Effect of Climate and Climate Change on Electricity Demand in Australia

S.M. Howden[a] and S. Crimp[b]

[a]*CSIRO Sustainable Ecosystems, GPO Box 284, Canberra, ACT, 2601 (mark.howden@cse.csiro.au)*
[b]*Queensland Department of Natural Resources and Mines, Meiers Rd, Indooroopilly, Qld, 4068*

Abstract: There is a growing consensus that future climate changes are likely due to human activities increasing atmospheric concentrations of greenhouse gases. Such changes may already be happening. The effects of climate change are likely to have pervasive effects due to the existing climate sensitivity of many sectors of the economy. To date there have been relatively few studies of climate change impacts on key non-agricultural industrial sectors. This study uses climate and electricity demand records to assess the climate sensitivity of demand for four Australian conurbations: Sydney, Melbourne, Brisbane and Adelaide. Highly significant relationships emerge for these Australian regions which provide a consistent picture of the link between climate variables and electricity demand. Climate change scenarios are then used to explore the implications for both weekly average and peak demand. Compensation between lower winter heating demand and increased summer cooling demand was evident in all locations but differences in the balance between these changes resulted in different outcomes. For Sydney and Melbourne, feasible temperature increases had relatively little effect on average demand (1.5% increase for 7°C rise) whilst for Brisbane, and particularly Adelaide, substantial increases may occur (10 to 28% for 7°C rise). Peak demand was even more sensitive to increased temperatures, suggesting that there will be a need to install additional generating capacity over and above that needed to cater for underlying economic growth, again particularly for Adelaide. However, the analysis suggests that there is significant and consistent adaptation to the existing climate in these four locations which, if transferable, could reduce the impacts on demand. The implications of such adaptation remain to be fully explored. This analysis does not take into account long-term socio-economic and structural changes. However, it could be linked with models which focus on such scenarios, providing a possible capacity to integrate climate change impacts, adaptation and mitigation issues in the context of broader scenarios of change.

Keywords: Climate change; Variability; Electricity; Demand; Energy; Adaptation; THI

1. INTRODUCTION

Increases in the concentrations of greenhouse gases are thought to be likely to affect global and regional climate [e.g. McCarthy et al., 2001]. Previous studies have shown that electricity demand is sensitive to climate and also that global warming may alter demand [Segal et al., 1992; Sailor, 2001]. The average increase in demand with climate change is region-specific with the average change varying in both magnitude and direction, often with decreased demand in cold climates but increases in warmer climes. If there is a net increase in demand, then the linkage between electricity demand (much of it provided by fossil-fuels) and CO_2 emissions may result in positive feedbacks in the global system (i.e. warming causes increased emissions which propagates further warming) provided the mix of energy sources does not change. Furthermore, such responses to anticipated temperature increases will make more difficult Australia's mitigation task under arrangements such as the Kyoto Protocol. Such feedbacks may be damped if there is adaptation to the new climate through changes in building infrastructure, habits (i.e. amount and type of clothing) and even physiological responses (acclimation).

Ensuring that peak electricity demand is met is currently a challenge for at least some regions in Australia (e.g. Adelaide) resulting in installation of new generation capacity. Critically, the problem periods are during hot summer days. The risk of demand not being met seems to be increasing as a result of increasing use of air conditioners as is happening in other cities in other nations [e.g. Segal et al., 1992; Lam 1998]. Climate change may feasibly increase the magnitude of peak demands, causing additional generating capacity to be installed at considerable cost and with an uncertain impact itself on greenhouse emissions. This study assesses the effect of climate on electricity demand in the Brisbane, Sydney, Melbourne and Adelaide regions and investigates the possible effects of climate change on demand.

2. METHODS

Half-hourly electricity demand was retrieved from the National Electricity Management Marketing Company (NEMMCO) website for the years 1999 and 2000 (www.nemmco.com.au). Demand was aggregated to weekly values (GWh).

All climate data were retrieved from the SILO Datadrill (www.dnr.qld.gov.au/silo/datadrill_frameset.html) from a region covering each state capital city to give an area-averaged climate file. This was done to restrict the impact that localised climatic events may have had. Primary independent variables were maximum, minimum and dewpoint temperatures, vapour pressure, solar radiation and evaporation. Further climate variables were derived from these.

