

Deconstructing the “Rosenfeld Curve”

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Abstract

Since the early 1970s, electricity consumption per capita in California has stayed nearly constant, while rising steadily for the United States as a whole. In the context of global energy policy making today, where both climate and energy security concerns play an increasingly large role, it is important to understand the factors behind California’s success in stabilizing electricity consumption. In this paper we use empirical data to estimate the fraction of the difference between California and the United States owing to policy independent characteristics such as climate or demographics, and the fraction that may be due to policy measures aimed at saving energy. We analyze both recent and historical data. For 2001, we find that up to about 23% of the overall difference between California and the United States could be due to policy measures, the remainder being explained by various structural factors.

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1 Introduction

California’s energy policies and energy use patterns have garnered much interest in recent years, partially because of the state’s relatively low per capita electricity consumption (compared to national levels) and declining energy intensities. Since the early 1970s, electricity consumption per capita in California has stayed nearly constant, while rising steadily for US as a whole. Consequently today, the state consumes 40% less electricity per person than the national average. Although part this difference is the result of natural advantages (mild climate and lighter industry), state policy has played a significant role. California’s energy policies have consistently encouraged energy efficiency programs and appliance and building standards. State policy has typically led the rest of the Nation. Many people have sought to draw a causal link between California policies and the differential between state and national electricity per-capita consumption levels. Indeed a graph comparing retail sales of electricity per capita for California and the United States is often casually referred to as the “Rosenfeld Curve”, after Arthur Rosenfeld, the influential member of California’s Energy Commission (See Figure 1). The more detailed comparison by sector is provided in

Figure 2.

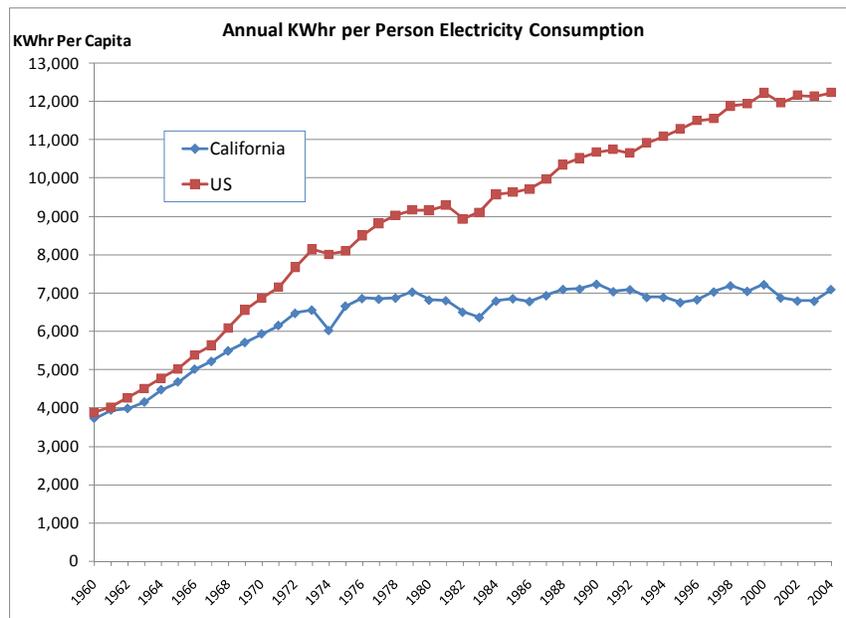


Figure 1. California vs US Electricity Use Per Capita (the “Rosenfeld Curve”)

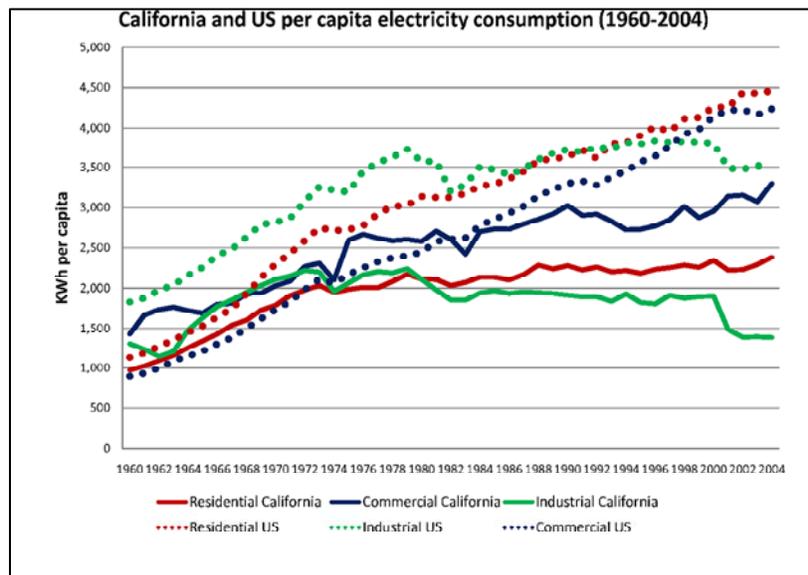


Figure 2. California and US per capita electricity consumption disaggregated by sector. Source: Energy Information Administration [2006]

In the context of energy policy making today, where climate and energy security concerns both provide strong motivation for reducing energy use, it is important to understand the underlying causes of California's stabilization of per capita electricity consumption. Understanding is important not just for those interested in California policy, but more generally for energy policymakers and analysts across the world. California occupies a position at the forefront of US policy encouraging efficient and environmentally sustainable energy use. Consequently, separating the impacts of California policy from the impacts of policy independent structural factors influencing per capita electricity use could have important implications for the United States as a whole. Most attempts to estimate efficiency savings have concentrated on the US as a whole and have reached mixed conclusions on the effects of utility programs (See for example Loughran and Kulick [2004], Auffhammer et al. [2007]). There have been very few studies seeking to directly quantify the role of various policies and programs in California. Bernstein et al. [2000] studied the public benefits of energy use changes and improved efficiencies in California without looking at the causes in detail. The California Energy Commission publishes savings estimates (see Section 5 and California Energy Commission [2003]) that are obtained

“bottom up” using a combination of model runs and exogenous inputs. The only California-specific empirical work of which we are aware is that of Schipper and McMahon¹ [1995].

