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Climate change and electricity demand in California

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Abstract The potential effect of climate change on California's electric power system is an issue of growing interest and importance to the state's policy makers. Climate change-induced temperature increases may exacerbate existing stresses on this system. Detailed recent data are used to estimate the relationships between temperature and both electricity consumption and peak demand at a sample of locations around California. These results are combined with new projections of regional climate change affecting California obtained by statistically downscaling recent global projections generated by two general circulation models, to yield estimates of potential impacts of future temperature changes on electricity consumption and peak demand, and illustrative economic cost estimates in several cases. Both current and prospective coping strategies, and priorities for further research, are summarized.

1 Introduction

California's electricity generation, transmission, and distribution network is an engineered and regulated system of substantial scope and complexity. In 2003, California's households, firms, and government agencies consumed an estimated 256 billion kilowatt-hours of electricity, a level exceeded only by Texas among the 50 US states, by France, Germany, Italy, and the UK among the 27 Western European countries, and by 12 of the more than 200 countries around the world. (CEC 2006; USEIA 2003). Electricity in California is provided by three large investor-owned utilities and more than 100 municipal utilities. Fuel sources include higher percentages of natural gas, hydro, and non-hydro renewables, and lower percentages of coal, petroleum, and nuclear, than both the average US state and the USA overall (USEIA 2006). Moreover, California is unique in its emphasis on demand-side

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policies and programs to meet the state economy's energy-services requirements through the diffusion of energy-efficient technology. These demand-side approaches are part of the state's more than three decade commitment to, and leadership in, mitigating the environmental consequences of electricity generation and consumption.

California's electric power system is confronting several technical and regulatory challenges (CEC 2005). Electricity demand is growing at a rate exceeding that at which new supplies are being added to the system. Transmission constraints are becoming increasingly costly. Following the electricity shortages of 2000–2001, the state's move toward electricity deregulation was suspended, and consensus has yet to be reached on the appropriate path forward. These issues are being addressed in the context of an effort to increase the share of renewable sources in the electricity system – the renewable portfolio standard – which itself is facing implementation hurdles.

These challenges are now being complemented by the need to address the potential consequences of global climate change, both in assessing its impacts on the state's natural and socio-economic systems and in developing strategies to reduce greenhouse gas (GHG) emissions, which has in recent years emerged as a major public policy and regulatory priority in California. Along with other regulatory initiatives, Governor Schwarzenegger's June 2005 announcement of dramatic greenhouse gas (GHG) emissions reduction goals, and the resulting set of studies reflected in this and the companion papers in this volume, constitute major initial steps in a long-term transition to a low-carbon California economy and energy system in a regional climate altered – perhaps substantially – by global climate change.

One important part of this transition will be preparing for the potential effects of climate change on the operation of California's electric power system, on both the supply and demand sides. This is also one of the most difficult areas for research and policy planning, inasmuch as it involves the future interactions among the climate system, a highly complex, engineered technical system, and socioeconomic trends that are difficult to project in their own right. This paper uses new projections of regional climate change affecting California to generate simple illustrative estimates of possible impacts on state electricity consumption, demand, and expenditures.

2 Previous research

Over the past several decades, a large research effort has focused on projecting the future evolution of the national and international energy-economies and the consequent trajectory of greenhouse gas (GHG) emissions – particularly CO_2 emissions from the combustion of fossil fuels.[1] A relatively small literature, however, examines the "reverse" pathway, the potential effects of climate change on energy demand; moreover, this literature is growing as concern about the risks of climate change grows and detailed information about potential magnitudes becomes available, particularly on sub-continental scales. Very generally, the primary focus in assessing potential effects and costs of climate change on energy demand has been comparing the relative magnitudes of increases in cooling demand with reductions in heating demand as temperatures increase. We sketch a number of results in this literature, beginning with national-scale analyses, followed by sub-national results in several locations around the world, and finally results specific to California.

[1] Well-known examples of this literature, addressing various aspects of the energy and CO_2 link, are Leggett et al. (1992), Nordhaus (1994), Weyant and Hill (1999), and Nakicenovic and Swart (2000).

