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What is driving the decline in electricity demand?

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Introduction

Investment in the electricity supply industry in generation, transmission, and distribution infrastructure is primarily driven by consumption. As with any other industry, revenues are based on sales, and if demand is not growing, or worse still falling, then there is little need for investment in new capacity.

In the National Electricity Market (NEM), demand for electricity has been falling in recent years. In this article, we examine demand in New South Wales with a view to identifying what is driving the reduction in electricity demand. In the process, we outline a methodology for analysing changes in demand from year-to-year.

Given the relationship between temperature and demand, we start by presenting a model to adjust for the impact of year-to-year weather variation on demand volumes. Applying this model to NSW, we show that the decline in demand cannot be explained by temperature variation. To account for the decline, we then estimate the impact of substitutes for grid-sourced electricity, such as rooftop photovoltaic systems (PVs) and solar water heaters.

Our analysis shows that a significant part of the reduction in demand in NSW can be attributed to a shift away from grid-sourced electricity. Does this represent a fundamental change in the nature of electricity supply and, if so, what are the implications for investment and planning? More broadly, does the trend of declining demand represent a threat to the profitability of on-grid power stations, regardless of whether they are renewable or fossil-fuel fired? We conclude by discussing these issues.

Defining Demand

Measuring demand is inherently problematic. In the NEM, demand for electricity is measured in terms of the electricity that is generated, since metering of the relatively small number of supply points is more efficient than and timely than collecting data from the far more numerous load points. In simple terms, for a given region we define demand for any interval as:

$$Demand = \sum_{p \in P} Generation_p - \sum_{i \in I} Net\_flow_i$$

where:

- P is the set of all power plants in the region;
- $Generation_p$ is the gross generation (ie, “as generated”) of the power plant, p;
- I is the set of all interconnectors that are incident to the region; and
- Net_flow_i is the net flow out of the region via the interconnector, i.

For the purposes of our analysis, generation includes all scheduled and semi-scheduled generation units, as well as all non-scheduled generation for which generation data is available[i] (eg, non-scheduled wind farms, and other non-scheduled generators whose output is metered). We have collected data on a five-minute interval basis from 1 January 2004 to 1 March 2012.

[i] We note that this definition varies from that used in the dispatch process, which does not include non-scheduled generation.

It is important to note that this definition is really a measure of the demand for *grid-sourced* electricity. It does not include generation from PV systems and larger embedded co- and tri-generation units, nor does it capture the energy used by solar water heaters. Large numbers of solar water heaters and solar panels have been installed across the NEM in recent years, spurred on by subsidies from the State and Commonwealth governments. Importantly the increase in these “off-grid” technologies displaces demand for grid-sourced electricity.