The purpose of this paper therefore is to estimate what fraction of the difference between California and the United States is the result of policy independent characteristics such as climate or demographics, and what fraction is the result of proactive policy measures aimed at saving energy.

In order to accomplish this end, we estimate the effects of various policy independent factors and successively subtract their contribution to the overall difference between the state and nation. The remaining “unexplained” difference forms an estimate of the role of state policy. We view this estimate as an upper bound on the role of state policy because we have not been able to completely rule out the possibility of other factors. We compare this bound with California Energy Commission (CEC) savings estimates, and find that our upper bound (obtained “top-down” by correcting for other factors), is close to the CEC direct savings estimate.

2 Residential Sector Electricity Consumption

The largest and fastest growing electricity consuming sector in California is the residential sector. It is both complicated and interesting because a variety of factors affect use of electricity and because many of these factors can be influenced to change consumption.

The basic consuming unit within this sector is the household; consequently our interest is in factors that influence electricity consumption of households. These include household income, size, location, climate, fuel mix choices, prices, “lifestyles”, appliance and building characteristics, and so on. In keeping with the goal of this paper, we quantify factors such as demographics or climate that are independent from energy efficiency policies, and distinguish these factors from other forces, such as prices and technology characteristics, that are direct consequences of energy efficiency policies. We examine affects of the following sectoral characteristics:

- Household distribution by income
- Household distribution by size
- Householder age profile
- Climate characteristics

¹ The authors concentrate on overall energy use per unit economic output (as opposed to electricity in this paper) across a variety of sectors. While not providing a complete breakdown of structural effects, they do correct for a number of factors and identify the role of state policies. They also identify areas needing further work and more data, many of which remain important today.

- Urbanization
- Housing unit floor space
- Housing unit age
- Fuel choices for space conditioning and water heating
- Appliance use patterns (“lifestyles”)

In attempting to quantify the impacts of these factors on residential sector electricity consumption, we employ the following general methodology. Beginning with empirical consumption and household data², we define test statistics that are measures of the expected household electricity consumption in California and the US, *corrected for state-nation differences in one factor alone*³. We test for statistically significant differences between the US and CA values. A significant difference between the two values is then attributed to state-nation differences in the particular characteristic in question. This procedure will become clearer later in this section.

2.1 Household Income Profiles

Household income is a key driver of energy consumption patterns, through its link to increased living standards and consequently lifestyle changes, greater appliance ownership and so on. In general, lower household incomes are associated with lower energy consumption. As income rises, so does the demand for energy. At high income levels some flattening or even reductions in consumption may be observed. This is due both to some saturation in energy demand (and demand for energy using devices in the home), as well as an increasing ability to afford energy efficient technologies. It is sometimes informally argued that California’s average household energy use is depressed by income inequalities and the presence of large numbers of poorly paid immigrants, resulting in an increase in households at lower income groups. We test for these factors.

In testing for the effect of household income we define two quantities

² Data are primarily from the decennial US Census reports, the American Community Surveys and from sample surveys such as the EIA Residential Electricity Consumption Survey (Energy Information Administration [2001]).

³ In forming these test statistics we use national averages for our energy consumption data (for example, national average household electricity consumption within a particular income group). State figures are used only for the factor being tested. The use of energy figures that are at the national level eliminates the effect of inherent efficiencies unique to California.

$$E_{ca}^{in} = \sum_i \frac{H_{ca}^i E_{us}^i}{T_{ca}} \quad \text{and} \quad \bar{E}_{us} = \sum_i \frac{H_{us}^i E_{us}^i}{T_{us}}$$

where,

H_{ca}^i and H_{us}^i are the numbers of CA and US households in income group i , respectively,

T_{ca} and T_{us} are the total numbers of households in California and the US, respectively,
and

E_{us}^i is the national average household electricity consumption (annually) for a household in income group i

\bar{E}_{us} is the average household electricity consumption in the United States. E_{ca}^{in} estimates what would be the average household electricity consumption in the United States if the US distribution of households by income group were the same as the CA distribution. Differences between E_{ca}^{in} and \bar{E}_{us} can then be interpreted as differences in average per capita consumption that result purely from differences in the distributions of households by income group. Formally, we test the hypothesis $H_0 : E_{ca}^{in} = \bar{E}_{us}$ versus the alternative hypothesis $H_1 : E_{ca}^{in} \neq \bar{E}_{us}$.

We found that the difference in the distribution of households by income suggests a small difference between the national and state figures (about 3.9% of the US average), in the direction of *increasing* California's electricity use. This difference turns out to be just significant (at a 95% confidence level) and thus H_0 is rejected⁴.

Our conclusions are not very surprising since US census data indicates that California has a household distribution slightly more skewed toward higher income groups than the US. The common perception of large numbers of low income households is not borne out by the data⁵. We refer to this again in discussing appliance use patterns (see Section 2.7) where we argue that income alone cannot be used to explain differences in appliance ownership and use patterns between California and the United States.

⁴ We assume a Gaussian distribution for the t-statistic in this test because sample sizes involved are large, and treating the denominator (which is a complete population count from the census) as constant. The latter assumption allows the use of a standard Gaussian test as opposed to the much more complicated test for a normal ratio distribution.

⁵ This is perhaps because it is possible for a household to increase total income provided members work multiple jobs or if there are multiple working members.

2.2 Household Size Distribution

A demographic characteristic that could affect observed per capita electricity consumption is the average size of households in a state. Larger households are able to attain economies of scale (see O'Neill and Chen [2002]) and therefore systematic differences in the size of households in California as compared to the national average could reduce per capita residential energy consumption figures. Census data indicates that such a difference does exist, with the average household size in 2001 in California being 2.92 members as compared to 2.60 for the United States.

The test statistic in this case is conceptually the same as that for household income. However, because our data source (RECS 2001) provides information on average household *energy* consumption by size (as opposed to electricity consumption), we estimate electricity consumption levels within each group by assuming that the overall ratio of electricity consumption to energy consumption within the household remains constant across size groups. Thus we define the two quantities:

$$E_{ca}^{si} = \alpha_{us} \sum_i \frac{H_{ca}^i E_{us}^i}{T_{ca}} \quad \text{and} \quad \bar{E}_{us} = \alpha_{us} \sum_i \frac{H_{us}^i E_{us}^i}{T_{us}}$$

where, for these quantities,

α_{us} is average US household electricity consumption as a fraction of energy consumption

H_{ca}^i and H_{us}^i are the numbers of CA and US households in size group i , respectively,

T_{ca} and T_{us} are the total numbers of households in California and the US, respectively, and

E_{us}^i is the national average household electricity consumption (annually) for a household in size group i .

