The transformative effect of unscheduled generation by solar PV and wind generation on net electricity demand

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The transformative effect of unscheduled generation by solar PV and wind generation on net electricity demand

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Abstract

This study investigates the transformative effect of unscheduled solar PV and wind generation on electricity demand. The motivations for the study are twofold, the poor medium term predictions of electricity demand in the Australian National Electricity Market and the continued rise in peak demand but reduction in overall demand. A number of factors contribute to these poor predictions, including the global financial crisis inducing a reduction in business activity, the Australian economy's continued switch from industrial to service sector, the promotion of energy conservation, and particularly mild weather reducing the requirement for air conditioning. Additionally, there is growing unscheduled generation, which is meeting electricity demand. This growing source of generation necessitates the concepts of gross and net demand where gross demand is met by unscheduled and scheduled generation and net demand by scheduled generation.

The methodology compares the difference between net and gross demand of the 50 nodes in the Australian National Electricity Market using half hourly data from 2007 to 2011. The unscheduled generation is calculated using the Australian Bureau of Meteorology half hourly solar intensity and wind speed data and the Australian Clean Energy Regulator's database of small generation units' renewable energy target certificates by postcode.

The findings are that gross demand rather than net demand helps explain both the overall reduction in net demand and the continued increase in peak demand. The study has two main conclusions. Firstly, a requirement for policy to target the growth in peak demand via time of supply feed-in tariff for small generation units. Secondly, modellers of electricity demand consider both net and gross demand in their forecasts. The time of supply feed-in tariffs are intended to promote the adoption of storage technologies and demand side participation and management. Modellers considering both net and gross demand are required to model unscheduled generation. This requirement ensues that more comprehensive solar intensity data be provided by the Bureau of Meteorology and that the Australian National Electricity Market Operator provide data in GIS format of each demand node using the Australian Statistical Geography Standard developed by Australian Bureau of Statistics to enable easier integration of large quantities of geographic data from a number of sources. The applicability of these finding become more relevant to other countries as unscheduled generation becomes more wide spread.

This study is instrumental to a range of further research. Other sources of unscheduled generations should be considered to form a more comprehensive concept of gross demand, for instance, solar hot water and small hydro. Replacing electrical hot water heaters with solar hot water reduces the overnight demand, which may provide a considerable transformative effect on net electricity demand. In addition, energy efficiency is meeting demand for electricity; incorporating energy efficiency would form an even more comprehensive concept of gross electricity demand and could help improve longer term electricity demand projections.

The transformative effect of unscheduled generation by solar PV and wind generation on net electricity demand

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This paper investigates the transformative effect of non-scheduled solar PV and wind generation on electricity demand. The motivations for the study are twofold, the poor medium term predictions of electricity demand in the Australian National Electricity Market and the continued rise in peak demand but reduction in total demand. A number of factors contribute to these poor predictions, including the global financial crisis inducing a reduction in business activity, the Australian economy's continued switch from industrial to service sector, the promotion of energy conservation, and particularly mild weather reducing the requirement for air conditioning. Additionally, there is growing non-scheduled generation, which is meeting electricity demand. This growing source of generation necessitates the concepts of gross and net demand where gross demand is met by non-scheduled and scheduled generation and net demand by scheduled generation.

In this paper, the AEMO's "Total Demand" is the "Net Demand". AEMO (2012a, sec. 3.1.2) defines the "Total Demand" in the following way.

> "Total Demand" is the underlying forecast demand at the Regional Reference Node (RRN) that is met by local scheduled and semi-scheduled generation and interconnector imports after excluding the demand of local scheduled loads and that allocated to interconnector losses.
>
> "Total Demand" is used for the regional price calculations in Dispatch, Pre-dispatch and Five-minute Pre-dispatch 5MPD, and to determine dispatch targets for generating units.

Semi-scheduled wind farms are included in "Total Demand" but non-scheduled wind farms are excluded.

