Electricity and Natural Gas Consumption Trends in the Australian Capital Territory 2009-2013

Environment and Planning Directorate

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Contents

Executive Summary

This report examines seasonal and other factors that affect energy consumption in the ACT and identifies underlying structural energy consumption and demand trends.

The main results of the analysis are as follows:

- After accounting for weather and other effects, total electricity consumption in the ACT, and for small customers, decreased around 3% and 13%, respectively, between 2009 and 2013. This reduction can be attributed to underlying 'structural' changes such as improved building/equipment energy efficiency and changes in energy user behaviour.
- Per capita electricity demand in the ACT has exhibited a significant and persistent downward trend since 2009 – decreasing by around 19% to 2013. This supports the assessment that structural improvements in energy usage and efficiency are playing a role, compared to population movements over the period.
- The ACT electricity network appears to be slowly transitioning from a winter to a winter *and* summer peaking network, with very hot weather, as well as very cold weather both becoming a dominant factor in determining whether very high peak demand will occur. The highest ever demand on the network occurred on 2 February 2011 at 613MW, followed by 8 June 2011 at 611MW.
- Solar PV systems seem to be moderating and pushing back to later in the day, summer demand peaks, and have caused very high summer peaks to be lower than they would otherwise have been. This in turn, means that cold winter temperatures will remain a dominant driver of network peak demand for the foreseeable future.
- Electricity network utilisation is slowly decreasing in the Territory and this will place upward pressure on network costs and pricing should this trend continue. The demand factor, which refers to the ratio of average demand to peak demand, declined from 57% in 2009 to 55% in 2013.
- After adjusting for the weather effects, total gas consumption in the ACT remained generally stable between 2009 and 2013. However, there has been a steady decline in aggregate per capita gas consumption since 2009 – decreasing by around 7% to 2013.

These results have implications for energy policy in the ACT and support current reforms under consideration including those related to electricity metering, tariffs and demand side participation which can all mitigate declines in network utilisation and improve the over economic efficiency of the ACT's energy supply systems.

The patterns of change in energy consumption are broadly consistent with 'business-as-usual' projections in Climate Change Action Plan 2 (AP2). While it is too early to determine the specific impact of AP2 measures, it is likely recent observed reductions in energy consumption will be carried forward and reinforced by government policies that promote improved energy efficiency.

Introduction

Energy costs and demand

Electricity and natural gas consumption is a major cost for the ACT community equating to total costs of approximately $600 million and $240 million respectively in 2013-14[1]. The key components of these costs are the cost of purchasing electricity and gas from wholesale markets for supply to the ACT and the cost of maintaining and expanding electricity and gas infrastructure to deliver these energy sources to Territory customers.

While network costs are generally considered to be fixed costs (i.e. unaffected by levels of energy consumption) electricity and gas networks are sized to meet expected peak loads (demand). Expectations of growth in peak loads have resulted in higher network investment costs that have been passed onto consumers through regulated network charges. For example, the Productivity Commission has estimated that around 25% of NSW electricity charges are associated with electricity network infrastructure investment required to meet forecast loads that would occur for only 40 hours of very high consumption in a given year[2].

A key driver of peak demand is the proliferation of air-conditioning in residential and commercial applications that drive cost increases to all electricity users rather than just those using air-conditioners. The Australian Energy Market Commission (AEMC) estimates that a consumer using a large 5kW air-conditioner at peak times will add about $1,000 a year in additional network costs compared with a similar consumer without an air-conditioner, but the consumer with the air-conditioner only typically pays about an extra $300 in network prices. The remaining $700 is recovered from all other consumers through higher network charges.

Similar issues are also associated with solar installations. The AEMC has estimated that, nationally, a consumer using an average-size, north-facing solar PV system will save themselves about $200 a year in network charges compared with a similar consumer without solar. However, because most of the solar energy is generated at non-peak periods during the day, it reduces the network's costs by $80, leaving other consumers to make up the $120 shortfall through higher network charges.[3]

After many years of continuous growth in demand across much of the National Electricity Market (NEM), in recent years significant declines have been recorded in most sectors. While these changes have resulted in reductions in energy costs to users, limited savings in network costs have been achieved due to the long-run nature of network investments and uncertainty about whether those reductions will be sustained over time.

[1] EPD internal estimate based on aggregate demand values for the period.
[2] http://www.pc.gov.au/projects/inquiry/electricity/report/key-points
[3] http://www.aemc.gov.au/News-Center/What-s-New/Announcements/New-rules-proposed-for-distribution-network-prices

Greenhouse gas emissions

Electricity and natural gas consumption are major contributors to the ACT's greenhouse gas emissions profile accounting for approximately 61 and 9 percent, respectively, in the most recently published ACT greenhouse gas inventory[4].

The ACT has ambitious targets to reduce its greenhouse gas emissions that assume significant reductions in electricity consumption. The ACT Government's climate change strategy, AP2, estimated that the ACT's non-residential sector (including business and government) has the potential to reduce annual energy usage emissions by at least 180,000 tonnes CO_{2e}/yr through energy efficiency measures with a residential sector savings potential of 218,000 kilotonnes CO_{2e}e/yr by 2020. This is a saving of around 14% to 20% from projected business as usual emissions in 2020.[5]

Purpose of this study

Despite the importance of energy demand to meeting the ACT's energy policy and carbon mitigation goals, limited information has been available to determine trends in energy consumption or to develop a predictive model to determine likely future consumption.

While major annual energy consumption data is available, it is influenced by weather and climatic effects. The experience of many utilities, worldwide, has shown that weather is a significant driver of energy demand. Because weather varies from day to day, and climate varies from year to year, this obscures any analysis of underlying usage trends. By normalising energy consumption data for weather and climate effects through this study, it is possible to reveal underlying trends and structural change in the ACT economy.

[4] http://www.icrc.act.gov.au/wp-content/uploads/2014/09/Report-6-of-2014-ACT-GHG-Inventory-Report-2011-12.pdf

[5] http://www.environment.act.gov.au/__data/assets/pdf_file/0006/581136/AP2_Sept12_PRINT_NO_CROPS_SML.pdf

Weather, climate and energy consumption

Energy consumption is made up of two segments: base load and weather sensitive loads. While the weather-sensitive component is often in the order of 10% to 30% of total load in the residential and commercial sectors, it is negligible in the industrial sector[6]. Fluctuations in base loads mainly occur because of hourly and weekly work cycles, short and long term trends in energy intensity, as well as economics factors. Variability in weather-sensitive loads, on the other hand, is primarily due to air conditioning and heating needs that are impacted by weather conditions such as temperature, wind speed and humidity.

Figure 1 provides an example of a daily electricity load profile for a typical winter day in Canberra. This data is the Net System Load Profile so it represents all customers with an annual consumption below 100MWh per annum including all households and most small businesses. It shows clear peaks in the morning and evening resulting from residential electrical appliances including, in this case, residential space heaters.

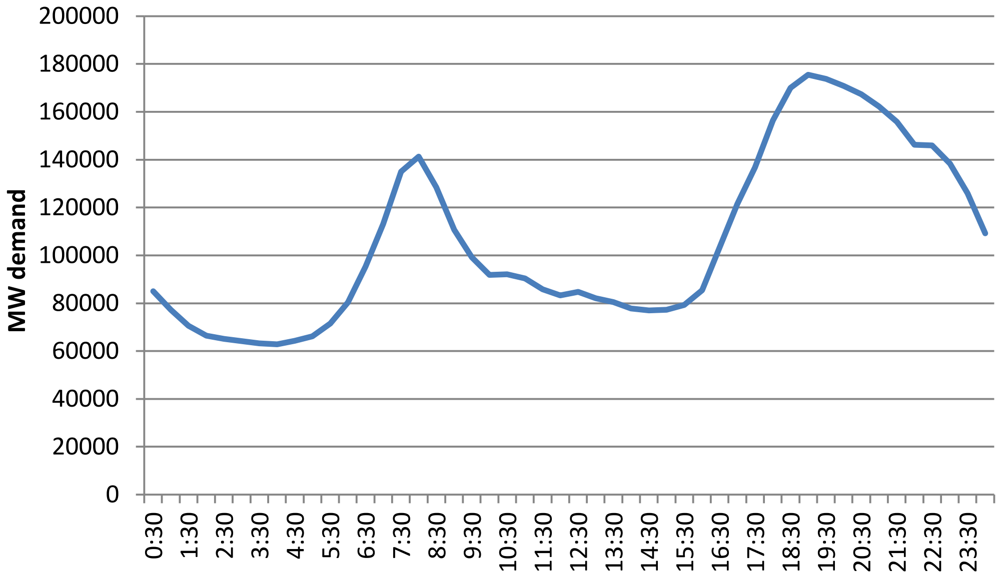

Figure 1.Net System Load profile (electricity demand by households and small businesses) for Thursday, 9 August 2012

In this report a linear regression model has been developed to study the effect of different variables on the ACT's energy demand. The primary variables analysed are daily aggregate ACT demand for electricity, the aggregate small customer load profile, electricity network peak loads and aggregate demand for natural gas. The period studied is between 1 January 2009 and 28 February 2014. [7]

[6] The base load varies in different regions and primarily depends on variety of factors such as social and economic conditions.