Note that \bar{E}_{us} remains the actual average electricity consumption per household for the US. This average need not be recalculated, but is the same average as calculated previously.

E_{ca}^{si} estimates what would be the average household electricity consumption in the United States if the US distribution of households by size group were the same as the CA distribution.

We test the hypothesis $H_0 : E_{ca}^{si} = \bar{E}_{us}$ versus the alternate hypothesis: $H_1 : E_{ca}^{si} \neq \bar{E}_{us}$

We find no statistically significant difference between E_{ca}^{si} and \bar{E}_{us} . This finding is consistent with the observation that economies of scale are obtained in larger households, allowing household size increases without significant increases in energy consumption. Since this is the case we may compute a per capita figure for electricity consumption by dividing the per household electricity consumption by the average household size. This was done for the United States and California, and the difference was found to be statistically significant, with a high Cohen's effect value. California's greater household size was found to explain approximately an 11% reduction ($\pm 4.4\%$) from the national average figures.

2.3 Climate Characteristics

In order to estimate the effect of climate on household electricity use, two distinct end uses were considered and separately analyzed - space heating and air conditioning. For space heating, two factors need to be taken into account. The first is the difference in (population weighted) heating degree days between California and the United States. The second is the choice of heating fuel - the popularity of natural gas over electricity for heating in California households reduces observed electricity consumption. We account for both by choosing a test statistic as follows:

$$E_{ca}^{heat} = \alpha_{ca} \frac{E_{us}}{HDD_{us}} HDD_{ca}$$

Here HDD refers to population weighted heating degree days (climate effect) and α_{ca} is the fraction of households using electricity as the heating source (fuel substitution effect). E_{us} is the national average electricity consumption for space heating in households that use electricity as the primary heating energy source.

For cooling, we distinguish between central and room air-conditioning. Electricity demand for air conditioning purposes is estimated as follows:

$$E_{ca}^{cool} = \alpha_{ca}^{cac} \frac{E_{us}^{cac}}{CDD_{us}} CDD_{ca} + \alpha_{ca}^{rac} \frac{E_{us}^{rac}}{CDD_{us}} CDD_{ca}$$

Here CDD refers to population weighted cooling degree days (climate effect) and α_{ca}^{cac} or α_{ca}^{rac} are the fractions of households using either (c)entral or (r)oom AC equipment. E_{us}^{cac} or E_{us}^{rac} is the national average electricity consumption of air-conditioning for households using equipment type cac or rac .

There are significant differences in HDD and CDD values between the nation as a whole and California. The milder climate in the state of California and fuel substitution possibilities in space heating, are reflected in a statistically significant difference in the expected electricity

consumption for space heating and cooling, independent of any other efficiency effects. We find that point estimates suggest about a 7.8% ($\pm 1.3\%$) reduction in electricity consumption for California due to reduced cooling needs, and a 8.0% ($\pm 1.4\%$) reduction due to differences in space heating demand (both as a percentage of total US household electricity consumption).

2.4 Urbanization

The distribution of households into cities, suburban areas and rural areas has a marked effect on energy use patterns. First there are differences in transport energy consumption (much has been said about the consequences of urban sprawl and long commutes to work). However, there are also observed variations in electricity consumption within the household. A number of factors could be responsible for this, including larger floor space outside cities and differences in lifestyles due to variations in living costs.

In order to obtain an estimate of the effect of urbanization, we begin by obtaining a distribution of households by location type from the 2000 US Census. Empirical data on electricity consumption as a function of location is available from the 2001 RECS. A practical problem involved with ascertaining the magnitude of this effect arises from the way in which the various location groups (Cities, Towns, Suburbs and Rural areas) are defined in different data sources. The RECS survey, unlike the census, uses a classification provided by the respondent as the basis of determining the location of a surveyed household. We therefore use the mapping in Table 1 to convert between RECS and census classifications⁶.

Carrying out a hypothesis test analogous to those described earlier suggests that urbanization can explain a statistically significant reduction in electricity consumption in California of about 10.4% ($\pm 4.0\%$) of the national average.

Census Classification	RECs Classification
Urbanized Area Central Place	City
Urban Cluster Central Place	Town
UA and UC Non-central Place	Suburb
Rural	Rural

Table 1. Mapping between Census and RECS household location classifications

⁶ We recognize that this introduces some error into the analysis. Unfortunately since the Census does not provide electricity use statistics and the RECS statistics on household location have an extremely high variance, we use this mapping as an estimate.

2.5 Housing Unit Floor Space

Rural and suburban locations tend to be correlated with larger households. Thus at least part of the effect of California's greater urbanization should be reflected in a comparison on the basis of household floor space distributions for the state and the nation. For a given household size, larger housing units tend to use more energy, with higher heating and cooling loads as well as a greater lighting load. Comparing the distribution of households by floor space between California and the United States reveals that within the state homes tend to be smaller than the national average⁷.

In order to estimate the effect of smaller housing units on electricity consumption we define the quantities

$$E_{ca}^{floor} = \alpha_{us} \sum_i \frac{H_{ca}^i E_{us}^i}{T_{ca}} \text{ and } \bar{E}_{us} = \alpha_{us} \sum_i \frac{H_{us}^i E_{us}^i}{T_{ca}}$$

where

H_{ca}^i and H_{us}^i are the number of California housing units and US housing units in floorspace group i , respectively,

α_{us} is the national average household electricity consumption as a fraction of household energy consumption

E_{us}^i is the national average household energy consumption (annually) for a unit in floorspace group i

T_{ca} and T_{us} are the total number of housing units in California and in US respectively.

Testing for differences between E_{ca}^{floor} and the national average figure \bar{E}_{us} suggested that floorspace differences could account for a statistically significant reduction in household electricity consumption of about 11% of the overall US figure. Note that since housing unit size is not independent of location, this reduction is correlated with the estimate obtained in Section 2.4. Consequently we do not incorporate both factors when assessing the contribution of structural factors (a possible underestimation of the overall reduction since the two need not be perfectly correlated).