Key terms – grid sourced electricity and off-grid technologies

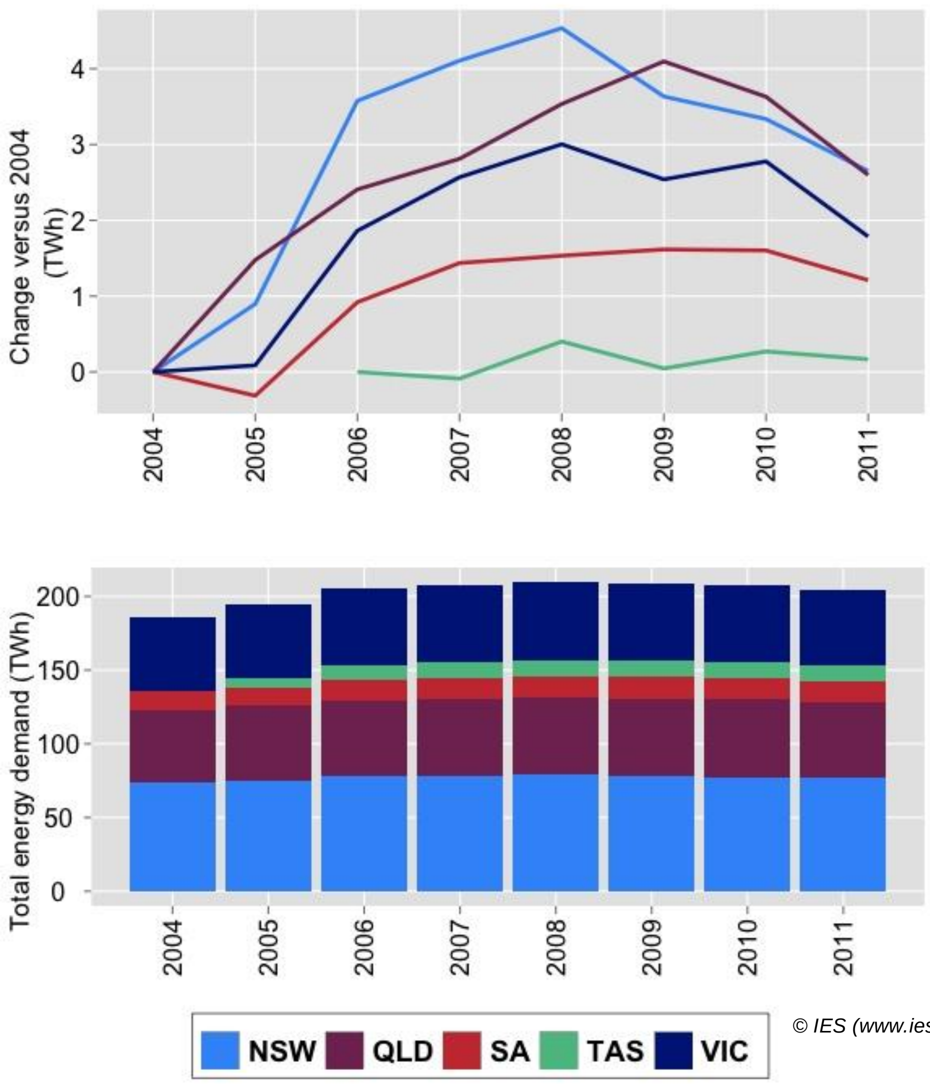
In this article, we use the term “grid-sourced electricity” to refer to electricity generated by all scheduled, semi-scheduled, and non-scheduled generators whose output is published by AEMO. This definition captures electricity supplied via the high-voltage network.

In contrast, we will refer to technologies that displace grid-sourced electricity as “off-grid technologies”. For our purposes these include solar water heaters, PV systems, co- and tri-generation units, and other embedded generators whose output is not published by the market operator or that are exempted from registration entirely.

Historical levels of electricity demand

Figure 1 shows historical electricity demand levels across the NEM for from 2004 to 2011. The top panel shows the change in annual energy demand versus the base year of 2004, whilst the bottom panel shows the total level of demand for each of the NEM regions.

Figure 1 Annual demand across NEM regions – 2004 to 2011



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Note: Loads from the Snowy region have been incorporated into Victorian demand for ease of comparison.

In 2004, total demand across the NEM was 185.6 TWh. By 2008, demand in the NEM (excluding Tasmania) had risen to 198.2 TWh, an increase of 6.8 % versus 2004. Since reaching a peak in 2008, however, total NEM demand has trended downwards and reduced by around 4.6 TWh or 2.2% – roughly equal to the annual output of a 650 MW power station with an 80% capacity factor.

The remainder of this article will focus on demand in NSW, which declined by 1.9 TWh (2.4%) from 2008 to 2011. Is this indicative of a decline in the underlying demand for grid-sourced electricity, or can the variation be explained by year-to-year temperature variation? In the process of answering this question, we present a methodology to adjust demand volumes for temperature variation.

Adjusting for the weather – a closer look at electricity demand in New South Wales

Figure 2 (see overleaf) shows average NSW demand versus average air temperature as measured at Bankstown Airport from 1 January 2004 to 28 February 2012. The plot is divided into 9 time periods that allow us to see the variation in demand over the course of the day. Each point represents an observation of temperature versus demand in that time period for a given working day.