[7] See Appendix A for the data description.

Calendar effects

A 'calendar effect' is determined, to account for the impact of weekends and public holidays, prior to an analysis of the effect of weather and climate effects.

The left pane of Figure 2 shows a time plot of the monthly consumption of electricity and gas in the ACT. It reveals a regular monthly and seasonal pattern, where it is evident that there is a difference in the quantity of consumption for the same months of each year. Figure 3 highlights discernible differences in average consumption between different days of the week over the 5 year period (i.e. a working day effect is evident).

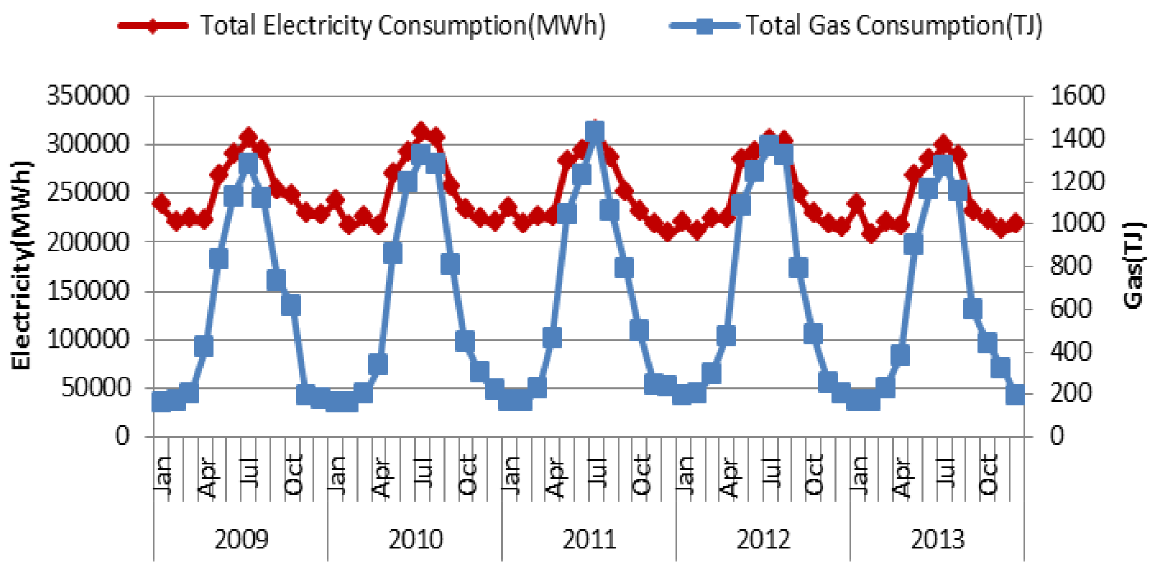

Figure 2. Monthly aggregate consumption (1 Jan 2013 -31 Dec 2013)

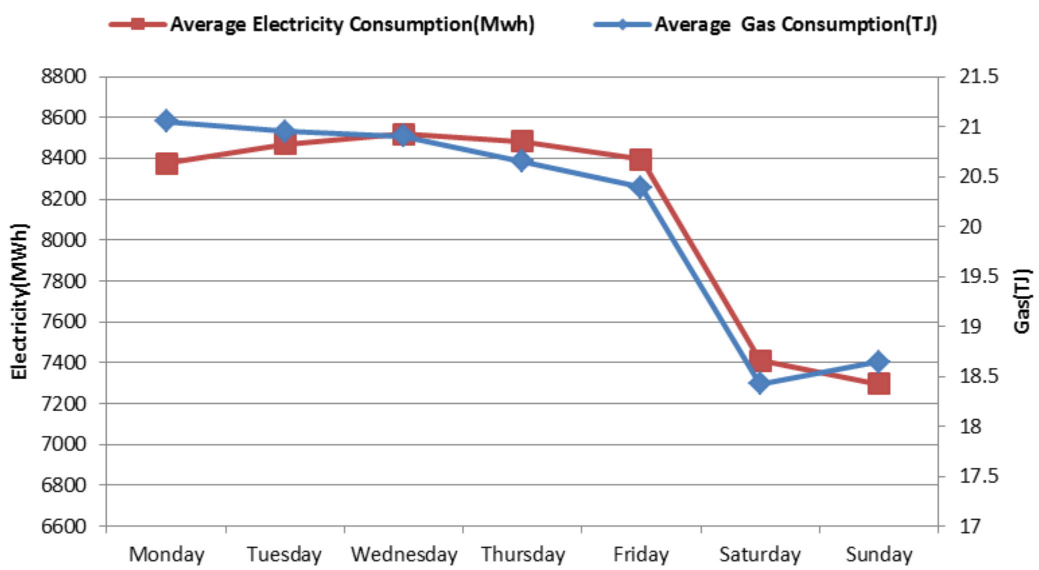

Figure 3. Average consumption per every day of the week (1 Jan 2013 -31 Dec 2013)

In order to capture the energy consumption variation caused by the calendar effect, a working day effect variable is defined as WD_t .This variable shows the calendar effect in the demand of a particular day as a percentage of electricity (or gas) demand on a reference day.[8] In this study, we use Wednesday as the reference day of the week, assigning it a calendar factor of one.

The working day effect variable for each day of the week is shown in[9] Table 1. These values represent the coefficient of equivalence of the different days that would transform any day into a Wednesday[10]. The days of the week with least electricity demand are (from lowest) Sunday, Saturday and Monday.

Table 1. Working Day (WD) effect for electricity

Type of day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Non-holidays	0.98	0.99	1.00	0.99	0.98	0.87	0.85
Week before Easter day	0.98	0.98	1.00	0.97	0.81	0.79	0.78
Easter Monday	0.93	-	-	-	-	-	-
Christmas	0.75	0.67	0.79	0.85	0.75	0.88	0.86
National and Regional holidays	0.89	0.89	0.89	0.89	-	-	-

Weather effects

Both electricity and gas consumption for small customers in the ACT show a strong relationship with temperature.

Figure 3 shows a nonlinear, U-shaped trend for electricity and an L-shaped one for gas. This reflects the fact that that while gas is used primarily for water and space-heating purposes, electricity is used for both space-heating and space-cooling purposes. The difference between the left and right-hand plots relates to the exclusion of non-working days from the dataset. As the energy loads of weekends and public holidays load are typically less than those of working days, the relationship between demand and temperature is distorted if the calendar effect is not removed from the dataset. Therefore, a 'filtering' procedure was applied by using the calculated working day variable, shown in Table 1, to subtract anomalies[11].

[8] The effect is computed separately from the seasonal, temperature effect, trend and economic conditions.
[9] The working day effect, on average, for gas consumption was negligible.
[10] For detail see Appendix B-1
[11] See Appendix B-2 for the technical notes. Negative values emerge because the data plotted is obtained by de-trending the data series. As it is a residual of a regression estimated by ordinary least squares, it has zero mean, and therefore, some values can be negative. In viewing these plots, it is the shape against temperature that is significant rather than the TJ consumption values.

