A Comparison of Per Capita Electricity Consumption in the United States and California

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ABSTRACT

With the growing importance of CO_2 emission reduction as an immediate public policy goal in the United States, demand-side management activities as well as generation, storage and transmission technologies need to be explored to determine the most economic and socially beneficial methods to reduce emissions. Numerous studies have looked toward energy efficiency and building standards in California as an example of the potential for energy savings throughout the United States. While California had the second highest retail sales of electricity in the U.S. in 2006, the per-capita consumption was the lowest in the nation.[1] This paper provides insight into California's electricity use by examining the underlying factors influencing statewide electricity consumption using publicly available data.[2] The intent is to provide an initial framework upon which more detailed comparisons can be made with the goal of better information for future policy decisions.

Electricity Use Trends

The National Energy Policy of 2001 called for a report from the Department of Energy on state-level energy intensity patterns throughout the U.S. in order to identify opportunities for energy efficiency improvement. This report looks at total source energy intensity changes in the residential, commercial, industrial, and transportation sectors from 1977 through 1999.[3] Bernstein et al conclude that while California shows the largest decrease in per capita residential energy consumption from 1979 to 1999, explanatory factors such as climate, demographics, and particularly high energy prices accounted for some of this decline. California also ranks within the top eight states in reduction of commercial energy intensity from 1988 to 1999. Here, the top ranking states were mostly in the West and Midwest – implying a potential difference in land use planning and growth constraints.[4]

Our paper limits the scope of study to the electricity sector but extends the period of study to 2005. The analysis is separated by sector – residential, commercial and industrial. Table 1 provides data on per capita electricity use by sector in 2005.

Total consumption per capita in California was 5,312 kWh/person or 43% less than that of the United States in 2005. On a sector-by-sector basis, industrial and residential differences

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[1] http://www.eia.doe.gov/fuelelectric.html

[2] Data are compiled primarily from the Energy Information Administration's State Energy Consumption, Price and Expenditure Estimates (SEDS) and EIA Form 906 and Re provided in Appendix A

[3] The report is Bernstein et al (2003). Here source energy refers to the amount of energy used to produce and transport the end-use energy product (electricity, natural gas, propane, etc.)

[4] Bernstein et al, pg 43

each account for about 40% of the difference while commercial consumption makes up the other 20%.

Table 1. Per Capital Electricity Use by Sector: 2005[5]

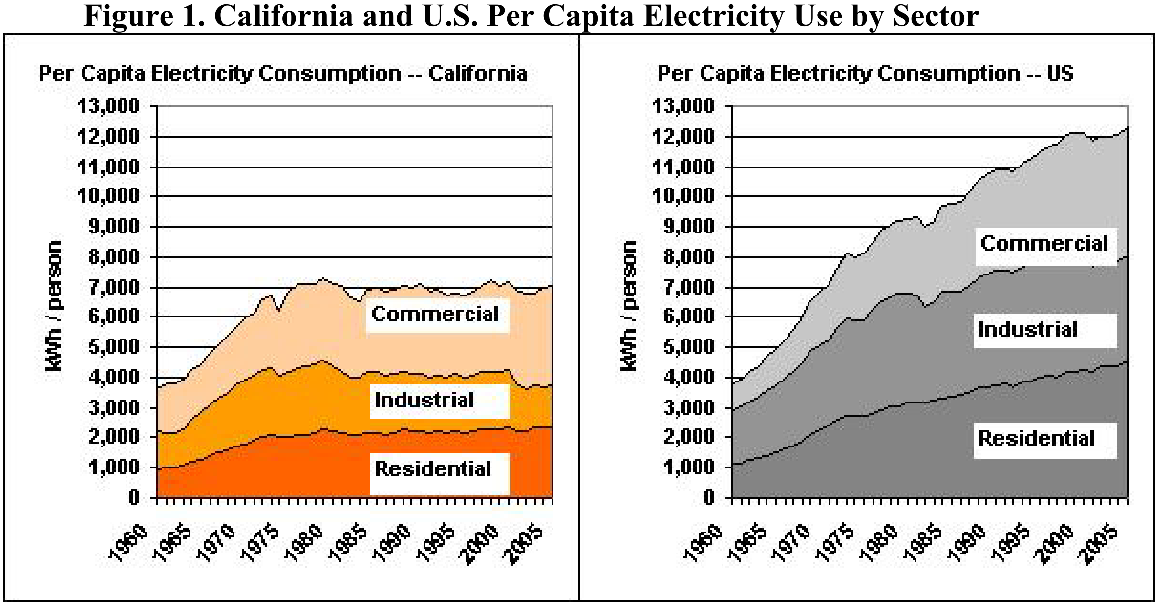
US and Cal compared in 2005 Per Capita Electricity Consumption