1 Methodology

The methodology compares the difference between net and gross demand of the 50 demand nodes in the Australian National Electricity Market (NEM) using half hourly data from 2007 to 2011. Equation (1) describes the relationship.

$$d_g(t, n) = d_n(t, n) + (p_s(t, n) + p_w(t, n)) / 1000 \qquad \text{Equation (1)}$$

Where

d_g = gross demand (MW)
t = time (half hourly)
n = node
d_n = net demand (MW)
p_s = non-scheduled solar power (kW)
p_w = non-scheduled wind power (kW)

The non-scheduled generation is calculated using the Australian Bureau of Meteorology (BoM 2012a) half hourly solar intensity, temperature and wind speed data, the Australian Clean Energy Regulator (CER 2012) small generation unit (SGU) installations by postcode and the Australian Bureau of Statistics (ABS 2012) postcode to statistical area translation.

The CER (2012) database excludes larger scale non-scheduled wind generators. Currently, there are twenty-one non-scheduled operating wind farms with a combined capacity of 1,157 MW. So, the CER (2012) database understates non-scheduled wind generation. The BoM (2012a) wind speed is measured 30 m above ground level, which is suitable of SGU but unsuitable for large wind generators that range between 60 to 140 m above ground level.

Additionally, the CER (2012) database will understate the amount of SGU installations because the database actually records renewable energy certificate that have been successfully redeemed, so does not include certificates that are pending registration or have been failed by the CER or its predecessor. Additionally, the renewable energy target (RET) legislation allows a 12 month creation period for registered persons to create certificates. So, the 2012 figures will continue to rise due to the 12 month creation period.

The CER database provides an aggregate figure of the redeemed certificate for the years 2001 to 2009 and provides monthly data from January 2010 onwards. This entailed some interpolations to convert the SGU kW installation data into half hourly form suitable for this paper. The assumption is made that prior to 2006 that there was zero SGU installed. This is not too onerous an assumption as the amount of SGU installed over 2010 and 2011 dwarfs the installations prior to January 2010.

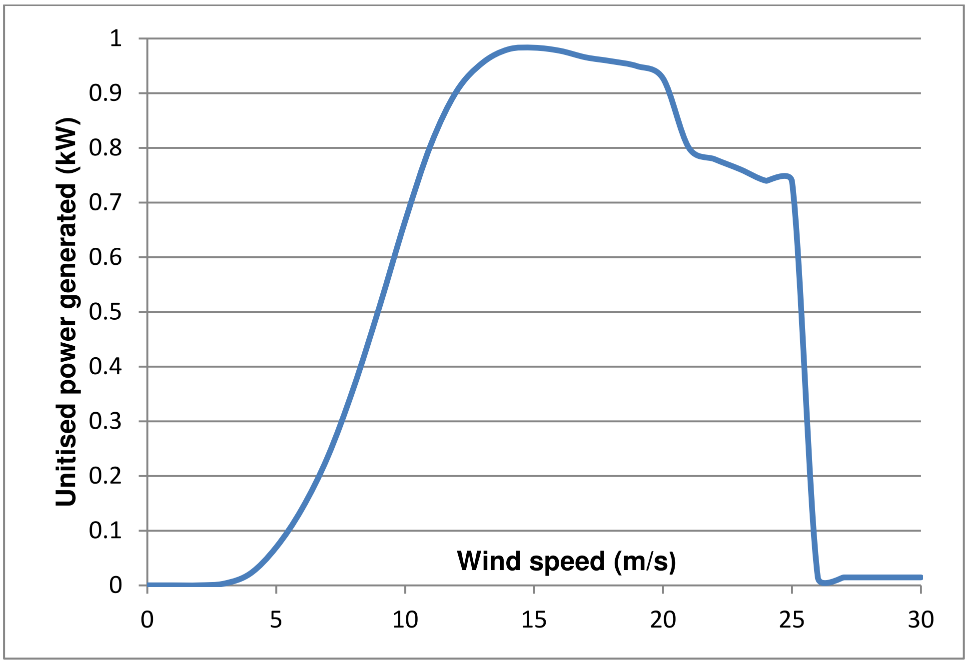
For wind and solar PV generators the post codes of the CER (2012) data are first converted to statistical areas level 2 (SA2) (ABS 2012). The perimeters of SA2 are described by a hierarchical sets of latitudes and longitudes describing smaller areas within Esri shapefiles (ABS 2011). These perimeter latitudes and longitudes are averaged to produce a latitude and longitude to approximate the centre of the SA2. This centre allows matching with the closest weather stations for power calculations and to find the closest node to attribute the power generated. Approximating an area with a point is justifiable because the SA2s are small areas. SA2 have an average population of about 10,000, with a minimum population of 3,000 and a maximum of 25,000. There are about 2,200 SA2s in Australia.