Heating and cooling degree days have been used to explain variance in electricity demand [e.g. Sailor, 2001]. They measure the deviation of mean temperature from a base temperature (T_b) which is a temperature where neither heating nor cooling is used. For Heating Degree Days (HDD), this is the deviation below the base temperature, for Cooling Degree Days (CDD) this is the deviation above. We also calculated an absolute deviation from the baseline for each region (absolute degree days; ADD). The base temperature T_b has been reported to be around 18.3°C for temperate environments and higher for warmer environments; for example being 21°C in Florida [Sailor, 2001]. Given the span of climate in the regions used in this study we assessed the appropriate base temperature for each region (Table 1) by iteratively sampling T_b to minimise the least squares difference between demand and ADD.

Table 1. Base temperatures (°C) for the heating/cooling degree day analysis (T_b) and THI analysis (THI_b).

City	T_b	THI_b
Brisbane	18.6	70.5
Sydney	17.5	69.7
Melbourne	16.9	68.2
Adelaide	16.8	66.3

The combined effects of temperature and humidity have been integrated in the Temperature-Humidity Index [THI: Johnson et al., 1963]. This has been shown to physiologically affect a range of mammals. Howden and Turnpenny [1997] have also shown that the stress calculated using this simple index is equivalent to that derived from complex physiological/micrometeorological models of heat and mass transfer of livestock. We calculated weekly THI from maximum temperature and dewpoint temperature from the climate files. We also calculated the daily deviation of THI (THI_{dev}) from a base level of THI (THI_b) for each region in a way similar to that used for ADD (Table 1).

Vapour pressure deficit (VPD) is the difference between the potential vapour pressure (at air temperature) and the actual vapour pressure. It is associated with the total heat load, being correlated with solar radiation, air temperature and evaporative demand [McKeon et al., 1998]. Daily VPD was calculated following the method of Tanner and Sinclair [1983].

Additional daily climate variables used were mean temperature and relative humidity. All direct and derived climate variables were aggregated to weekly values to remove within-week fluctuations evident in the data.

Stepwise regression was used to develop the simplest physically-significant model that maximised the variance accounted for (adjusted R^2 was the criteria used).

The relationships developed from the 1999-2000 data were tested against data for the first seven months of 2001. Consistent outliers for the weeks of the New Year and Easter were removed from all four relationships. During these weeks closure of industrial facilities reduced demand from this sector independently of climate.

2.1 Climate Change Scenarios

Recent climate change scenarios for Australia (www.dar.csiro.au/publications/projections2001.pdf) suggest increases in temperature of between 1 and 7°C for most of Australia by the year 2070. Changes in rainfall and other climate parameters are more uncertain so we limited this analysis to scenarios of temperature change as above. To implement these scenarios we added the requisite temperature change to maximum, minimum and dewpoint temperatures and recalculated the derived variables. Change in average electricity demand was calculated for each scenario as was change in peak demand.

3. RESULTS

3.1 Climate and Demand Relationships

Mean temperature has a marked effect on electricity demand (e.g. Figure 1). When other climate factors were evaluated, different sets of equations were found to best describe the variation in demand (Table 2). When tested against independent data for the first 7 months of year 2001 (Figure 2), these relationships described a significant proportion of the variance in weekly demand ranging from 63% (Melbourne) to 89% (Sydney). However, there was a consistent under-prediction of the order of 3 to 7%.

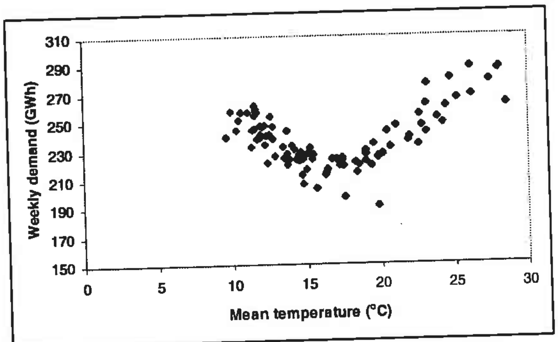

Figure 1. Weekly electricity demand (GWh) for Adelaide against mean temperature.