	United States (kWh/person)	California (kWh/person)	Difference (kWh/person)	% of Difference
Residential	4,586	2,369	2,216	42%
Commercial	4,302	3,253	1,048	20%
Industrial	3,438	1,391	2,048	39%
Total	**12,326**	**7,013**	**5,312**	**100%**

While per capita consumption provides an indication of energy attributed to the population in the state, it is often instructive to look at the efficiency with which energy is consumed. Energy efficiency, sometimes referred to energy productivity, is defined as the ratio of output or activity to energy use. It is the inverse of energy intensity (EI). [6] In the commercial and industrial sectors, EI is often measured as energy use per unit of GDP. Alternately in the commercial sector, EI is sometimes measured as energy use per total floor space. The residential sector poses a problem in that energy use cannot be directly translated into products and services. Energy use per unit of floor space could be used as a metric for the output of habitation. However, detailed statistics of average square footage of residences are not readily available for many locations in the U.S. This paper considers electricity use per capita as a surrogate measure of energy intensity in the residential sector.

A comparison of these three sectors is first made using EIA time series data from 1960 through 2005. Figure 1 shows the electricity consumption per capita in California and in the U.S in the residential, commercial and industrial sectors.

Figure 1. California and U.S. Per Capita Electricity Use by Sector

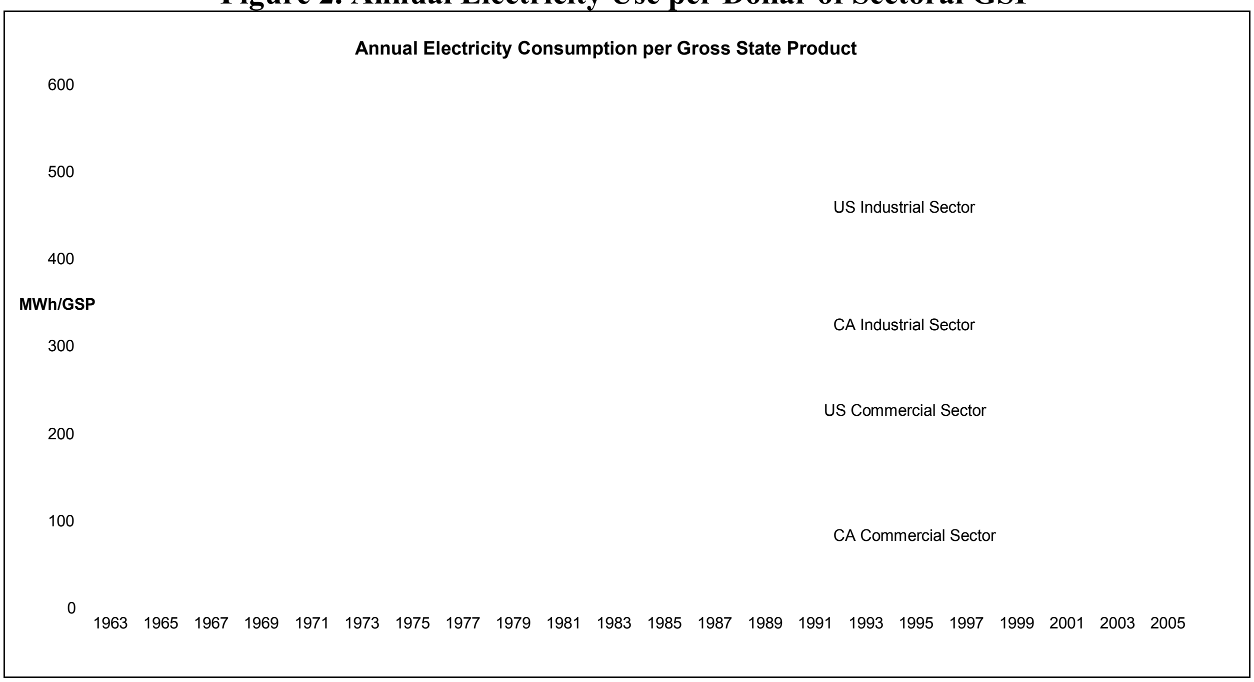


[5] In this paper, self generation of electricity for on-site consumption has not been considered.
[6] Shipper and McMahon 1995.