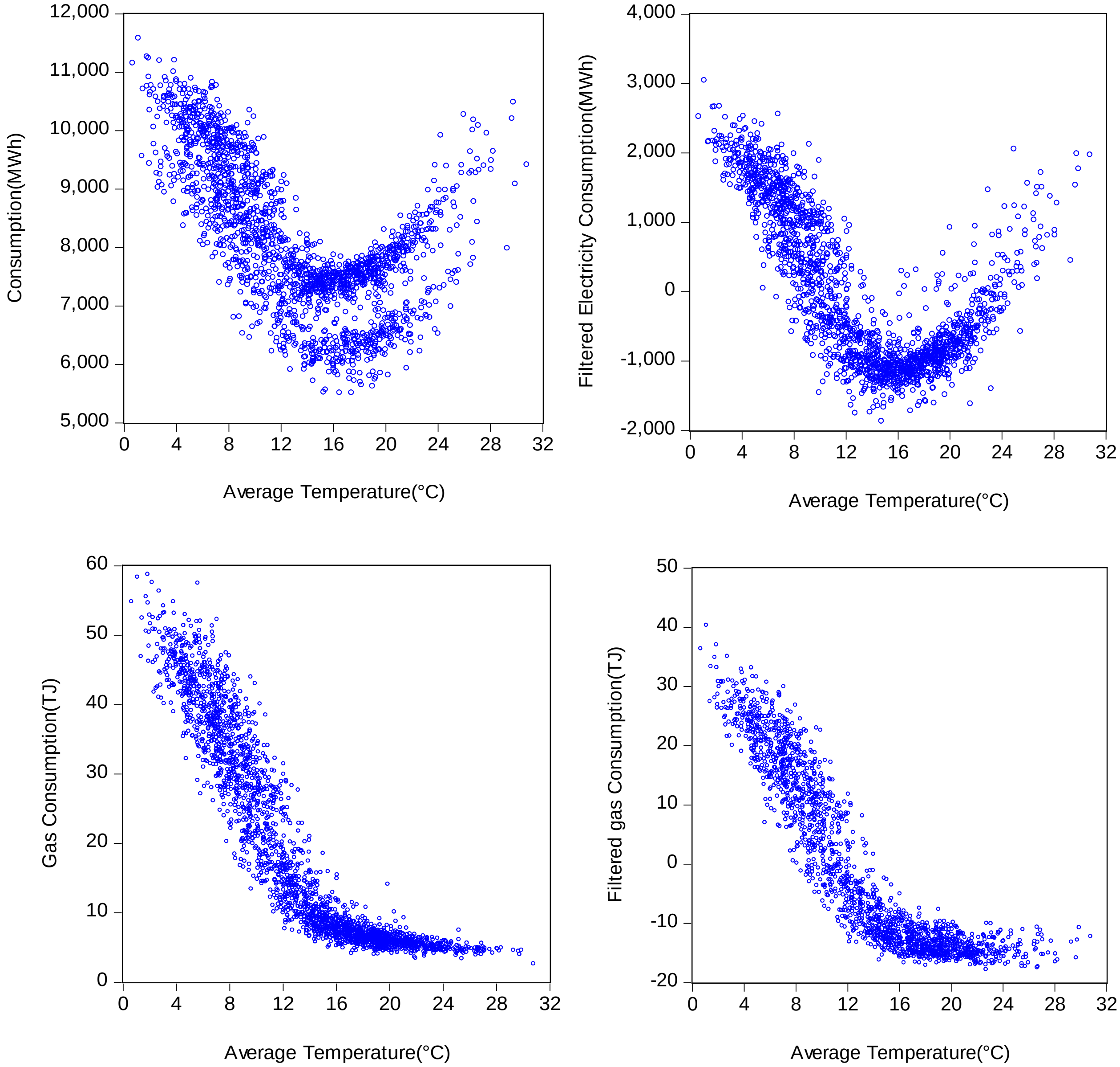

Figure 4. Relationships between temperature and energy consumption in the ACT, daily data. The right hand panels filters out weekends and public holidays to remove relationship anomalies.

It is evident that daily average temperatures in the range between around 15°C and 18°C do not significantly influence the ACT's electricity demand. Outside this range, however, consumption substantially increases, during both low and high temperature periods. Similarly, gas consumption is not sensitive to temperature when the temperature is above 16°C.

The amount of energy demanded at the balance point temperature interval [12] (i.e. the bottom of the U-shaped and L-shaped temperature–energy consumption function shown in Figure 4), is the non-temperature sensitive electricity load. Energy demand in excess of the balance point temperature demand level is the temperature-sensitive energy load.

12 . Between 14°C and 18°C for electricity and above 16°C for gas

Heating and cooling degree days

Heating degree days (HDD) and cooling degree days (CDD) are commonly used concepts to capture the relationship between energy consumption and weather/climate effects.

The heating degree-day index assumes that people will begin to use their heating equipment (e.g. space and water heating) when the mean daily temperature drops below a given balance point (14°C and 16°C for electricity and gas, respectively, in this study). HDD represent the number of degrees below the balance point on such a day.

Similarly, the use of air-conditioning starts to materially impact electricity consumption when the mean daily temperature exceeds the balance point for electricity (18°C).[13] CDD represents the number of degrees above that balance point on a given day.

Normalising for weather effects

Energy demand varies according to the type of day and climatic conditions, amongst other factors. Therefore, these influences need to be isolated to normalise demand in order to provide a consistent basis for demand analysis. Generally, when calendar effects and weather affects have been clarified, the main remaining sources of demand variability are socioeconomic and technological factors. These can be referenced to as 'structural' factors. The objective of weather normalisation is to ascertain what demand would have been under normal weather conditions to reveal underlying structural trends.

To compute weather-normalised energy consumption for each year, the following process is applied:

1. Regression of daily energy consumption data (or daily per capita consumption) against the relevant HDD, CDD, and WD per day for the relevant year (i.e. 2009 to 2013)

2. Substituting the average daily HDD, CDD, and WD[14] into each regression equation, then multiply by 365[15].

[13] CDD has not been defined for the gas consumption model.

[14] The average (i.e. normal) daily HDD, CDD, and WD for electricity were 2.99, 0.36, and 0.74 respectively. The average daily HDD for gas was 4.19.

[15] The adjusted R^2 values were above 0.85 for all regression analysis suggesting that the developed model has predicted regional demand variability at daily intervals with reasonable accuracy. Also, coefficients were statistically significant at the 5% level.

Results

Electricity consumption

The growth rate of all of the ACT's electricity consumption has slowed in recent years and, consistent with broader trends for the National Electricity Market, began to decline from around 2009. This study shows that while some of that decline can be accounted for by favourable weather conditions in 2013, specifically a warmer winter that resulted in lower winter electricity and gas consumption for heating[16], a structural reduction has also occurred which is most noticeable between 2009 and 2012. (Figure 5).

After adjusting for this climate effect, the greatest drop in electricity consumption can be seen between 2010 and 2012 while it remained roughly stable throughout 2013. Without weather normalisation, the average decline over the 4 year period between 2009 and 2013 was significantly higher with the largest period of decline between 2012 and 2013.

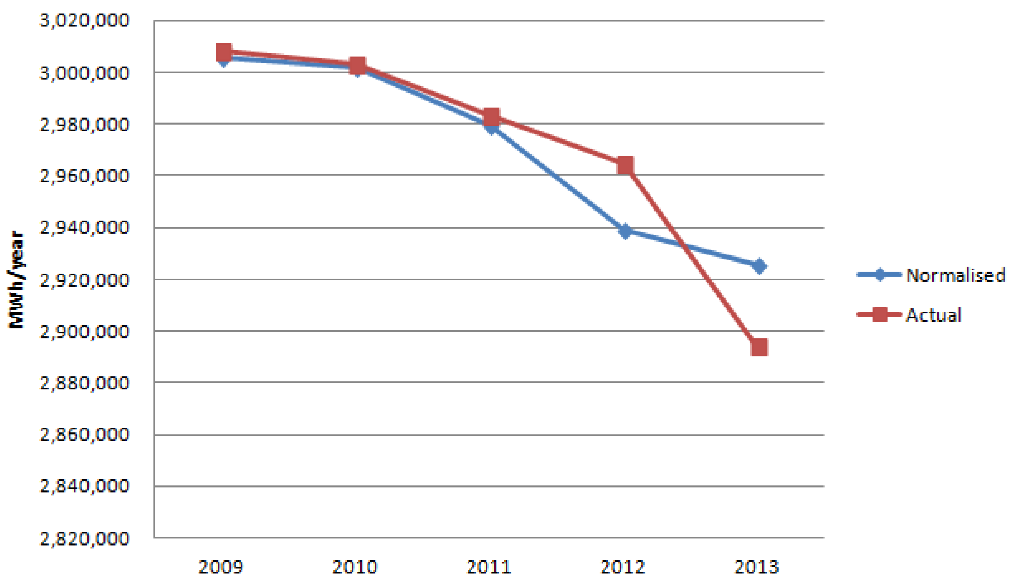

Figure 5. Normalised versus actual total electricity consumption

Figure 6 shows a reduction in per capita electricity consumption in the ACT over the period of 2009-2013 that is statistically significant, with an average annual rate of decline for actual and weather normalised electricity consumption of 2.7% and 2.4%, respectively. The variance between 2012 total and per-capita consumption data sets can be accounted for by fluctuations in population growth rates in that period. Specifically, a higher population growth rate in that period was not matched by a proportionate increase in electricity consumption.

16 . Total Heating degree days are equal to 1,243 and 970 for 2012 and 2013, respectively (based on the defined balance point of 14°C).