Smith and Tirpak (1989) was an early comprehensive assessment of the potential effects of climate change on the USA, across a range of sectors including electricity. At the national level, a climate change-induced temperature increase in 2010 of 1 to 1.4°C from a baseline projection was estimated to result in increases from baseline of 3 to 6% in peak demand, 1 to 2% in consumption, and 3.5 to 6.5% in combined annual costs and cumulative capital costs. An increase of 3.7°C from baseline in 2055 was estimated to result in increases of 13 to 20% in peak demand, 4 to 6% in consumption, and 9 to 12% in combined annual and cumulative capital costs, with the ranges a function of variations in temperature distribution and projections of economic growth. The so-called "MINK" (Missouri, Iowa, Nebraska, Kansas) study projected a small net increase in energy demand in this region due to climate change, as well as a potential supply risk in the form of reduced hydroelectric output (Darmstadter 1991).

Rosenthal et al. (1995) estimated that a 1°C increase from baseline temperature in 2010 resulting from global warming would reduce total US energy expenditures in that year by $5.5 billion (1991 dollars), which would under certain assumptions regarding baseline expenditures be about 0.7%.[2] This finding results from estimated reductions in heating costs exceeding increases in cooling costs.

Hadley et al. (2004) estimated energy impacts to 2025 of a climate change scenario applied to the US, disaggregated by the nine census regions; they applied the US Department of Energy's National Energy Modeling System (NEMS), and disaggregated the analysis by the nine US census regions represented in that model. As would be expected, there was substantial inter-regional variation in temperature and energy outcomes. Their results included a net decline in energy consumption in the first half of the forecast period, followed by a net increase in the second half as increases in cooling costs came to outweigh reductions in heating costs. They estimated that, on a national level, the net change from a baseline projection in heating and cooling costs would be a decline of approximately 0.4% of 1% from 2003 to 2014, and an increase of 2% from 2015 to 2025.[3]

A number of methodological papers have focused on historical relationships between climatic and weather conditions and energy demand at the state, regional, or metropolitan levels. Sailor and Munoz (1997) developed and compared two statistical models based on different sets of monthly independent variables, one with "primitive" meteorological variables and one with derived variables measuring heating and cooling degree days, applied to eight US states. They found that the degree-day model yielded better results for electricity while the primitive variable model was preferable for natural gas. Lam (1998) presented results of a statistical model applied to historical data for Hong Kong, in which monthly and annual electricity demand was predicted by household income and size, electricity price, and cooling-degree days. Sailor and Pavlova (2003) analyzed the relationships among temperature, electricity consumption for space cooling, and the market saturation of air conditioning in 12 cities in 4 US states, and found a significant saturation response to increases in cooling degree days, implying that projections of the electricity

[2] Rosenthal et al. did not report this estimated expenditure effect as a percent change from a baseline. To estimate the effect in percentage terms, we used the reference case forecast of total energy expenditures in 2010 from the US Department of Energy, Energy Information Administration's *Annual Energy Outlook* 2005; this figure is $962 billion 2004 US dollars. Using the GDP (implicit price) deflator to convert the expenditure figure to 2004 dollars, we obtained $7.1 billion, or 0.7%. While this estimate would of course change with a different baseline estimate, the order of magnitude would not.

[3] Hadley et al. did not report these results in percentage terms. To obtain these percentage estimates, we used the baseline total energy expenditures in the Energy Information Administration's Annual Energy Outlook 2003.

consumption response to climate change-induced temperature increases may be significantly underestimated if this saturation effect is not incorporated.

The pace of research on the potential energy effects of climate change on sub-national scales has accelerated in recent years as the risks of global climate change become more salient and the degree of spatial resolution available in climate and meteorological projections increases. An example is Amato et al. (2005), who examined potential changes in electricity and natural gas use in the residential and commercial sectors in Massachusetts under the IS92A climate change scenario. Their findings include an estimated 2.1% increase in per capita residential electricity consumption in 2020 under a climate change scenario relative to a baseline climate projection, and a decrease in residential natural gas demand under the same scenario of 7 or 14%, depending on the general circulation model used.