The CER (2012) database provides the name plate value of the SGU installed but lacks details of the SGU's manufacturer or model. So, simplifying assumptions are made to model generic wind and solar PV generators.

1.1 Wind generation modelling

A power curve relates the wind speed (m/s) to the power (kW) produced by a wind turbine generator. Figure 1-1 shows the power curve used in this paper, which is developed from averaging the power curves of 69 different wind generators sourced from the Idaho National Laboratory (INL 2005).

Figure 1-1 Unitised power curve for generic wind generator



Before averaging, the individual power curves are normalised to a value of 1 kW, so the paper's power curve represents a generic 1 kW wind generator response to wind speed.

Equation (2) shows how the name plate value *n* and power curve function *f* is used to convert the wind speed into power generated for each SA2 containing small wind generators for each half hour.

$$p_w(t, x) = n(t, x) * f(s(t, x)) \qquad \text{Equation (2)}$$

p_w = power generated by wind (kW generated)
t = time (half hourly intervals)
x = location (SA2 by latitude and longitude)
n = nameplate value (kW installed) (Source: CER 2012)
f = power curve (kW generated per kW installed) (Source: INL 2005)
s = wind speed (m/s) (Source: BoM 2012a)

However, the half hourly data from the weather stations is incomplete, so the four closest weather stations to the centre of the SA2 are used in the calculation where the power per weather station is calculated, which is then averaged. Finally the power by SA2 is converted into power by node.

1.2 Solar PV generation modelling

This section describes how the half hour solar intensity and temperature readings from BoM (2012a) and the nameplate value of the solar PV from CER (2012) are converted into power (kW) generated per node.

AEMO (2012b, p. 65) notes that a typical solar PV array consists of multiple panels which produce DC power. Panel generation output is roughly linear with the incident solar insolation, but is also impacted by the cell temperature. This simple relationship is captured in Equation (3), which calculates the usable AC power generated by solar PV for this paper and is adapted from the US National Renewable Energy Laboratory (Marion et al. 2001). Other factors influence generation, such as, the effect of wind speed on PV module temperature and changes in inverter efficiency with power but Marion et al. (2001) consider these factors are small relative to measurement error, so ignore them in their calculations.

$$p_s(t, x) = d * i(t, x) * n(t, x) * (1 - 0.005 * (T(t, x) - 25)) \qquad \text{Equation (3)}$$

p_s = usable AC power generated by solar PV (kW)
d = de-rating factor for converting total DC generated into usable AC
t = time (half hourly intervals)
x = location (SA2 using latitude and longitude)
i = solar intensity (kW/m^2)
n = name plate values at STC (kW generated per kW/m^2 solar intensity)
T = ambient temperature (^oC)

The de-rating factor *d* for converting total DC generated into usable AC incorporates losses by inverters and resistance in wiring. The US National Renewable Energy Laboratory (NREL 2013) estimates that the de-rating value for the whole of the NEM is 0.77.

Regarding solar intensity *i*, the BoM (2012a) provides solar exposure for each half-hour in solar time in MJ.m-2 per half hour for five weather stations within the NEM region. This solar data is converted kW/m^2 for use as *i* in Equation (3). The weather station closest to the SA2 containing the solar PV is used. There are only five weather stations with solar data with half hourly data in the NEM, unlike with the wind generation, averaging over four weather stations is not an option. Hence the missing half hourly data from a solar weather station is interpolated by averaging the previous and next day's data of the same half hour period.

A nameplate capacity *n* of a panel is typically expressed in terms of its output under standard test conditions (STC) to provide a reference point for plant design. The STC are 1000 W/m^2 insolation with a cell temperature of 25 °C. The *n* in Equation (3) represents the total name plate value present every half hour in each SA2.

Regarding ambient temperature *T* in Equation (3), an increase in temperature above 25 °C reduces the power produced by solar PV and a decrease below 25 °C increases the power. The average temperature of four weather stations closest to the centre of the ABS statistical area containing the solar PV is used to provide both a more representative temperature of the region and cover any missing data. Temperature has a linear relationship in Equation (3), which allows the use of the average temperature across the weather stations.

