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Electricity Use in California:
Past Trends and Present Usage Patterns

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Abstract

This paper provides a general overview of electricity consumption and peak load in California, by both sector and end-use. We examine the growth in electricity demand between 1980 and 2000, as well as the composition of electricity end-uses in 1999. One of the main conclusions from this analysis is that electricity use in California in the 1990s did not grow explosively, nor was the amount of growth unanticipated. In both absolute and relative terms, growth in electricity use was greater in the 1980s than the 1990s. During the 1990s, most of the growth in electricity use has been in the buildings sector, particularly commercial buildings. In 2000, the building sector accounted for 2/3 of annual electricity consumption and 3/4 of the summer peak load.

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Introduction

One of the most important lessons of the past 30 years of energy policy is that analyzing how people use energy, and how energy use changes over time, can yield important policy insights. Yet this lesson has largely been ignored in the popular discussion of the California electricity crisis. To help fill this information gap, this paper provides a general overview of electricity consumption and peak load in California. We examine the growth in electricity demand over the last twenty years, as well as the current composition of electricity end-uses. The analysis presented in this paper is primarily based on data compiled by the California Energy Commission. We do not address the functioning of electricity markets in California. This topic has been extensively covered in the popular press, and Faruqui et al. (2001) summarize academic studies that have been conducted to explain and draw lessons from California's power crisis.

Definitions

To avoid confusion and allow accurate comparisons, it is important to first define key terms. We use the term *electricity use* to refer generally to electricity consumption measured over any period. This includes both *annual consumption* (energy) and *instantaneous load* (power). *Peak load* is the maximum simultaneous electricity demand for some portion of the electrical system, typically averaged over an hour. *End-use peak load* is measured at the customer's electricity-using equipment; thus, it includes loads served by self-generation. *System peak load* is measured at the power plant busbar, representing the load served by generating plants[1]. The simultaneous peak load for all end-users (e.g., statewide) is referred to as the *coincident peak load*. Subgroups of end-users (e.g., a utility service territory, or all industrial customers) will have their own simultaneous peak load, which is referred to as *non-coincident peak load* for a sector or customer class. Many analysts use the terms *demand* and *load* interchangeably.

Sectoral Electricity Use Trends

To investigate California's electrical demand, we start with aggregate statewide consumption. Table 1 illustrates the extent to which California's electrical consumption and summer peak load have grown over the last twenty years (CEC, 1998; Rohrer, 2001). The first observation about these data is that annual consumption and peak load are both about 50% larger in 2000 than they were in 1980. Looking at the absolute growth by sector, consumption and peak load increased the most in commercial buildings, followed by residential buildings, and then industry. In percentage terms, electricity consumption and load have grown over the last two decades at just over 2% per year, with the highest growth rate observed in commercial buildings. Growth was highest during the 1980-1990 period. The recession of the early 1990s resulted in slower growth between 1990 and 1995.

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[1] System loads are reported by utilities to the Federal Energy Regulatory Commission (FERC).

Table 1: Historical Trends in California Electricity Consumption and Economic Indicators

Indicator	Sector	Year					% Annual Growth[c]			
		1980	1985	1990	1995	2000	1980-2000	1980-1990	1990-2000	1995-2000
Annual Electric	Residential	52	59	68	70	78	2.0%	2.7%	1.4%	2.1%
Consumption[a]	Commercial	50	59	75	81	92	3.1%	4.1%	2.1%	2.6%
(TWh)	Industrial	42	46	51	51	55	1.3%	1.9%	0.7%	1.7%
	Agricultural	13	17	21	14	18	1.5%	4.6%	-1.4%	4.7%
	Other	10	12	14	16	15	2.4%	3.7%	1.2%	-0.4%
	Total	167	193	228	231	258	2.2%	3.2%	1.2%	2.2%
Annual Electric	*Residential*	*1.00*	*1.12*	*1.30*	*1.34*	*1.49*				
Consumption	*Commercial*	*1.00*	*1.18*	*1.50*	*1.62*	*1.84*				
(index: 1980=1)	*Industrial*	*1.00*	*1.09*	*1.21*	*1.20*	*1.30*				
	Agricultural	*1.00*	*1.29*	*1.56*	*1.08*	*1.36*				
	Other	*1.00*	*1.23*	*1.44*	*1.65*	*1.62*				
	Total	*1.00*	*1.16*	*1.37*	*1.38*	*1.54*				
Peak Load[b]	Residential	13	14	14	17	18	1.7%	1.2%	2.2%	1.2%
(GW)	Commercial	10	12	17	16	19	3.4%	5.3%	1.6%	4.2%
	Industrial	6	7	8	7	9	1.8%	2.6%	1.1%	3.3%
	Agricultural	2	3	3	2	2	0.2%	3.8%	-3.3%	0.4%
	Other	2	2	3	3	3	2.6%	3.7%	1.6%	1.9%
	Total	33	37	45	45	51	2.3%	3.1%	1.4%	2.6%
Peak Load	*Residential*	*1.00*	*1.11*	*1.13*	*1.31*	*1.40*				
(index: 1980=1)	*Commercial*	*1.00*	*1.18*	*1.67*	*1.59*	*1.95*				
	Industrial	*1.00*	*1.07*	*1.29*	*1.22*	*1.44*				
	Agricultural	*1.00*	*1.16*	*1.45*	*1.01*	*1.03*				
	Other	*1.00*	*1.14*	*1.44*	*1.52*	*1.68*				
	Total	*1.00*	*1.13*	*1.36*	*1.37*	*1.57*				
Gross State Product										
(1996 $billions)		$575	$718	$923	$943	$1,260	4.0%	4.8%	3.2%	6.0%
(index: 1980=1)		*1.00*	*1.25*	*1.61*	*1.64*	*2.19*				
State Population										
(millions)		23.8	26.4	29.9	32.1	33.9	1.8%	2.3%	1.2%	1.1%
(index: 1980=1)		*1.00*	*1.11*	*1.26*	*1.35*	*1.42*				
Housing Units										
(millions)		9.3	10.0	11.2	11.8	12.2	1.4%	1.9%	0.9%	0.8%
(index: 1980=1)		*1.00*	*1.08*	*1.21*	*1.27*	*1.32*				
Service Employment[d]										
(millions)		6.8	7.7	9.2	9.5	11.0	2.4%	3.1%	1.8%	3.0%
(index: 1980=1)		*1.00*	*1.13*	*1.35*	*1.39*	*1.61*				

Notes to Table 1:

[a] Annual electric use is site electricity consumption at the customer's meter.

[b] Peak load is the end-use load, excluding transmission and distribution losses, and including loads served by self-generation. Statewide peak load is the sum of non-coincident loads from the utility service territories.

[c] Annual growth is expressed as compound annual growth rates.

[d] "Service" employment consists of all workers not employed in the agricultural, mining, construction, or manufacturing sectors. Data on service employment are not yet available for 2000. We assumed the 1999 ratio of non-manufacturing to total non-agricultural employment applies to 2000 as well.

Table 1 Data Sources:

Annual Electric Use:

1980-1997: 1998 Baseline Energy Outlook, California Energy Commission (CEC, 1998).

1998-2000: 2000 California Energy Demand, California Energy Commission(CEC, 2000a).

Peak Load:

1980-1996: 1998 Baseline Energy Outlook, California Energy Commission(CEC, 1998).

1997-2000: 2001 California Energy Demand, California Energy Commission(Rohrer, 2001).

Gross State Product:

1980-1998: Bureau of Economic Analysis, U.S. Department of Commerce (BEA, 2000).

1999-2000: Estimate from California Department of Commerce (OER, 2000).

Constant dollars estimated using GDP deflator from Bureau of Economic Analysis, U.S. Department of Commerce (BEA, 2000).

State Population:

1980-1999: California Statistical Abstract, Table B-1 (based on Census Bureau data) (CA Department of Finance, 2000)

2000: U.S. Department of Commerce, Bureau of the Census, Year 2000 Census (US Bureau of the Census, 2001).

Housing Units:

1980-1998:U.S. Census Bureau, U.S. Department of Commerce (US Bureau of the Census, 1999).

2000: California Statistical Abstract, Table I-10 (CA Department of Finance, 2000).

Service Employment:

1980-1999: California Statistical Abstract, Table C-3 (CA Department of Finance, 2000).

2000: California Department of Finance. 2001 California Economic Indicators, Jan/Feb. (CA Department of Finance, 2001).

Interestingly, both annual consumption and peak load have grown at similar rates, suggesting that overall electricity use is not becoming significantly “peakier.” Commercial buildings and industry are somewhat more peak-dominated in 2000 (i.e., peak load has grown more rapidly than annual consumption), compared to residential buildings and agriculture. This finding for residential buildings is somewhat surprising, in light of the increasing saturation of residential cooling, which contributes greatly to peak load. One possible explanation is that strong growth in the residential miscellaneous end use (which tends to have a relatively flat load shape) is offsetting growth in residential cooling. However, we currently do not have the data to validate this hypothesis.

The share of overall electricity use due to buildings has grown only slightly over the past two decades, while commercial buildings have become a larger share of building-sector electricity use. During this time, the building sector has grown from 61% to 66% of all electricity consumption and from 69% to 72% of peak load. This trend is expected to continue in the future (CEC, 2000a).