Smith and Tirpak (op cit.) included an analysis of potential climate change impacts on California's electricity market. Under the climate change scenarios noted above, it was found that California generation would increase by 1 to 2% in 2010 and 3 to 5% in 2055, depending upon the assumed demand baseline. Using a different methodology, Baxter and Calandri (1992) also estimated changes in electricity consumption and peak demand in 2010 under two climate change scenarios. In their "worst case," a 1.9°C temperature increase resulted in a consumption increase of 2.6% and a peak demand increase of 3.7%, with increased demand for cooling accounting for 80% or more of these impacts. They emphasized that, while these potential effects would be substantial, uncertainties in other drivers such as economic growth projections have effects at least as great, or greater, on projections of state electricity demand. In a recent very long-range analysis, Mendelsohn (2003) estimated that in 2100 a 1.5°C increase in temperature would increase total state net energy expenditures (increased cooling and decreased heating demand) by 4% from baseline and a 5°C increase would increase these expenditures by up to 22%.

3 Regional climate projections

New climate scenarios for California have recently been developed by statistically downscaling the results of the Geophysical Fluid Dynamics Laboratory (GFDL) global circulation model and the Parallel Climate Model (PCM) for the National Center of Atmospheric Research (NCAR) and the US Department of Energy (Cayan et al. 2006). These models were selected for several reasons including the published research record of the modeling groups, their levels of sensitivities to GHG forcings that are representative of the different models available for the IPCC Fourth Assessment report, and the performance of the models in simulating regional climate structure in California during the historical period. The GFDL model is a medium climate sensitivity model and the PCM model has a relatively low climate sensitivity.[4] We also report some results for the HadCM3 model which has a relatively high climate sensitivity. The statistical downscaling technique is based on the method developed by Wood et al. (2002), which is an empirical statistical technique that maps precipitation and temperature during a historical period (1950–1999 for

[4] This terminology refers to the models' predictions of the change in mean global surface temperature from a doubling of atmospheric CO_2 concentration above the pre-industrial level. The sensitivity of the PCM is approximately 1.8°C (3.2°F), and the GFDL's sensitivity is approximately 3°C (5.4°F). The sensitivity of the third model used in the accompanying California scenario analysis, the Hadley Climate Center Model Version 3, is approximately 3.3°C (5.9°F). The Intergovermental Panel on Climate Change has stated that the likely range for this quantity is 1.5 to 4.5°C (2.7 to 8.1°F).

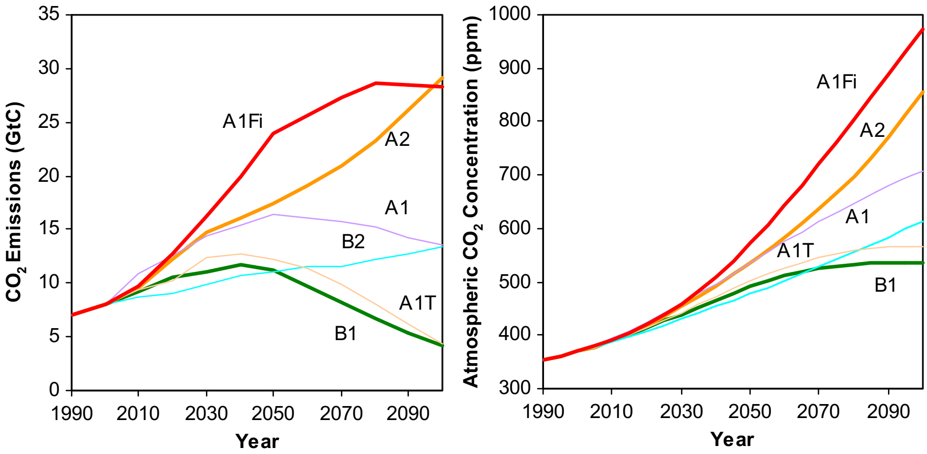

Fig. 1 Trajectories of worldwide emissions and atmospheric CO_2 concentrations

our study) from a global climate model to the concurrent historical record. The method also attempts to statistically correct some of the bias present in the global climate models. The probability distributions of the observations are reproduced by the bias corrected model data for the overlapping historical period, while both the mean and variability of future climate can evolve according to the global climate projections. The combined bias correction/spatial downscaling method has been shown to compare favorably to different statistical and dynamic downscaling techniques (Wood et al. 2004). In the present study, the downscaling produced estimated meteorological parameters for California at a grid resolution of about 12 km (7 miles).