1.3 Producing historical half hourly electricity demand by node

Wild and Bell (2011) develop regional load data for Queensland and New South Wales using regional load traces supplied by Powerlink and Transgrid. This data was then re-based to the state load totals published by AEMO (2010) for the 'QLD1' and 'NSW1' markets. For the other three states, the regional shares were determined from terminal station load forecasts associated with summer peak demand (and winter peak demand if available) contained in the annual planning reports published by the transmission companies Transend in Tasmania, Vencorp in Victoria and ElectraNet in South Australia. These regional load shares were then interpolated to a monthly based time series using a cubic spline technique and these time series of monthly shares were then multiplied by the 'TAS1', 'VIC1' and 'SA1' state load time series published by AEMO (2010) in order to derive the regional load profiles for Tasmania, Victoria and South Australia.

The summer and winter peak load demand were annual values in the transmission planning reports. The cubic spline techniques was used to convert to a monthly share basis with the spline technique joining the summer and winter peak demand periods in terms of regional shares on a calendar basis, summer peak demand was assumed to occur around December to January and winter peaks June to July. The state totals were half hourly and would encompass actual high peak demand in summer and winter – these representing high half hourly demand values. For each month, the method applied the same regional share values which changed on a month by month basis as determined by the cubic spline technique.

2 Results

The first section relates gross demand to net demand using the non-scheduled SGU. The second section looks at the effect of non-scheduled generation on peak demand. The third section views intermittency.

2.1 Relating gross demand to net demand using non-scheduled SGU

Figure 2-1 and Figure 2-2 shows the NEM's daily average non-scheduled generation from solar PV and wind SGU. The drastic increase in 2011 is notable.