One of the often-cited indicators of electricity use is the number of households that can be served by one MW of generating capacity. The rule-of-thumb typically used is 1000 households per MW of capacity, implying a load of one kW per household, although we are not aware of a source that documents this value. Using the CEC data presented here, we examine how appropriate this value is for California households. As indicated in Table 2, the average annual load for a typical California household is only three-fourths as large as the rule-of-thumb value, while the peak load is approximately 50% larger. Thus, one MW of capacity can serve about 1200 California homes on average, or about 600 homes at peak. Table 2 also shows significant variation in these values between utilities.

It is worth noting here some of the details about the data that affect our calculation of growth rates. First, peak load varies somewhat from year-to-year due to factors such as weather, economic activity, and load curtailment programs. Thus the selection of a beginning and end year from which to calculate trends can affect the observed growth rate, particularly over time periods shorter than ten years. Extreme summer weather can cause up to a 5-8% increase in peak load, compared to a typical year (CEC, 2000a). We did not weather-normalize the load data reported here. In addition, the loads reported here include the effect of load curtailment programs (in other words, end-use loads do not include loads that were interrupted). Since the California Independent System Operator (CA ISO) began operation in 1998, summer peak loads in the ISO control area have been slightly more than 45,000 MW each year. In 1998 through 2000, interrupted loads on the peak days were 1337 MW, 0 MW, and 1710 MW, respectively (CAISO, 2000). These data suggest that there is not a simple relationship between the aggregate peak load and the amount of load curtailed. Adding the interrupted loads to the end use loads reported here would slightly increase the growth rates reported in Table 1 (with most of the effect concentrated in the industrial sector). Because we do not make this adjustment here, the data presented in this paper do not represent end-use load growth in an "unconstrained" market, but accurately portray the realities of the current electricity market.

Table 2: Average Electricity Use per California Household, 1999

	Los Angeles Dep't. of Water & Power	Pacific Gas & Electric	Southern California Edison	San Diego Gas & Electric	Sacramento Municipal Utility District	Statewide Total
Residential Customers[a] (millions)	1.2	4.0	3.8	1.1	0.4	11.3
Aggregate Residential Consumption[b] (TWh)	7.1	29.5	25.9	6.3	4.0	75.4
Aggregate Residential Peak Load[b] (GW)	1.5	6.9	6.2	1.2	1.4	17.2
Annual consumption (MWh/customer)	5.9	7.4	6.9	6.0	9.0	6.6
Average T&D loss[c]	13%	9.0%	6.5%	6.9%	6.4%	8.1%
Peak T&D loss[c]	11%	9.3%	7.4%	9.3%	9.0%	8.6%
Capacity needed to meet average load[d,e] (kW/customer)	0.8	0.9	0.8	0.7	1.1	0.8
Customers served by MW of capacity on average	1,300	1,100	1,200	1,400	900	1,200
Capacity needed to meet peak load[e] (kW/customer)	1.3	1.9	1.8	1.3	3.4	1.6
Customers served by MW of capacity at peak	800	500	600	800	300	600

[a] Residential customers are for 1998, as reported in CEC (1999a).
[b] Annual consumption and peak load data are from CEC (Tian, 2001). Peak load is the statewide residential-sector non-coincident peak load.
[c] Transmission and distribution losses are from CEC (CEC, 2000a), expressed relative to end-use consumption or load. Losses for LADWP are higher than other utilities because they include losses associated with the north-south DC transmission inter-tie (CEC, 1995). Peak losses for LADWP are lower than average losses because their generating plants within the Los Angeles air basin tend to only run at peak times, due to air quality regulations. These in-basin plants have lower transmission losses than do plants outside the basin.
[d] Average load = annual consumption ÷ 8760 hours.
[e] "Capacity needed to meet load" includes T&D losses but does not consider residential self-generation.

Second, many of the data presented in this paper are estimates and therefore somewhat uncertain. The values for annual consumption are the most accurate because they are based on metered consumption for the purpose of customer billing. The end-use peak load values are more uncertain because there is relatively little load metering conducted on an ongoing basis. To improve accuracy, these estimates are calibrated to actual load and weather data whenever possible. Despite the inaccuracies, these data are accurate enough to provide a general picture of how and when electricity is used in California, which is the purpose of this analysis.

Factors Contributing to Electricity Growth

Media reports about the California electricity crisis often cite "explosive" load growth as a root cause of the problem. Some reports attribute the growth to unanticipated end uses such as the Internet, cell phones, and other new devices. The data in Table 1 suggest that on the contrary, load growth has been modest (in percentage terms) over the last decade and, in fact, lower than the growth during the 1980s (in both absolute and relative terms). In terms of annual growth rate, electricity consumption grew over the second half of the 1990s at a lower rate than any other 5-year period during the 20th Century–except for the Depression and the oil crisis years of the early 1970s (Williams, 1997).

Other explanations for the electricity crisis sometimes site "unanticipated" load growth as a contributing factor. The CEC recently examined the accuracy of their electric peak load forecasts dating back to 1988 and found that they generally *over*estimated peak load (CEC, 2001a), indicating that the demand growth was not unanticipated. Moreover, the CEC load forecasts were generally off by 5% or less (3,000 MW or less in absolute terms) from the actual statewide peak load. We analyzed the 1990 CEC electricity forecast (CEC, 1990) in more detail to determine how accurate that forecast was at the sectoral level. The period analyzed is 1987 to 2000[2]. Figure 1 compares growth in electricity consumption, as forecast and actually realized, while Figure 2 compares load growth. The 1990 forecast anticipated 11% greater growth in consumption and 30% greater peak load growth than actually occurred. Some of this difference can be attributed to the economic recession of the early 1990s (CEC, 2001a), which was not anticipated by the forecasters in 1990.

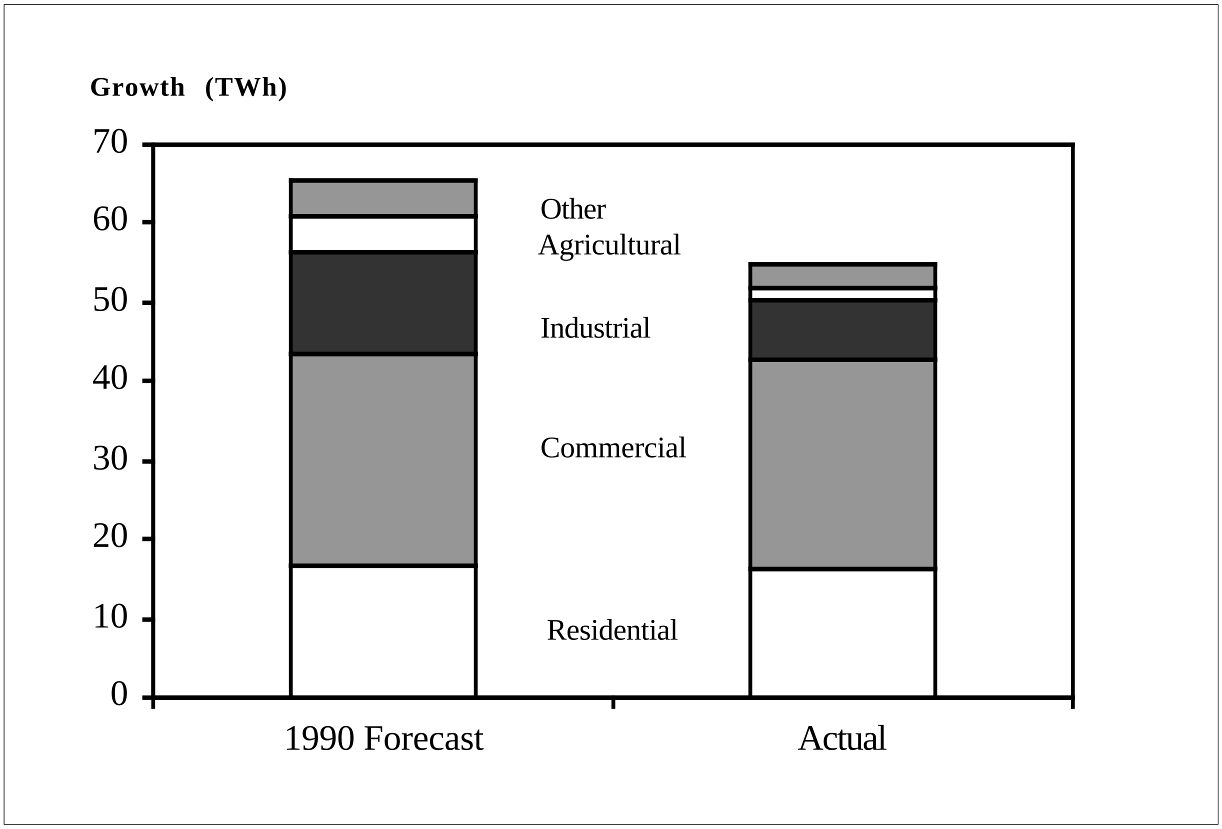
We find that the buildings sector (particularly commercial buildings) was responsible for nearly 80% of the actual consumption and load growth, which is a somewhat higher fraction than the CEC had anticipated. Correspondingly, the agricultural and "other" sectors grew more slowly than expected. In absolute terms, the CEC's forecast of electricity consumption growth in the building sector was within 1% of the actual growth that occurred. While there is undoubtedly an element of luck in this result (and keep in mind we did not weather-normalize the observed demand data), it is nonetheless a very accurate long-term forecast. The relative accuracy of the sectoral forecasts also reflects the fact that our understanding of electricity use in the building sector is much more advanced than that of the other sectors.