The research groups working with these two models submitted the results of new simulations to the Intergovernmental Panel on Climate Change (IPCC) for its fourth Assessment Report, to be released in 2007. These results were obtained using three greenhouse gas emissions scenarios described in the IPCC Special Report on Emissions Scenarios:“A2,” projecting moderate-to-high fossil fuel emissions, and “B1,” which assumes that social, political, and economic trends will result in the onset of a decline in worldwide emissions within the next three-and-one-half decades. Figure 1 shows the carbon dioxide (CO_2) emissions associated with both scenarios and the resulting atmospheric carbon dioxide concentrations as estimated by the MAGICC model.[5]

In addition to the two scenarios and climate model outputs described above, Hayhoe et al. have developed similar sets of climate projections for California using the results of the Hadley model (version 3) for the “A1Fi” scenario, which is a high-emission scenario for CO_2, as illustrated in Fig. 1 (Hayhoe et al. 2004). This paper does not estimate impacts for the A1T and A1 scenarios shown in Fig. 1 because there are no climatic scenarios projected for California for these two emission scenarios. For this study, statistically downscale temperature fields were created, as described above, for each of the three scenarios used in

[5] The trajectories in Fig. 1 do not exactly match those in official IPCC documents because the results reported here are based on revised emissions projections subsequently made available by IPCC; these are available at http://sres.ciesin.columbia.edu/. In addition, the authors used a new version of Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) available from http://www.cgd.ucar.edu/cas/wigley/magicc/index.html. The differences between Fig. 1 and similar figures provided by the IPCC, however, are minor and do not affect the discussion in this paper.

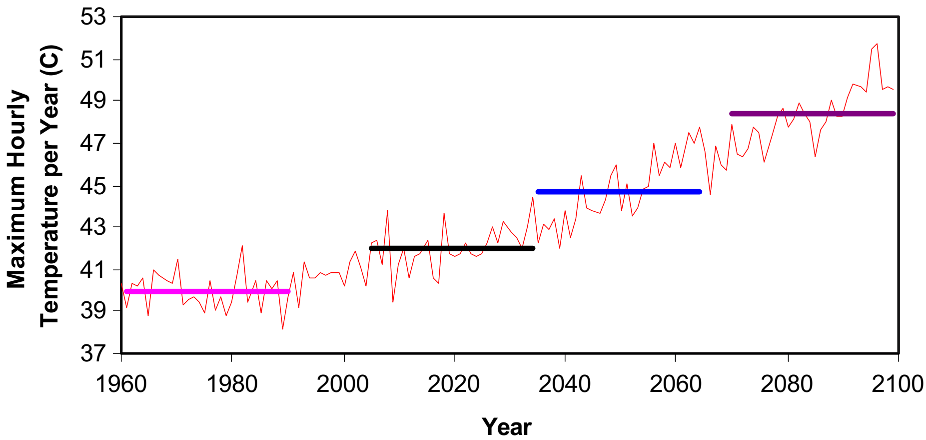

Fig. 2 Maximum hourly temperatures by year, simulated historical (1961–1990), and projected (2005–2034, 2035–2064, 2065–2099): Hadley3 A1Fi

the California analysis (AiFi, A2, and B1). We used the outputs from grid points adjacent to San Jose, Sacramento, Fresno, and Pomona (east of Los Angeles). Downscaled data from the Hadley A1Fi scenario for these locations are plotted in Figs. 2 and 3, in which the climate projection is divided into three periods (2005–2034, 2035–2064, 2070–2099). Figure 2 shows, for each year, the maximum of the simulated hourly maximum temperatures averaged across these four locations for that year.[6] This figure shows that the 30 year climatologically averaged temperatures (horizontal lines) for the three periods increases from approximately 40°C during the historical period to approximately 48°C by the end of this century. Moreover, as shown in Fig. 3, the variability of the maximum temperature is also projected to increase, with the standard deviation increasing by more than 50% from the first to the final period (from 0.79 to 1.84°C).[7]

4 Estimating potential impacts of climate change on electricity demand

Projecting the potential effects of regional climate change on electricity consumption and demand in California poses a number of technical challenges. First, a basic trade-off exists between incorporating long time horizons – up to a century – in order to assess these effects on the appropriate scale of major climatic trends, on the one hand, and incorporating sufficient detail on the electric power system, socioeconomic trends, and other interacting factors so that very specific effects can be estimated, on the other. Such details cannot be reliably projected even a few decades into the future. Second, in part because of the time scales involved, there are many uncertainties affecting future electricity demand that must be addressed even in the absence of potential climate change, including rates of economic growth and technological change, demographic trends such as household sizes and spatial

[6] That is, for each year, the maximum hourly temperatures calculated that year using the downscaling procedure described above for San Jose, Sacramento, Fresno, and Pomona were averaged, and this quantity is plotted. The horizontal lines in turn indicate the average of these quantities during each of the four periods.

