associated scenarios used in this study are primarily limited to existing technology paradigms.

Key Data Inputs

CEC end use forecasting data. After a thorough review of all available data sources, we determined that, for the purpose of this study, the best data available was the CEC's end-use forecasting data. These data are the most comprehensive, complete and consistent California specific data available. Although there have been changes in raw input sources and collection methods over time and changes in forecasting unit calculations methods, all told, these data present a reasonable picture of residential energy consumption at the end-use level from 1970 to the present. These data have been reconciled to actual electric energy consumption on a periodic basis and have been the used by the State of California in their planning and forecasting processes. Furthermore, the CEC data has been used, scrutinized and vetted to a greater degree than any other known data set that could be used for this study.

The data used in this analysis was provided by the CEC in September 2005 (CEC 2005a and 2005b). The last year for which the forecast data was reconciled to actual load data was 2004. All data presented for the years between 1970 and 2004 are historic. Data presented for the years 2005 through 2016 are primarily CEC forecast data. Data presented for the years 2017 through 2050 are forecasts by the authors of this study.

Market segmentation. We segmented the market into single-family and multi-family households. For end-uses that are particularly climate sensitive, including heating and cooling, we further segmented into the CEC's 16 forecasting climate zones.

Population and housing considerations. Energy consumption calculations at the end-use level are based on the number of households that have each end use. While CEC data contains household estimates for the years 1970 through 2016, there are no readily available estimates of the number of households by housing segment out to the year 2050. The best proxy data available are total population forecasts. Our analysis considered two sources of projected population estimates for the year 2050. The first source is the California Department of Finance, which provides county level population forecasts by decade through 2050 (CADOF 2006). The second source is a study of baseline projections for California's urban footprint through 2100 (Landis 2003). The latter study provides forecasts of population for the years 2000, 2020, 2050 and 2100 for each county. The two studies project different total population estimates for California in the year 2050, as well as different population regional distribution patterns. California's population grew at an average annual rate of 1.7 percent between the years 1970 and 2000. Landis 2003 projects an average annual rate of 1.3 percent between the years 2000 and 2050, while the DOF forecast is slightly lower at 1 percent per year annual growth rate. The results presented in this paper are based on the DOF population forecast.

Global Assumptions

Energy consumption is strongly correlated to economic activity, however, our task in this study is not to predict a future economy, whether robust or in decline, but rather to isolate the potential impacts of improvements in energy efficiency in reducing future electricity consumption for the purpose of supporting the state's research on green house gas emissions and mitigation strategies. To this end we developed several alternative future scenarios to explore how changes in key electricity drivers could affect residential electricity consumption over the next 45 years. We used the following guiding assumptions for our modeling and scenario development:

- We assume a stable economy with no major economic collapse.
- Reductions in UECs are assumed to result from improvements in technology efficiency rather than decreases in desired energy service levels. People will continue to have home lighting, appliances, and indoor air temperatures, at least on par with what they have today, as well as increasing utilization of technologies for information, communication, and entertainment.
- People in 2050 will be essentially the same as people today. People will continue to act more or less in their own self-interest, as they perceive it today. The balance between long-term self-interest and short-term self-interest will be continue to be reflected in implicit consumer discount rates that are similar to those observed today.
- California will have a mix of socio-economic classes similar to those that are present today in an approximately the similar distributions as today.
- Innovation and subsequent product development will be similar in scale and scope to today, yielding increasing utilization of electricity-consuming products and advancements efficiency.

Scenario Definitions

Scenarios were developed to assess the influence of population, end-use saturation increases, land use and housing development changes, and efficiency increases, on future electricity consumption. Two major scenarios were developed to assess the potential effect of efficiency improvements and their corresponding policy implications. In addition, a Frozen Efficiency Forecast was also developed to provide a comparison benchmark for the other forecasts.

Frozen efficiency forecast. This scenario is included to provide a benchmark under which we assume that there will be no further improvements in efficiency levels on the margin (that is, efficiency levels are generally frozen at the marginal UECs in the CEC's end use forecast). Reductions in some average UECs still occur over time due to the natural turnover of technologies and housing stock, which result in homes moving from the average UEC to the marginal UEC. Utilization increases resulting from increased demand for energy services are also included in this scenario, which increases some UECs, as described further below.