Table 2. Regressions between climate variables used to explain variation in weekly electricity demand in four Australian cities along with adjusted R^2 values.

City	Equation	Adj R^2 (%)
Brisbane	$726.5+2.49VPD+6.394THI_{dev}$	69
Sydney	$1153+4.74CDD+4.15HDD$	89
Melbourne	$789.2+.207HDD+12.84THI_{dev}$	63
Adelaide	$202.5+1.037CDD+1.170HDD$	72

3.2 Climate Change Scenarios

The response of average electricity demand varied substantially between regions (Figure 3). For Sydney and Melbourne there was an initial but slight (1 to 1.5%) drop in demand with global warming up to about 3°C, followed by an increase such that demand was about 1 to 1.5% greater than the current demand with a warming scenario of 7°C. In contrast, increases in demand were indicated for Adelaide with warmings above 1°C and with any warming in Brisbane. For these sites demand may increase by 10 and 28% respectively with a 7°C increase in temperature.

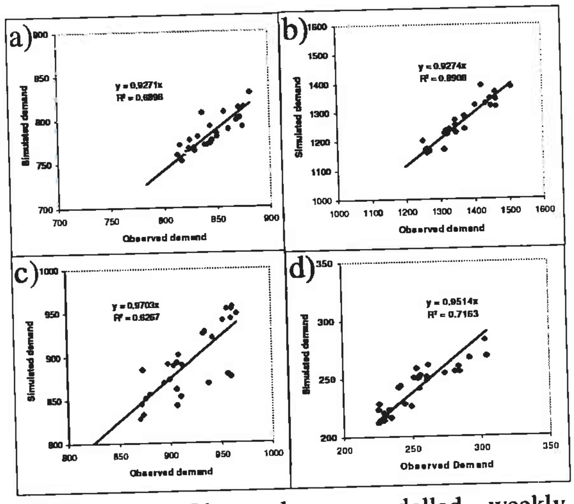

Figure 2. Observed vs modelled weekly electricity demand data for a) Brisbane, b) Sydney, c) Melbourne and d) Adelaide.

For the three sites except Sydney, the responses for change in peak demand differed from those for average demand (Figure 4). Largely linear increases were calculated for Brisbane and Adelaide with these being about 14 and 35% respectively for a 7°C rise. For Melbourne there was a small decrease followed by an increase up to about 22% with a 7°C increase.

Changes varied across seasons (Figure 5) with summer demand increasing with increasing temperature but winter demand initially decreasing (1°C to 3°C warming) but then increasing (5°C warming).

4. DISCUSSION

Climate has a strong impact on electricity demand in the four Australian regions studied, with simple relationships explaining a large proportion of the observed variance in demand as found for other regions in other nations [e.g. Sailor, 2001; Segal et al., 1992; Lam, 1998].

There appears to be trends in electricity demand with increases of about 2 to 5% per year when the effects of climate variation removed. This level of increase corresponds with the 3.4% p.a increase in electricity use over the past 9 years derived from the National Greenhouse Gas Inventory (NGGI, 2001). The cause of these trends is likely to be due to both general increases in base load from economic growth and additional demand from greater use of air conditioners in commercial and residential situations. Increase in air conditioner use in other nations has resulted in increases in sensitivity of electricity demand to hot weather [Lam, 1998; Segal et al., 1992].