[7] Note that these standards deviations apply to the A1Fi scenario as modeled by the Hadley model.

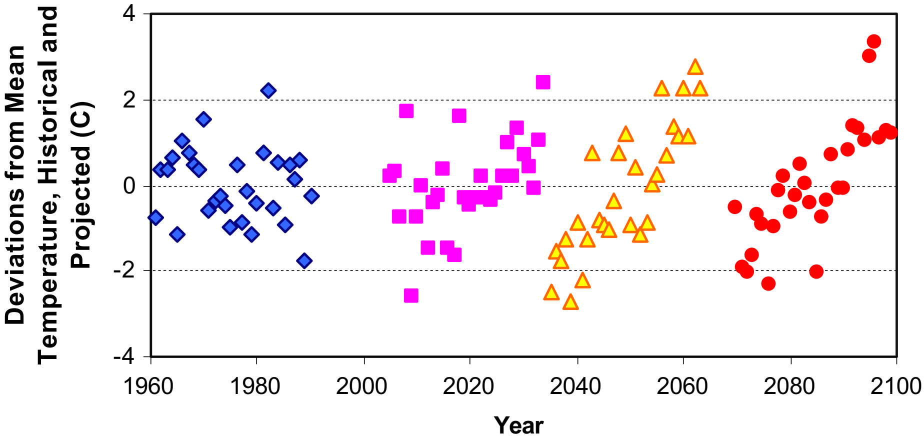

Fig. 3 Temperature variation, simulated historical (1961–1990), and projected (2005–2034, 2035–2064, 2065–2099): Hadley3 A1Fi

distributions, and the effects of public policies. Uncertainties in these factors will interact with any future climate change effects and, depending upon the timing and magnitude of these effects, may dominate them.

Below we report simple estimates to illustrate the potential implications for electricity consumption and demand of the new regional climate projections described above. For this purpose, we apply these projections to data on the historical and current configuration and operation of the regional electric power system, and, implicitly, current demographics. In other words, we imagine the newly projected temperature increases in the coming century imposed on our current system, assuming the underlying relationships between temperature and consumption and maximum temperature and peak demand remain invariant. There are of course many non-trivial simplifying assumptions underlying such calculations; for example, the interaction between higher temperatures and the trend towards greater development – requiring greater amounts of cooling–in the state's interior. That is, these estimates are *ceteris paribus*.[8] However, assumptions of this type are present in one form or another in all the analyses reviewed above, and indeed are unavoidable in estimating projected impacts. Moreover, for the reasons noted in the previous paragraph, there is an upper limit to the degree of detail that can be included before exceeding the plausible level of precision given the many uncertainties. Exactly how to make such trade-offs in a rigorous manner is an important topic for future research on climate change impacts in a variety of sectors. In the meantime, we regard these results as providing a useful departure point for further analysis.

One aspect of this study that represents an advance over most of the existing literature is the use of higher-resolution consumption data. We used hourly electricity consumption data provided by the California Independent System Operator (CalISO)[9] and daily temperature data from the California Irrigation Management Information System (CIMIS).[10] Figure 4 shows daily demand of electricity for the area serviced by the CalISO in 2004 and 2005 as a

[8] It is also the case that the downscaling method did not provide information on relative humidities or wind conditions, which also affect loads.

[9] Available at California ISO Oasis (http://oasis.caiso.com/).

[10] Available at the CIMIS website (http://www.cimis.water.ca.gov/cimis/welcome.jsp).