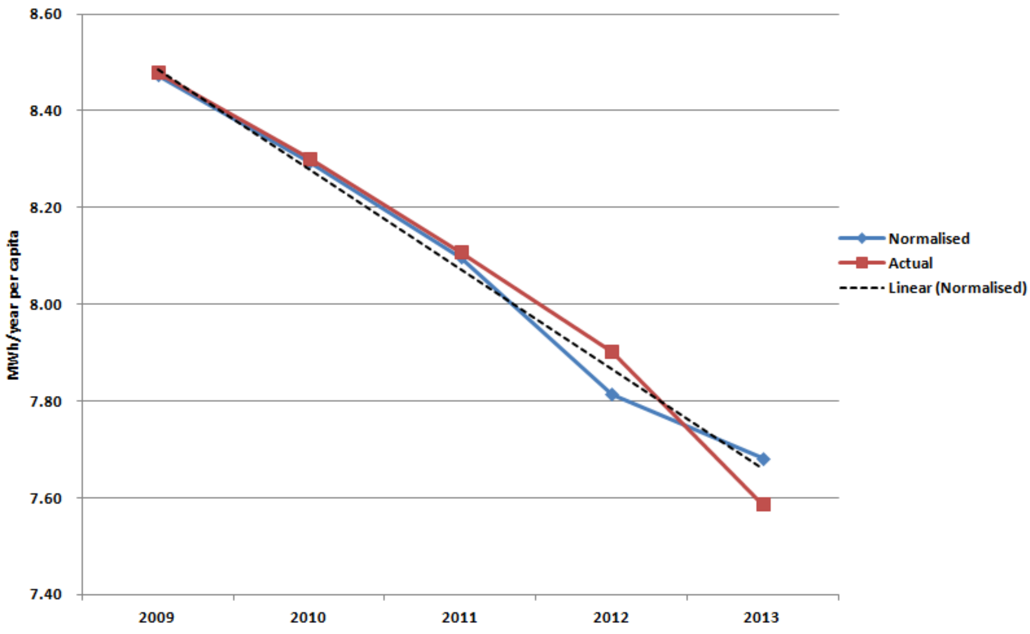

Figure 6. Normalised versus actual per capita electricity consumption

Small electricity customers

Data used in the previous analysis was obtained from ActewAGL Distribution and does not discriminate between residential and non-residential customers. In order to explore the differences in trends in these two sectors, the Net System Load Profile (NSLP) for the ACT was used as a proxy for the consumption profile of consumers with accumulation meters (Type 6) or digital accumulation meters read as accumulation meters (Type 5). The NSLP is used by ACT electricity retailers to settle non smart-metered customers in the wholesale electricity market. The ACT NSLP includes residential and small business customers, with an annual electricity consumption of less than 100MWh. Residential accounts for around 80% of the NSLP[17].

The previously discussed approach for normalisation against calendar and weather effects was applied to this data to produce a 'small customer' weather-normalised daily electricity consumption data set.

The results, shown in Figure 7, show a trend of decreasing small customer electricity consumption since 2009. However, after weather normalisation, a slight increase in 2013 shows that demand would have been higher in 2013 under normal climate conditions. In other words, the reduction in electricity demand in 2013 can be attributed to more favourable weather conditions rather than structural changes in energy usage in the residential and small business sectors.

In terms of per capita electricity use, as shown in Figure 8, the trend of decline in per capita energy consumption continued in 2013 even after adjustments for favourable weather conditions in that year.

[17] Based on ICRC reported residential consumption for 2011-12: http://www.icrc.act.gov.au/wp-content/uploads/2013/08/Report-7-of-2013-August-2013.pdf

favourable weather effect of 2013 accounts for much of the decrease in 2013 rather than structural decreases in energy use. .

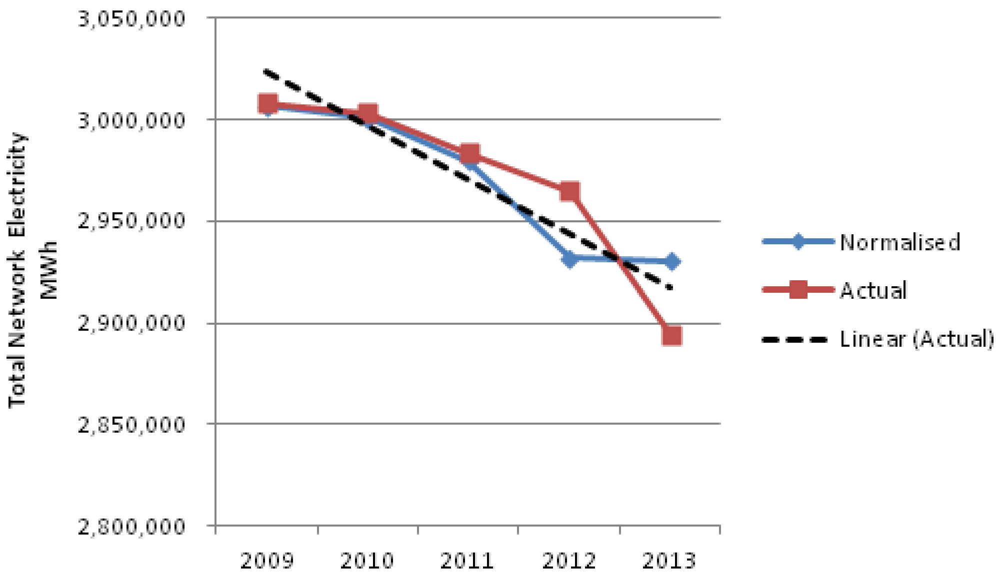

Figure 7: Normalised versus actual electricity consumption for small customers

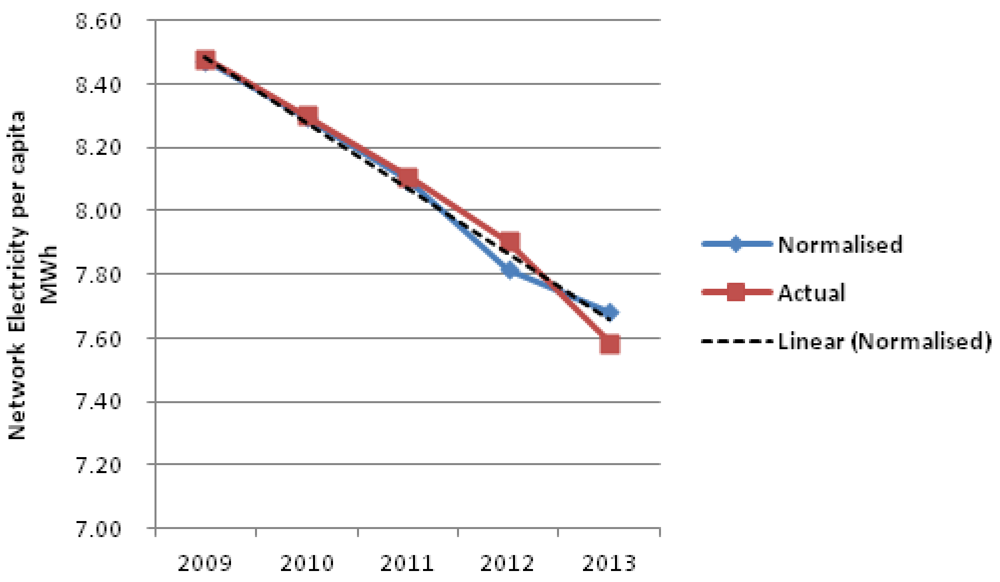

Figure 8. Normalised versus actual per capita electricity consumption for small customers

Electricity peak demand

Peak electricity demand is a critical reliability and costs driver for the ACT's electricity supply system. Peak demand typically correlates with high wholesale market costs and is a driver of medium and long term network investment costs.

As this analysis focuses on peak demand as a driver of higher electricity costs, the dataset is truncated so that only working days are taken into account (i.e. all Saturdays and Sundays were removed from the dataset). This is because daily peak demand for the whole ACT electricity system is significantly lower during weekends, being, on average, around 11% lower in winter and 19% lower in summer, compared to weekdays.

The ACT has both a summer and a winter peak that result in similar peak demand levels at around 600MW. The highest ever demand on the network (in the period 2009 to 2013) occurred on 2 February 2011 at 613MW, followed by 8 June 2011 at 611MW.
Figure 9, below, shows the distribution of maximum demand events in the period 2009 – 2013. The top 1% of events in the ACT are above approximately 633MW.

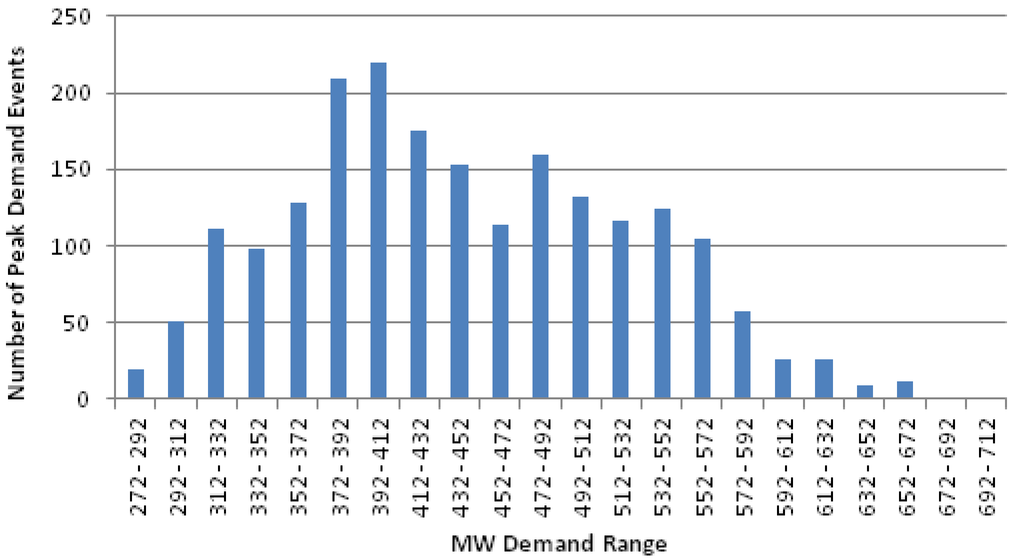

Figure 9: Distribution of Maximum Demand Events

Figure 10 shows that most daily high electricity demand periods (greater than 500MW) in winter, for the whole ACT electricity supply system, occur between 8.00 am and 8.30 am and between 5:30 pm and 7 pm. Increases in lighting demand, due to shorter daylight periods as well as increased heating requirements, are likely to be the main causes of high demand at these times.