In examining trends over time, one looks for related indicators that can help explain and better understand these trends. Table 1 summarizes several readily available indicators of economic activity to compare their growth rates to that of electricity use. Attributing causality to any of these factors is beyond the scope of this analysis, but examining these factors helps

[2] The CEC forecast is for the year 2001. We estimated the consumption in 2000 using the 1995-2001 compound annual growth rate.

provide context for understanding changes in electricity use. We find that electricity use (both consumption and load) has grown more slowly than the state's economy, as measured by Gross State Product (BEA, 2000; OER, 2000). This is particularly evident in the last five years, when electricity use has grown at less than half the rate of the overall economy.

Figure 1: Comparison of Forecast and Actual Electricity Consumption Growth, 1987 to 2000. Forecast values for 2000 were estimated using the 1995-2001 compound annual growth rate. Source: California Energy Commission data (CEC, 1990; 1998; 2000a).

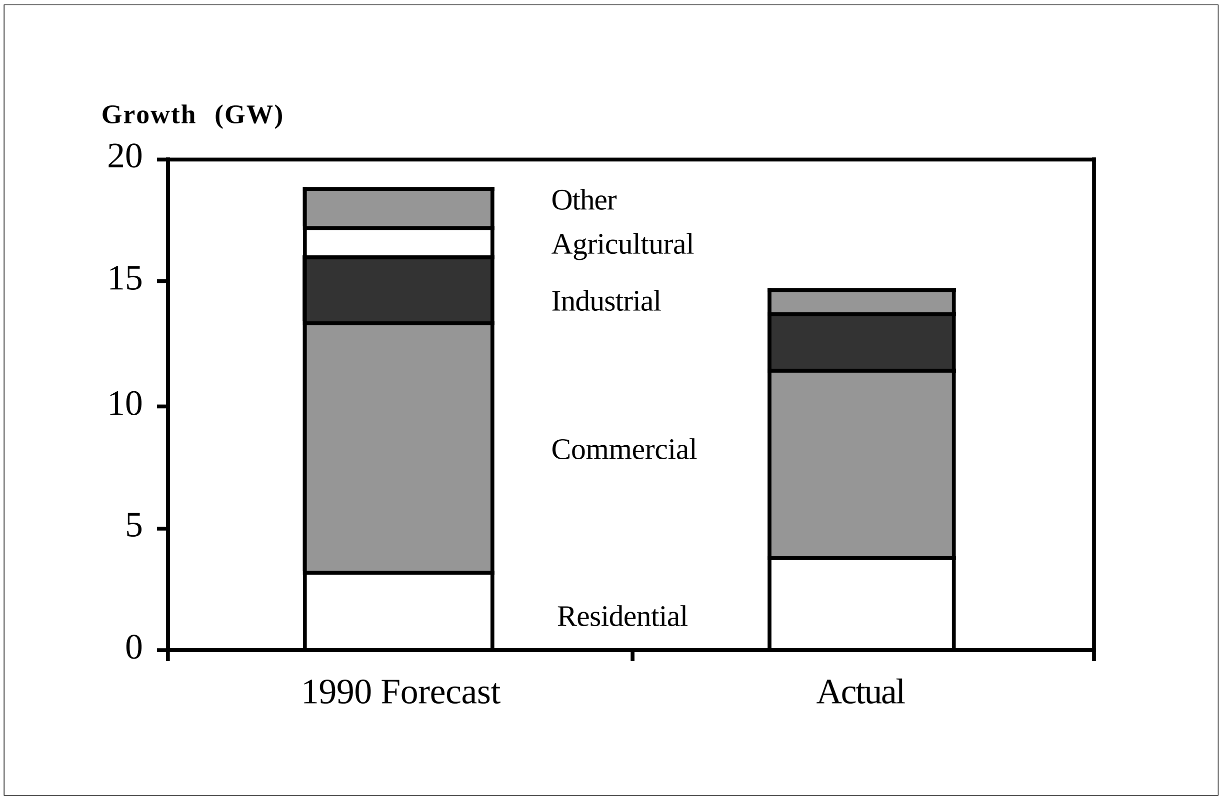


We also examined population growth (CA Department of Finance, 2000; US Bureau of the Census, 2001), since it is generally considered an important driver of energy use. Over the last twenty years, growth in electricity use has been slightly larger than population growth (approximately 2% annual growth). The residential energy growth rate is most similar to the population growth rate (although this relationship seems to have diverged in the last five years, with residential energy consumption growing faster).

The number of housing units is also a factor in electricity growth, particularly the residential sector. These data indicate that residential electricity use in California is growing more quickly than the stock of housing units (CA Department of Finance, 2000; US Bureau of the Census, 1999). This could be due to more persons per household (CEC, 2000a) and increasing saturation of electricity-using devices.

Finally, we examined "service" (non-agricultural, non-manufacturing) employment as an indicator of activity in commercial buildings (CA Department of Finance, 2000, 2001). Service employment has grown more slowly than commercial building electricity consumption, except during the last five years when employment grew slightly faster than electricity consumption. Peak load in commercial buildings has grown even more rapidly than consumption, thus even further outpacing employment growth. These data suggest that commercial buildings are becoming more electricity-intensive per employee, which is consistent with the observed trends of increased office automation and more intensive space conditioning. A recent study by Davis, Sanstad, and Koomey (2001) quantified the contribution of certain factors such as weather and fuel mix to changes in electricity use at the national level. This methodology could also be used to examine changes in electricity use in California.

Figure 2: Comparison of Forecast and Actual Electricity Peak Load Growth, 1987 to 2000. Forecast values for 2000 were estimated using the 1995-2001 compound annual growth rate. 2000 actual peak load growth for the agriculture/water pumping sector does not appear in this figure because it was a decrease of 300 MW. Source: California Energy Commission data. (CEC, 1990; 1998; 2000a).



A previous study by Schipper and McMahon (1995) analyzed historical energy consumption in California to assess the causes of changes in consumption. That study found that residences in California became less energy intensive[3] over the period 1970-1993, due to both structural effects (e.g., shifts in fuel shares) and efficiency effects (e.g., improvements in appliance efficiency). They also found that commercial-building electricity intensity increased very slightly (5% in total) over the period 1975-1991, mainly driven by increases in office equipment and air conditioning intensity in office buildings. At the same time, their data show

[3] Energy intensity in this context is a measure of energy consumption per unit of activity (such as heated or cooled floor area). Schipper and McMahon did not provide data on changes in residential *electricity* intensity.

that aggregate commercial-sector electricity consumption increased approximately 50% over a 19-year period (1975-1993). This aggregate growth is consistent with the data in Table 1, and suggests that buildings in California have become less energy intensive since 1975. These gains, however, have been more than offset by increases in building sector activity (number of buildings, floor area per building, etc.). In examining the manufacturing sector, Schipper and McMahon again found that industry in California became less energy intensive over the period 1978-1990, but that these gains were offset by increases in activity (e.g., manufacturing output).

Another previous study of electricity use in California (Mills and Rosenfeld, 1987) also found that from 1977 to 1984, absolute electricity consumption in California grew at a rate of 1.4% per year. However, at the sectoral level, electricity intensity (measured by electricity consumption normalized to economic activity within the sector) was declining at a rate of 0.5% to 3% per year. This supports the hypothesis that gains in California electricity efficiency were more than offset by increased population and economic activity.

California Electricity End-Uses

We now analyze the composition of end-use electricity consumption and loads in 1999, based on data from the CEC forecasting models (Tian, 2001). 1999 is the latest year for which historical data are available (1999 is a representative year but electricity use will vary from year-to-year). Table 3 presents these data for end-uses within the buildings sectors, as well as the other sectors. Table 4 presents these same indicators for sub-sectors within the industrial sector. The rightmost three columns in Tables 3 and 4 compare annual consumption to peak load for each end-use–the alternative indicators provide different "views" of the same electricity-usage hours. Load factor is the ratio of average annual load to peak load, and is a measure of the "peakiness" of a particular load. We provide MWh/kW because it is a useful parameter for comparing demand- and supply-side technologies using screening curves (Koomey et al., 1990a; Koomey et al., 1990b).

The sectoral breakdown of the 1999 peak load is dominated by the buildings sector, which accounts for about 73% of the statewide peak load. On an energy basis, buildings consume about two-thirds of the state's annual electricity. Within the building sector, the top two end-uses on a peak load basis are residential and commercial cooling, which account for over 40% of building sector load and nearly 30% of total load. The hot, dry characteristics of the California climate lead to cooling loads that are dominated by conduction and solar gains, with significant diurnal temperature swings. This leads to cooling loads that peak sharply in the late afternoon, and consequently electrical loads as well. On the other hand, cooling accounts for less than 10% of annual electricity consumption, which is reflected in the low load factors for these end-uses reported in Table 3. Interior lighting in commercial buildings is another significant end-use, in terms of both peak load and annual consumption.

Another interesting observation from Table 3 is that the fifth and sixth largest end-uses are "miscellaneous," meaning various devices with annual electricity consumption that are not tracked separately. In the residential sector, the more significant components of "miscellaneous" include lighting, portable and whole-house fans, and consumer electronics. In the commercial sector, "other" includes office equipment, portable fans, and task lighting. Another surprisingly large end-use is residential dryers, both in peak and energy terms.