⁷ It is interesting that while the average household size in California is larger than the national average, the average size of the housing unit appears to be smaller

2.6 Fuel Choices for Water Heating

Household fuel-mix differences expectedly translate to variations in electricity demand. As it happens, the RECS 2001 reveals that on a national level electricity makes up 39.48% of the total energy consumed, while in California the same figure is 32.58%. We have already accounted for electricity demand differences due to the greater use of natural gas for heating in California. A similar analysis of electricity consumption for water heating applications reveals that California's greater reliance on fuels other than electricity for water heating⁸, would account for some reduction in overall electricity demand in this sector. To be specific, water heating fuel choices account for a statistically significant reduction in California's electricity demand of about 5.6% of the national average household electricity consumption.

Before closing this discussion, we should acknowledge that it could be argued that state policy does have an influence on fuel-mix decisions. For example, Title-24 building standards may have made it harder to construct all electric homes. Similarly, high electricity prices (influenced in part by regulations and various legislative measures), do make fuels such as natural gas attractive. However, simple switches in the form of energy used leads to only small reductions in energy use and carbon emissions. For this reason we separately quantify reductions in electricity consumption due to fuel mix differences. This ensures that the "unexplained" difference that remains credits policy only for reductions in electricity energy use that do not simply shift the forms of energy consumed.

2.7 Other Factors

The role of householder age⁹ and housing unit age variations in reducing California's electricity demand was not found to be statistically significant in our analysis. Householder age profiles is very similar in the state and nation. California does have slightly newer housing. However when combining housing unit age with electricity consumption as a function of age, insufficient evidence was found (based on the RECS 2001 survey and standard errors in those figures) to conclude that the effect was significant.

Apart from these factors, it is also interesting to look at the role of "lifestyles" in influencing electricity use. We have not attempted to quantify such differences and it would be necessary to

⁸ Nationwide, over 38% of households use electricity as the primary fuel for water heating, while in California this fraction is just under 15% (based on the 2001 RECS).

⁹ A demographic characteristic that is a partial determinant of household energy consumption is the age of the householder (see O'Neill and Chen [2002]). In part, this is because household income is correlated with age, with income rising with age. However, apart from the income effect, there is evidence to suggest that householder age differences may independently affect energy use patterns.

obtain more data to do so accurately. However the RECS datasets do reveal some evidence of differences in the way Californians live when compared with the rest of the nation. Regarding heating for example, more Californian houses have programmable thermostats (35.6%) than the national average (23.4%). More Californians lower the temperature in the day when the house is empty and while sleeping. As many as 40% of Californian residents report that they switch off heating when the house is empty as opposed to about 10% for the nation as a whole. Factors such as prices and climate may influence these numbers; but they are interesting nonetheless. Explicitly switching off heating both at night and when the house is unoccupied does reduce energy use - whether motivated by cost or other considerations. Similar differences obtain when looking at other appliances. For example almost 32% of Californian households report not possessing a washing machine, compared to about 21% of US residents. Fewer Californians own a separate freezer than the national average (about 18% of households as against 32% nationally). California's higher electricity tariffs may have a role to play in explaining these numbers.

These various estimated impacts are combined numerically in a later section of this paper.

2.8 A Note on Electricity Prices

Thus far we have not addressed the role of electricity prices in influencing electricity demand. California's electricity tariffs are high in comparison with the rest of the state. But electricity bills are often lower than the national average (in part thanks to lower consumption aided by greater efficiency of use). In this paper we do not attempt to directly estimate electricity demand reductions due to California's higher tariffs. This is partly because electricity prices are strongly influenced by state policy, including regulations on utilities and the supply sources they are allowed to use. As such, we regard any reductions due to higher tariffs as being heavily policy dependent. These effects would thus form a part of the component of California-US consumption differences that remains after we account for structural causes¹⁰. This remaining share should thus be viewed as an aggregation of the effect of policies aimed at increasing efficiencies, price effects that are influenced by state policy, and other factors that we may not have accounted for in our analysis.

The response of consumers to price changes in California is difficult to estimate. Estimates of consumer price and substitution elasticity for energy sources and electricity have been derived in the past (see for example, Roy et al 2006 and Branch 1993). Even so, there remains considerable debate about how consumers respond to price changes and how much lag exists in demand shifts. Short-run and long-run elasticities are likely to be quite different, further complicating such an

¹⁰ See section 2.6 for a little more detail on the difference between real savings in electricity consumption and apparent savings due to fuel mix differences.

analysis. Thus it is difficult to compare California, with higher tariffs but lower baseline consumption, with states that may have lower tariffs but higher baseline consumption.

Some issues to be considered in evaluating the role of price changes are discussed in Reiss and White (2004). They build a model to evaluate the effect of alternative tariff schemes on demand, for California, based on RECS survey data. They find that electricity demand can be broken down into an inelastic baseline component, and incremental use (for appliances such as pumps, air conditioners, swimming pools, refrigerators) that is elastic. The price elasticity for the elastic component varies depending on the end use category (the authors set up eight appliance categories including baseline use). In addition, the authors find that the demand response of consumers is highly heterogeneous, with a small proportion accounting for most of the demand response, and with most consumers exhibiting very low price elasticity. A mean value for price elasticity was estimated to be -0.4, but as the authors point out, other studies in the residential sector have shown widely varying estimates.

3 Industrial Sector Electricity Consumption

Measured on a per capita basis, in 2001 about 20.50% of California's electricity sales were reported to the industrial sector. This was a lower percentage than the corresponding figure for the United States in the same year, where industrial sales made up about 28.5% of the total. In absolute terms also, per capita industrial electricity consumption in California is significantly lower than for the nation as a whole. For the state per capita industrial sales in 2002 were 1393 KWh, 60% smaller than the national average of 3475 KWh (all figures computed using EIA retail sales figures).

Part of the difference between the state of California and the nation could be due to smaller, lighter industry in California, relative to the national industry profile. There are two important aspects of the industrial sector that influence energy use. The first is obviously the type of industry - refineries and chemical industry units for example, are far more energy intensive than firms manufacturing microprocessors. Apart from the type of industry, the size of units makes a substantial difference to energy intensities - partly due to economies of scale, and partly because the product mix of smaller and larger manufacturing units may differ.