Optimistic Efficient Technology scenario. The Optimistic Efficient Technology (OET) scenario assumes the penetration of energy-efficient technologies that are at the edge of cost-effectiveness today but become widely adopted by 2050. It assumes that the cost of energy will grow in real terms over time but within a magnitude and rate that can be absorbed by the economy without a major disruption or restructuring of the California lifestyle relative to the cycles and within the variance that has been experienced over the past 50 years.

Green Dream scenario. The Green Dream (GD) scenario assumes the adoption of the most energy efficient technologies expected to be available over the forecast period - within existing technology paradigms. Technologies adopted in this scenario are not necessarily expected to be cost effective based on today's perspective. The Green Dream scenario purposefully pushes the envelope of what could be expected from efficiency improvements and associated policies absent significant technological and socio-economic paradigm shifts.

Observations from Retrospective Analysis

In preparation for developing our scenario forecasts, we conducted extensive analysis of the CEC's data on California's electric end use holdings and UECs for the period 1970 to 2004. In addition, some electricity-driving factors such as population were analyzed for longer periods using other sources. In the course of this analysis we observed the following historic trends:

- Aggregate end-use consumption has continually increased. For many end-uses, this aggregate growth has been driven by the combination of population growth and increasing end-use saturation levels. Major electric saturation growth areas included central air conditioning, clothes dryers and dishwashers (CEC 2005).
- Adoption of an increasing array of electronic products contributed strongly to increases in household electricity consumption (Calwell 2005).
- New home sizes increased at the rate of 25 square feet per year for single-family dwellings (NAHB 2005) and 5 square feet per year for multi-family (USDOS 2006).

- There is recent evidence that energy service demands for illumination continue to increase (RLW 2005 and Siminovich 2005).
- A significant portion of California's maintenance of fairly constant per capita electric energy consumption was the result of fuel switching away from electricity to natural gas, in particular, away from electric space and water heating (CEC 2005 and Sharp 2006).
- Major efficiency improvements have been achieved in many but not all end-uses. End-uses associated with major efficiency improvements over the past 25 years include refrigeration and space conditioning; those with more negligible improvements include clothes dryers, clothes washer motors, and furnace fans. Several end uses are now in transition to higher efficiency levels such as hot water associated with clothes and dish washing and lighting (CEC 2005).
- The existing literature on the effect of price on end-use efficiency improvements is inadequate. Existing long-term electricity elasticity values tend to be driven by fuel substitution impacts and are confounded by the temporal correlation between price increases and policy interventions for the period during and following the energy crises of the 1970s. We know of no residential elasticity studies that can provide reliable end-use values for California exclusive of fuel substitution effects. Over the long term, it appears that consumers do not permanently change their usage of many major electric appliances due to increases in electricity prices.
- Instead, there is stronger evidence that most of California's significant increases in end-use efficiency levels were driven by the combination of state and federal appliance and building standards and energy efficiency programs (Bernstein, et al., 2000). In a few cases, notably electronics, efficiency improvements have occurred as a byproduct of other product performance objectives, for example, the need to reduce heat which would otherwise shorten product live (Calwell 2005).
- Within the range of historic price fluctuations, the cost of energy alone may have done little to accelerate efficiency development for many residential end uses.

Efficiency Improvement and Service Demand Factors

Our forecasts of end use UECs for 2050 account for changes in both technology efficiency and energy service demand. The relative changes in these factors are shown in Table 1. We developed the changes in energy service levels by analyzing historic trends and making relatively conservative estimates about how they may increase in the future. Changes in efficiency levels are based on analysis of existing data on energy efficiency improvement opportunities as well as interviews with technology experts whom we asked to forecast optimistic and best-case efficiency levels by 2050 (again, while remaining within existing technology paradigms). We discuss below some of the end use specific considerations for these target values.