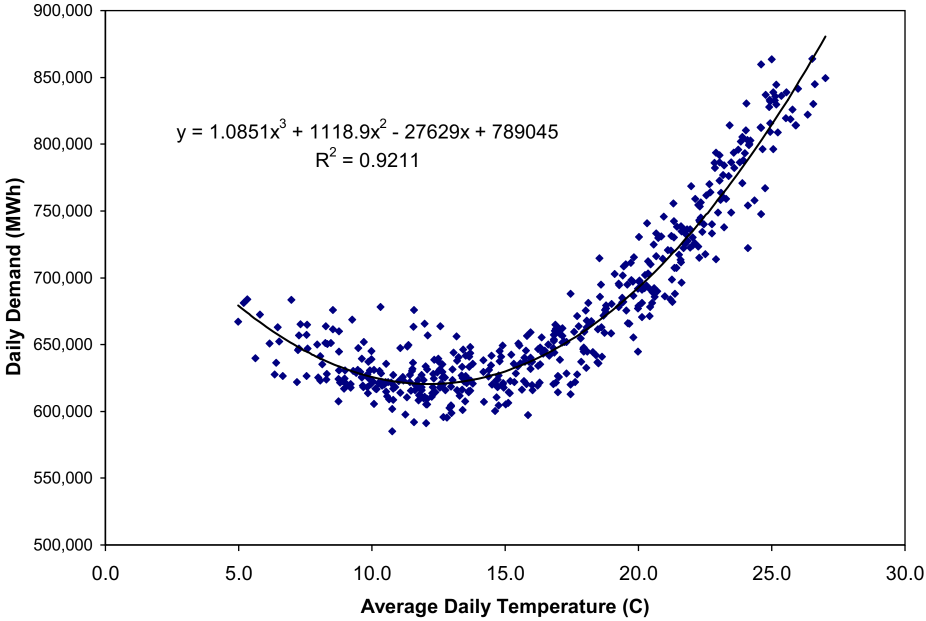

Fig. 4 Electricity demand in the CalISO area as function of average daily temperatures: 2004–2005

function of the simple average of daily temperatures for sites close to the grid points used for the downscaling above: San Jose, Sacramento, Fresno, and Pomona. The figure only includes demand during weekdays (excluding holidays). Note that while The CalISO covers most of California, its territory does not include the cities of Sacramento or Los Angeles. We used the temperature in Sacramento as a proxy for the temperatures observed in the Sacramento Valley and the upper San Joaquin Valley, and the temperature in Pomona as proxy for Southern California. Using population weighted temperature data did not significantly improve the correlations.

As indicated in Fig. 4, there is a high correlation between the simple average daily temperature from the four sites selected and daily electricity demand in the CalISO region, which comprises most of California. A cubic polynomial was found to fit the data well ($r^2 >$ 0.9). As the figure illustrates, at low temperatures, temperature increases initially result in reduction in electric space heating and to some extent a reduction in the use of indoor appliances, the utilization of which increases during cooler weather. At higher temperatures, the effects of space cooling via air conditioners and the uses of other appliances predominate.

Peak electricity demand occurs mostly in the summer and is well predicted by maximum hourly temperatures. Figure 5 presents hourly peak electricity demand in the CalISO region as a function of average of the hourly maximum temperature measured in the four locations on non-holiday weekdays, using data from 2004–2005. Electricity consumption during weekends and holidays tends to be lower: on average, the maximum system load is about 9% lower during weekends and the daily system load about 10% lower.

Given the relationships between demand and peak load in the previous figures, it is possible to estimate the effects of projected higher temperatures on annual and peak summer demands. For this, we used the downscaled temperature fields noted above for grid points close to the cities listed in the previous paragraphs to be compatible with the