Table 3: 1999 California Electricity Consumption and Peak Demand by End Use

Sector & End-Use	Coincident Load		Annual Energy		Load	MWh/	kW/
	GW	% of Total	TWh	% of Total	Factor[b]	kW	MWh
Commercial Sector							
Air Conditioning	7.1	14%	13.8	5%	22%	1.9	0.51
Interior Lighting	5.4	11%	30.3	12%	64%	5.6	0.18
Other	3.1	6%	19.9	8%	73%	6.4	0.16
Ventilation	1.7	3%	9.1	4%	62%	5.5	0.18
Refrigeration	0.9	2%	6.5	3%	87%	7.7	0.13
Office Equipment	0.3	1%	1.6	1%	69%	6.1	0.16
Domestic Hot Water	0.1	0%	0.5	0%	53%	4.6	0.22
Exterior Lighting	0.1	0%	5.0	2%	606%	53.1	0.02
Cooking	0.1	0%	0.6	0%	77%	6.8	0.15
Space Heating	0.0	0%	2.1	1%	-	-	0.00
Total - Commercial	18.7	38%	89.5	36%	55%	4.8	0.21
Residential Sector							
Air Conditioning	7.5	15%	4.8	2%	7%	0.6	1.56
Miscellaneous	3.1	6%	24.6	10%	92%	8.1	0.12
Refrigerator	1.8	4%	13.7	5%	85%	7.5	0.13
Cooking	1.2	2%	3.6	1%	33%	2.9	0.34
Dryer	0.9	2%	5.7	2%	71%	6.2	0.16
Pools & Spas	0.8	2%	4.1	2%	60%	5.3	0.19
Domestic Hot Water	0.6	1%	4.2	2%	86%	7.5	0.13
Television	0.5	1%	3.4	1%	83%	7.3	0.14
Freezer	0.3	1%	2.5	1%	83%	7.3	0.14
Dishwasher	0.3	1%	2.0	1%	71%	6.2	0.16
Waterbed Heater	0.1	0%	2.1	1%	175%	15.3	0.07
Clothes Washer	0.1	0%	0.7	0%	75%	6.6	0.15
Space Heating	0.0	0%	4.0	2%	-	-	0.00
Total - Residential	17.2	35%	75.4	30%	50%	4.4	0.23
Industrial Sector							
Assembly	5.4	11%	33	13%	71%	6.2	0.16
Process	2.0	4%	14	6%	79%	6.9	0.14
Other	0.9	2%	6.1	2%	78%	6.8	0.15
Total - Industrial	8.3	17%	53.5	21%	73%	6.4	0.16
Agricultural Sector							
Total - Agricultural	2.3	5%	17.8	7%	88%	7.7	0.13
Transport & Street Lighting							
Total - Transport & St. Ltg.	2.9	6%	15.3	6%	60%	5.3	0.19
Statewide Total							
Total - Statewide[a]	49.6	100%	251.6	100%	58%	5.1	0.20

Source: CEC Demand Analysis Office (Tian, 2001).

[a] Statewide coincident load is estimated using utility-level coincidence factors from Table 5.

[b] Load Factor is the ratio of average annual load to coincident peak load. The load factors for commercial exterior lighting and residential waterbed heaters are very high because their consumption is mainly off-peak.

Table 4: 1999 California Industrial Electricity Consumption and Peak Demand

	Coincident Load		Annual Energy		Load	MWh/	kW/
	GW	% of Total	TWh	% of Total	Factor[b]	kW	MWh
Assembly Industries							
Electronics & Electric Equip.	1.0	2%	5.6	2%	67%	5.8	0.17
Food Products	0.8	2%	4.2	2%	62%	5.4	0.19
Chemicals	0.5	1%	3.9	2%	83%	7.2	0.14
Transportation Equipment	0.5	1%	3.2	1%	72%	6.3	0.16
Computers & Machinery	0.5	1%	2.9	1%	68%	6.0	0.17
Rubber & Plastics	0.4	1%	2.3	1%	74%	6.4	0.16
Instruments	0.3	1%	1.9	1%	64%	5.6	0.18
Fabricated Metal Products	0.3	1%	2.0	1%	74%	6.5	0.15
Primary Metal Industry	0.3	1%	2.1	1%	93%	8.1	0.12
Printing & Publishing	0.2	0%	1.3	1%	69%	6.0	0.17
Paper Products	0.2	0%	1.4	1%	76%	6.7	0.15
Apparel & Textiles	0.2	0%	0.9	0%	59%	5.2	0.19
Stone & Clay Products	0.1	0%	1.0	0%	78%	6.9	0.15
Miscellaneous	0.1	0%	0.4	0%	73%	6.4	0.16
Furniture & Fixtures	0.1	0%	0.3	0%	69%	6.1	0.16
Total - Assembly	5.4	11%	33.5	13%	71%	6.2	0.16
Process Industries							
Petroleum Refining	1.1	2%	7.8	3%	82%	7.1	0.14
Food Processing	0.3	1%	1.6	1%	63%	5.6	0.18
Glass & Cement	0.3	1%	2.2	1%	85%	7.5	0.13
Pulp & Paper	0.2	0%	1.2	0%	79%	6.9	0.14
Lumber & Wood Products	0.2	0%	1.1	0%	80%	7.0	0.14
Total - Process	2.0	4%	13.9	6%	79%	6.9	0.14
Other Industries							
Oil & Gas Extraction	0.7	1%	5.0	2%	81%	7.1	0.14
Construction	0.2	0%	0.9	0%	59%	5.1	0.19
Metal Mining	0.0	0%	0.2	0%	83%	7.3	0.14
Total - Other	0.9	2%	6.1	2%	78%	6.8	0.15
Statewide Industry							
Total - Industrial[a]	8.3	17%	53.5	21%	73%	6.4	0.16

Source: CEC Demand Analysis Office (Tian, 2001).
[a] Statewide coincident load is estimated using utility-level coincidence factors from Table 5.
[b] Load Factor is the ratio of average annual load to coincident peak load.

Figure 3: California Electric End-Use Load:Energy Ratio

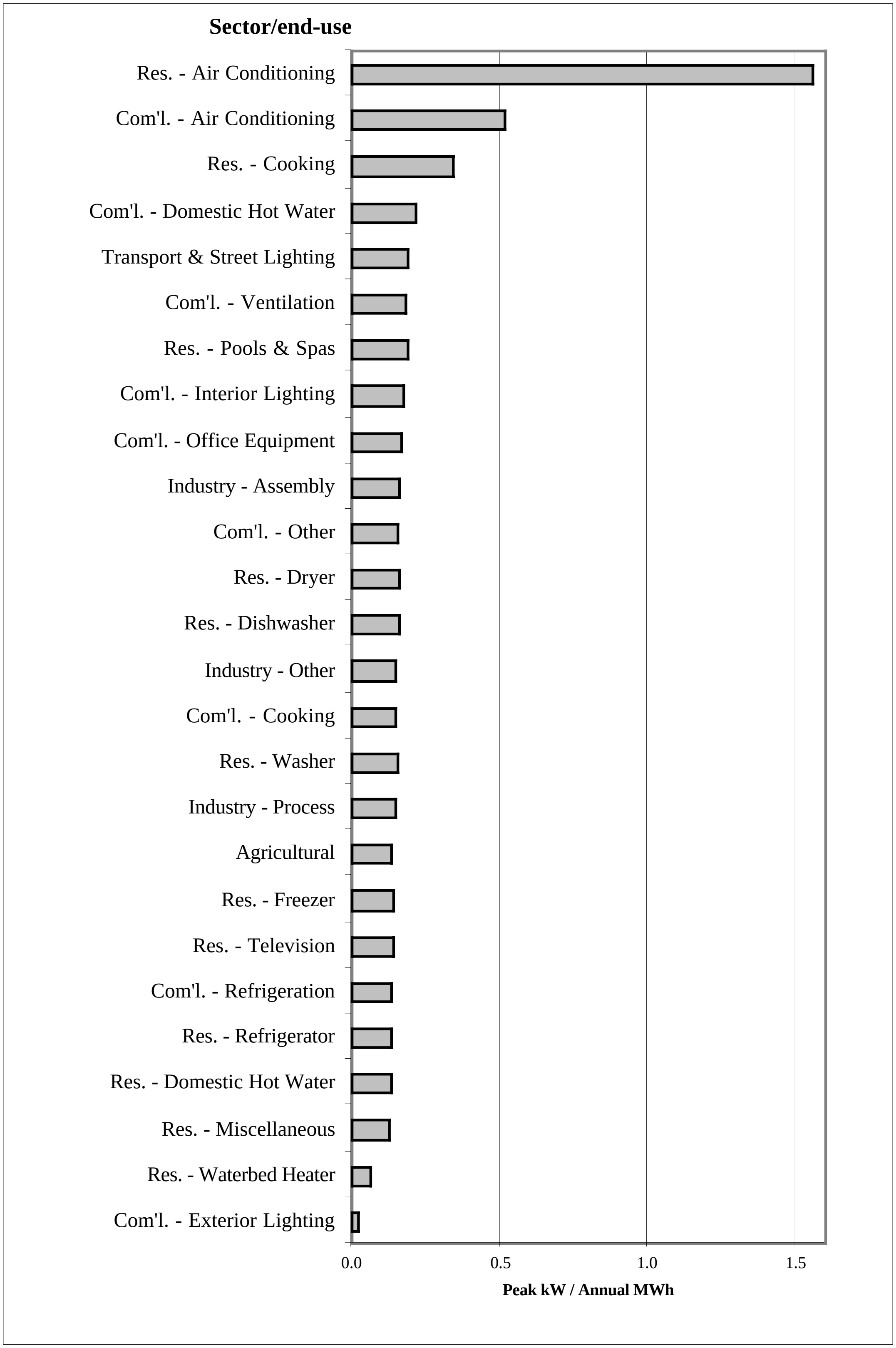


Table 4 indicates that no single sub-sector dominates the industrial sector, as is the case in the buildings sector. Petroleum refining is the single largest sub-sector, followed by electronics and food product manufacturing. Load factors in the industrial sector tend to be higher than the other sectors due to the long operating hours of industrial facilities. The lowest load factors are in the apparel industry (which tends to have shorter operating hours) and food processing (which is a seasonal industry, peaking in the late summer at the same time as electrical loads). To identify the end-uses that most contribute to peak loads, relative to their annual energy impact, we have calculated the load:energy ratio for each end-use (Figure 3).