Figure 2-1 NEM's daily average non-scheduled solar PV generation for 2007-11

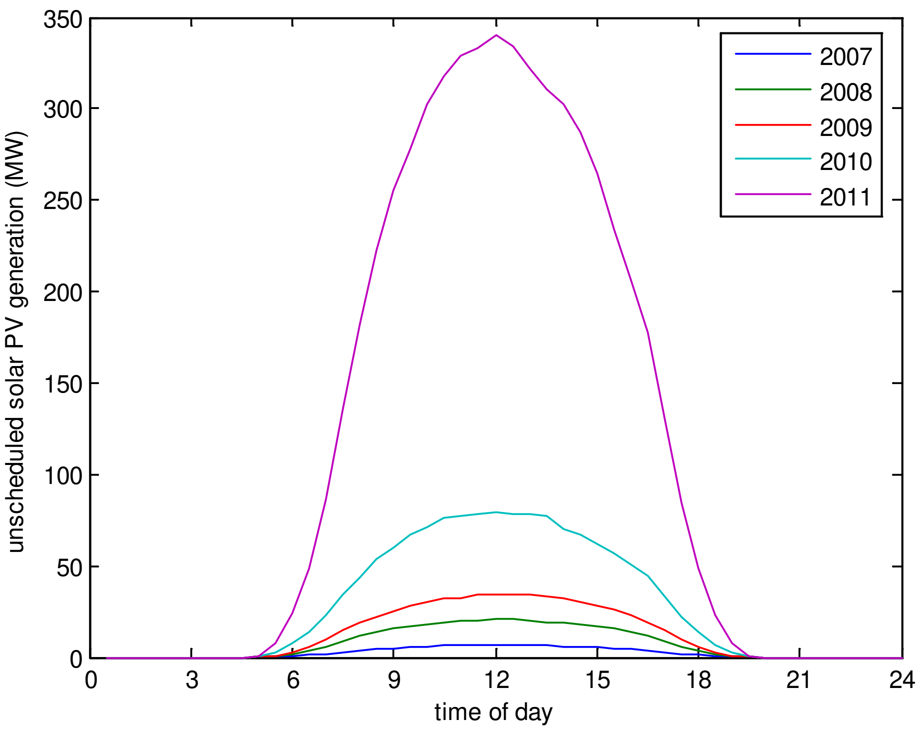


Figure 2-2 NEM's daily average non-scheduled wind generation (SGU) 2007-11

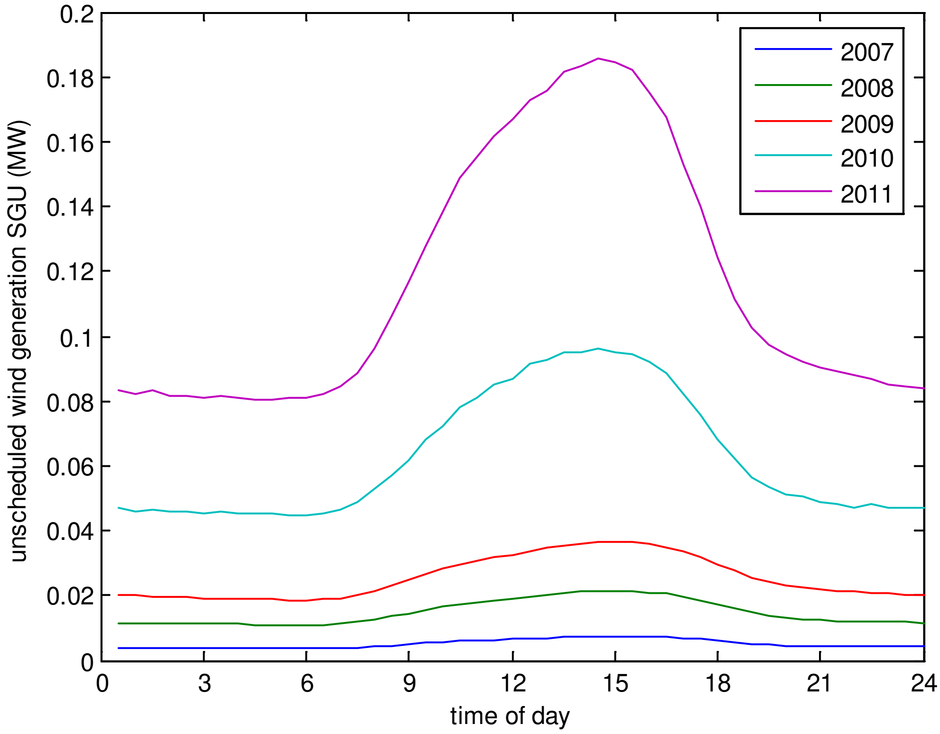


Figure 2-3 and Figure 2-4 show the NEM's daily average net and gross demand. Notable is the difference between gross and net demand in 2011 and previous years.