Residential electricity consumption in California has remained almost flat since 1973 (up 14% in this thirty year period), while US consumption has increased by 60% over the same time period. The differences in this sector account for 42% of the difference in total per capita electricity consumption between the US and California.

The industrial sector accounts for 39% of the difference in the total per capita consumption. California has seen a substantial decline in electricity use per capita from its industrial sector: between 1973 and 2005, a reduction of 39% has occurred. More than half of this reduction has occurred since 1999. On the other hand, US industrial consumption of electricity is up 6% since 1973. However, the US also experienced significant declines in this sector since 1999. Some of the decline in California consumption is due to the very expensive electricity prices experienced in the western US wholesale markets in 2000 and 2001. Both the US and California show a clear trend of declining industrial use. In 1960, industrial use accounted for nearly 50% of US electricity sales and 35% of California's. More recent data show US industrial consumption at less than 30% of electricity sales and California's near 20%. While California's electricity use in the industrial sector is less than that of the US, the trend in the industrial gross domestic products of California and the US has remained similar - although California sees more volatility in industrial GDP.[7] California is less energy intensive in the industrial sector than the US as a whole and this difference contributes 39% to the gap in per capita electricity use. In this paper, we will not attempt to explore why California industry is less energy intensive than that of the US.

Figure 2. Annual Electricity Use per Dollar of Sectoral GSP



[7] Industrial Gross Domestic Product for California and the US are calculated using the following SIC/NAICS categories: Agriculture and Fish, Mining, Construction, Manufacturing. *Source:* BEA, *Regional Accounts Data,* "Gross State Product" (n.d.)

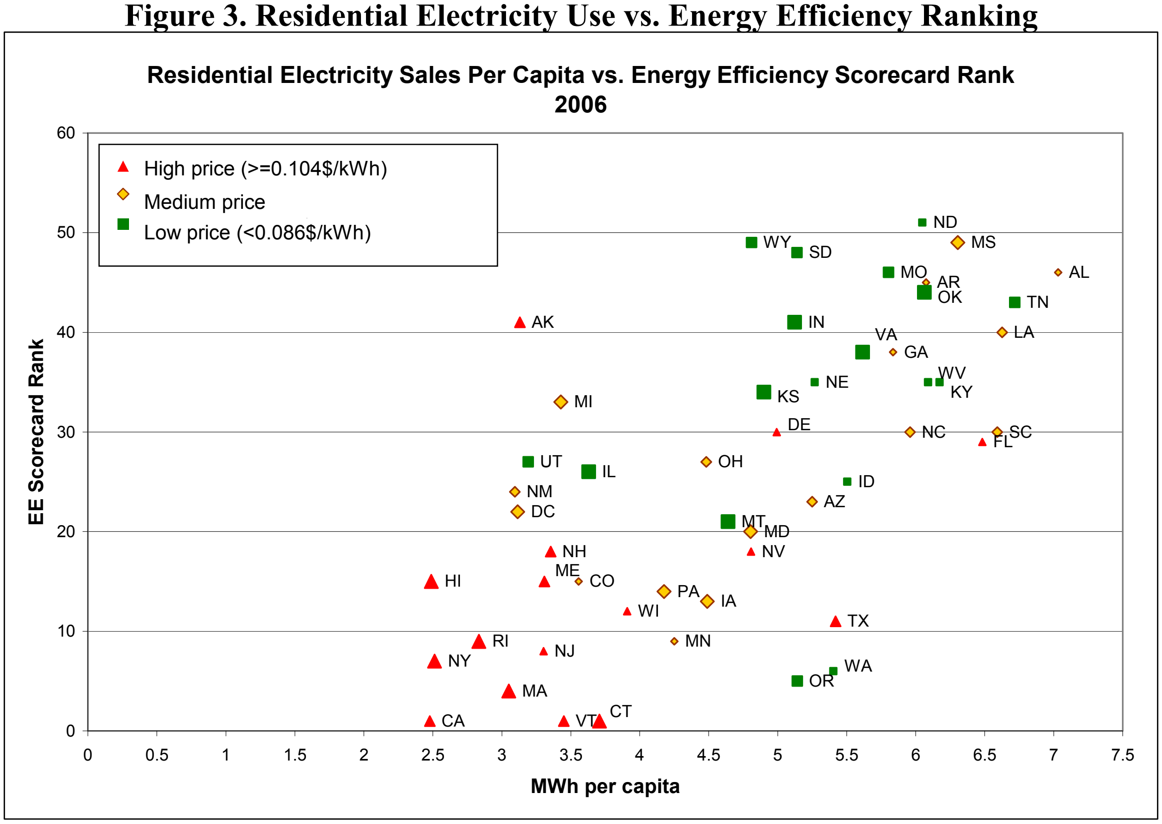
In the commercial sector, the US growth rate on a per capita basis has averaged 3.6% per year from 1960 thru 2005 while California's growth rate has been about one-half of that of the US. Focusing on the change since 1973, the US's consumption has about doubled while California's is up by a bit more than one-third. Differences in this sector account for 20% of the total differences between the US and California, as indicated in Table 1.