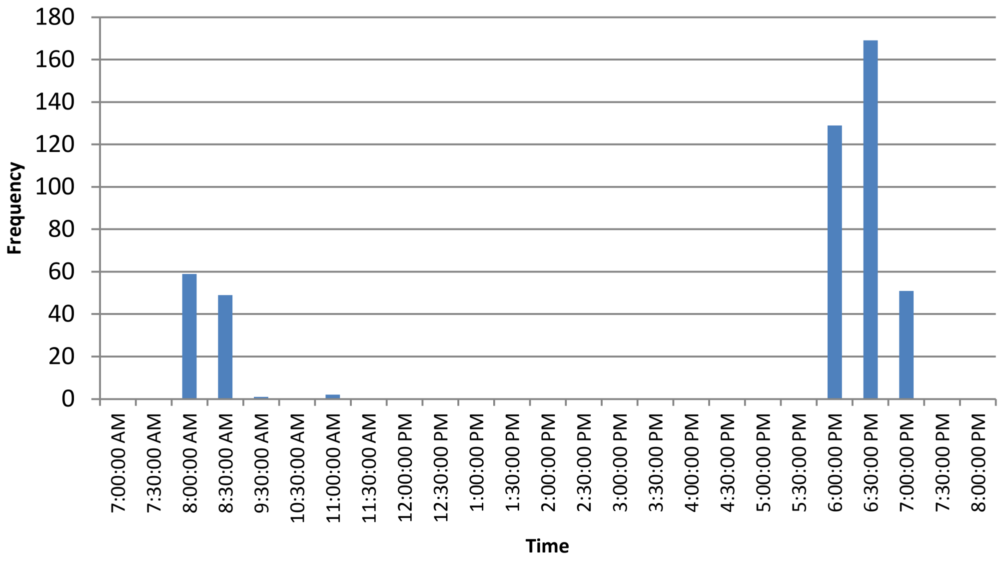

Figure 10. Frequency of high daily demand peaks (>550MW) in winter: 01 Jun 2009- 31 Aug 2013

On the other hand, as shown in Figure 11, the timing of high demand periods in summer is different from winter. Summer peak periods are usually the product of electric cooling systems, such as fans and air conditioning equipment, used by both commercial and residential customers.

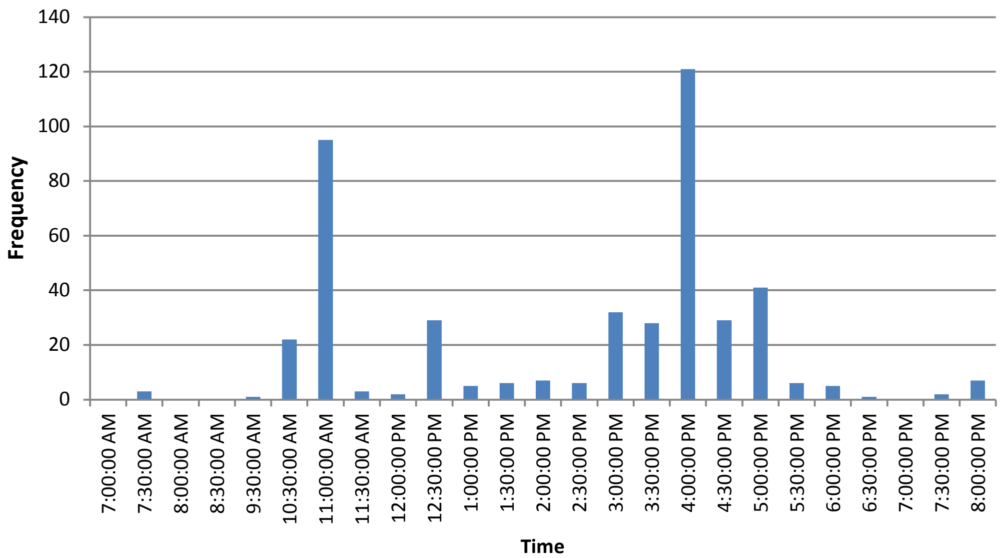

Figure 11. Frequency of high daily demand peaks (>550MW) in summer: 01 Dec 2009-28 Feb 2014 (451 days)

Figure 12 and Figure 13 are plots of net maximum demand for the whole ACT electricity system against temperature for winter and summer seasons showing the linear relationship between the two variables. This linear regression model can be employed to analyse the effect of temperatures on the variability of the ACT peak daily electricity demand. The regression coefficient represents the temperature dependence of electricity peak demand for a particular day in a particular year. Positive coefficients for a summer regression mean that a higher maximum temperature leads to higher peak electricity demand; positive coefficients in winter mean that a higher temperature leads to lower electricity peak demand[18].

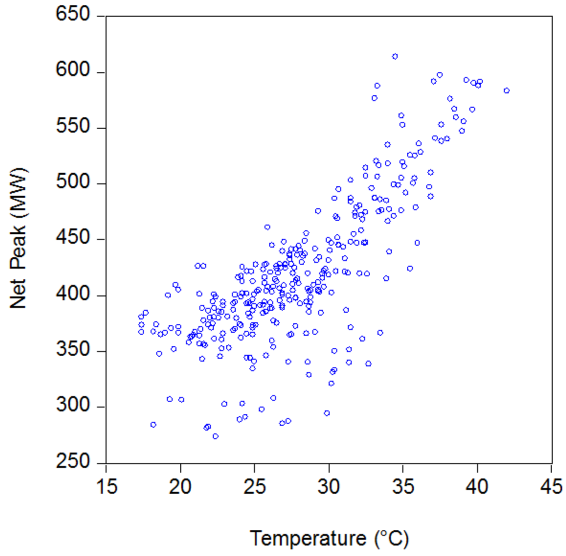

Figure 12. Relationship between temperature and daily maximum demand during the summer season (working days)

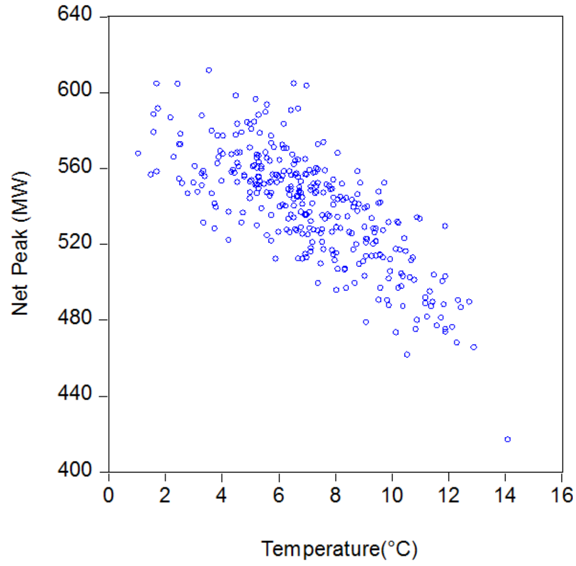

Figure 13. Relationship between temperature and daily maximum demand during the winter season (working days)

The result suggest, all other things being equal, that a 1°C *decrease* in minimum temperature in winter would result in around a 15MW increase in the ACT peak demand. In summer a 1°C *increase* in maximum temperature would increase demand by a round 13MW.[19]

In addition, the relationship between the duration of a weather event and its associated peak demand suggest that temperature variables can have a lagged effect on electricity peak demand because:

- The thermal insulation of commercial and office buildings (preventing instantaneous interaction between outside and internal temperatures).
- Consumers have an increased tendency to use heating or cooling appliances on a given day when extreme weather was experienced in previous days[20].

Figure 14 shows an incidence of peaks above a threshold of 550MW between 2009 and 2014. This shows that the ACT experiences more frequent high electricity demand events in winter, but high demand events in summer have risen over the period.