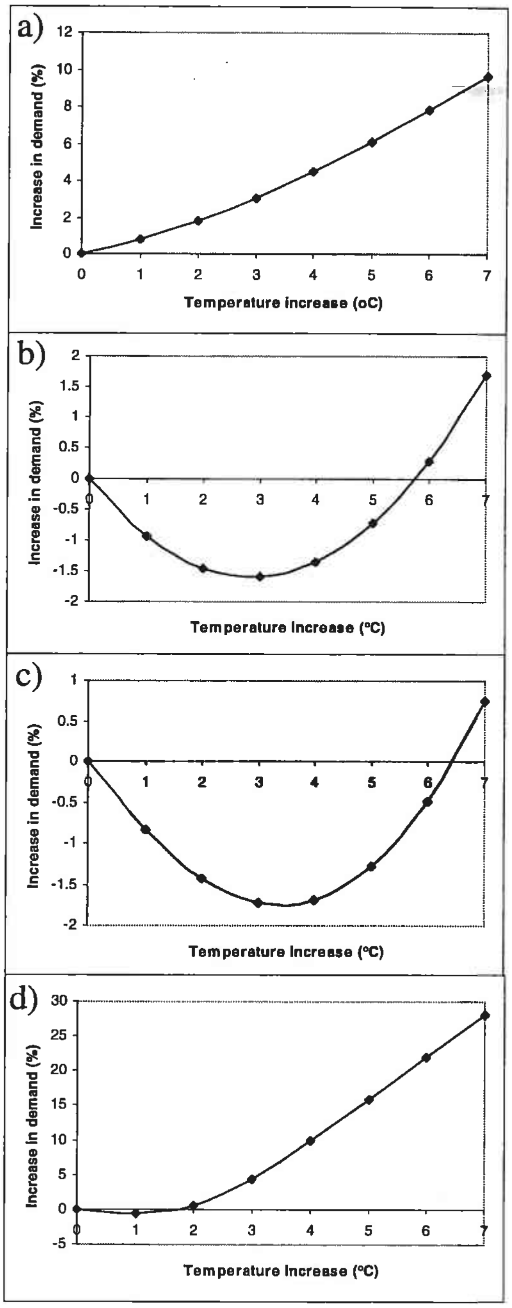

Figure 3. Change in electricity demand (%) with scenarios of global warming (^{O}C) for a) Brisbane, b) Sydney, c) Melbourne and d) Adelaide.

The climate change scenarios used had markedly different effects depending on location. In all cases, the global warming scenarios resulted in decreases in demand for winter heating and increases in demand for summer cooling, however, the balance between these varied. For Sydney and Melbourne, this balance was very even, resulting in little increase in average demand. In contrast, Brisbane and Adelaide showed marked increases in demand with climate change due to a larger summer effect compared with winter. Indeed, under the higher rates of warming, the trend to lower consumption during winter was reversed as increasingly higher proportions of days started to require air conditioner usage. The range of response recorded in this study are similar to those in the US. There, a 3°C rise was suggested to increase average demand by between 3.5 and 13% for tropical locations, 2.5 to 7% for temperate locations and decrease demand by about 5% for a cool location [Sailor, 2001]. The comparatively muted response found in Sydney and Melbourne may reflect the relatively low penetration of space heating and cooling in homes in these locations compared with equivalent US cities.

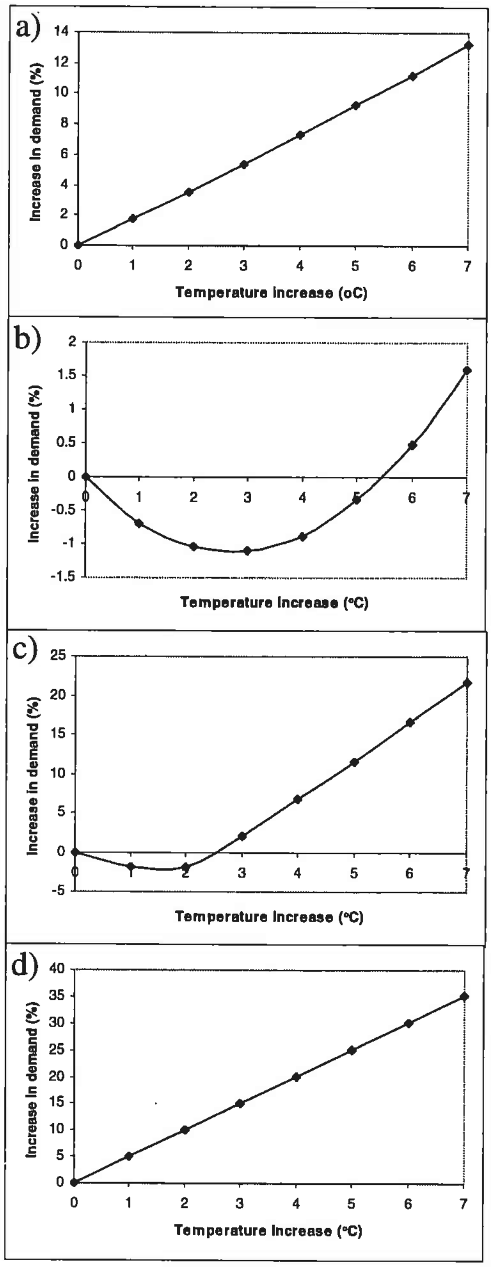

Figure 4. Change in peak electricity demand (%) with scenarios of global warming (^{O}C) for a) Brisbane, b) Sydney, c) Melbourne and d) Adelaide.