Cooling in buildings (particularly residences) again dominates the other end-uses, along with residential cooking and commercial water heating. High load:energy ratio (or low load factor) may indicate end-uses that are candidates for load shifting (shifting electricity consumption to non-peak hours).

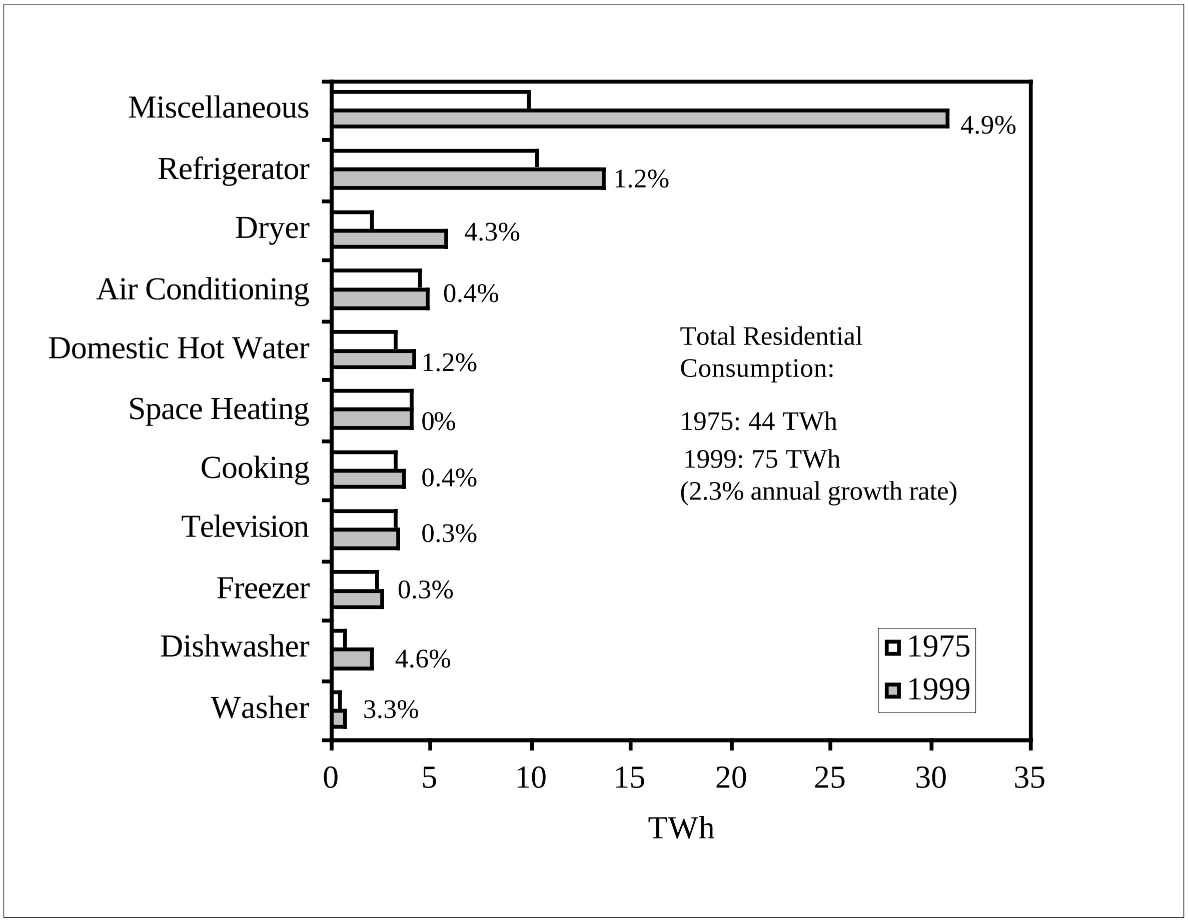
It can be instructive to examine how the composition of end-use electricity consumption changes over time. In past years, the CEC generally did not publish detailed end-use data from its forecasting models. Lacking this time series, we compare the current end-use breakdown for the residential sector to an estimate from 1975 (Berman et al., 1976), shown in Figure 4. In the nearly 25 years between these two studies, aggregate electricity consumption in California residences increased by about 70%. Most of this growth was concentrated in the miscellaneous end-use (which includes lighting, small appliances, consumer electronics, and computers), most likely due to the increasing saturation and usage of these miscellaneous devices.

Refrigerators also showed a significant increase in consumption. This is somewhat surprising because national refrigerator consumption has been decreasing since the mid-1980s due to California and Federal efficiency standards that have driven down unit consumption at a faster rate than the refrigerator stock is expanding. In the 1990s alone, the Energy Information Administration estimates that U.S. residential refrigerator consumption declined from 152 TWh in 1992 to 126 TWh in 1999, a 2.6% annual rate of decline (US DOE, 1995, 2000). Looking back to 1975, however, it is entirely plausible that aggregate refrigerator consumption was lower than in 1999. There were about 50% fewer refrigerators in the stock, these refrigerators were smaller, and they had fewer features (compared to 1999), thus leading to lower unit energy consumption (UEC) (National Research Council, 2001). The aggregate 1975 refrigerator consumption was probably higher than the value cited here, however, due to the exponential retirement model used by Berman et al. This type of model overestimates the number of older units–which at that time consumed less energy–and understates the number of newer ones. Thus, we believe that the increase in aggregate refrigerator consumption since 1975 could be a real phenomenon, although probably not as large as the values in Figure 4 would indicate.

Clothes dryers and dishwashers also exhibited significant consumption growth between 1975 and 1999, primarily due to increasing saturation. Surprisingly, both space heating and air conditioning remained relatively constant, despite a much larger housing stock. We believe this is mainly due to state building energy efficiency standards (Title 24) and efficiency standards for heating and cooling equipment. The finding that statewide air-conditioning consumption is only slightly higher after 25 years is particularly surprising, given that the saturation of central air conditioners is much higher now, and much of the residential construction during that period was in areas with significant cooling loads (central valley and high desert).

Over the last 25 years, the residential sector in California has changed in many ways that would tend to increase electricity use–more housing units, greater floor area, increasing equipment saturation, and more intensive use of appliances. Counteracting these trends, higher electricity prices and energy efficiency policies (both efficiency standards and utility demand-side management programs) have served to reduce electricity use. Our observation that most residential electricity end-uses have had low growth rates (compared to growth in housing units) suggests that the latter factors have predominated, although more research is needed to ensure this is not simply a modeling artifact of the studies examined here.

Figure 4: California Residential End-Use Electricity Consumption (TWh and annualized growth rate). The miscellaneous end-use includes lighting (which was reported separately in the 1975 data), and pools, spas, and waterbed heaters (which were reported separately in the 1999 data). For reference, California had 7.4 million housing units in 1975, and 12.1 million units in 1999 – a 1.7% annual growth rate. Source: 1975 data derived from Berman et al. (1976). 1999 data derived from Sharp (2001) and Tian (2001).



End-use Load Shapes

While Tables 3 and 4 present the peak load shares for a given hour (the peak hour), it is also very useful to estimate the load shares over the entire peak day. This gives a better sense of the demand over time, and can help identify candidates for load shifting. Figure 5 presents the 1999 peak day (July 12, 1999) load shape for the largest building-sector end-uses, along with the non-building sectors. The cooling end-uses have much lower load factors than the other end-uses, thus contributing relatively more to the peak hours. Interestingly, the residential miscellaneous end-use has relatively large non-coincident peak load, but it occurs later in the evening (probably due to lighting and portable fans). Another somewhat surprising observation from these data is the lower than expected coincidence of commercial lighting with the time of peak load. The non-building end-uses have relatively stable loads, thus contribute to peak load less than one would expect based on their energy consumption.