[18] . The results are shown in Appendix B-3.
[19] The possibility of three more weather variables being incorporated in the analysis was explored: dewpoint temperature, wind speed and hours of bright sunshine. Our results suggest that dewpoint temperature and sunshine duration should be considered when modelling electricity peak loads in summer, however there was no obvious evidence of the importance of sunshine in winter peak demand modelling. On the other hand, wind plays an important role in winter. It is noteworthy that these factors are often included in models that aim to predict abrupt and sudden demand changes. Ultimately, however, the incorporation of these variables was beyond the scope of this study.
[20] . The five highest peak demands and temperature of two previous days is shown in the Appendix D.

Although not included in this chart, eight of these high peak events were recorded in summer 2014 indicating a continuation of the trend towards more frequent summer peaks.

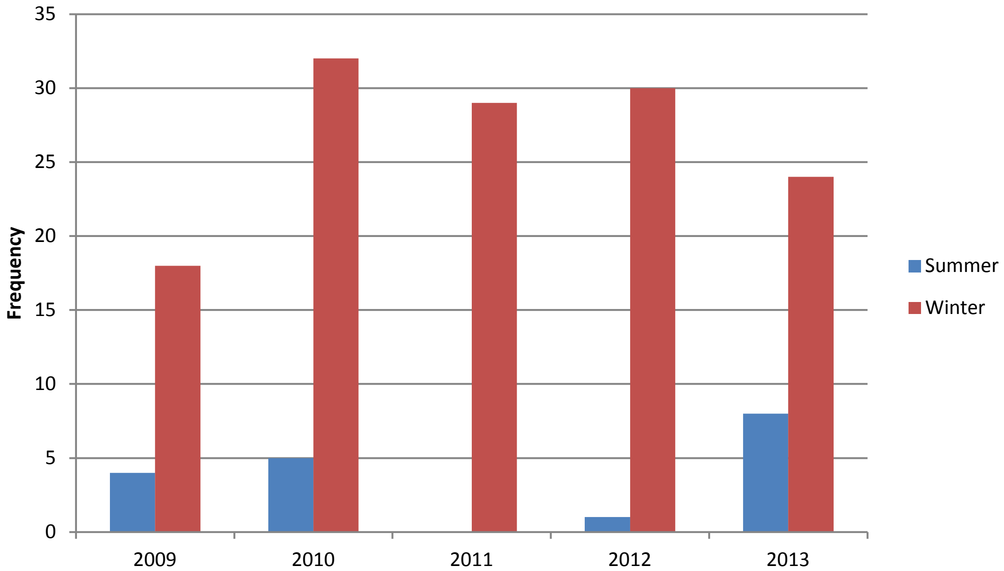

Figure 14. Yearly frequency of occurrence of high demand day (>550 MW)

Electricity network utilisation

While overall demand is declining in the ACT and across the NEM generally, peak demand continues to increase. As outlined above, peak demand events drive investment – as the networks must be built to meet these events and the network is underutilised at all other times.

The 'load factor' – the ratio of average demand to peak demand – reflects effective utilisation of a network. The load factor for the whole ACT network showed a downward trend over the period 2009 to 2013 – decreasing from 57% to 55%. This illustrates that peak demand is growing faster than average demand, and subsequently electricity network use efficiency is declining.

Solar energy generation

The impact of increasing solar PV penetration on overall ACT electricity demand and ACT peak electricity demand was also assessed.[21] Based on a comparison of annual electricity inflow into the ACT and the calculated PV system output, solar PV reduced total ACT small customer demand for electricity by 3.8%, or 1.7% of the total ACT network aggregate demand, in 2013.

A proportion of electricity generation by solar systems occur in summer and overlaps with the summer peak demand periods (3pm to 5pm). Therefore, it can be expected that expansion of PV panels will reduce critical summer load peaks in the ACT thereby decreasing the need for future expansions of network capacity to meet summer peak demand loads.

[21] Data for total installed capacity was obtained from ActewAGL Distribution and the annual output was calculated using the ACT capacity factor for PV of 0.16.

While it is difficult to quantify the effect of solar on summer peak demand with available data, the analysis supports the conclusion that solar generation is likely contributing to reducing peak demand and shifting peak demand to later in the day. Based on 44MW of installed PV capacity at the end of 2014, it is possible that a future peak demand at the historical summer maximum of 614MW at 3:30PM would be up to 3.6% higher without the installed PV capacity.[22]

However, solar is not able to reduce winter peak demand due to the lack of coincidence with winter peak periods which generally occur on winter evenings. This suggests that while solar may have mitigated growth in summer peak demand, electricity storage would be required for solar to contribute to reductions below current winter peaks.

Natural gas

This study shows that fluctuations in annual natural gas consumption can be almost entirely attributed to changes in climatic conditions during winter months. Figure 15 and Figure 16 show that while weather normalised total gas consumption in the ACT was broadly stable between 2009 and 2013, per capital natural gas consumption has experienced a significant and steady decline since 2009. Weather normalised per capita gas consumption decreased at an average annual rate of 1.9% during the period 2009– 2013, slightly lower than the 2%/yr rate of decline for non-weather normalised per capita consumption.

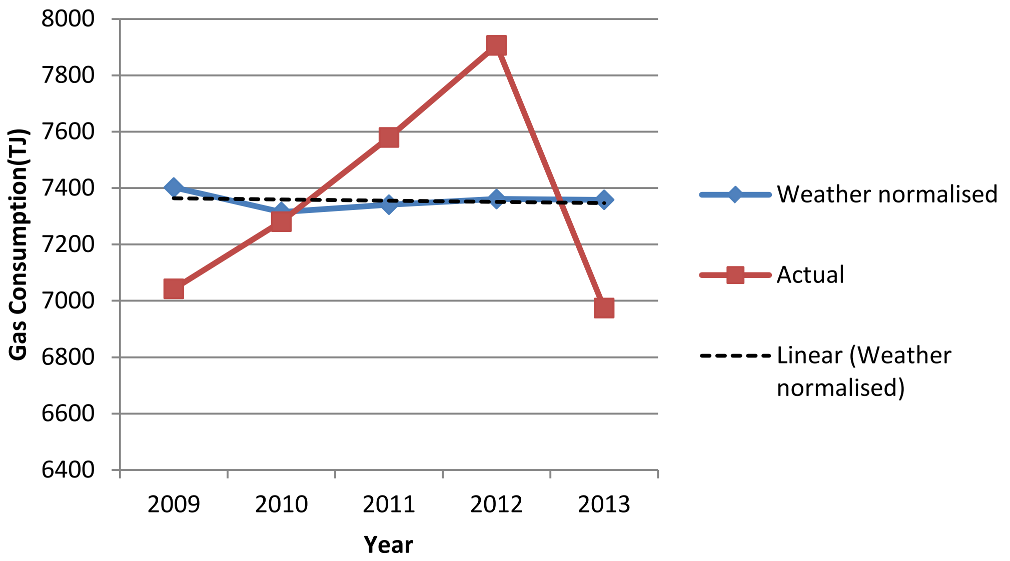

Figure 15: Weather normalised versus actual gas consumption

[22] Based on analysis of 7 household PV generation profiles provided by ActewAGL Distribution, it is estimated that the generation capacity of PV at 3 to 5pm in summer should be discounted by a factor of 50%.

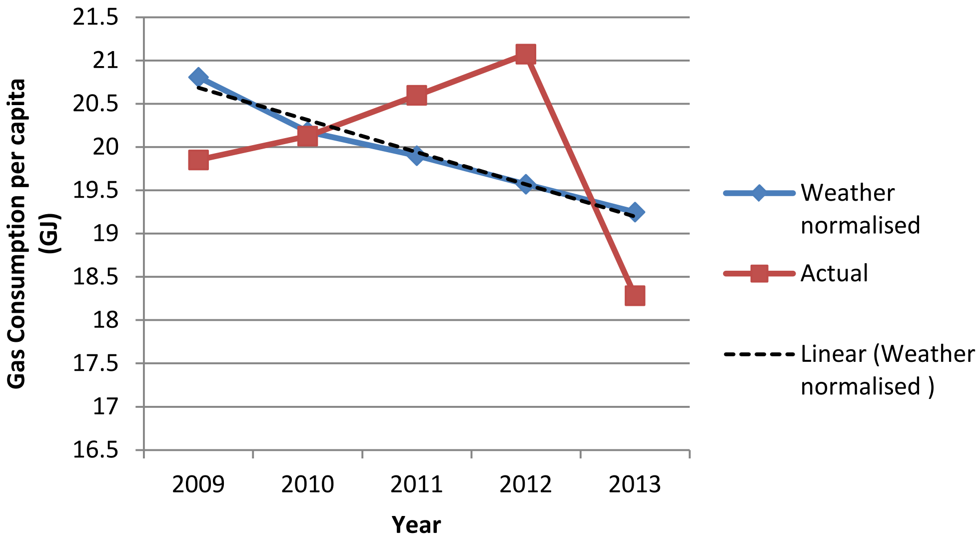

Figure 16: Weather normalised versus actual gas consumption (per capita)

Given that a reduction in per-capita demand can be observed in the ACT's small customer electricity consumption, the trend may reflect structural changes such as improved energy efficiency of dwellings as well as water and space heating appliances. Another factor may be urban development changes that are shifting householders into high density environments resulting in reduced use of natural gas for space and water heating purposes.