The first stage in our analysis of this sector is therefore to account for differences due to the nature of industry. We disaggregate the sector first by industry type (based on NAICS codes) and second by size, as measured by the number of employees. We use the latter metric of size because our eventual interest is in comparing per capita values of electricity consumption. Corresponding to this choice we form the following expression for per capita industrial electricity consumption:

$$E_{ca}^{ind} = \frac{\sum_i \sum_j \alpha_{ij} \eta_i p_{ij}}{P}$$

Where

E_{ca}^{ind} is the California industrial electricity consumption per capita correcting for industry size and type only.

α_{ij} is the national average energy use per employee in industry type i , belonging to size group j

η_i is electricity as a fraction of total energy consumption in industry type i

p_{ij} is the number of employees working in units of type i and size group j

P is the total population.

We use the 2002 United States Economic Census and the 2002 Statistics of US Business survey to obtain information on the distribution (by number of employees) of different industries in both California and the United States. We use the 2002 Manufacturing Energy Consumption Survey (Energy Information Administration [2002]) as well as US Department of Energy figures to obtain data on energy intensities (energy use per employee) for different unit sizes and NAICS codes. The industrial sector was categorized into manufacturing industries, construction, mining and agriculture, forestry and fishing subsectors. The manufacturing sub-sector was further broken down into different industry types covering over 95% of the total number of employees in manufacturing.

It was found that a significant fraction of the observed difference in industrial electricity consumption between the nation and the state may be explained simply by which industries make up the largest share of the industrial sector, and the unit sizes most prevalent. Based on these factors alone, California's per capita industrial electricity sales are predicted to be about 62% of the nationwide figure (or about 2,154 KWh). For the 2002 US figure of 3,475 KWh, California's industrial sector makeup and the scale of industry units would be broadly consistent with a reduction by about 38% of the national average.

3.1 Industry Self Generation

Aside from the structural makeup of the industrial sector, an additional factor influencing retail electricity sales is the percentage of electricity generated on-site, since electricity generated on-site is not included in data on electricity sales, even though it represents electricity use. There is a greater fraction of on-site generation in California than in the United States. While the total national on-site generation stood at 152,600 KWh in 2002 (15.54% of total industrial sales), in California the corresponding figure was 17,142 KWh (35.45% of state industrial electricity

sales). This difference would explain a decrease in state retail electricity sales to the industrial sector by about 7.4% of the national per capita industrial electricity consumption.

4 Commercial Sector Electricity Consumption

As a primarily services oriented economy, most of California's economic output comes from activities in this sector and thus it is not surprising that on a per capita basis nearly half of electricity sales are to offices, schools, universities, hotels, restaurants and so on. Unlike in the case of industry, most use of electricity in this sector is for lighting, temperature conditioning and the use of various appliances (such as office equipment). Because most energy demands in the sector are associated with building related loads, a natural unit to use to measure energy intensities and the size of the sector is building floor space. Thus just as we used the household as the basis for studying the residential sector, we shall use square feet of building space (with characteristics differing depending on the end use) as the basis for studying the commercial sector. In this section therefore, energy intensities are expressed in KWh per sq.ft, and the size of the sector is measured in terms of the floor space occupied.

While almost all end uses classified as "commercial" have energy loads associated with buildings and offices (as opposed to machinery or industrial processes in the manufacturing sector), the energy intensity of different parts of the sector differ widely. For example, food sales and food service (restaurants, cafeterias, food stores, etc.) uses about 50 KWh of electricity per square foot, significantly more than the educational sector, where energy intensities are about 11 KWh per sq ft (national average figures, from the 2003 Commercial Buildings Energy Consumption Survey). Thus differences in the composition of the commercial sector can potentially have a significant impact on electricity consumed. In the case of California, the fraction of total commercial floorspace for the different end uses is similar to national patterns. However, there are significant differences in the per capita density of commercial floorspace between the two. The US as a whole uses more commercial floorspace per capita, across all end uses, than does California (see

Figure 3). Consequently even though the nature of end uses is similar, California per capita electricity consumption is reduced because of this difference.

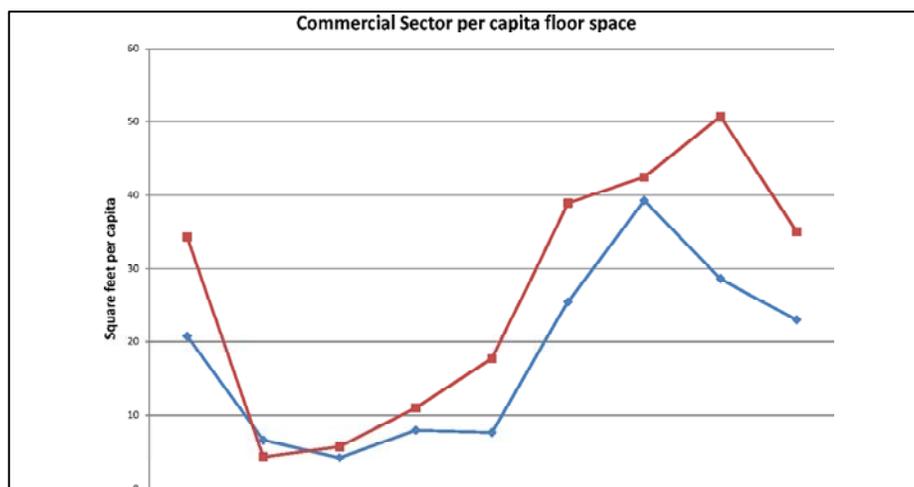


Figure 3. Commercial floorspace per capita in California and the United States (California Energy Commission [2003], Energy Information Administration [2003])

Per capita commercial electricity sales may be estimated as

$$E_{ca}^{com} = \sum_i \frac{\alpha_i f_i}{P}$$

where

α_i is the electricity intensity for floorspace belonging to end use type i

f_i is the floorspace occupied by buildings of type i

P is the total state population.

Evaluating E_{ca}^{com} for both California and the United States indicates that the difference in the per capita size of the sector and slight differences in the sectoral makeup together account for a reduction in California's per capita consumption by about 27% of the national figure. The actual difference in 2003, based on a comparison of CEC sales figures for the state and EIA statistics for the nation, was somewhat greater (33% of the US figure). It therefore seems to be the case that a significant amount of the difference between state and national level commercial electricity sales can be explained by differences in floor space intensity (floor space per capita), with a small contribution from differences in usage shares. The unexplained fraction of the total difference could be due to efficiency measures, utility programs and appliance and building standards.