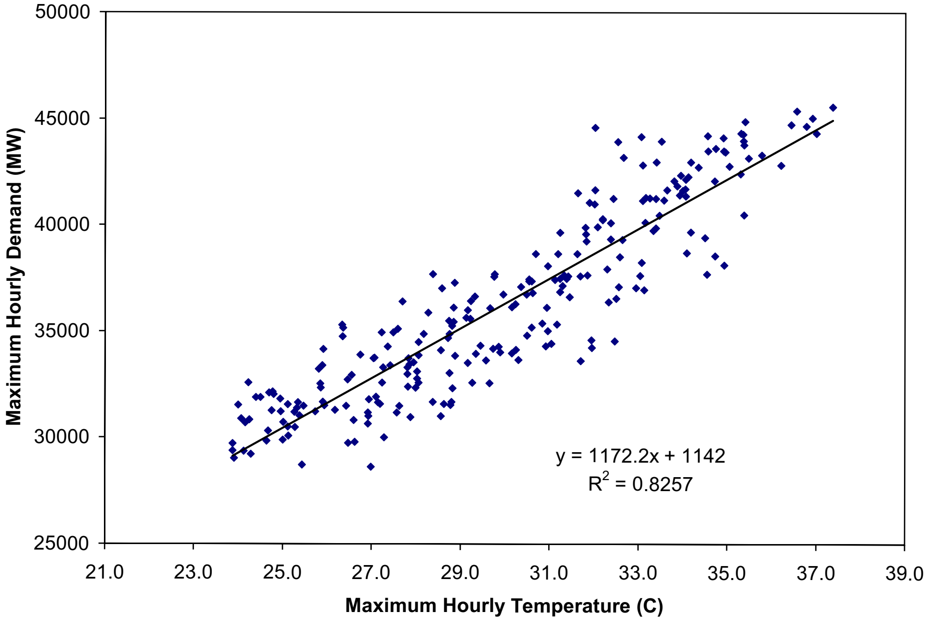

Fig. 5 Peak electricity demand in the Cal ISO area as a function of maximum hourly temperature: 2004–2005

temperature fields used to estimate the functional relationships shown in Figs. 4 and 5. We used both the modeled historical period 1961–1990 and the three future intervals used in Figs. 2 and 3.

Table 1 applies our estimates of the relationship between average daily temperature and daily consumption in the CalISO area in 2004 and 2005, and the relationship between peak demand and average daily maximum temperature over the period 1961–1990 to estimate future consumption and demand as a function of projected temperatures, simply assuming these historical relationships remain invariant. In addition, to obtain the results in Table 1, these calculations were augmented by estimating the corresponding relationships for weekends and holidays.[11]

Total annual expenditures on electricity in California were approximately $26 billion (2000 dollars) in 2003.[12] Therefore, even the small percentage increases in energy demand shown in Table 1 would substantially raise energy-related expenditures. For example, were these expenditures to continue growing at the mean annual growth rate from 1990–2003, a 3% increase in electricity demand by 2020 would translate to about $930 million (2000 dollars) in additional annual electricity expenditures. Also note that such direct temperature-driven impacts would be exacerbated by potential losses in hydroelectric supply due to direct and indirect effects of temperature changes on hydroelectric generation. At the

[11] Data for a corresponding analysis of natural gas consumption were unavailable on a statewide basis. We were able to obtain data for so-called "core" end use customer classes (primarily residential, commercial, and industrial customers) for the Pacific Gas and Electric Service territory in northern California for 2004. A set of calculations similar to those used for Table 1, but restricted to the Northern California temperature measurement sites, yielded, as expected, predictions of decreased natural gas use under the various climate scenarios due to reduced demand for heating. Extending this analysis and integrating it with the electricity analysis will be a focus of future research.

[12] US Energy Information Administration, US Dept. of Energy, State Energy Price and Expenditure Series.

Table 1 Estimated changes in annual electricity and peak load demands for the A1Fi, A2, and B1 scenarios, relative to the 1961–1990 base period

Climate model	Year	Emission scenario	Annual electricity (%)	Peak demand (%)
Hadley3	2005–2034	A1Fi	3.1	4.9
	2035–2064	A1Fi	8.1	11.2
	2070–2099	A1Fi	17.8	19.8
PCM	2005–2034	A2	1.1	1.0
		B1	0.8	1.5
	2035–2064	A2	2.3	2.2
		B1	1.6	1.6
	2070–2099	A2	4.8	5.7
		B1	2.9	4.2
GFDL	2005–2034	A2	2.6	3.8
		B1	2.3	4.2
	2035–2064	A2	4.6	5.2
		B1	3.8	5.1
	2070–2099	A2	9.9	12.4
		B1	5.3	7.5

average level of hydro-supplied megawatt-hours (MWh) from 1990–2002 and a price of $0.10 per kWh, a 10% decrease in hydro supply would impose a cost of approximately $350 million in additional electricity expenditures annually.[13]

5 Potential coping strategies

As emphasized by Baxter and Calandri (op cit.) and as we noted in Section 4, climate change is only one of several drivers of electricity consumption. Demographic trends – including both increases in state population and changes in its spatial distribution – economic growth, developments in energy markets such as dramatic changes in natural gas prices, and other policy decisions affecting the electric power system must be considered simultaneously. Thus, climate change will not simply be superimposed on the existing system but rather is an increasingly important dimension that must be taken into account in planning for the future development of the system as well as for demand-side policies. In California, a particularly important pathway through which climate change is likely to affect the electric power system is growth in cooling demand, which is already accelerating due to population growth in the state's hotter interior regions.

