CLIMATE CHANGE AND ELECTRICITY DEMAND IN CALIFORNIA

WHITE PAPER

A Report From:
California Climate Change Center

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Arnold Schwarzenegger, *Governor*

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies

The California Climate Change Center (CCCC) is sponsored by the PIER program and coordinated by its Energy-Related Environmental Research area. The Center is managed by the California Energy Commission, Scripps Institution of Oceanography at the University of California at San Diego, and the University of California at Berkeley. The Scripps Institution of Oceanography conducts and administers research on climate change detection, analysis, and modeling; and the University of California at Berkeley conducts and administers research on economic analyses and policy issues. The Center also supports the Global Climate Change Grant Program, which offers competitive solicitations for climate research.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, these reports receive minimal editing, and the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contact the Energy Commission at (916) 654-5164.

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1.0 Background

The potential effect of climate change on the operation of California's electric power system—on both the supply and demand sides—is an important impact category for research and for policy planning and management. It is also one of the most challenging to analyze, 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.

2.0 Previous Work

Over the past decade or more, 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. Less attention has been paid to "closing the loop" by analyzing how resulting climate change might affect the energy system in turn, and still less to regional or micro-scale effects of this type, although a small number of such studies have focused on California.

One of the first studies of these regional effects—for any location—was conducted by Baxter and Calandri (1992) using very detailed data and electricity demand forecasting models of the California Energy Commission. With an analysis period of 1990 to 2010, under a worst-case scenario (a 1.9ºC (3.4ºF) increase in mean statewide temperature), electricity requirements in 2010 increased by about 7,500 gigawatt-hours (GWh) and required an additional peak capacity of 2,400 megawatts (MW), representing increases of about 2.6% and 3.7% in energy and peak generation capacity, respectively, from their 2010 base case, which is their projected energy demand in 2010, assuming a stationary climate. The authors observed both that these would be significant effects and that other drivers—such as uncertainties in the state's economic growth rate—would have comparable or larger impacts on consumption and demand over this 20-year projected estimation.

A more recent study estimated that by 2020, increases in electricity expenditures for cooling for human comfort outweighs decreases in expenditures for natural gas used to heat residential and commercial buildings (Mendelsohn 2003). According to this study, net expenditures could be relatively small if a mild warming scenario unfolds, or they could be on the order of $2 billion, in an extreme case by 2020. The method used by the author does not allow the estimation on the electricity sector alone, but rather the combined net effect of changes in electricity and natural gas demand.

3.0 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) of the National Center of

Atmospheric Research (NCAR) and the U.S. Department of Energy (Cayan et al. 2006). The GFDL is a medium-sensitivity model and the PCM a low-sensitivity model.[1] 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.[2]

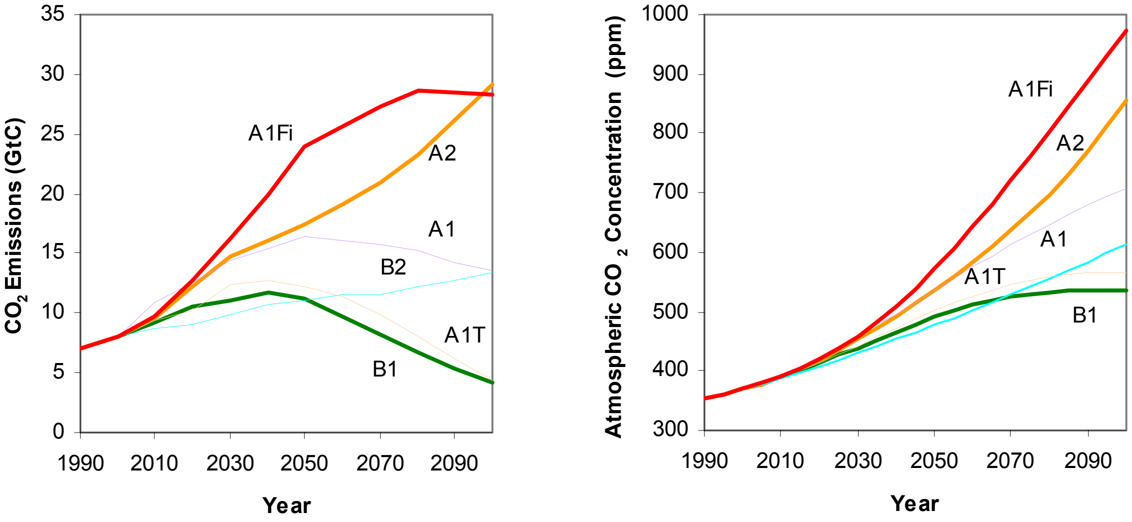

Figure 1. Trajectories of worldwide emissions and atmospheric CO_2 concentrations

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[1] 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°C to 4.5°C (2.7°F to 8.1°F).

[2] The trajectories in Figure 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 Figure 1 and similar figures provided by the IPCC, however, are minor and do not affect the discussion in this paper.