5 Energy Commission Savings Estimates

Over the years California has gradually instituted many programs and policy measures aimed at demand side management, energy savings and energy efficiency. These include programs run by investor owned utilities, rebates to emerging technology, retrofitting aid and surveys, education and training programs, appliance recycling and advocacy efforts. In addition, building and appliance standards of increasing stringency have been enforced by the California Energy Commission (CEC), acting under the Warren Alquist Act. Recent efforts include instituting widespread demand response management schemes allowing utilities to exercise some control over peaking loads and aggressive incentives for the investor-owned utilities to assist their customers invest in energy efficiency.

It remains a difficult task to accurately quantify savings gained from these efforts, in large part because of the variety and number of individual utility programs. However, the CEC does produce savings estimates, based on a various quantification methodologies applied to utility programs, on a detailed energy system model, and smaller models for various policy measures. Education, training and awareness building programs are excluded from savings due to the

difficulty estimation. Details on the methodology used in making forecasts and savings estimates are available in the Energy Demand Forecast Methods Report (California Energy Commission [2005]). CEC estimates for savings due to the various energy efficiency and conservation policies are about 1,233 KWh per capita, 771 KWh per capita, and 210 KWh per capita in 2001, 1990 and 1980 respectively (California Energy Commission [2003]). These figures are cumulative over all sectors.

6 Historical Trends in Electricity Consumption

The preceding discussion has focused on deconstructing the contributing factors to low electricity consumption in California, for a snapshot of time in the recent past. We focus on recent data in part because of the relative ease of obtaining data. As we go further back in time it becomes progressively more difficult to obtain state disaggregated data of the kind used in this analysis. That said, it is important to examine the years before 2001 in order to test whether the time trend in

Figure 2 can be explained by similar factors. Given that the difference between California's electricity consumption levels and the national average has gradually increased over the last four decades, it is important to test whether the various factors combine to predict increasing differences between the state and nation as well.

We conducted analysis for previous years, using the same methods described earlier in this paper. For the residential sector we used the RECS surveys for previous years and US census data. However, these surveys provide only insufficiently disaggregated electricity use data for previous years. Therefore, in some cases we assumed that the relative distribution of electricity use for different types of households (for example when testing for income and urbanization effects) has remained the same as in 2001. We use data on actual levels of consumption, but assume only that their variation across household groups is held constant. In addition, some of 1981 data for California (specifically information on appliance saturation used to quantify heating and cooling loads) has been sourced from CEC energy model outputs. In some cases standard errors cannot be estimated because the source statistics in these cases are not from sample surveys. Similarly for the commercial sector we draw upon historical floorspace data from the CEC Demand Forecast model runs. For both these sectors our primary source of data (RECS and the Commercial Buildings Energy Consumption Survey), is not available for California before 1997.

Data constraints are most severe for the industrial sector as a result of the switch from the SIC to NAICS classification in 1997. This reclassification has made it difficult to obtain comparable employee data for years before 1997. Fortunately however, the difference in electricity consumption levels between the state and nation in the industrial sector has changed very slowly over the past twenty years. Both the United States and California display relatively flat levels of industrial electricity consumption (per capita) in recent years. As indicated earlier, this trend is not surprising since energy costs are an important part of total costs in some industries. Economically beneficial energy savings are likely to spread faster nationwide in the industrial

sector than in the residential sector. Thus it is possible that the relatively stable difference is primarily a consequence of consistent differences in industrial sector composition and on-site generation differences, with a small residual share due to efficiency policies or other causes. For the industrial sector therefore, we do not perform a disaggregation in previous years, instead we scale our estimate for 2001 by the modest trend over the past 20 years to compute an estimate of the difference for 1990 and 1980.

7 Results

Our analysis of residential, industrial and commercial sectors uses the latest data available to us, but the year of analysis differs across the three sectors (because the EIA surveys used do not follow identical time schedules). Our initial disaggregation of the Residential, Industrial and Commercial sectors was for the years 2001, 2002 and 2003 respectively (displayed in Table 2.)¹¹

Residential Sector (2001)	
US per capita residential electricity sales	4,253
CA per capita residential electricity sales	2,225
Heating load reduction (climate and fuel choices)	340 (8.00±1.36 %)
Cooling load reduction (climate, appliance type)	332 (7.80±1.30 %)
Water Heating load reduction	238 (5.60±0.97 %)
Household income effect	-130 (-3.90±3.60 %)
Household size effect	382 (11.0±4.40 %)
Urban rural distribution	321 (10.4±4.04 %)
Possible policy share	545
Industrial Sector (2002)	
US per capita industrial electricity sales	3,475
CA per capita industrial electricity sales	1,393
Industry type and size differences	1,321 (38.00±3.60 %)
On-site electricity generation differences	257 (7.40 % ±NE)
Possible policy share	504
Commercial Sector (2003)	
US per capita industrial electricity sales	4,170
CA per capita industrial electricity sales	2,803
Reduction due to lower floor space intensity	1,132 (27 % ± NE)
Possible policy share	236

Table 2. Summary of Results

¹¹ Some statistically significant differences were not included because other highly correlated factors have been included. Numbers in brackets indicate reductions as a fraction of US per capita consumption, followed by a 95% confidence interval also expressed as a percentage of the US total. NE means that a 95% interval could not be estimated due to insufficient information about the source data errors.

To combine the three we convert our results to a common year (2001) and display the results in Figure 4. For the industrial sector conversion, we assume percentage reductions due to sector composition and self generation remains the same in 2001 as in 2002. For the commercial sector, variations are greater, and therefore we repeat our analysis using the 1999 CBECS survey and interpolate between 1999 and 2003 reductions to obtain estimates for 2001.