The statewide end-use load shapes were derived as follows. The initial inputs were the forecasted 1999 end-use load shape data for the major California utilities–Pacific Gas and Electric (PG&E), Southern California Edison (SCE), San Diego Gas and Electric (SDG&E), Los Angeles Department of Water and Power (LADWP), and Sacramento Municipal Utility District (SMUD)–from the CEC Hourly Energy and Load Model (HELM) model (Tian, 2001). These were then calibrated to match the sum of utility-coincident sectoral peak loads for each utility that result from the CEC HELM post-processor (CEC, 1995). These utility-level load shapes were then summed to derive a statewide end-use load shape. To ensure this resulting load shape matches the coincident statewide loads, we calibrated the hourly load values to the utility peak coincident system load reported to FERC (FERC, 2000). To derive the statewide system loads, we summed the FERC system load data for CA ISO, Burbank, Glendale, Imperial Irrigation District, and Los Angeles Department of Water and Power. Before calibration, the FERC system loads were translated to end-use loads by applying self-generation factors and T&D losses estimated by CEC (2000a). Load shapes for the Burbank, Glendale, Pasadena (BGP) planning area were based on the SCE end-use load shapes. The load shape for the California Department of Water Resources (DWR) was drawn directly from the FERC data.

In Figure 5, this calibration takes the form of a "residual" which is simply the difference between the CEC and FERC hourly loads. Several factors contribute to this residual, including the fact that the CEC forecasts include only the major utilities, whereas the FERC data include all California-based utilities. There also appears to be real variation in the FERC data that is not captured in the forecasting models, such as the small spike around 9pm.

Figures 6 and 7 show the load shapes for all end-uses in the residential and commercial sectors, respectively, while Figure 8 shows the load shape for the industrial, agricultural, transportation, and street lighting sectors.

Figure 5: California 1999 Summer Peak-day End-use Load (GW). The ten largest coincident building-sector end uses are shown separately, while the smaller building end uses are aggregated together in "Remainder of Buildings Sector." The end uses are ordered the same vertically in the graph and the legend. Res. = residential buildings, Com'l. = commercial buildings. The non-building sectors are shown as sectoral totals. Thus, the buildings sector accounts for all but the bottom two segments of the graph. The Residual (top-most segment) is the difference between FERC system loads and the CEC forecasting model outputs. This difference is mainly due to small utilities not included in the CEC forecasting model. The "Agriculture & Other" sector includes water pumping, transportation and street lighting. Based on data from Tian (2001) and FERC (2000).

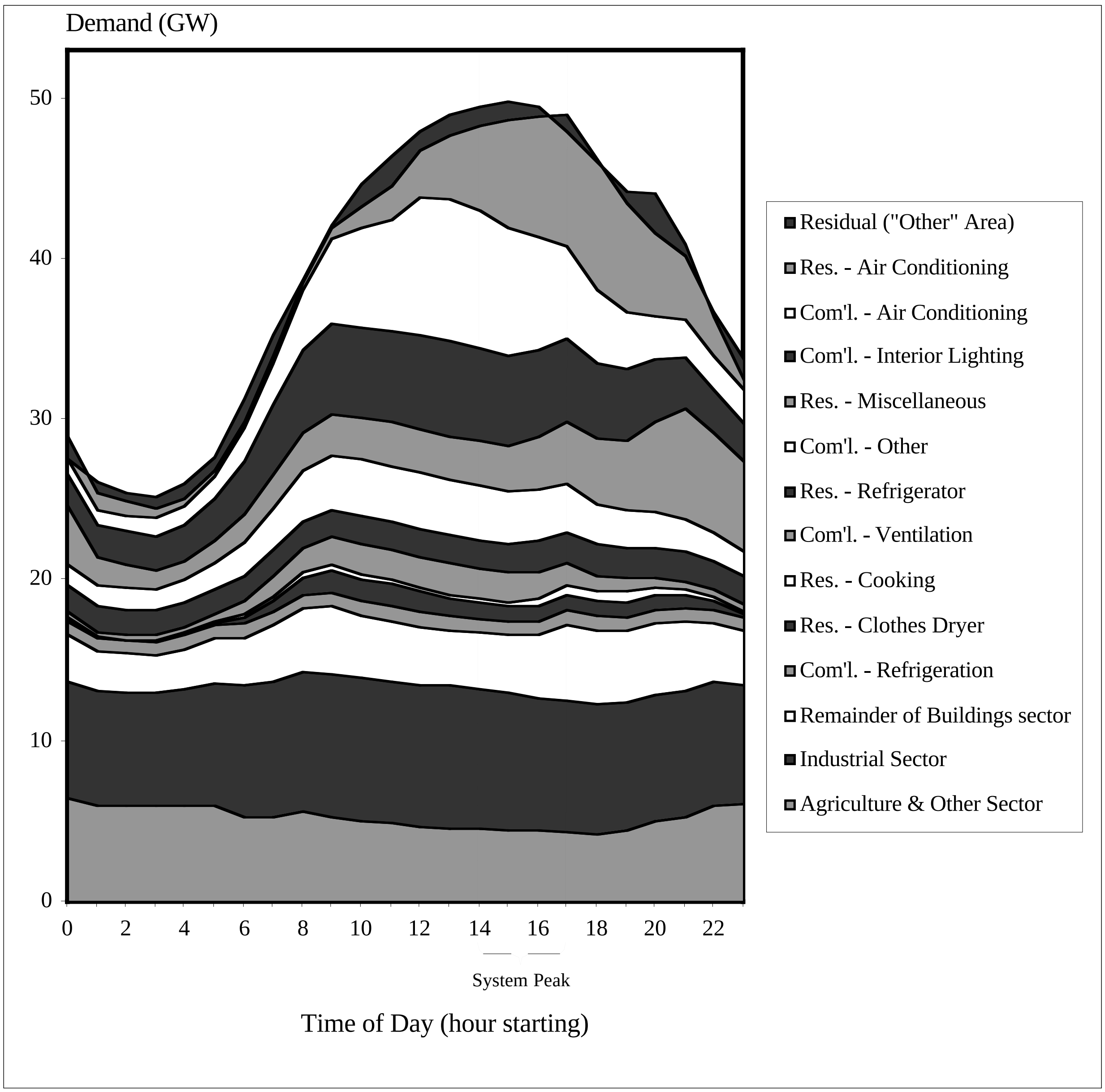


Figure 6: California 1999 Summer Peak-day Residential Building End-use Load (GW). The end uses are ordered the same vertically in the graph and the legend. The miscellaneous end use includes lighting, pools, spas, waterbeds, and small appliances. This figure does not include the Residual ("Other" area) segment from Figure 5. Based on data from Tian (2001).

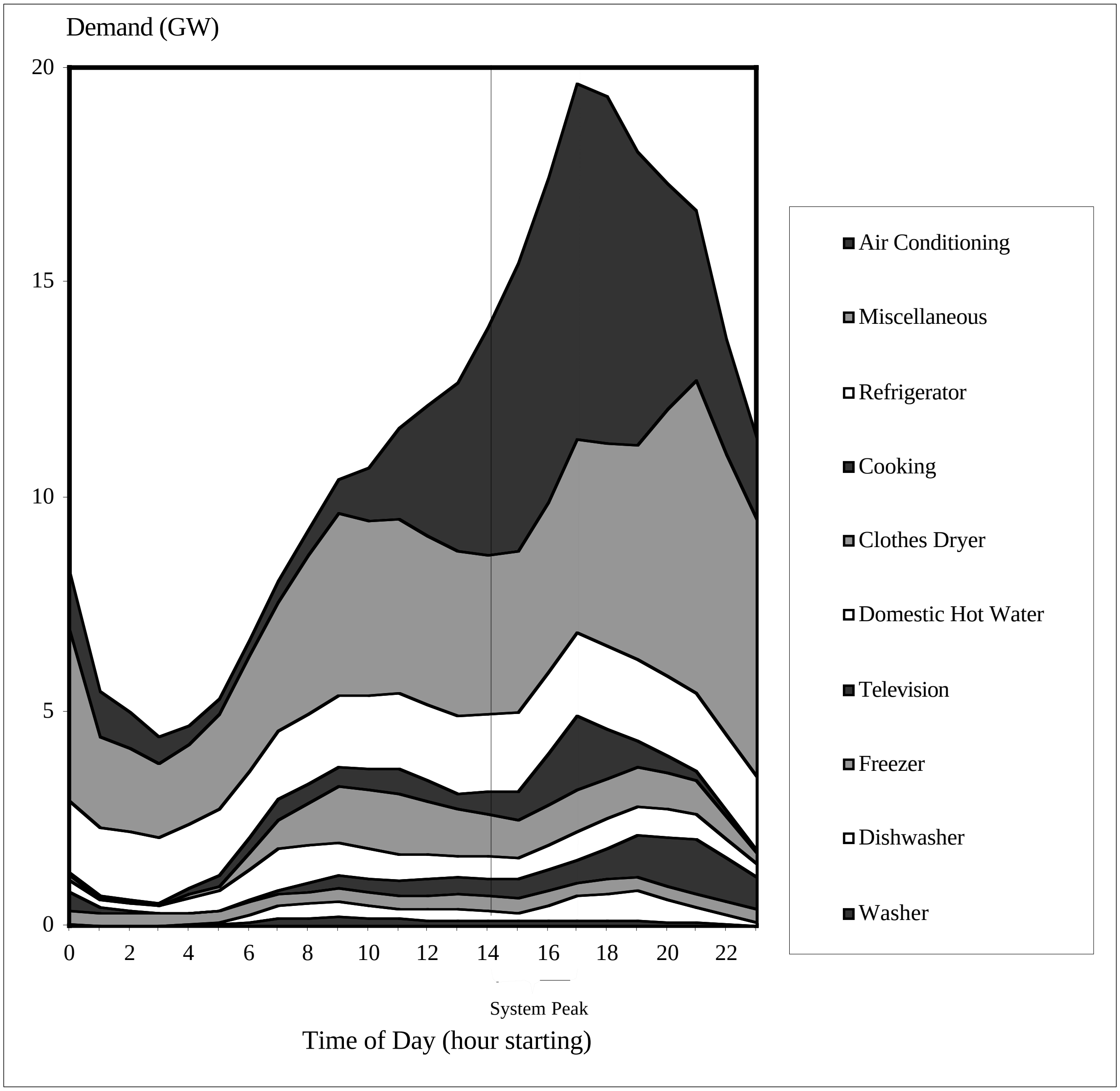


Figure 7: California 1999 Summer Peak-day Commercial Building End-use Load (GW). The end uses are ordered the same vertically in the graph and the legend. This figure does not include the Residual ("Other" area) segment from Figure 5. Based on data from Tian (2001).