Space Conditioning

In this study we assume that people in 2050 will operate their heating and cooling systems in ways similar to today. We assume that people will keep their living spaces within similar temperature ranges. We have not, as yet, included any impact that climate change might have on heating and cooling loads. Electric energy use for space conditioning is influenced by an increase in home size. New homes are forecast to be larger than existing homes and many existing home will have additions built that will increase their size. However, note that the rate of increase in home size we assume is far less than what has been observed for the past 50 years; we assume that the trend toward larger homes will plateau over the next 50 years. We assume that the average single-family household in 2050 will require only 5 percent more space conditioning over present consumption due to increased house size. Efficiency improvements affecting central air conditioning are assumed to reach over 50 percent under the OET scenario and up to 70 percent under the GD scenario. The former level represents close to the upper limit for refrigerant-based cooling and the latter assumes alternative technologies like indirect-direct evaporative and passive cooling achieve almost complete market penetration (Bourne 2006). For electric space heating, of which there is very little in California, efficiency improvements are assumed to be about a 25 percent under the OET scenario and almost 50 percent under the GD scenario.

Lighting

Over the past several decades, Californians' have desired increasing levels of illumination in their homes. Based on the trends of both increasing levels of illumination and increasing home size, we forecast the utilization of lighting to increase through 2050 by 10 percent for single-family and 5 percent for multi-family households relative to present lighting levels. Efficiency increases are assumed to reach roughly 25 percent in the OET scenario and about two-thirds in the GD scenario. The former would require about a third of all residential lighting needs to be meet by CFLs or other more efficient lighting technologies, while the latter would require almost complete penetration of CFLs or a more radical alternative such as LED lighting. There is also some possibility for efficiency improvements in incandescent lighting, which would have the advantage of generating savings without the quality of service reduction still associated with CFLs and LED (Siminovitch 2006).

Table 1. Assumed Relative Changes in Energy Service and Efficiency Levels for Residential Electric End Uses from 2004 to 2050 by Scenario and Dwelling Type

	Energy Service Change		Efficiency Change Optimistic Eff. Tech		Efficiency Change Green Dream	
End Use	Single	Multi	Single	Multi	Single	Multi
Water Heating	102%	100%	90%	90%	48%	47%
Dishwasher	106%	100%	102%	97%	75%	70%
Water Heating - Dishwasher	108%	107%	103%	101%	54%	53%
Clothes Washer	105%	100%	108%	102%	113%	107%
Water Heating - Clothes Washer	108%	107%	86%	85%	38%	37%
Clothes Dryer	106%	94%	70%	63%	50%	45%
Miscellaneous	150%	160%	138%	149%	123%	132%
Cooking	106%	100%	101%	96%	81%	77%
Refrigerator	110%	105%	63%	61%	45%	43%
Freezer	100%	100%	57%	59%	41%	42%
Swimming Pool Pump	99%	100%	82%	87%	73%	78%
Lighting	110%	105%	73%	72%	33%	31%
Space Heating	105%	101%	73%	74%	56%	57%
Furnace Fan	105%	101%	100%	96%	84%	81%
Central Air Conditioning	105%	101%	46%	40%	31%	27%
Room AC	105%	101%	87%	85%	68%	66%

Refrigeration

Refrigerators have grown significantly in size and energy consuming features over the past 25 years. Over the same time period, efficiency has also increased significantly, with the net result being substantial reductions in consumption per unit. We assume that the average single-family refrigerator service demand will be 5 to 10 percent greater in 2050 due to increases in size and features. Efficiency increases are assumed to be roughly 40 percent in OET and approximately 55 percent in GD.

Miscellaneous

According to the CEC (CEC 2005a), the miscellaneous end use has grown rapidly and far more than any other end use over the past 25 years. While most other UECs have declined over this period, the miscellaneous UEC has grown significantly. The CEC forecasts this historic rate of growth to continue to 2016. For 2017 through 2050, we used a growth rate for miscellaneous usage that is half the average historic and CEC's forecast growth rate. In decreasing the rate of growth in the miscellaneous usage from its historic average we assume that the new products will continue to be introduced and adopted, but that these products will start to displace older energy consuming items rather than present completely new loads. For example, over the past ten years products like home computers, cell phones, printers, faxes, set-top boxes, and other electronic devices have added significant new incremental loads to residential homes. However, there is some indication that these devices may be consolidated in the future into fewer products that also displace older pieces of equipment (e.g., the traditional home stereo). On the other hand, other factors could just as easily cause a continuation of the historic rate of growth in this end use.[2]

Other End Uses

Most of the other end uses were derived from a linear extrapolation of the CEC's 2016 forecast of these UECs. The estimates are conservative because they disregard any embedded efficiency improvements and simple take the UEC growth as total usage gain.