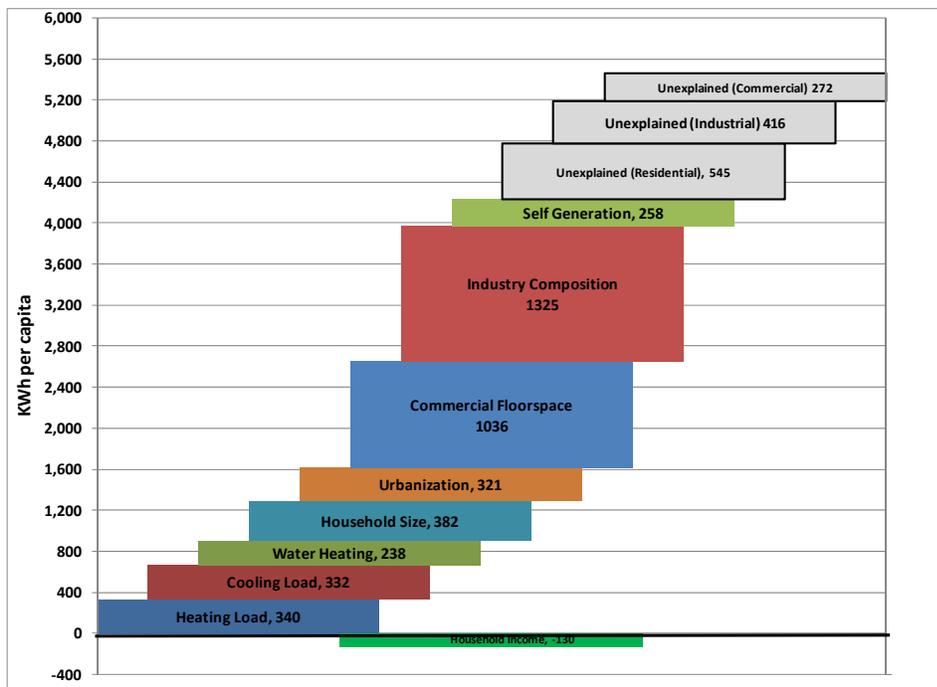


Figure 4. The role of policy-independent factors in reducing California’s per-capita electricity consumption, relative to US per capita consumption, across all three sectors. The “unexplained” bars represent our estimate of the possible impacts of policy initiatives.

We obtain an “unexplained” difference of about 545 KWh per capita for the residential sector, 416 KWh per capita for the industrial sector and 272 KWh per capita for the commercial sector. We conclude that for 2001, up to about 23% of the overall difference between California and US per capita electricity consumption could be due to state policy.

We also present the result of our analysis of the historical data. Figure 5 compares CEC model estimates to the “unexplained” reductions we obtain at different time points in the last three decades. The CEC model estimates and our “unexplained” reductions are very similar over time,

although in 1980 the “unexplained” reductions are about 50% greater than the CEC estimates of policy-induced energy demand reduction.

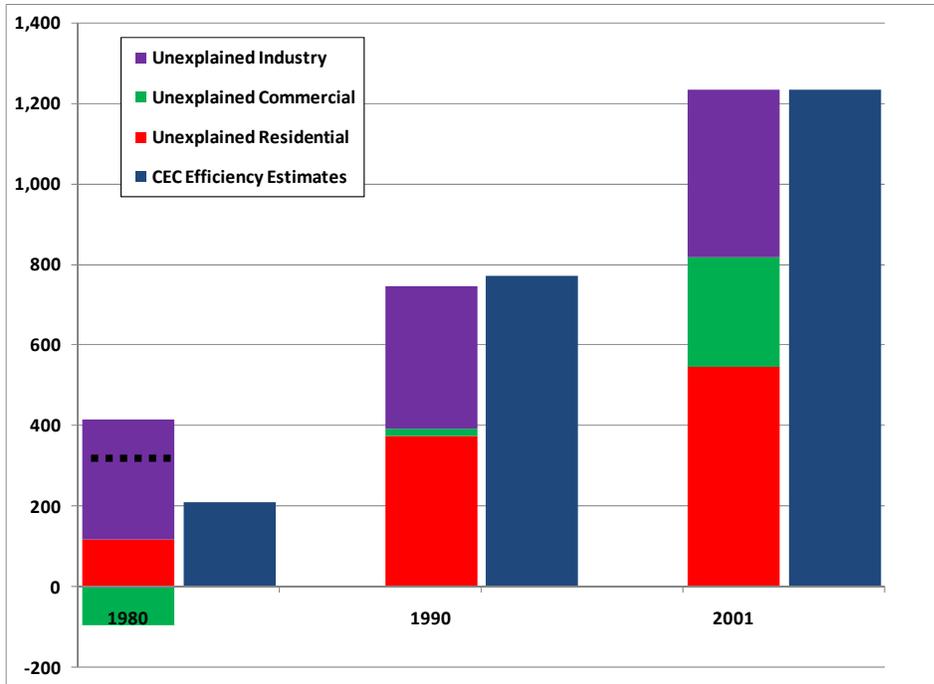


Figure 5. A comparison of CEC savings estimates with upper bound estimates of policy savings, at three time points in the past

In addition, for the residential and commercial sector we can graph the actual California per capita consumption, the impacts of the various factors, and the “unexplained” per capita reductions. However, it is not possible to do so consistently over time because of the NAICS classification in 1997.

Figure 6 shows the data from the residential sector; Figure 7 shows the data from the commercial sector. The qualitative trend of increasing per capita electricity consumption, and an increasing role for policy measures with time, is reflected in our estimates.