Peak demand was more affected by climate change than average demand for all cities except for Sydney. For Melbourne, Brisbane and Adelaide, global warming may significantly increase peak weekly demand with increases of 22, 13 and 35% respectively for a 7°C rise in temperature. Some of these cities are already having difficulty in meeting peak demands with current generating and transmission capacity and additional loads imposed by the combination of economic growth and climate change will require installation of new capacity. The economic implications could be significant. Furthermore, the limited expected expansion of renewable energy sources and the exclusion of nuclear options means that the majority of this increase in demand suggested in all cities under the warmer scenarios is likely to be satisfied by fossil-fuel combustion. This will further raise national emissions and increase the difficulty of Australia meeting any emission targets such as those proposed under the Kyoto Protocol. Additionally, as suggested by Considine [2000], the year-to-year variation in demand (and hence emissions) may need to be incorporated into such targets as variations of the order of several percent in emissions could occur due to natural causes.

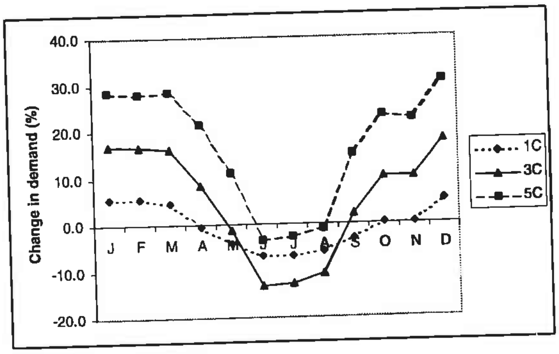

Figure 5 Change in monthly electricity demand (%) from the current levels for Adelaide under scenarios of 1°C, 3°C and 5°C temperature increase.

There appears to be a significant capacity to adapt to prevailing climate conditions as the base values for heating and cooling days (T_b) and for the THI (THI_b) varied systematically over the four locations. There was a consistent reduction in T_b with transitions to the colder locations, suggesting that the inhabitants find progressively lower temperatures tolerable (i.e. the temperature at which heaters are turned on is lower than in the north). Similarly, there was a systematic decline in THI_b indicating that the tolerance to hot, humid conditions was greater in the sub-tropical location than in the more temperate locations further south (i.e. the conditions of heat and humidity are more severe before air conditioning is turned on compared with the southern locations). Possible causes of this adaptation could be the design of infrastructure, behaviour such as the clothing worn and physiological adjustment. If these adaptations are transferable, at least some of the negative impacts of climate change on electricity demand could be offset.

In contrast with other studies [e.g. Sailor, 2001], CDD and HDD were not necessarily the most effective climate variables to use to model electricity demand. The equations used here included vapour pressure deficit and deviation of THI from a base level, with the climate variables used varying from location to location. In many cases, alternative sets of variables provided only slightly less explanatory power. In the two locations where used, the regression coefficients of the CDD and HDD terms of the regression were similar in value. This contrasts with the US where the coefficients for CDD are always considerably greater than those for HDD [Sailor and Munoz, 1997]. This difference may be due to lower air conditioner usage, alternative cooling systems (i.e. evaporative coolers, fans) or greater tolerance of discomfort from hot and humid weather.

This analysis does not include socio-economic data which is important in assessing longer-term changes in total demand rather than the short-run variation in demand due to weather analysed here. Such analyses could be made in a model of the physical stocks and flows within the economy [e.g. Poldy et al., 2000], providing a way to integrate climate change impacts, adaptation, emissions with broader socio-economic scenarios.

5. ACKNOWLEDGEMENTS

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