As can be seen in Figure 1, the total California per capita electricity consumption in all three sectors has remained relatively flat – growing by 9% since 1973 while the total US consumption increased 52% over this same time period.

That said, the energy intensity of the commercial and industrial sectors is better measured by the electricity consumption per dollar of gross domestic product in that sector.[8] Figure 2 shows these energy intensities in the commercial and industrial sectors.

Since 1985, both industrial and commercial energy intensity are lower in California than in the United States as a whole. In 2006, California was around 15% lower in the industrial sector and around 34% lower in the commercial sector.

Figure 3. Residential Electricity Use vs. Energy Efficiency Ranking



8 Industrial GDP is comprised of Agriculture and Fish, Mining, Construction and Manufacturing SIC/NAICS categories. Commercial GDP is comprised of Wholesale Trade, Retail Trade, Finance, Insurance, and Real Estate (F.I.R.E.), Services and Government SIC/NAICS categories.

Residential Model

In Figure 3, the ACEEE's 2006 energy efficiency (EE) rank of each state is plotted against its residential MWh per capita consumption, while dot shapes and colors indicate energy price terciles (averaged across all 3 sectors)[9]. Energy use clearly increases as the state EE ranking becomes larger, indicating less energy efficiency activity and investments. While the general cluster of high, medium and low electricity price states follows a logical progression from low, medium to high energy use respectively, there is some mixing of states that follow the trajectory of their respective EE ranking.

How much of the correspondence between EE practices and lower electricity use is due to those practices, and how much is due to other factors? How much of California's low per capita electricity usage is due to EE? We now turn to our regression analysis to try to understand other factors that may influence electricity use. In our analysis, energy efficiency is not included as an independent variable. Thus, residuals can be partially attributed to EE activities in the state.

Choice of Regression Variables

The selection of variables in the residential regression model was informed by previous studies and data availabilty. Sudarshan uses the 2003 EIA Residential Energy Consumption Survey (RECS) data to compare the electricity consumption in California with the U.S.[10] In this study, heating and cooling load, electric water heating, household income and size, and urban-rural distributions accounted for a reduction of more than 2000 kWh/person/year from the U.S. average. A portion of the unexplained reduction of 594 kWh/person can be ascribed to energy efficiency, and building and appliance standards in the state. Bernstein et al apply a panel regression where the state effect coefficients and the residuals represent partial attribution to energy efficiency and state policies. Here, average household size, disposable income, employment, electricity and gas prices, CDD and HDD are used to model changes in residential energy intensity. California was shown to have the largest reduction in residential energy intensity from 1988 to 1999. It was also shown to have favorable characteristics such as milder weather, larger household size, and high energy prices providing an additional contribution to the decreased residential energy intensity.[11]

One of the most striking differences between California and the average United States is the milder California climate. Between 1990 and 2005, California had 2460 average annual heating degree days (HDD) and 941 cooling degree days (CDDs) while the U.S. had 5181 HDDs and 1133 CDDs. Another significant difference in California is the average household size. Since 1980, California has seen an increase in household size while the U.S. has seen a decline. In 2005, California had around 2.8 persons per household and the U.S. had 2.6. California also has a higher concentration of urban areas – resulting in a higher number of multi-family housing units. All of these characteristic help to lower the per capita residential energy use in California relative to the U.S. A regression is necessary to see whether they account for the entire difference seen in Figure 1.

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[9] Eldridge et al., 2007

[10] Sudarshan, Anant, 2008, p. 38

[11] Bernstein et al., 2003, p. 35

Regression Approach

We regressed kWh consumer per capita per year on independent variables relating to weather, demographics and fuel use for each of the 48 contiguous states from 1990 to 2004. Then we explored relationships between the residuals, or unexplained aspects of electricity use, and efficiency policy.