Cooling-degree days and heating-degree days

In the aggregate, we see that demand rises from a low during the off-peak periods, and remains relatively stable before dropping away after 7 o'clock in the evening. However, there is substantial variation on a daily basis, as can be seen from the spread of points in each time period.

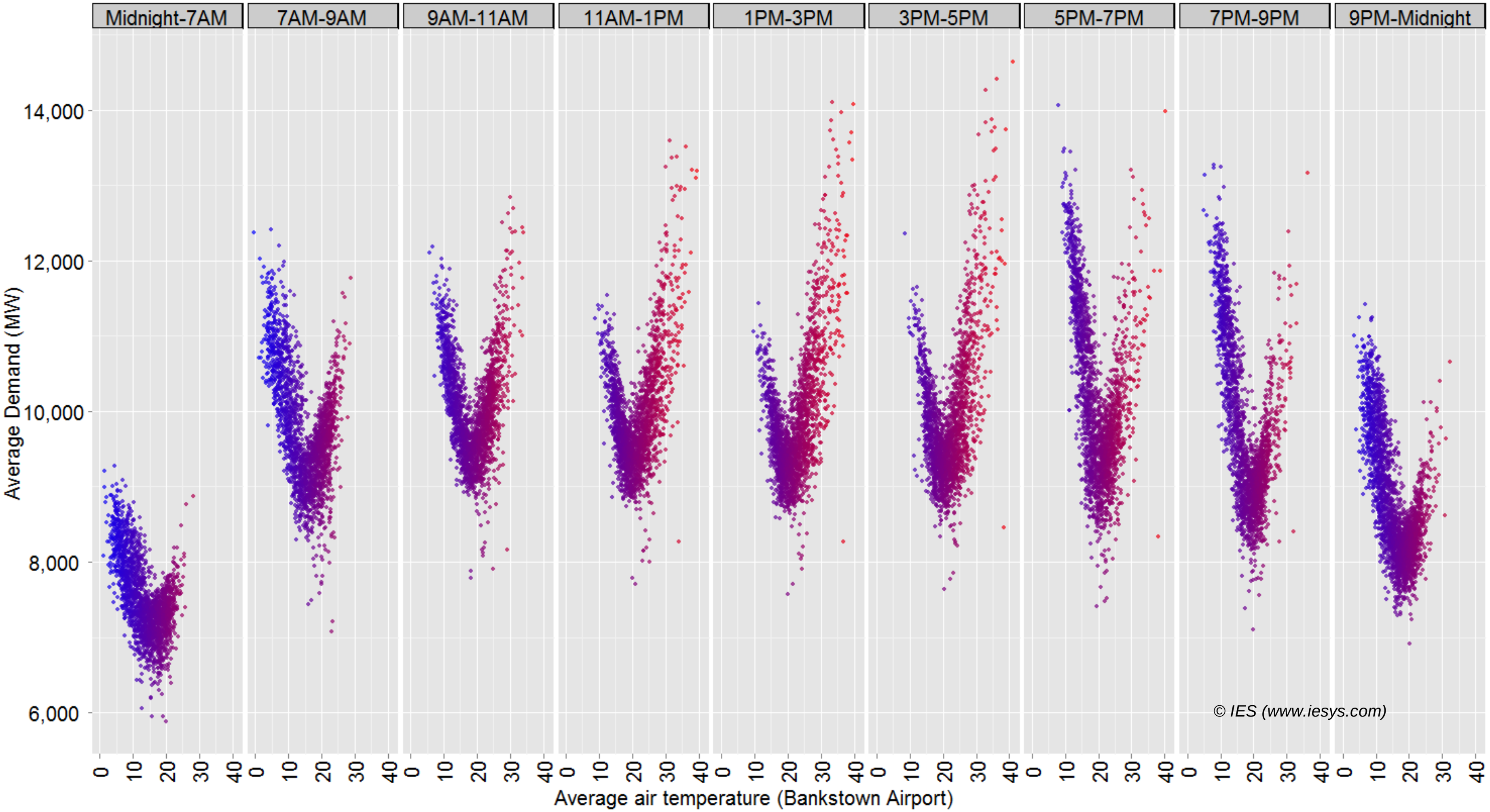
The spread can largely be accounted for by changes in temperature. The striking feature of the graph is the vee-shaped structure in each time period. The join of the vee in peak periods is around 19-20°C. As temperatures increase above 21°C, demand increases with the increased use of air-conditioning. Similarly, at temperatures below 17°C, heating loads increase.