Conclusion

Residential and commercial energy use in the ACT is highly sensitive to weather conditions because of the significant proportion of energy used for space heating and cooling. Therefore, correction for weather and climatic changes is crucial to understanding structural trends in the Territory's energy consumption over time.

This study shows that once weather factors have been accounted for, there has been a strong and consistent trend of decline in per capita aggregate electricity and gas consumption since 2009. This is possibly due to the role of energy efficiency policies such as building energy efficiency regulations and tighter appliance energy efficiency standards as well changes in the urban form including urban consolidation. Because these trends are particularly apparent in the energy consumption patterns of small customers, there is strong evidence of widespread energy efficiency flowing from energy efficiency improvements by households and small businesses, rather than simply being a result of the decommissioning of large energy-intensive facilities. These improvements include behaviour change by households and small businesses.

ACT solar production has experienced significant growth since 2009 with an average annual growth rate of 146%. The cumulative installed PV power capacity has grown from 1,851 kW at the end of 2009 to 39,460 kW in September 2013. In our view, a significant proportion of the reduction in maximum peak demand in summer in the ACT can be attributed to a rise in solar panels that are displacing demand for grid-sourced electricity. However, as solar contributes little to winter evening peaks, and as these remain a dominant driver of network investment, solar is only able to mitigate growth in summer peak demand rather than contribute to further reductions in peak demand for the network as a whole.

This study tells a story of declining, or stabilising, aggregate energy demand and stable or increasing peak demand periods in the ACT electricity distribution network. This trend, if continued, will lead to further decreases in network utilisation. This will likely result in higher network charges for all users under current tariff arrangements than would otherwise be the case, but also lower greenhouse gas emissions and reduced requirements for renewable energy investments. As climate change can be expected to increase the incidence of very hot days in summer, and reduce the incidence of cold days in summer, over the long term, climate change can be expected to amplify these effects.

Policy implications

This analysis supports the current trust of ACT energy market reforms that aim to make energy pricing reflect the cost of delivering services at times of peak demand thereby encouraging lower peaks and a smoother network load profile. These policies include the potential introduction of cost-reflective network charges for small customers and the introduction of competition in advanced metering services to allow for more innovative tariff structures and customer demand responses. Overall, the objective of these policies is to encourage energy use behaviour that reduces costs of managing the electricity supply system for the benefit of all consumers. In practice this means, through pricing and technology responses, encouraging users to reduce consumption and shift consumption to off-peak times.

The increasing penetration of solar by customers has the potential to both exacerbate and mitigate the problem of decreasing network utilisation. On one hand, solar generation can contribute to reductions in summer peak demand thereby reducing network augmentation requirements in some parts of the network. On the other hand, solar generation can result in overall reductions in network charges being collected from solar customers resulting in higher network charges for non-solar users. It is important to note however that solar has positive environmental externalities for the Territory associated with reduced greenhouse gas emissions.

The ACT's electricity distribution network is relatively unique in having winter and summer peaks roughly in balance. As a result, in order to mitigate growth in peak demand, both winter and summer peaks must be addressed.

As the major increases in summer peak demand are associated with air-conditioning, there is a strong argument for a policy response to ensure cross subsidies for air-conditioning users are mitigated through more cost-reflective pricing including, potentially, capacity or demand charges for small customers. Such charges may require air-conditioning users to pay an ongoing charge for the ability to exceed normal demand levels. Based on the above mentioned AEMC analysis, for such charges to be fully cost reflective, they may rise significantly for some customers resulting in distributional and transitional issues.

More cost-reflective pricing for customers with air-conditioners and solar panels could also encourage innovative technology responses such as using battery storage to shift demand to off-peak times, particularly in winter, or encouraging air-conditioning customers to undertake space cooling at times when their solar is generating. The greatest positive impacts of storage technologies would be associated with systems that allowed energy to be predicably dispatched at times of critical peak demand.

Without energy storage, further PV penetration is unlikely to improve winter peaking outcomes. These can be addressed by improving the energy efficiency of heating appliances, building fabric improvements and general household and business appliances and equipment. Many of these improvements will also have a positive impact on summer peaks.

More fine-grain data, at the individual feeder level is required to fully understand the potential capital cost savings that might accrue from specific demand management initiatives and tariff reforms. Future analysis could also seek to more precisely separate residential and small business energy use patterns and the impact of solar PV in mitigating commercial and residential sector network loads. While peak demand analysis for these groups across the Territory could not be undertaken due to limitations in current metering infrastructure, feeder level data would provide some opportunity to undertake further analysis based on samples of residential and non-residential feeders.

Appendix A: Data sources

Quantity of energy

Historical daily aggregate electricity consumption data for the Australian Capital Territory from the 1 January 2009 to 1 July 2014 was obtained from ActewAGL. The data includes the electricity demands of the industrial, commercial, residential and agriculture sectors. It is important to define the term 'consumption'. We used the words 'electricity consumption', 'electricity demand' and 'electricity use' interchangeably to refer to total energy inflows to the ACT distribution network.

Net System Load Profile (NSLP) data is provided for each half hour of the day by the Australian Energy Market Operator (AEMO). NSLP is a method used by the AEMO to approximate how much electricity is used by all consumers with accumulation meters (the small customer) in a region. The NSLP is used because it is not possible to develop individual consumption profiles for consumers with accumulation meters.

Historic daily natural gas consumption data for the Australian Capital Territory from the 1 January 2008 to 30 July 2014 was obtained from ActewAGL. The data comprises the gas demands of the industrial, commercial, residential and agriculture sectors.

The metrological data

Dataset acquired in stations of the Bureau of Meteorology in ACT (Canberra Airport and Canberra Airport Comparison).

HDD and CDD variables in this study are defined in the following way:

$$HDD_d^{Electricity} = Max(14°C - T_{average}, 0)$$
$$CDD_d^{Electricity} = Max(T_{average} - 18°C, 0)$$
$$HDD_d^{Gas} = Max(16°C - T_{average}, 0)$$

Where the mean daily temperature employed in this work was calculated of the three hourly reported temperatures:

$$T_{average} = \frac{\sum_{i=1}^{8} Air\ temperature\ observation\ at\ i\ hours}{8}$$

Appendix B: Methodology and regression results

The method we use to obtain the calendar factor[23] consists the following steps. First, we estimate the weekly calendar variation index, WCVI, as $WCVI = \frac{D_{d/W}}{W_w}$ where $D_{d/W}$ is the electricity consumption on day d of the week w, W_w is the electricity demand on Wednesday of the same week w. Since the effects of trend, seasonality, temperature and economic conditions are negligible, and $D_{d/W}$ and W_w are sufficiently near, we can conclude that all the effects cancel out, except for the calendar effect which is captured by the WCVI variable. The second step consists in regressing the WCVI variable on a combination of dummies reflecting the week of the day (Monday, Tuesday,....) and the types of holidays, and then, to group the holidays and/or week days with similar values of the WCVI.

In order to define the balance point and specify the relationship between energy demand and temperature, we eliminate the working day effect by running the regression:

$$Consumption_t = \alpha + \beta_1 t + \beta_2 t^2 + \beta_3 WD_t + FC_t$$

Where

$Consumption_t$ = energy consumption of day t, t= time trend, and WD: Working Day effect

FC_t = Filtered Consumption (residual component of the estimation)

Also, the data in this approach has been trend-adjusted to take into account historical changes in energy usage patterns (e.g. reductions in use due to improved appliance efficiency)

Table 2. Regression results for winter

Dependent Variable: PEAK
Method: Least Squares
Sample (adjusted): 4 460
Included observations: 454 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	627.5917	4.462426	140.6391	0.0000
MIN_TEMP	-3.118266	0.287115	-10.86068	0.0000
MIN_TEMP(-1)	-0.530475	0.228932	-2.317175	0.0209
MIN_TEMP(-2)	-0.463137	0.230950	-2.005358	0.0455
MIN_TEMP(-3)	-0.473724	0.206307	-2.296212	0.0221
TEMP_3	-5.190000	0.486579	-10.66631	0.0000
TEMP_12	-2.426119	0.484704	-5.005366	0.0000
WIND	0.654971	0.142366	4.600602	0.0000
DEW	-0.873967	0.305567	-2.860143	0.0044
DUMMY	-54.81079	1.522549	-35.99937	0.0000

R-squared	0.859427	Mean dependent var	523.5130
Adjusted R-squared	0.856578	S.D. dependent var	38.51399

23 . This approach adopted from: Moral-Carcedo J, Vicéns-Otero J. Modelling the non-linear response of Spanish electricity demand to temperature variations. Energy Econ 2005;27