Regressions show how the independent variables affect the dependent variable, and relegate left-out factors to the error term. For example, information on home square footage was not available; hence a regression formula might under-predict energy use in states and times with the biggest homes. Humidity was not included, so CDD's regression coefficient will capture the average effect of hot weather over humid and dry states, making it possibly over-predict electricity use in the driest hot states.

Some of this can be mitigated by having state-specific indicator (dummy) variables to capture and hence control for the "fixed effects" of unobserved systematic differences between states or across time. We controlled for inherent differences between years by including a dummy variable for each year other than 1990, but we chose not to include dummy variables for states in the interest of drawing conservative conclusions about the differences between California and other states. State-specific dummies captured so much of the differences between states that too little was left to be captured by the other independent variables we wanted to control for.

See the appendix for details on how the regression estimation dealt with differing error variances between states, and correlations between states' or time periods' errors.

Regression Results and Interpretation

Figure 4 shows the regression results.

Taken from the Bureau of Economic Analysis, average income has a small positive impact on electricity use per capita: $1000 more a year corresponds to an increase of 40 kWh, almost 1% of the 4329 kWh per capita average.

Hot weather (CDD) as reported in Global Energy's Velocity Suite database[12] increases electricity use substantially, cold weather (HDD from the same database) has an insignificant effect. As the negative correlation between CDD and HDD variables is high (-.85), the regression results cannot perfectly distinguish their effects - making the HDD coefficient's confidence intervals cross zero.

As expected, adding another person to the households to share electric services lowers the per capita usage on average by 2320 kWh, 54% of mean usage. People per household data come from the U.S. Census Bureau.

A one cent per kWh rise in electricity price corresponds to a 174 kWh drop in electricity use, 4% of average usage. This effect should have little or no simultaneity (reverse causality) bias because electricity usage in a given year affects electricity price that year minimally, if at all. Through the time period of our analysis (1990 – 2005) most electricity service to residential and commercial customers in the U.S. was provided through regulated fixed yearly tariffs based on anticipated costs that would be incurred given forecasts of load levels and fuel cost, with "true-ups" often occurring when actual consumption differed from forecasted consumption.

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[12] http://www1.ventyx.com/velocity/vs-overview.asp

Higher demand levels led to slightly higher marginal generation costs but slightly lower fixed costs per kWh , hence almost no meaningful net price effect. Electricity prices come from the Energy Information Administration (EIA).

Figure 4. Regression Addressing Residential kWh Usage per Capita

	coefficient	standard error	*t* statistic	*p* value	*notes*
intercept	13534.7	260.6	51.93	0.000	
real per capita income	40.1	5.0	7.97	0.000	*thousands of year-2000 $*
cooling degree days	403.0	23.0	17.54	0.000	*thousands*
heating degree days	10.9	10.6	1.03	0.305	*thousands*
people per household	-2329.9	86.9	-26.80	0.000	
real electricity price	-174.3	6.5	-26.83	0.000	*year-2000 cents per kWh*
fuel and natural gas usage	-45.5	1.9	-23.42	0.000	*million btu per capita*
approx homes per building	-1121.4	67.2	-16.69	0.000	*interpolated*
year 1991	130.8	45.2	2.90	0.004	
year 1992	10.7	49.7	0.21	0.830	
year 1993	211.3	50.5	4.19	0.000	
year 1994	118.1	50.7	2.33	0.020	
year 1995	133.7	51.6	2.59	0.010	
year 1996	290.3	51.7	5.61	0.000	
year 1997	99.6	52.5	1.90	0.058	
year 1998	-179.3	55.6	-3.22	0.001	
year 1999	-86.8	55.8	-1.56	0.120	
year 2000	-92.7	57.5	-1.61	0.107	
year 2001	-206.2	59.5	-3.47	0.001	
year 2002	-82.2	58.0	-1.42	0.156	
year 2003	-27.9	58.1	-0.48	0.631	
year 2004	-162.6	60.3	-2.70	0.007	

$$\bar{R}^2 = .83$$

The best proxy we could find for availability of gas- or fuel-based heating was the amount of BTUs of these fuels consumed per capita. Its regression coefficient of -45.5 represents ∂kWh/∂FuelUsage, the negative effect on electricity use of having more fuels usage while holding all other explanatory variables constant, including weather variables.