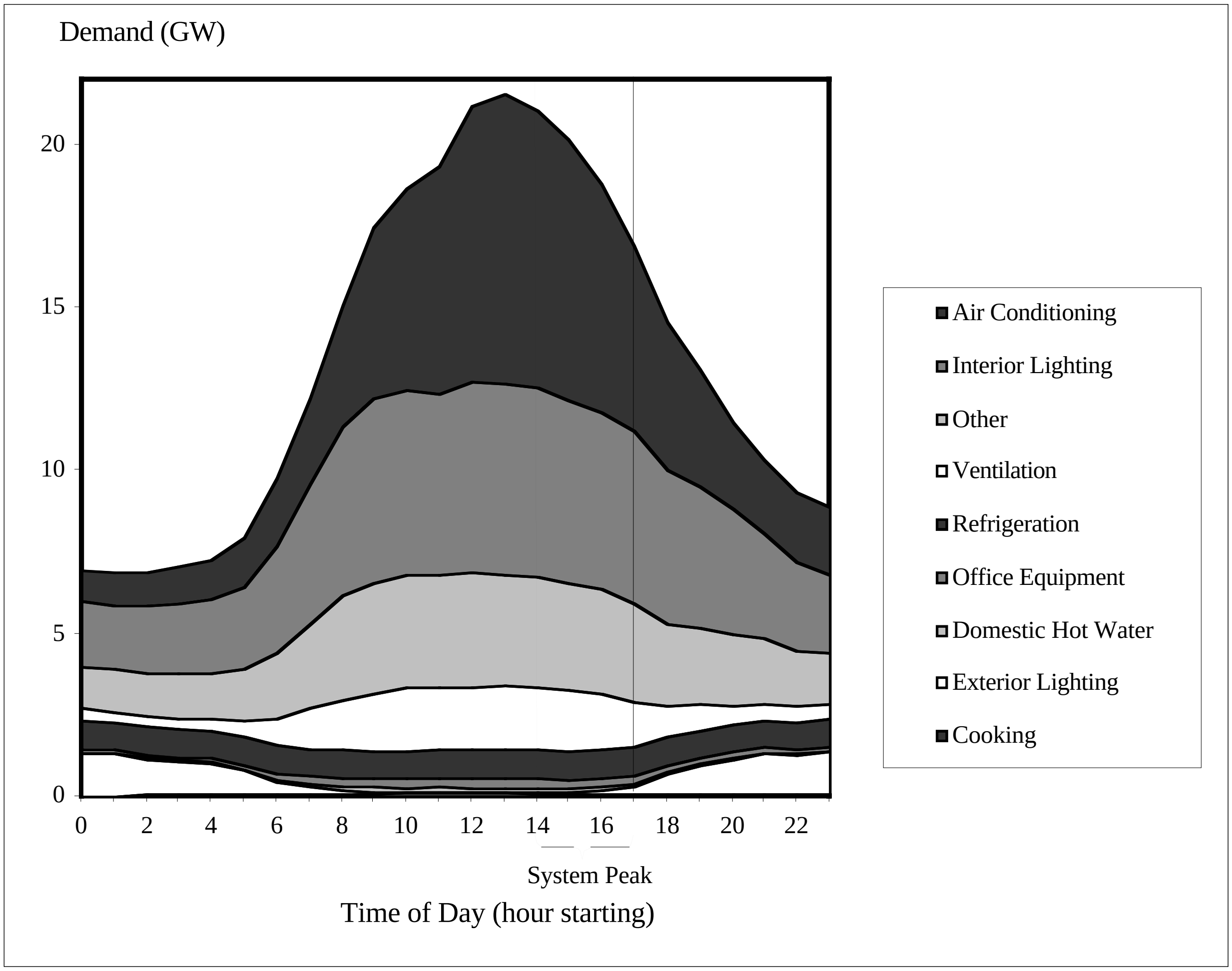
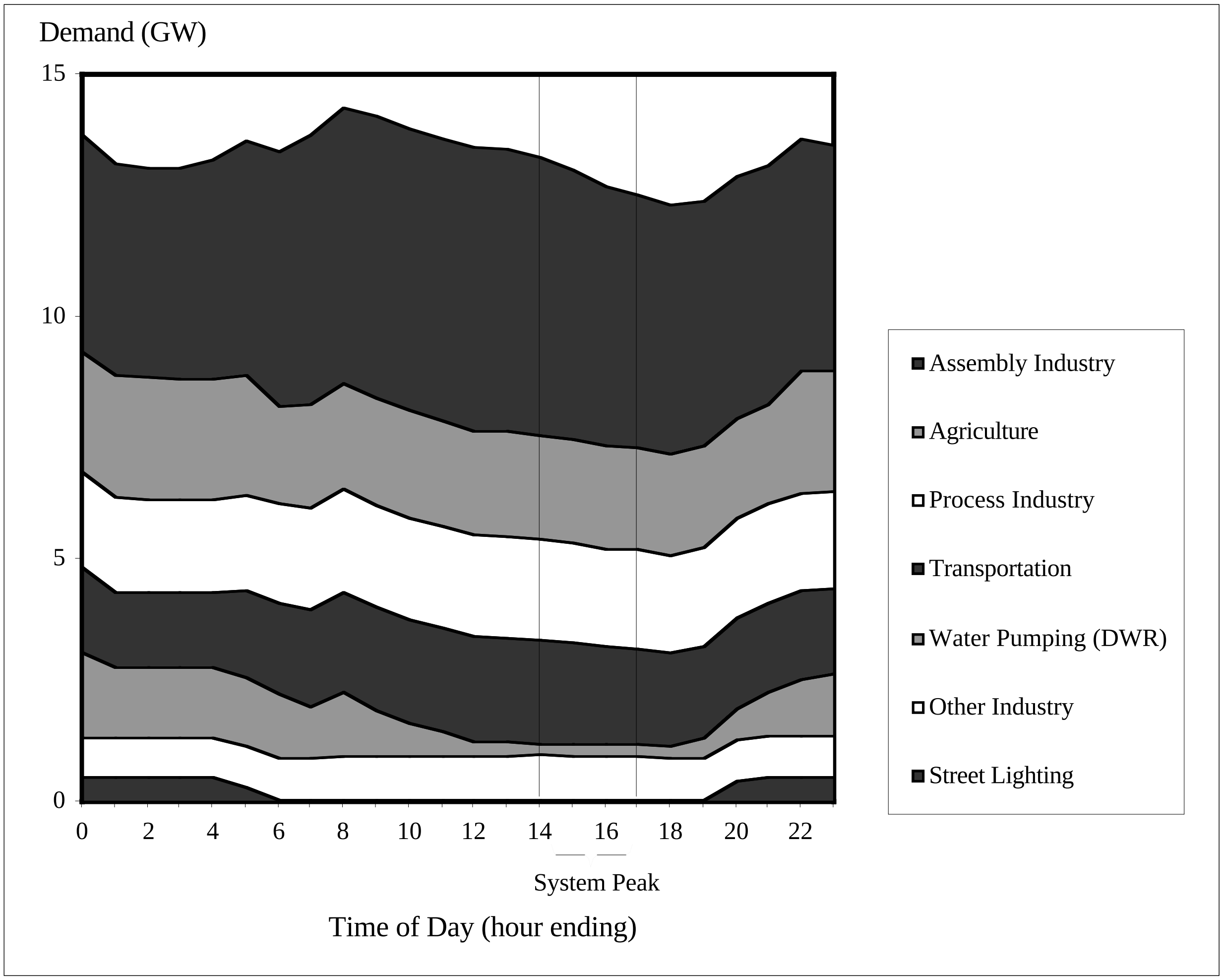


Figure 8: California 1999 Summer Peak-day Industrial, Agricultural, and Other Sectoral Load (GW). The end uses are ordered the same vertically in the graph and the legend. This figure does not include the Residual ("Other" area) segment from Figure 5. Based on data from Tian (2001).



Utility-Level Peak Loads

The FERC data are also useful for examining how the peak load varies, in both magnitude and time, by utility. Table 5 presents these data, indicating that the statewide peak load for 1999 occurred between 3 and 4pm on July 12th. The peak load for most utilities is highly coincident with the statewide peak. The ISO control area accounts for nearly 90% of the statewide peak load.