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 Figure 1 (Hayhoe et al. 2004). This paper does not estimate impacts for the A1T and A1 scenarios shown in Figure 1 because there are no climatic scenarios projected for California for these two emission scenarios. For the three scenarios used in the California analysis (AiFi, A2, and B1), statistically downscaled temperature fields were created by Cayan et al. (2006) for the California region. The downscaling method used properties of observed data (Wood et al. 2002), to correct the biases of the global circulation models and to produce estimated meteorological parameters for California at a grid resolution of about 12 kilometers (7 miles). For the analysis presented here, the authors used the outputs from grid points adjacent to San Jose, Sacramento, Fresno, and Los Angeles. Downscaled data from the Hadley A1Fi scenario for these locations are plotted in Figures 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.[3] This figure shows that the 30 year climatologically averaged temperatures (horizontal lines) for the three periods increases from approximately 40 degrees °C during the historical period to approximately 48 degrees °C by the end of this century. Moreover, as shown in Figure 3, the variability of the maximum temperature is also projected to increase, with the standard deviation increasing by more than 50% during this period.

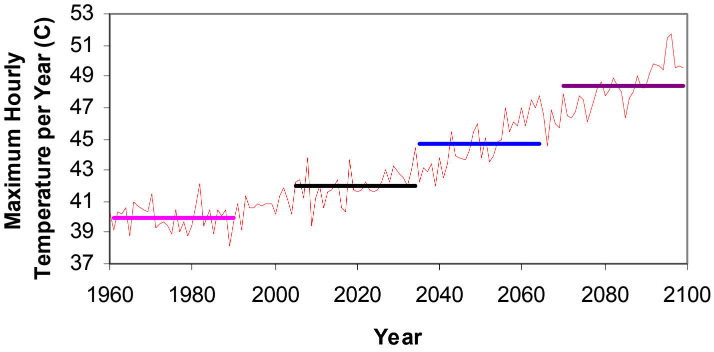

Figure 2. Maximum hourly temperatures by year, simulated historical (1961–1990), and Projected (2005–2034, 2035–2064, 2065–2099): Hadley3 A1Fi

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

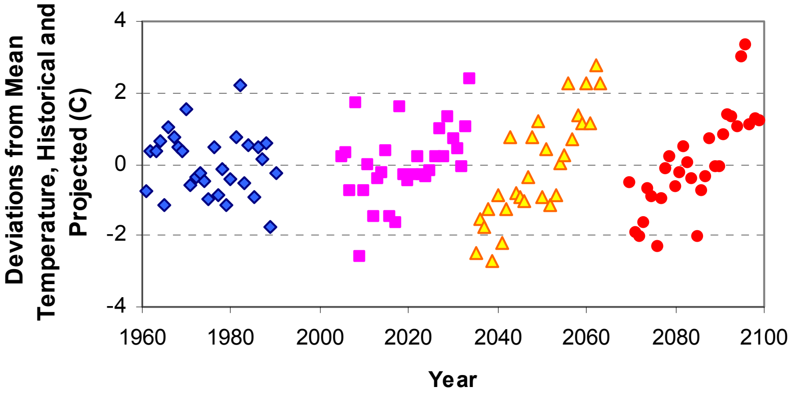

Figure 3. Temperature variation, simulated historical (1961–1990), and projected (2005–2034, 2035–2064, 2065–2099): Hadley3 A1Fi

4.0 Electricity Demand and Climate Change: Some Simple Estimates

Projecting the potential effects of regional climate change on electricity consumption and demand in California poses a number of technical challenges. Among others, a basic trade-off exists between incorporating very long time horizons—on the order of 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.

This paper aims only to obtain simple, first-order 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 a number of 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. For such reasons, these results are therefore not forecasts but rather "thought experiments" that, in our view, provide a useful starting point to understanding potential orders of magnitude of the relevant effects.

This study used hourly electricity consumption data provided by the California Independent System Operator (CalISO)[4] and daily temperature data from the California

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

Irrigation Management Information System (CIMIS).[5] Figure 4 shows daily demand of electricity for the area serviced by the CalISO in 2004 as a 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 Los Angeles. The figure only includes demand during weekdays (excluding holidays).

As indicated in Figure 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. The U-shape of this relationship (2nd order fit) shows that at low temperatures electricity demand increases from its minimum as a function of electric space heating and the higher indoor use of electrical appliances during cooler weather, to its maximum with space cooling via air conditioners and other appliances.