Our best proxy for housing compactness was average residential units per building, from the U.S. Census Bureau. We only had year 1990 and year 2000 observations, with much more between-state than in-state variation. We interpolated between the two snapshots and set post-2000 values to year-2000 values as a best guess. This is a regressor measured with error and will produce an effect biased towards zero, but less so than leaving it out altogether. Results confirm that more apartment dwelling corresponds to less electricity per person.

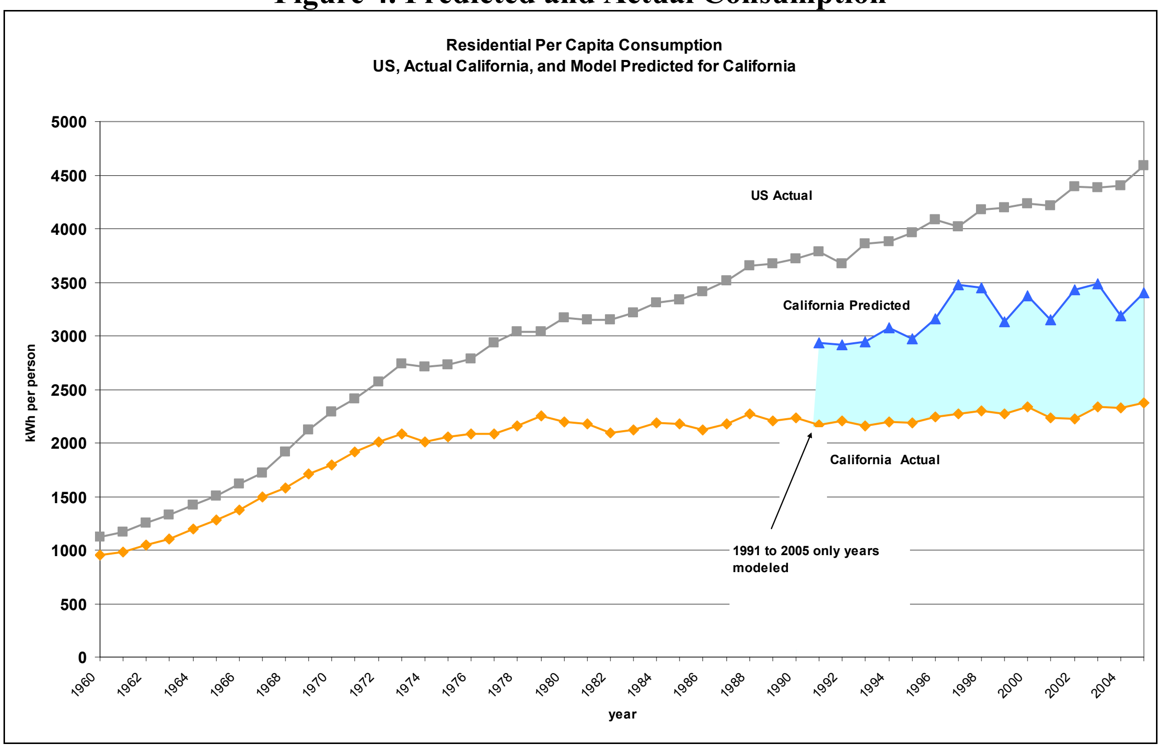
Yearly dummies did not generally increase, because the rise in residential per capita consumption over time was already explained by included variables.

California and Energy Policy

California's regression residuals range from -769 in -1205 with a mean of -978, meaning Californians used on average 978 kwh less than their weather and demographics and natural gas availability could explain. This section explores how much of that might be due to energy efficiency policy.

Only four states, New Mexico, California, Colorado and Arizona had very large negative residuals (averaging -1432, -978, -931 and -864, respectively). Negative residuals indicate that the regression model over-predicts per capita consumption compared to actual consumption. In Figure 4, California's actual consumption and the model's predicted consumption for California are compared to the US's actual consumption. The area shaded in blue represents the unexplained part of California's lower electricity use (its height is the magnitude of the negative annual residuals). There is probably no single reason that can explain these large negative residuals, as the regression could not include all possible variables and even if it had would still not have produced a perfect fit. One possible component of the over-predictions may be low humidity, easing the air-conditioning loads in all four states. An analysis of the residuals provides a better indication of the energy efficiency contributions in each state.