Each degree that the temperature increases past the level at which cooling loads start to respond is known as a "cooling-degree", and a cooling-degree that occurs over an entire day is known as a "cooling-degree day". Similarly, we can define "heating-degrees" and "heating-degree days" for temperatures that fall below 17°C[ii].

Also prominent in Figure 2 are the increases in demand at peak times associated with very hot days. In particular, between 3pm and 5pm the right arm of the vee splays out reflecting the days where extreme temperatures lead to high demand events.

[ii] For example, if cooling loads come online when the daily average exceeds 21°C, two cooling-degree days can either be two days with a daily average of 22°C, or one day with a daily average of 23°C.

Figure 2 NSW electricity demand versus average temperature – 1 January 2004 to 28 February 2012



Note: Data points are only shown for working days.

A model for daily electricity demand

Based on this relationship between demand and temperature, we can construct a model to compare demand in different years with an adjustment for the temperature. We can define a simple model as follows:

$$Daily\ Electricity\ Demand\ (GWh) = \alpha + \beta \cdot H(t) + \gamma \cdot C(t)$$

where:

- α, β, γ are non-negative parameters;
- t is the average temperature on a given day; and
- $H(t) = \max(0, 17 - t)$ and $C(t) = \max(0, t - 21)$ are the "heating-degree" and "cooling-degree" functions – temperatures of 17°C and 21°C provide the best fit of historical data for NSW.

In rough terms, α represents the demand for electricity in the absence of heating or cooling; β represents the increase in cooling load for each additional cooling-degree; and γ represents the increase in heating load for each additional heating degree. Fitting this model to annual data from 2004 to 2011 we obtain the results shown in Table 1.

Table 1 Estimated parameters for NSW demand – Working days only

Year	α – Underlying demand (GWh)	β – Responsiveness to heating-degrees (GWh/°C)	γ – Responsiveness to cooling-degrees (GWh/°C)
2004	195.7	4.9	4.3
2005	200.4	4.5	3.9
2006	203.9	5.4	4.0
2007	207.1	5.1	4.3
2008	206.7	5.1	4.3
2009	205.0	4.3	5.5
2010	203.4	5.1	4.5
2011	199.5	5.3	5.2