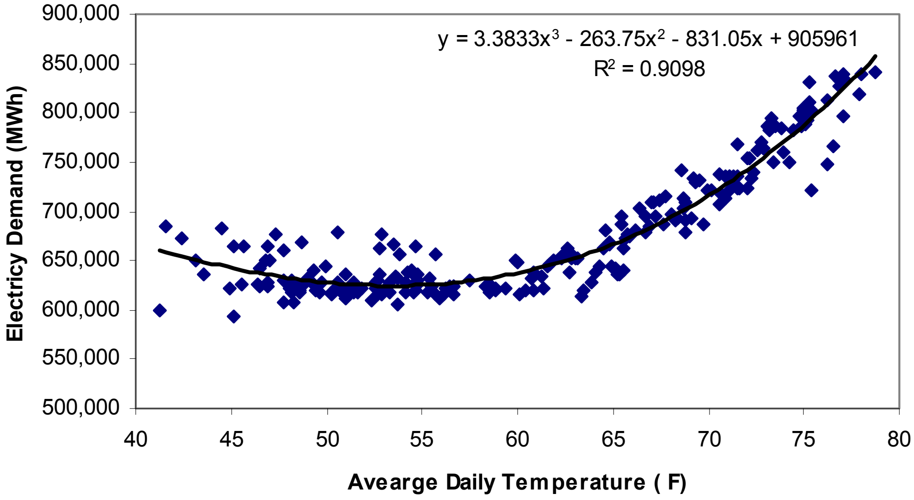

Figure 4. Electricity demand in the CalISO area as function of average daily temperatures: 2004

Peak electricity demand occurs mostly in the summer and is well predicted by maximum daily temperatures. Figure 5 presents the daily peak energy demand in the CalISO region as function of the average daily maximum temperature measured in the four locations on non-holiday weekdays. Electricity consumption during weekends and holidays tends to be lower.

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

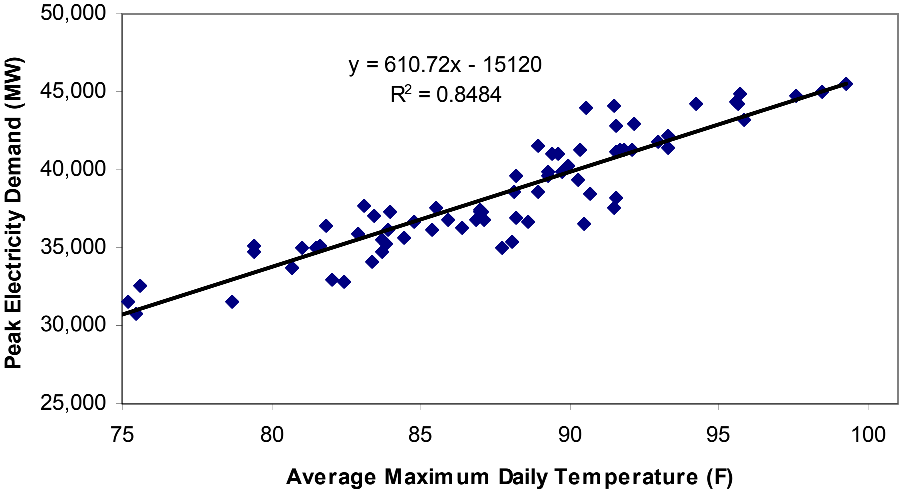

Figure 5. Peak electricity demand in the CalISO area as a function of maximum daily temperature: June–September 2004

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 temperature fields used to estimate the functional relationships shown in Figures 4 and 5. We used both the modeled historical period 1961–1990 and the three future intervals used in Figures 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 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. That is, the change in annual energy consumption as a function of projected mean temperature change in each of the three time periods was calculated using a functional relationship estimated from the historical data analogous to that plotted in Figure 4, and the change in peak demand as a function of maximum temperatures was similarly estimated using a functional relationship estimated from the historical data analogous to that presented in Figure 5. Note that because this study uses only weekday temperatures, these calculations assume a proportional response on the weekends; better resolution of any differences can be accounted for in a more finely calibrated calculation of this form.

Table 1. Estimated increases 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	3.4	4.8
	2035–2064	A1Fi	9.0	10.9
	2070–2099	A1Fi	20.3	19.3
PCM	2005–2034	A2	1.2	1.0
		B1	0.9	1.4
	2035–2064	A2	2.4	2.2
		B1	1.7	1.5
	2070–2099	A2	5.3	5.6
		B1	3.1	4.1
GFDL	2005–2034	A2	2.9	3.6
		B1	2.5	4.1
	2035–2064	A2	5.0	5.0
		B1	4.2	5.0
	2070–2099	A2	11.0	12.1
		B1	5.8	7.3

Total annual expenditures of electricity in California were approximately $26 billion (2000 dollars) in 2003.[6] 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 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.

5.0 Potential Coping Strategies

As emphasized by Baxter and Calandri (1992), climate change is one of several drivers of impacting 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

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[6] U. S. Energy Information Administration, U. S. Dept. of Energy, State Energy Price and Expenditure Series.

future development of the system as well as for demand-side policies. 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 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 to homes and buildings.

6.0 Future Work

Better understanding the detailed relationships between temperature—including temperature extremes—and patterns of electricity consumption and demand in California is a clear research priority. 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. Even in the very near term, before major climate change impacts are likely to occur in California, such methods 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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