In devising coping strategies, a guiding principle should be "resilience" – enhancing the capacity of the power system to operate under a range of future environmental and socioeconomic conditions that we can currently anticipate as possible and plausible but that we cannot predict with certainty. In the near term, several policies, measures, and research

[13] It might seem counterintuitive that, although the B1 global emissions scenario is significantly lower than the A2 scenario after a few decades, in two cases we estimate that peak demand will increase by more for the B1 scenario than for A2 (while annual electricity totals follow the expected trend). However, both cases fall within the 2005–2034 period. During this period, the effect of global trends on estimated (downscaled) maximum temperatures is sufficiently weak that small differences in cross-scenario peak demand projections are within the error/noise of the projections, while the effect on average daily temperatures is sufficiently large to exceed the error/noise.

efforts that are underway or anticipated will help to provide such resilience given the current basic architecture of the system. Recent work, for example, suggests that the management of our water reservoirs could be substantially improved with the use of modern probabilistic seasonal and short-term hydrologic forecasts and numerical decision support tools. A demonstration project is underway with funding from the CALFED Bay-Delta Program, the National Oceanic Atmospheric Administration (NOAA), and the Public Interest Energy Research Program (PIER) that, if successful, will pave the way for the operational use of these new management tools (Georgakakos et al. 2005). Some studies also suggest that these tools will also result in an improved capacity to better cope with long-term increased climate variability and change (Carpenter and Georgakakos 2001; Yao and Georgakakos 2001).

The impacts of climate change on the electricity system could also be mitigated by, for example, an increased penetration of photovoltaic (PV) systems, which reduce the effects of peak demand because this energy source closely matches the diurnal demand for electricity (Borenstein 2005). In addition, very aggressive energy efficiency and demand response targets for California's investor-owned utilities such as those recently enacted by the California Public Utilities Commission can, if extended beyond the current 2013 horizon, provide substantial "cushioning" of the electric power system against the effects of higher temperatures. Other examples of feasible near-term actions include reducing urban heat island effects with the use of more reflective surfaces for roofs and pavement, and planting trees to shade homes and buildings.

6 Future work

We estimated the effect of projected changes in regional climate on electricity demand in California using historical relationships between demand and temperature. This is equivalent to estimating changes in electricity demand using more or less current socio-economic conditions but under postulated future climates. A more rigorous analysis would involve developing socio-economic-technologic scenarios for California for individual SRES or SRES-type scenarios and using them to estimate changes of energy demand.

Better understanding the detailed relationships between temperature – including temperature extremes – and patterns of electricity consumption and demand in California is a clear research priority, as is incorporating the effects of meteorological factors other than temperature. Micro-level analysis is critical, but depends upon the availability of data down to the household level that is not in general publicly available at this time. In addition, it is important to better understand the long-run, dynamic joint evolution of electricity demand and end-use technology; this is an issue that does not arise directly in the very extensive analyses available for short-run energy efficiency potentials. Finally, at a larger scale, it is important to continue developing and applying analytical methods for incorporating appropriate levels of uncertainty simultaneously in key climatic, technological, and socioeconomic trends, and developing policy strategies for developing and managing the electric power system that are robust against these multi-dimensional uncertainties. Such work could integrate the effects of regional climate change at various scales on energy supply as well as demand, such as the potential loss of hydropower resources due to snowpack attenuation. Other such possible feedbacks, such as changes in the economic attractiveness such technologies as PV and wind due to regional climate change, are also important to better understand. Even in the very near term, before major climate change impacts are likely to occur in California, such methods, and a larger analytical framework, could enhance state decision-makers' capacity for coordinating diverse policies and measures directed toward achieving multiple economic, technical, and environmental goals related to electricity generation and consumption.

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