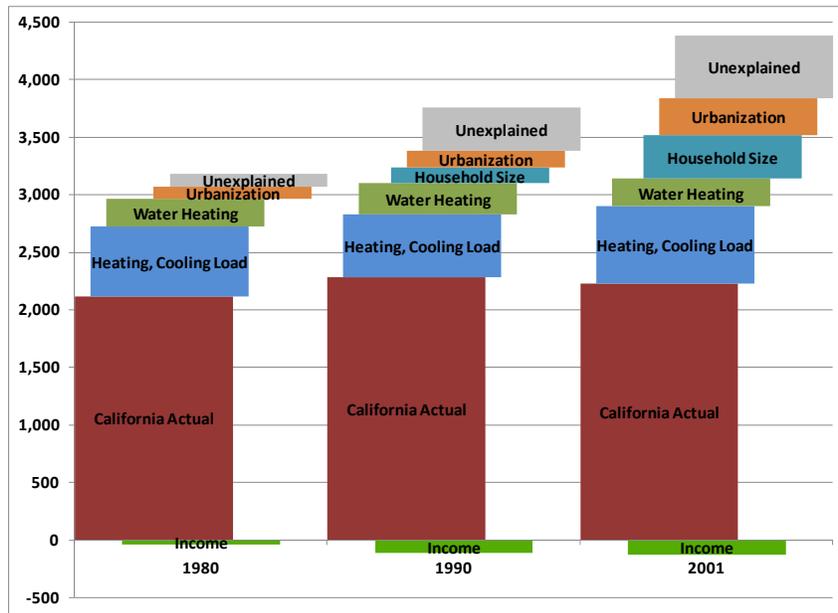


Figure 6. Impacts on Per Capita Residential Sector Consumption: Three Years

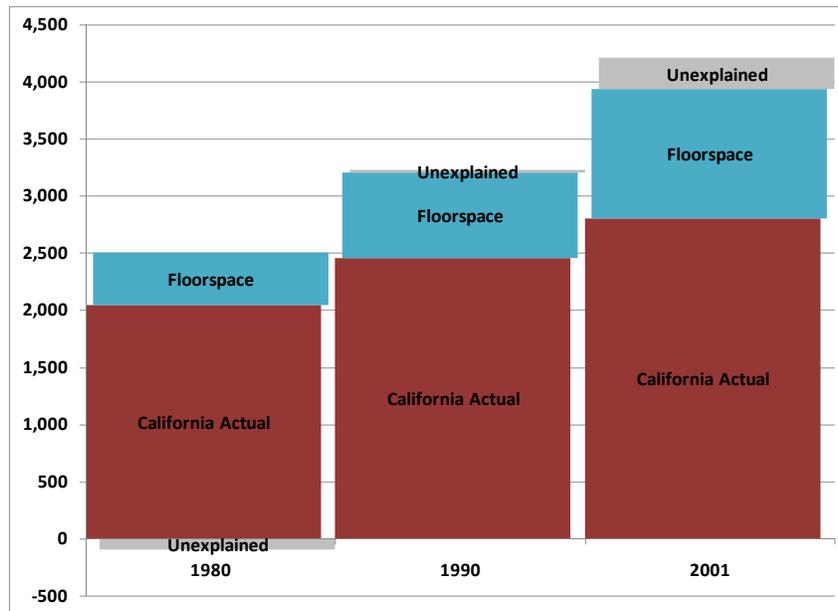


Figure 7. Impacts on Per Capita Commercial Sector Consumption: Three Years

The residential sector “unexplained” reduction grows over time, as does the differential that is explained by the various factors. The climate advantage – heating and cooling load – remains roughly constant over time, as does the differential associated with the low fraction of electric water heating. However the impacts of household size and of urbanization grow sharply over time, accounting for a large share of the difference between California and US per capita residential consumption¹².

For the commercial sector, in 1990 nearly all historical differences between the state and nation can be explained by floorspace differences, with virtually no difference “unexplained.” In 1980, the “unexplained” amount was a small negative number; the California-US differential was smaller than would be expected based simply on differences in the mix of commercial activities and the amount of floorspace.

The industrial sector shows an only slowly growing “unexplained” reduction. However, the change of sectoral definitions makes the industrial sector difficult to compare over time. And it is unlikely that the industrial sector policy impacts in 1980 are 3/4 as large as in 2001. Thus it is likely that other factors, including the high price of electricity in California, explain the relatively constant “unexplained” industrial sector differential.

8 Discussion and Conclusions

The purpose of this work is to estimate what fraction of the difference between California and the United States is the result of policy independent characteristics such as climate or demographics, and what fraction may be due to proactive policy measures aimed at saving energy. In order to accomplish this, we estimate the effect of various policy independent factors and successively subtract their contribution from the overall difference.

We recognize however that there is room for significant improvement in this effort. First, our methodology needs to be seen as an attempt to explain the Rosenfeld curve, i.e the difference between California and US (including California) electricity consumption. Our results do not therefore correct for spillover affects into other states due to California’s policies¹³. Accounting

¹² Some examples from the residential sector show how household characteristics have changed to increase the electricity gap between state and nation. California’s average household size rose from 2.5 in 1970 to about 2.92 in 2001. The US in contrast showed declining household sizes, from 3.11 members in 1970 to 2.59 in 2001. Similarly with rising air-conditioning and heating appliance saturation over time, the effect of climate differences has increased as well.

¹³ In the case of refrigeration for example, there is evidence indicating that California’s minimum energy efficiency standards increased the efficiency of refrigerators sold in the US as a whole well before federal standards were adopted.

for such spillover benefits is a difficult task, but to the extent they exist, they make state policy even more significant than this type of comparison can reveal.

Secondly, we acknowledge that there exist potential endogeneity problems in two areas. The first involves indirect influences of policy on some of the other explanatory factors we have studied¹⁴. The second, potentially more serious, concern involves possible correlations among household characteristics. This is not an issue for those variables for which we have directly estimated end use electricity consumption needs (such as cooling and heating), but is a potential problem for others. In order to statistically estimate and correct for such dependence we would need enough additional sample points - in this case obtainable only from spatial or time series data. Unfortunately household energy use data for California has been collected by the EIA only in recent years¹⁵ and is not available even in those years for almost all states (excepting the 4 largest). Correcting for this is an important objective for future research into this problem, though a complete treatment does not seem possible without data from many more states becoming available. In the present analysis, we attempt to minimize the effects of such correlations by subjectively taking into account cases where strong correlations are intuitively expected. For example, though both housing floorspace and geographical location (urban/rural) are individually significant effects, we include only one in our final estimate of the policy independent share because it seems likely that the two would be significantly correlated.

Finally it would be desirable in subsequent work to carry out a more detailed historical analysis (going back beyond 1980), as well as to separately estimate the effect (if any) of what seem to be real lifestyle differences between California and the average US citizen. This last question is of particular interest because public education campaigns are an important policy tool, whose efficacy is currently not estimated by the California Energy Commission.

¹⁴ However we do feel that in cases where there are hidden second order effects of policy on other variables, there are benefits in not assigning the “credit” for those effects to policy, insofar as this allows us to judge policy against its claimed and intended consequences.

¹⁵ Since the 1997 RECS to be precise, which is also part of the reason for having to make some of the assumptions referred to in Section 6.

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