Table 5: 1999 Peak System Electrical Load[a] by Utility

Utility	Non-coincident Peak[b]			Coincident[c]	Coincidence
	Demand (GW)	Date	Hour of day[e]	Peak Load (MW)	Factor[d]
Anaheim	0.526	13 July 99	15	0.523	0.99
Burbank	0.270	12 July 99	14	0.270	1.00
California Department of Water Resources	1.853	23 July 99	0	0.055	0.03
California Independent System Operator (ISO)[f]	45.857	12 July 99	15	45.857	1.00
Glendale	0.286	12 July 99	14	0.286	1.00
Imperial Irrigation District	0.728	25 Aug 99	14	0.660	0.91
Los Angeles Department of Water and Power	5.368	12 July 99	15	5.368	1.00
Modesto Irrigation District	0.564	12 July 99	16	0.563	1.00
Metropolitan Water District	0.294	18 Jan 99	0	0.280	0.95
Northern California Power Agency	0.721	12 July 99	15	0.721	1.00
Pasadena	0.285	12 July 99	15	0.285	1.00
Pacific Gas & Electric	17.676	12 July 99	16	17.671	1.00
Redding	0.211	12 July 99	16	0.206	0.98
Riverside	0.473	12 July 99	15	0.473	1.00
Southern California Edison	19.122	13 July 99	15	18.611	0.97
San Diego Gas & Electric	3.649	13 July 99	15	3.626	0.99
Sacramento Municipal Utility District	2.759	12 July 99	16	2.726	0.99
Santa Clara	0.425	30 June 99	15	0.425	1.00
Turlock Irrigation District	0.398	12 July 99	15	0.398	1.00
Vernon	0.193	13 July 99	10	0.151	0.78
Western Area Power Authority	0.344	9 Feb 99	13	0.258	0.75
Statewide[g]	52.441	12 July 99	15	52.441	1.00

Source: Federal Energy Regulatory Commission, Form 714 (FERC, 2000).

[a] Loads include transmission and distribution losses, and exclude loads served by customer self-generation.

[b] Non-coincident peak load is the maximum hourly system load in a specific utility service territory (irrespective of when the statewide peak load occurs).

[c] Coincident peak load is the system load from 3-4pm on 12 July 1999.

[d] Coincidence factor is the ratio of total utility demand at time of statewide peak load to the non-coincident peak load for that utility. Coincidence is measured at the time of statewide peak load.

[e] Time of day is the hour starting at that time, e.g., "0" signifies midnight to 1am on that date.

[f] California ISO load data include all utilities above, except Burbank, Glendale, Imperial Irrigation District, and Los Angeles Department of Water and Power.

[g] Approximately 1% of total statewide load is not reported in this table because it is served by utilities based in Nevada and Oregon.

Implications for Electricity Markets and Regulatory Policy

Observers of the California power crisis generally agree that the primary cause of the crisis was a fundamental mismatch of electricity supply and demand, which in turn caused the newly restructured electricity market to become unstable and ultimately collapse (Borenstein, 2001). As we pointed out earlier, however, the California Energy Commission (the government body charged with approving applications for siting new power plants) knew at least as early as 1990 that approximately 30 new central station power plants would be needed to meet demand by the end of the decade. Despite this forecast, California's generating capacity grew by the equivalent of only two new plants during the 1990s[4] (Fisher and Duane, 2001).

What led to this breakdown in utility planning? While many factors were at work, the primary one seems to be that power plant developers (either utility or non-utility) were unwilling to invest in new generating capacity during the 1990s due to great uncertainty about the regulatory and market conditions that would prevail when those plants came on-line. In order to affect the electricity supply situation in 2000, the long construction lead-time for central station power plants would require that those plants begin construction in the mid-1990s, which was precisely the period of greatest uncertainty about the nature of the restructured electricity market. The fact that no power plant applications were received by the CEC between 1994 and 1997 supports this hypothesis (CEC, 2001b). Hirst (2001) suggests that California's strict and complicated siting reviews may have also deterred investment in new generating capacity.

Besides the lack of new generating capacity, another important factor contributing to the mismatch of supply and demand was higher-than-normal generator outage rates, particularly during winter 2000/2001. There are several explanations for these outages, including lack of emission permits, deferred maintenance that led to forced outages, and intentional withholding of capacity to manipulate prices.

While it is not the goal of this paper to suggest broad policy solutions for the California electricity market, several policy principles applicable to electricity demand can be drawn from this experience. First, accurate demand forecasts are not a sufficient condition for electricity markets to function reliably and efficiently. We suggest that an accurate understanding of future demand is *necessary* for electricity markets to work well, but that electricity demand must be considered in a comprehensive planning framework that is concerned with the long-term health of the electricity system. It seems that one result of the California restructuring process was neglect for long-term system planning, with disastrous consequences.

Second, given that the electricity system is very intolerant of supply/demand imbalances–leading to disruptions in the market and large social costs–we believe there is a policy rationale for developing an electricity system (including both the physical infrastructure and the market) that can more dynamically balance supply and demand. On the supply side, small-scale distributed generation offers the potential of increasing generation capacity in the

[4] Fisher and Duane make the case that the capacity shortfall in 2000/2001 was not just a California phenomenon, but affected the entire western U.S. In a typical year, California imports about 20% of its power during its summer peak, making it dependent on generation resources in neighboring states. It turns out that all the western states added very little new capacity during the 1990s (less than 1,000 MW/year, in aggregate), while electricity demand increased much faster than in California. Thus the option of importing extra power was not available to California to bridge its significant supply/demand imbalance.

time-scale of months rather than years[5]. But the most promise would seem to be on the demand side, where a range of policies, from real-time retail prices to incentives for purchasing energy efficient products, could reduce electricity demand in the aggregate and make demand more responsive to supply shortages. Electricity consumption data, such as those presented in this paper, are important to determining the potential of these policies and optimizing their design.

Even in the current power system, in which demand is relatively inelastic, good information about the nature of electricity end-use is important to developing sound electricity policies. For instance, end-use analysis helps policymakers and system planners understand changing usage patterns, thus allowing them to plan accordingly. In addition, energy efficiency and load reduction programs can be made more cost-effective by targeting them at the most appropriate end uses. However, restructuring of the electric industry has complicated the collection of necessary data by government agencies, and in some cases important data (such as end-use load shapes) are no longer being collected. According to the CEC staff (Lang et al., 1998),

> "If these [end-use data collection] programs are completely discontinued in the future then there will be a loss of a great deal of information about current and future consumption patterns as compared to in the past. Maintaining the flow of this information will be especially important as competitive market generation prices causes energy use patterns to change and the old end-use shapes become less relevant."

The CEC has laid out their data needs in a series of reports (e.g., Jaske, 1998; Lang et al., 1998), leading to a proposal for a new method of collecting end-use data (CEC, 2000b). We believe the data collection efforts at the state level should be supported by state policymakers, and Federal agencies where possible, in order to best inform the transition to a "post-restructuring" power system.

Future Work

First, we have limited understanding of the contribution of various end-uses to the historical growth in annual electricity consumption and peak load, particularly in the commercial building sector. Better historical data will help improve forecasts and better inform the policy process. By looking at the end-use breakdown for more years of peak load data, we also can better account for annual variation due to weather and other factors. The fact that we did not anticipate some findings from this study, such as the low growth in residential cooling consumption and the relatively low coincidence of commercial lighting, suggests that more work is needed to better understand electricity use at the end-use level. Second, the data used in this analysis do not distinguish residential lighting from the residential miscellaneous end-use. By separating lighting from miscellaneous, we can better understand the magnitude of the miscellaneous end-use. The data needed to estimate lighting consumption exist (CEC, 1999b), but it will take careful work to integrate these data into the CEC forecasting model. Finally, it would be useful to determine the effect of factors such as retail electricity prices on the growth in electricity use.

In order to prioritize efforts to reduce peak loads, a comprehensive estimate of peak-load savings potentials is needed. This study should be based on the documented performance of load

[5] Policies to reduce, or at least coordinate, outages at central station power plants would also help to better utilize the existing generation capacity.

reduction technologies and programs. Because the literature on load reduction technologies and programs is relatively smaller than that for energy savings, field tests or demonstrations may be needed to quantify and verify the savings potential from certain load reduction technologies. To further guide efforts at reducing building cooling demand, an analysis of the contribution of building components (e.g., windows, ceiling, ducts, etc.) to the peak cooling load is needed. An analysis of the peak load contribution of the "miscellaneous" end-uses would also be very useful in selecting load reduction strategies. Finally, because occupant behavior is a strong driver of many building end-uses, we need to better understand how occupants interact with buildings and equipment, and the potential for modifying behavior to reduce peak load.

Conclusions

One of the main conclusions we draw from this analysis is that electricity use in California in the 1990s did not grow explosively, nor was the amount of growth unanticipated. In both absolute and relative terms, growth in electricity use was greater in the 1980s than the 1990s (for both annual consumption and peak load). The popular view that the Internet or other forms of information technology have accelerated the use of electricity is not borne out in the aggregate data (this conclusion also holds at the national level–see Koomey (2000)). It appears that economic growth and population increases are the main factors correlated with electricity growth.

Over the last decade, most of the growth in electricity use has been in the buildings sector, with commercial buildings accounting for the majority of this growth. In 2000, the building sector accounted for 2/3 of annual electricity consumption and 3/4 of the summer peak load. In large part, peak load is a buildings-related phenomenon. Within the building sector, the largest end-uses in terms of annual consumption are commercial lighting, miscellaneous (commercial and residential), commercial air conditioning, and residential refrigerators. Peak load is strongly dominated by air conditioning, followed by commercial lighting and miscellaneous. Residential air conditioning alone accounts for nearly as large a portion of peak load as the entire industrial sector.

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