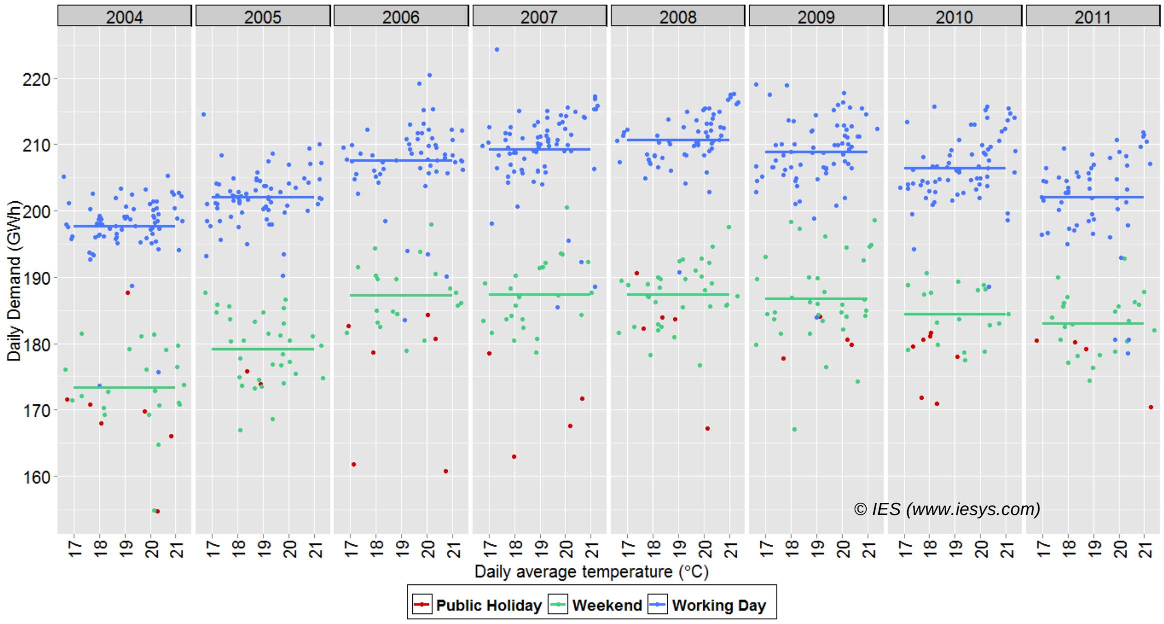
Note: Parameters shown in this table are for working days only. We have used a more detailed model to capture the variation in usage between working days, weekends, and public holidays as is illustrated by Figure 4.

Our results suggest that underlying demand for electricity (represented by the parameter α) rose from 2004 to 2008, and has since declined in every subsequent year. At present, we estimate it to be just under 200 GWh per day. Responsiveness of demand to cooling degrees has increased since 2004, reaching a peak in 2009. This gives weight to the claim that greater penetration of air-conditioning has led to increasing sensitivity of loads to temperature.

Using this model, we found that adjusting demand volumes for temperature versus 2008 resulted in only minor changes for each year since 2008: -0.22% in 2009, -0.16% in 2010, and +0.24% in 2011. This confirms that year-to-year variations in weather are not the cause of the reduction in demand.

To provide a more intuitive explanation – and to convince readers who are perhaps justifiably sceptical of linear models – Figure 3 shows a plot of daily demand against mean temperature for moderate temperature days (ie, days with an average temperature of 17 to 21 degrees) from 2004 to 2011. Working days are shown in blue, weekends in green, and public holidays in red. The blue and green horizontal lines indicate the mean daily demand for working days and weekends respectively.

Figure 3 NSW demand versus daily average temperature – moderate temperature days



The increase to 2008 and the subsequent decrease to 2011 is clear, and closely matches the profile of total demand in NSW. Similar analysis of heating- and cooling-degree days reveals the same profile. The immediate conclusion is that there has been a change in the underlying demand for electricity – that is, the level of demand on any given day regardless of temperature.

To summarise, we think that there has been a gradual but persistent decline in the underlying demand for electricity in NSW since the 2008 peak, and this decline cannot be attributed to year-to-year variation in weather. Having ruled-out temperature variation, the question remains: what is the cause of the reduction in demand in NSW?

The increasing role of off-grid generation

As we noted previously, our definition of demand only includes grid-sourced electricity, and does not capture consumption associated with "off-grid" technologies. In our view, a significant proportion of the reduction in demand in NSW can be attributed to a rise in off-grid technologies that are displacing demand for grid-sourced electricity.

The rise in off-grid technologies has likely been fuelled by increasing retail prices for electricity coupled with sizable government subsidies – most notably for PV systems. Many consumers have thus considered alternatives to sourcing their electricity exclusively from the grid. We consider three of the major off-grid technologies: rooftop PV systems, solar water heaters, and larger embedded generators.

Rooftop PV systems

Throughout 2010 and 2011, around 1 GW of small-scale solar generation capacity was installed across the NEM[iii]. These systems would be expected to reduce demand for grid-sourced electricity, due to both reduced off-take and via electricity exported to the distribution system.