Figure 4. Predicted and Actual Consumption



A regression was run to explore the effects of energy efficiency practices on how much states' electricity use differed from what their economic, demographic and weather variables would predict. The dependent variable was the state residuals coming from the residential regression model for the two most recent years (2003-2004). The regression can only give a sense of relationships because the independent variables were ordinal rankings created for ACEEE 2006 scorecard for energy efficiency in the residential sector[13], with ranges of 0-2, 0-3 or 0-5. Some variables were ranked based on rigor (residential building codes and state EE resource targets), others on counts (number of types of appliances regulated, number of

[13] Eldridge et al, 2007

categories getting tax incentives) "Lead by example" was based on the existence or absence of state EE procurement policies, state building EE performance critera, and research and development programs. To correct for heteroskedasticity (uneven variance) observations were weighted by the reciprocal of each state residuals' standard error in the residential regression model.

Table 2 presents the results. While most individual effects were insignificant, the collective effect was significant at the 95% confidence level, despite the ordinal nature of the independent variables.

Table 2. Regression of Year 2003-2004 Unexplained Electricity Use on Residential Efficiency Rankings

Variable	*Coefficient*	*Std. Error*	*t-statistic*	*p-value*	
const	205.036	94.5468	2.1686	0.03275	**
bldg_stds	-0.979949	29.7675	-0.0329	0.97381	
appliance_stds	-7.9825	58.8066	-0.1357	0.89233	
lead_by_example	-119.707	45.2909	-2.6431	0.00969	***
ee_res_std	-25.9246	24.2256	-1.0701	0.28742	
tax_incentives	-82.978	95.5056	-0.8688	0.38725	

$\bar{R}^2 = .07$, F-statistic (5, 90) = 2.321 (p-value = 0.0495)

Applying each of these coefficients to California's high residential EE rankings, we get a California effect attributable to these rankings ranging from -76 to -881 (95% confidence interval), with a point prediction of -479 kWh. That is, on the order of 40% of California's average 2003-2004 residual of -1100 can be predicted from these imperfect measures of policy, lending support to the idea that California's energy efficiency policies help explain the California difference.

Commercial Model

The commercial model examined how energy intensity, measured as kWh per dollar of commercial GSP, responded to weather, price, employment, and demographics, subject to data availability, using 27 years of data (1980 to 2006) but only 40 states (for the others we were unable to obtain reliable data). For this sector, fuel and natural gas usage had small and insignificant coefficients, so we excluded them. We included state dummy variables (intercepts) in this model, making variable coefficients be optimally purged of state effects (in contrast to the residential model where we conservatively chose to err on the side of attributing as many California differences as possible to included independent variables). Here effects that could be either attributed to states or to for example price are allocated between these two possibilities in the way that minimizes the regression criterion (weighted sums of squared errors). We do no analysis of regression residuals and simply note that after correcting for price, labor intensity, population density and weather, California's commercial energy intensity starts .02 kWh/$ below then trends downward while the US intensity trends upward, demonstrating that these factors alone cannot account for the better energy performance of California shown in Figure 2.

Regression results are shown in Figure 6. Coefficients may be explained as follows:

A 1 cent higher real commercial price of electricity per kWh corresponded to a .00086 lower energy intensity. (At the average real price of 9.9 cents and average energy intensity of 0.21 kWh/$, a 10% higher price corresponds to an 0.4% lower intensity. Insofar as this represents a demand response rather than a change in demand/supply equilibrium, 10% higher prices cause .4% of production's energy footprint to vanish, and could cause an unmeasured quantity of production to cease.)

More labor-intensive commerce used more energy: if employees per $gsp increased .01 (half their average of .02) then kWh/$gsp rose by around 10 (half its average of 21).

For a fixed level of employees, another person using commercial services per $ of output increases energy intensity negligibly and not for sure (90% confident effect is nonzero).

Commercial electricity intensity responds meaningfully to hot weather and very slightly to cold weather.