Figure 2-3 NEM's daily average net demand for 2007-11

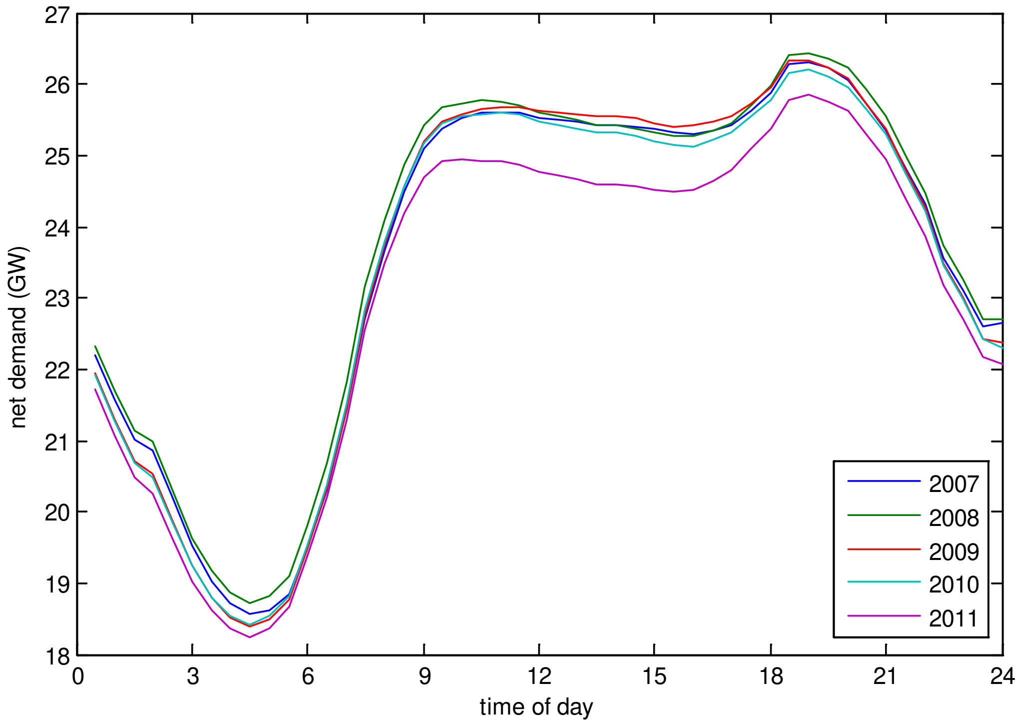


Figure 2-4 NEM's daily average gross demand for 2007-11

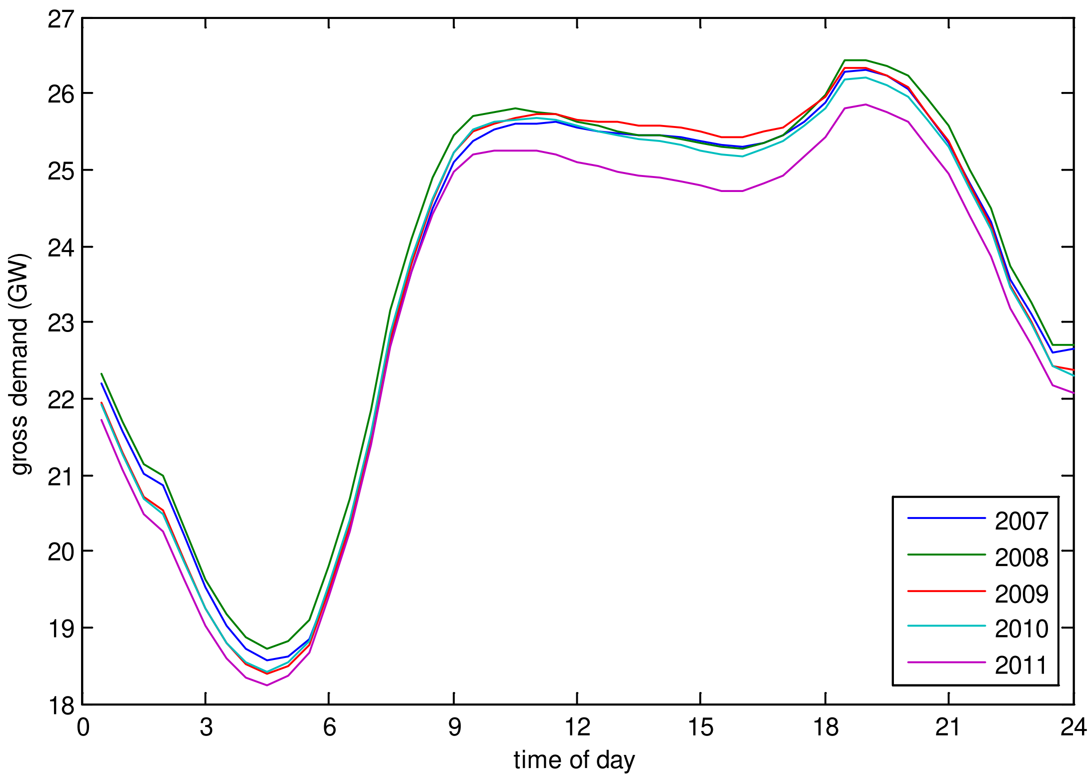
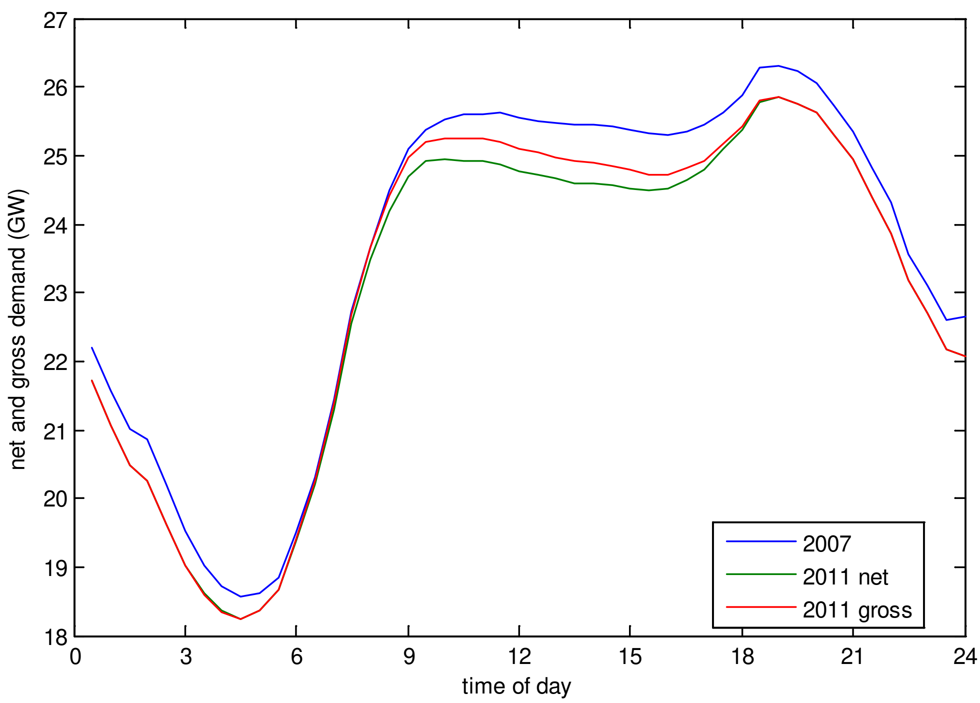