Scenario Results

In Table 2 and Figure 1 we present the aggregate summary results for our scenario analyses. Under the Frozen Efficiency benchmark forecast, electricity consumption increases from roughly 83 TWh today to nearly 140 TWh by 2050. Most of this increase is driven by California's growing population and per household growth in the miscellaneous end use. Continued increases in electric saturation of traditional end uses are forecasted to level off and account for only 3 percent of the increase in consumption. Note that the rate of growth under Frozen Efficiency is less than what occurred from 1970 to 2005. This is because efficiency levels are frozen on the margin at levels tied to the latest California and federal standards, which require efficiencies significantly above current stock averages.

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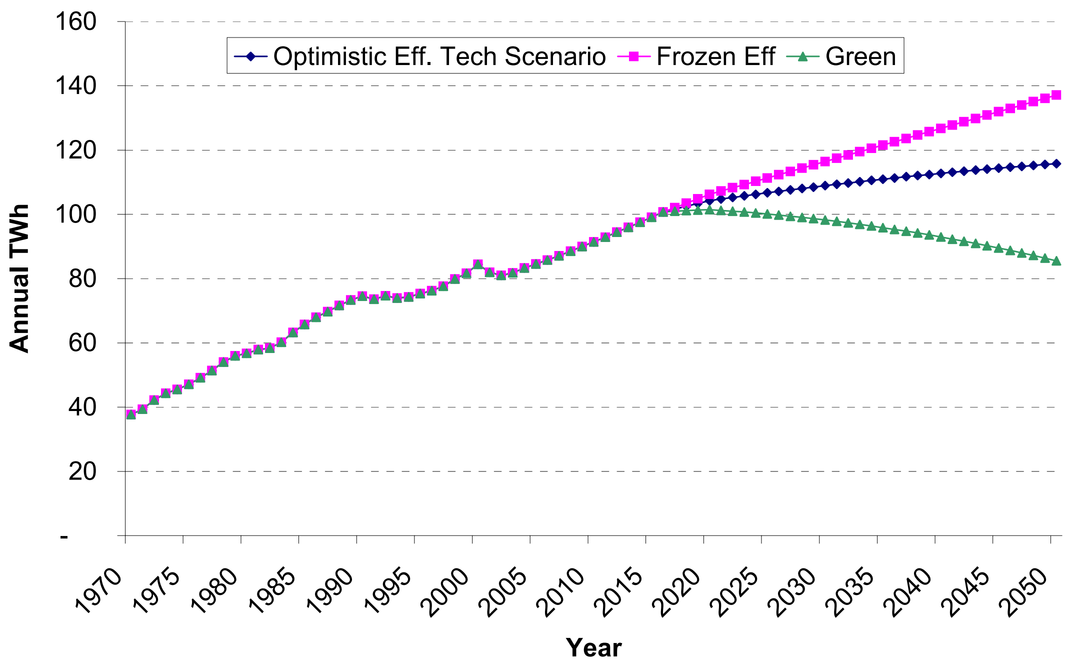
[2] For example, consumers' desire for greater convenience shows no sign of ebbing and may be increased by the demands of an aging population that may give rise to a proliferation of yet more plug-in products such as exercise equipment, home and health monitoring equipment, electric ice pads, climate controlled cabinets for special purposes, new home atmosphere altering technologies, and personal transport vehicles.