Table 3. Regression results for summer

Dependent Variable: NET_PEAK
Method: Least Squares
Sample (adjusted): 3 276
Included observations: 201 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	109.5633	20.62695	5.311658	0.0000
MAX_TEMP	7.420981	1.108667	6.693606	0.0000
MAX_TEMP(-1)	0.599079	0.845970	0.708157	0.4797
MAX_TEMP(-2)	1.409485	0.673399	2.093090	0.0377
TEMP_9	2.714209	1.277708	2.124279	0.0349
DEW	0.909357	0.465937	1.951676	0.0524
WIND	0.553570	0.697124	0.794077	0.4281
SUN	-0.960205	0.943682	-1.017508	0.3102
DUMMY	-89.50907	5.050602	-17.72246	0.0000

R-squared	0.783015	Mean dependent var	401.6060
Adjusted R-squared	0.773974	S.D. dependent var	67.37959

Appendix C: Highest Peak demands in summer and winter over the period 2009 to 2013

Table 4. Five highest peak demands over the period of 2009-2014: Summer

Rank	Net Peak Date/Time	Net Peak (MW)	Maximum temperature in 24 hours after 9am in	Minimum temperature in 24 hours before 9am in	Evaporation in 24 hours before 9am (in mm	Air temperature observation at 12 hours in	Air temperature observation at 15 hours in	Air temperature observation at 18 hours in	Dew point temperature observation at 15 hours in	Dew point temperature observation at 18 hours in	Number of hours of bright sunshine in the 24 hours	Wind speed at 12 hours measured in km/h	Wind speed at 15 hours measured in km/h	Wind speed at 18 hours measured in km/h
1	02 Feb 2011 15:30	613.796	34.5	22.2	10.8	31.8	33.6	24.3	17.4	21	8.3	18.4	16.6	9.4
2	06 Feb 2009 15:30	606.624	40.3	20.1	11	32.6	38.4	38.6	7.8	4.2	12.7	13	24.1	13
3	31 Jan 2011 16:00	597.192	37.5	15.8	8.4	33.3	36.9	35.8	12.2	10.1	13.3	14.8	9.4	16.6
4	05 Feb 2009 16:00	596.496	37.8	18	7.2	32.3	35.9	36.6	11.8	12	12.7	20.5	20.5	7.6
5	03 Feb 2014 16:30	592.661	39.3	13.9	NA	30.8	36.8	37.4	6.9	3.2	NA	16.6	20.5	22.3

Table 5. Five highest peak demands over the period of 2009-2014: Winter

Rank	Net Peak Date/Time	Net Peak (MW)	Maximum temperature in 24 hours after 9am in	Minimum temperature in 24 hours before 9am in	Evaporation in 24 hours before 9am (in mm	Air temperature observation at 12 hours in Degrees C	Air temperature observation at 15 hours in	Air temperature observation at 18 hours in	Dew point temperature observation at 15 hours in	Dew point temperature observation at 18 hours in Degrees C	Number of hours of bright sunshine in the 24 hours midnight to midnight	Wind speed at 12 hours measured in km/h	Wind speed at 15 hours measured in km/h	Wind speed at 18 hours measured in km/h
1	08 Jun 2011 18:00	611.557	8.2	-1.1	2.4	7.3	6.4	3.1	-4	-2.1	9.4	31.3	33.5	24.1
2	24 Jun 2013 18:00	604.687	10	5.1	NA	6.9	7.6	7	6.7	5.3	NA	24.1	14.8	20.5
3	12 Jun 2009 18:00	604.560	4.1	-3.1	1.4	2	3.8	2.7	1.6	1.2	0	9.4	11.2	1.8
4	29 Jun 2010 18:30	604.416	9.1	-3.1	1.9	7.2	7.9	2.7	-2.2	-2.3	9.5	13	24.1	18.4
5	21 Jun 2011 18:00	603.438	10.9	7.4	NA	5.3	6.1	3.1	3.3	0.6	1.4	18.4	25.9	20.5

Appendix D: Consecutive hot or cold days effects on exceedances

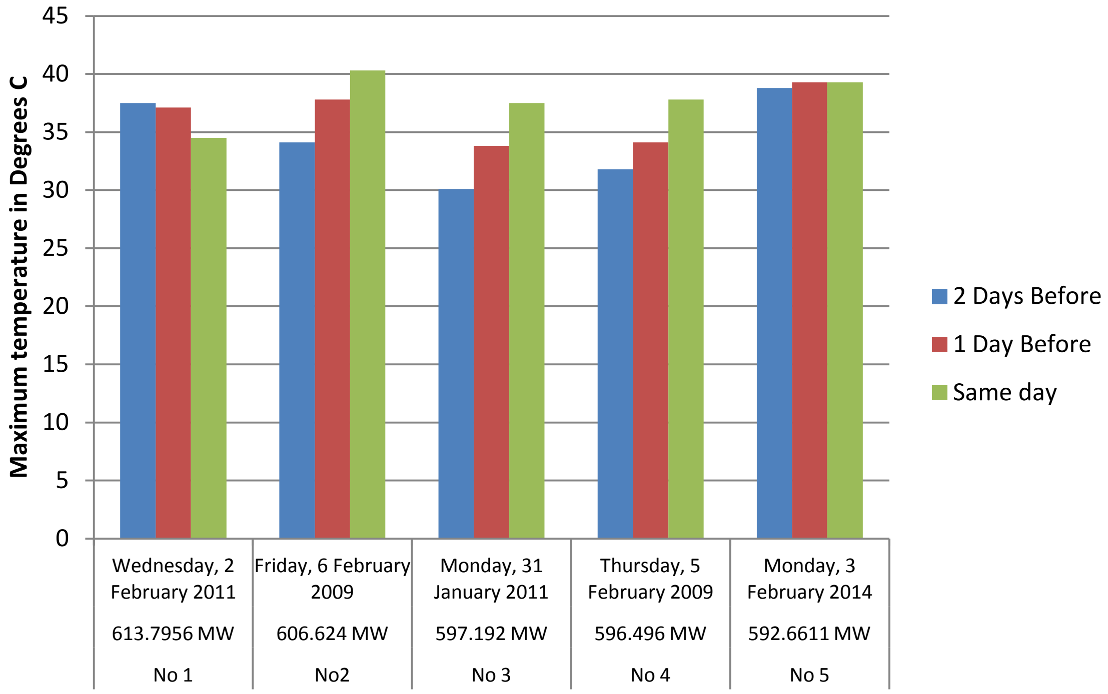

Figure 17. Five highest peak demands in summer over the period and maximum temperature of two previous days

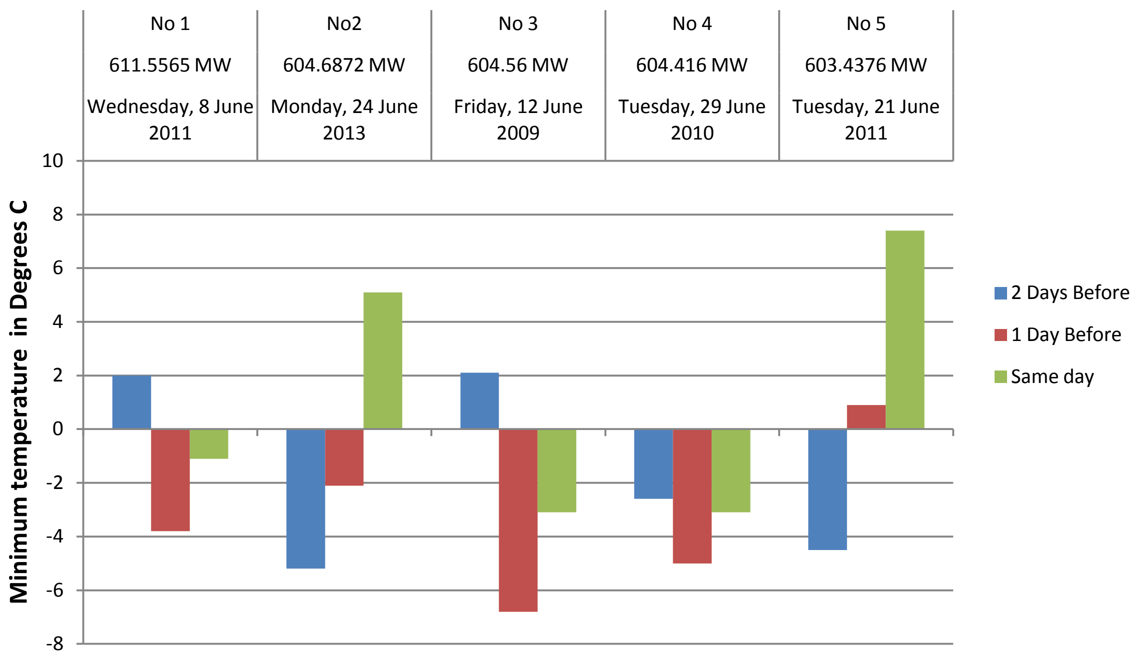

Figure 18. Five highest peak demands in winter over the period and minimum temperature of two previous days