Figure 2-5 compares the daily average net and gross demand for 2011 with 2007. The gross and net demand in 2007 is similar, so only one line is necessary to represent both.

Figure 2-5 Comparing daily average gross and net demand for 2007 & 2011



2.2 Gross and net peak Demand

The significance of framing discussion of demand in terms of gross and net becomes apparent when considering the effect of non-scheduled SGU on peak demand. Figure 2-6 shows the distribution of the peak loads by time of day for the maximum peak loads from 2007 to 2011 at each node in the NEM. At 15:00 the disparity between gross and net demand shows the success of SGU in addressing peak demand. However at 17:00 when framing the discussing in terms of net demand non-scheduled SGU appears less effective at addressing peak demand. The net demand analysis, however, misses the point that non-scheduled generation has already addressed some peak demand issues and by doing so makes the remaining peaks in net demand peaks appear more prominent.

Figure 2-6 Distribution by time of day of the maximum peak loads from 2007 to 2011 at each node in the NEM

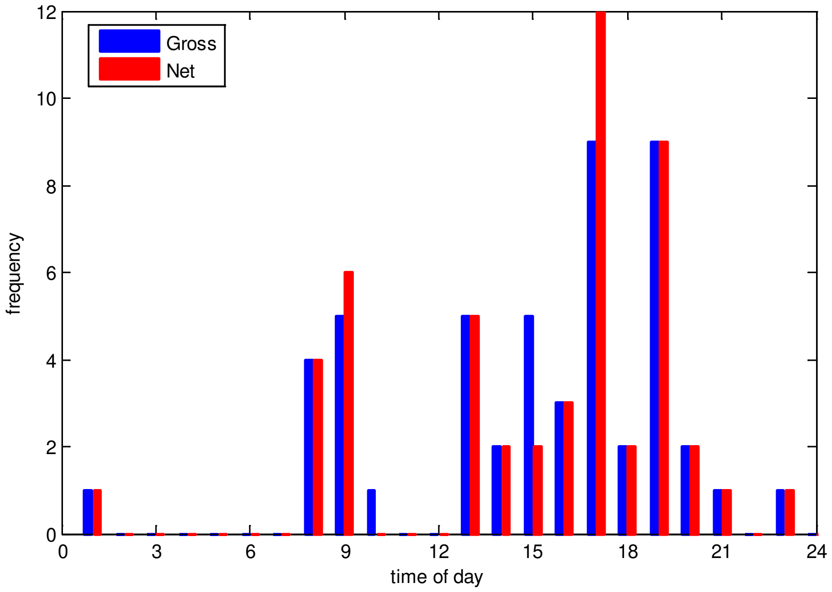
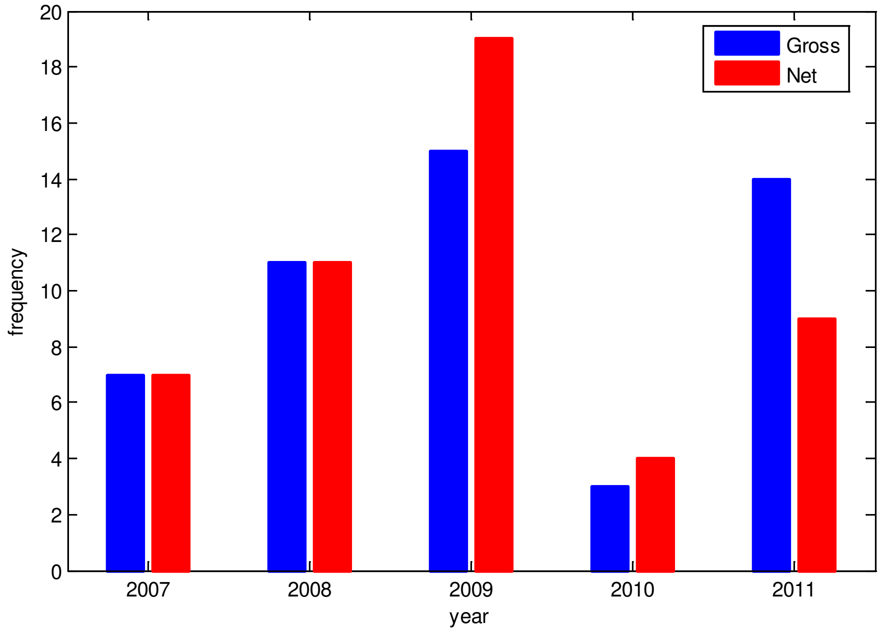