Modelling the output of distributed solar generation using solar traces of representative meteorological years, we estimate that in 2011 rooftop solar panels in NSW generated 419

[iii] We have based their calculations on installations of small-generation units by post-code as published by the Clean Energy Regulator. This is available at: http://ret.cleanenergyregulator.gov.au/REC-Registry/Data-reports. These numbers have been adjusted upward slightly to reflect a lag between installation and registration of a PV system.

GWh, up from 121 GWh in 2010. This accounts for around 20% of the total reduction since 2008, and has manifested itself in demand outcomes over the course of 2010 and 2011[iv].

Solar water heaters

In recent years there has been a wave of installations of solar hot water systems, the majority of which have replaced existing electric systems. Spurred on by subsidies from the Commonwealth Government, installations of solar water heaters peaked in 2009, with around 81,000 systems being installed in New South Wales alone. We estimate that the 142,000 solar water heaters installed to replace electric water heaters since mid-2008 displaced an additional 431 GWh of grid-sourced electricity in NSW in 2011. Solar water heaters thus account for roughly another 20% of the reduction since 2008.

Larger embedded generators

The rise in embedded generation is not restricted to PV systems. The number of embedded generators whose output is not published by AEMO, or who are exempted from registration entirely, has also increased over the last few years. Like PV systems, these units displace existing generation and reduce demand for grid-sourced electricity.

Generation data for many embedded generators is not publicly available. Embedded renewable power stations are an exception, as they must register their generation with the Clean Energy Regulator (CER) to receive renewable energy certificates.

Using data obtained from the CER LGC Registry[v], we have identified an additional 330 GWh of generation in NSW in 2011 versus 2008. Examples include 60 MW of additional bagasse-fueled cogeneration capacity at the Condong and Broadwater sugar mills that came online in late 2008[vi]. These plants have allowed industrial users to reduce their usage of grid-sourced electricity.

There are other embedded generators that have been installed across NSW in the last few years. For example, we have been able to identify a total of 10.7 MW of tri-generation capacity that has been installed in Sydney since mid-2008. Taking a conservative view of the operating levels for these plants, we would estimate that these installations have displaced around 90 GWh per annum.

In total these larger embedded generators account for an additional 420 GWh in 2011, or roughly 20% of the reduction of electricity demand in NSW since 2008.

Summary

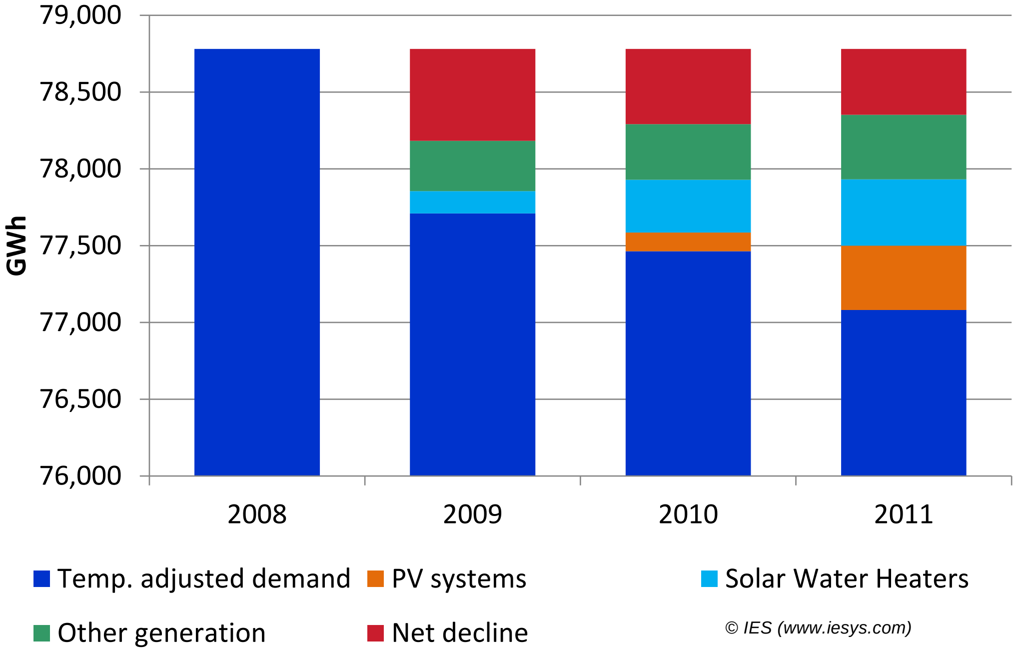
Figure 4 combines our estimates to show what has contributed to the decline in demand since 2008, namely:

- temperature corrected annual demand is shown in dark blue;
- the impacts on demand of additional PV systems, solar water heaters, and other embedded generators installed since 2008 are shown in orange, cyan, and green, respectively.

The reduction in demand that remains unaccounted for is shown in red. While it might be tempting to attribute this reduction to energy efficiency measures or reduced usage in response to price increases, this could only be confirmed by billing data for both industrial and residential customers, which is not publicly available.

[iv] Some PV systems were installed prior to 2010, but they represent a small proportion of total installed capacity and have been excluded due to a lack of adequate data.
[v] Data is available at http://ret.cleanenergyregulator.gov.au/REC-Registry.
[vi] Although these plants are registered with AEMO, their generation volumes are not publicly available and thus we have not included them in our original calculation of grid-sourced demand.

Figure 4 Components of the decline in NSW grid-sourced demand since 2008



In summary, we note the following:

1. Demand for electricity in NSW has been falling since 2008, and this decline cannot be attributed to year-to-year variation in weather patterns.
2. A large proportion of the decline can be explained by a rise in off-grid technologies.
3. Even after adjusting for the displacement caused by off-grid technologies, we estimate that there has still been a decline in total electricity consumption of around 430 GWh between 2008 and 2011.

Our analysis has focussed on New South Wales, but we think that the findings, particularly those related to the impact of off-grid technologies, are relevant to other NEM regions that have experienced a decline in demand.

Conclusion

There are two related but distinct issues that arise from our analysis: the increasing role of off-grid technologies, and the broader reduction in demand for grid-sourced electricity.

Off-grid technologies – has there been a shift in the nature of electricity supply?

We estimate that PV systems and solar water heaters are now displacing around 1 TWh of grid-sourced electricity in NSW each year. Similarly, small co- and tri-generation systems that diminish the demand for grid-sourced electricity may grow to represent a significant proportion of demand when aggregated. As a result, off-grid technologies now represent a significant component of supply.

These changes have implications for reliability, network planning, and future investment in generation. For example, while it may take years for a large power station to receive planning approval and be constructed, smaller embedded generators can be rolled out very rapidly, as was observed with PV systems in 2010 and 2011. A rapid reduction in demand of this nature has the potential to undermine the profitability of grid-connected power stations, regardless of whether they are renewable or fossil-fuel fired.

We think that, if it is not already the case, off-grid technologies will soon have a significant impact on market outcomes. Even though subsidies have been wound back, we think that the continuous rise in retail electricity prices and the decline in prices for off-grid technologies will result in higher penetration of these technologies, and thus further displacement of demand for grid-sourced electricity in the coming years.

The broader implications of shrinking demand

In the case of NSW, even if we remove the impact of off-grid technologies, there has still been a reduction in demand for grid-sourced electricity. We think that persistent rises in retail electricity prices have led consumers to reduce their usage of grid-sourced electricity, either by curtailing their electricity consumption, investing in energy efficiency, or substituting off-grid sources of electricity. Regardless of the cause, the downward trend in demand for grid-sourced electricity has significant implications.

If the trend continues, power stations at the top of the merit order will see their sales volumes eroded, and reduced spot-market prices will eventually translate into lower contract prices for all generators. Transmission networks will also be affected, with cost-recovery issues for transmission companies. Moreover, the reduction in demand creates risks for future investment in transmission infrastructure – namely whether the reduction in demand for grid-sourced electricity is a transient phenomenon, or an enduring change that will eventually lead to the stranding of assets.

About the Authors and IES

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