Figure 6. Regression Explaining Commercial Energy Intensity (kWh/$)

	coefficient	s.e.	t	p value
Commercial Price ($/kWh)	-0.08558	0.01665	-5.14	3.29E-07
Employees/$	0.010314	0.000212	48.595	0
Population/$	0.00006551	3.98E-05	1.646	0.100008
thousand CDDs	0.00368	0.00064	5.78	9.9E-09
thousand HDDs	0.0008	0.00038	2.094	0.036526
CA trend	-0.00118	0.00014	-8.216	6.7E-16
US trend	0.00092	0.00008	11.591	0

state intercepts (with standard errors in parentheses):

ME	NV	SD	RI	IA	WI	PA	MA
-0.07397	-0.06687	-0.05187	-0.05007	-0.04919	-0.047	-0.04677	-0.04567
(0.00614)	(0.00632)	(0.00912)	(0.00514)	(0.00619)	(0.00760)	(0.00515)	(0.00509)
CT	UT	IN	NY	IL	CA	DE	CO
-0.03298	-0.02807	-0.02464	-0.02266	-0.01944	-0.01807	-0.0157	-0.01551
(0.00467)	(0.00615)	(0.00577)	(0.00463)	(0.00654)	(0.00427)	(0.00429)	(0.00668)
NJ	OH	MO	AR	FL	ND	GA	NE
-0.01438	-0.01225	-0.00293	0.00035	0.00158	0.0019	0.00556	0.01308
(0.00461)	(0.00547)	(0.00666)	(0.00647)	(0.00630)	(0.01029)	(0.00528)	(0.00615)
TX	AL	KS	AZ	KY	OR	WV	NM
0.01689	0.01712	0.02532	0.03068	0.03249	0.03254	0.03546	0.03557
(0.00615)	(0.00769)	(0.00538)	(0.00617)	(0.00566)	(0.00734)	(0.00591)	(0.00719)
MS	WA	NC	VA	SC	LA	OK	WY
0.03768	0.04045	0.0445	0.04502	0.06079	0.06104	0.06662	0.12473
(0.00834)	(0.00771)	(0.00539)	(0.00623)	(0.00594)	(0.00694)	(0.00640)	(0.01335)

adjusted $R^2 = .93$

Policy Discussion and Conclusions

It is clear that California uses considerably less electricity per capita and per dollar GSP than the US as a whole, and in fact less than most states. In the residential sector, we have shown that roughly half of the difference between the per capita electricity consumption of California and the U.S. has been explained by independent variables used in the regression model. These variables include electricity price, demographic data and weather. Correlation between efficiency activity rankings and state-specific energy use suggests that efficiency policy could account for some of the unexplained differences between California and the U.S. However, further investigation is needed, specifically related to an analysis of energy policies in other states. This analysis, along with additional statistical, behavioral and historic studies can be used to further elucidate the effectiveness of policy strategies and helps to clarify the specific attribution of market and policy mechanisms.

Appendix: Technical Details of the Regressions

Regression residuals were correlated geographically and, in the residential sector temporally, and their variances differed by state, violating the white noise assumption of ordinary least squares regressions, so we developed a generalized least squares (GLS) program using the "R" language. Since 16 years formed an insufficient sample size for unbiased estimation of state-specific first-order autocorrelation coefficients ("ρ_i's"), we estimated each ρ_i by including observations from all states with residuals correlated to state *i*, weighted by that state to state correlation. We then used our estimated ρ_i to transform the regression data, and estimated GLS on the transformed data. For the commercial model, overall autocorrelation was small (.15) and insignificant, so we did not treat it. Residential model ρ_i's ranged from 0 to 0 .4.

Our GLS covariance matrix Σ incorporated observed correlation between state residuals, first grouping states into correlated clusters to make the weighting matrix block diagonal so the computer could accurately invert both Σ and the regression formula component $X'\Sigma^{-1}X$ despite the large number of observations. Each element of Σ corresponds to the relationship between 2 observations, one of state i at some point in time, the second of state j at some potentially other point in time. The Σ element σ_{ij} is the covariance of states i and j estimated over all time periods observed for those states, if the two states fall in the same cluster, but set to zero otherwise. Clusters were chosen by a computer search to maximize correlations between states within the cluster, subject to their estimated σ_{ij}'s being at least the minimum value that allowed accurate matrix inversion: 0.6 in the residential model and 0.8 in the commercial model. The state clusters in the residential model were (SC, GA, MS, AL, LA), (WV, KY, FL), (WA, ID, OR), (VA, NC), (MO, AR), (RI, CT), (NJ, NH) and (TX, NV). … In the commercial model they were (MO, GA, MA, RI), (NC, FL, CT, NJ, KS), (SD, ND), (MS, AL, KY), (LA, CO, TX, OR, AZ), (VA, OH, OK), (NV, NE, WY, NM), and (WA, IL, SC). We iterated all steps of this process until parameters converged.

*This work does not represent or reflect the opinions or positions of the California Energy Commission.

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