Table 2. Aggregate, Per Household, and Per Capita Forecasts of Residential Electricity Consumption in California

Forecast Scenarios	GWh	KWh per Household	KWh Per Capita
2050 Frozen Efficiency	137,129	7,530	2,503
2050 Optimistic Eff. Tech	115,752	6,356	2,113
2050 Green Dream	85,539	4,697	1,562

Historic Values	GWh	KWh per Household	KWh Per Capita
Consumption in 1990	74,528	7,232	2,499
Consumption in 2004	83,265	6,983	2,276

Figure 1. Forecasts of California Residential Electricity Consumption to 2050



Under the Optimistic Efficient Technology (OET) scenario, consumption is forecasted to increase to 116 TWh, or roughly 16 percent less than under the frozen efficiency benchmark scenario. Consumption under the Green Dream scenario is forecasted to decline, after a rise from 2005 to 2016, to 85 TWh, or 37 percent less than under frozen efficiency. Much of the savings in both of these scenarios are associated with improvements in the refrigeration, central air conditioning, and lighting end uses. Considering the significant improvements in the first two end uses over the past 25 years, our forecasts of continued improvements should be considered aggressive, especially in the case of Green Dream. Other end uses such as water heating, electric space heating, clothes drying, and ventilation systems contribute less to overall reductions in consumption because they have either smaller relative savings potential or are end uses with low electric saturation. Despite aggressive efficiency potential assumptions in the Green Dream scenario, population increases and growing miscellaneous consumption keep aggregate consumption from dropping below current levels.

Implications

The primary objectives of this project were to develop a method to analyze energy consumption under different alternative futures for California and to develop initial estimates of possible electricity consumption levels for the residential sector by 2050. An effective modeling framework has been developed with transparent assumptions that can be easily modified to test the effects of alternative assumptions on population, housing density, energy service levels, and end-use efficiency potentials. Implications associated with our initial scenario results are discussed below.

Frozen Efficiency

Although the rate of growth in consumption slows under this scenario as compared to the period 1970 to 2005, this is likely due to our assumptions that the rate of growth increases in home size and the miscellaneous end use will decrease somewhat. If growth in home size and the miscellaneous end use do not slow, new policy interventions may be needed simply to keep consumption from exceeding those in this forecast.

Optimistic Efficient Technology

Under this scenario, California would need to pursue energy-efficiency policies at least consistent with, and likely more aggressive than, those presently in place. There will need to be periodic updates to energy efficiency standards, increased and improved enforcement of those standards, and continued support for public goods and utility-procurement funded efficiency programs. Significant continued improvements in efficiency levels will be needed for key end uses as well as increased motivation among consumers to adopt high-efficiency products. Given consumers high implicit discount rates, the low consumption levels many residential end uses are already at, and current electricity prices, the increased adoption levels associated with this scenario would likely require increases in real electricity prices or a greater shift toward decision making based on socio-environmental rather than individual well being.

Green Dream Implications

Under this scenario, California would almost certainly be required to pursue polices that give preference to energy efficiency over other issues. Appliance and home building standards would need to be extremely stringent, continuously increased, and rigorously enforced. It is likely that a significant carbon tax, higher electricity price, or equivalent indirect incentives would be needed to both radically increase consumer adoption of extremely efficient technologies and motivate the increased R&D necessary to develop and commercialize them. Policies might also be needed to promote greater density and smaller homes, construction methods that employ passive cooling and shading, appliance size or feature constraints, virtual elimination of secondary refrigerators, increased daylighting, the elimination of standard efficiency incandescent light bulbs, and deployment of effective lighting controls. While the efficiency advances included in this scenario are plausible within existing technology paradigms, they push toward the upper end of what many technologists believe is possible in this time frame.

In summary, our results show that even if energy efficiency improvements continue to provide significant reductions in electricity consumption through 2050, aggregate consumption also continues to increase due to increasing population and energy service demands. Under the Green Dream scenario, residential electricity consumption is reduced by 2050 to today's level; however, this scenario requires reducing per capita consumption by almost 40 percent, which would be an unprecedented accomplishment, given historic efficiency achievements. Continuation of existing efficiency programs and standards, along with new, more much more aggressive policies, and a change in consumer adoption behavior, would likely be necessary to achieve these reductions.

Next Steps

The modeling framework developed in this study for the residential electricity sector will be expanded to address the commercial and industrial sectors, as well as natural gas. When completed, the results from this forecasting process will be integrated into a long-term general equilibrium model of the California economy being developed by UC Berkeley for the CEC. That model will be used to assess the effects of alternative approaches to reducing GHG emissions in California.

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