Figure 2-7 shows the distribution of the peak loads by year for the maximum peak loads from 2007 to 2011 at each node in the NEM. The frequency of maximum peaks for net demand between the years 2011 and 2009 shows the greatest disparity. Using net demand to frame the discussion could misattribute the decline to mild weather in 2011 compared to 2009. Using a gross demand analysis shows that much of the decline in the frequency of peak demand is attributable to non-scheduled SGU.

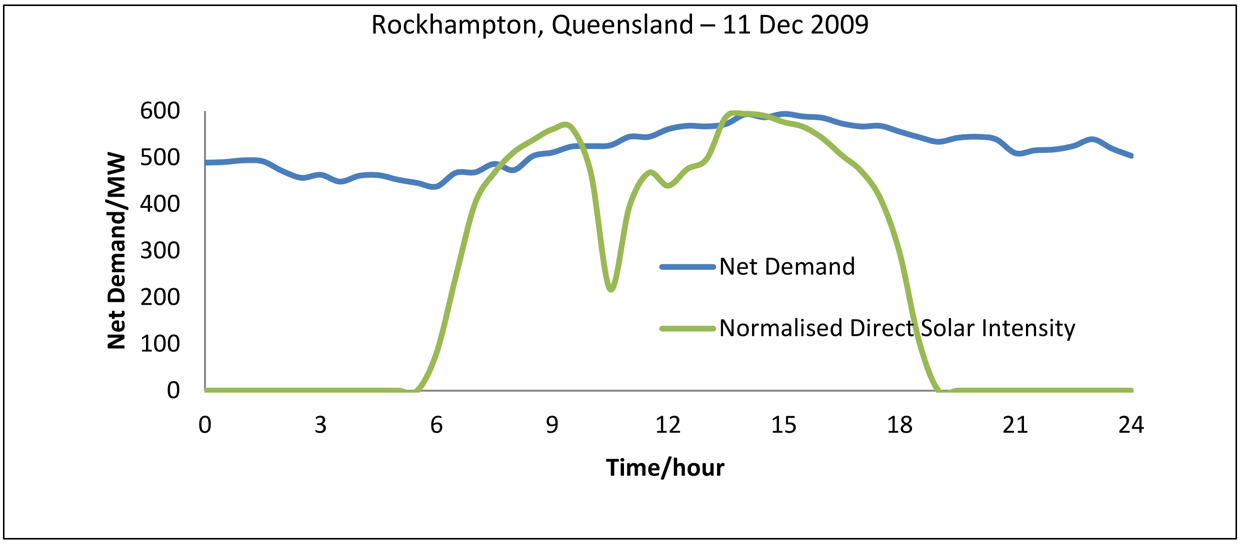
Figure 2-7 Distribution by year of the maximum peak loads from 2007 to 2011 at each node in the NEM

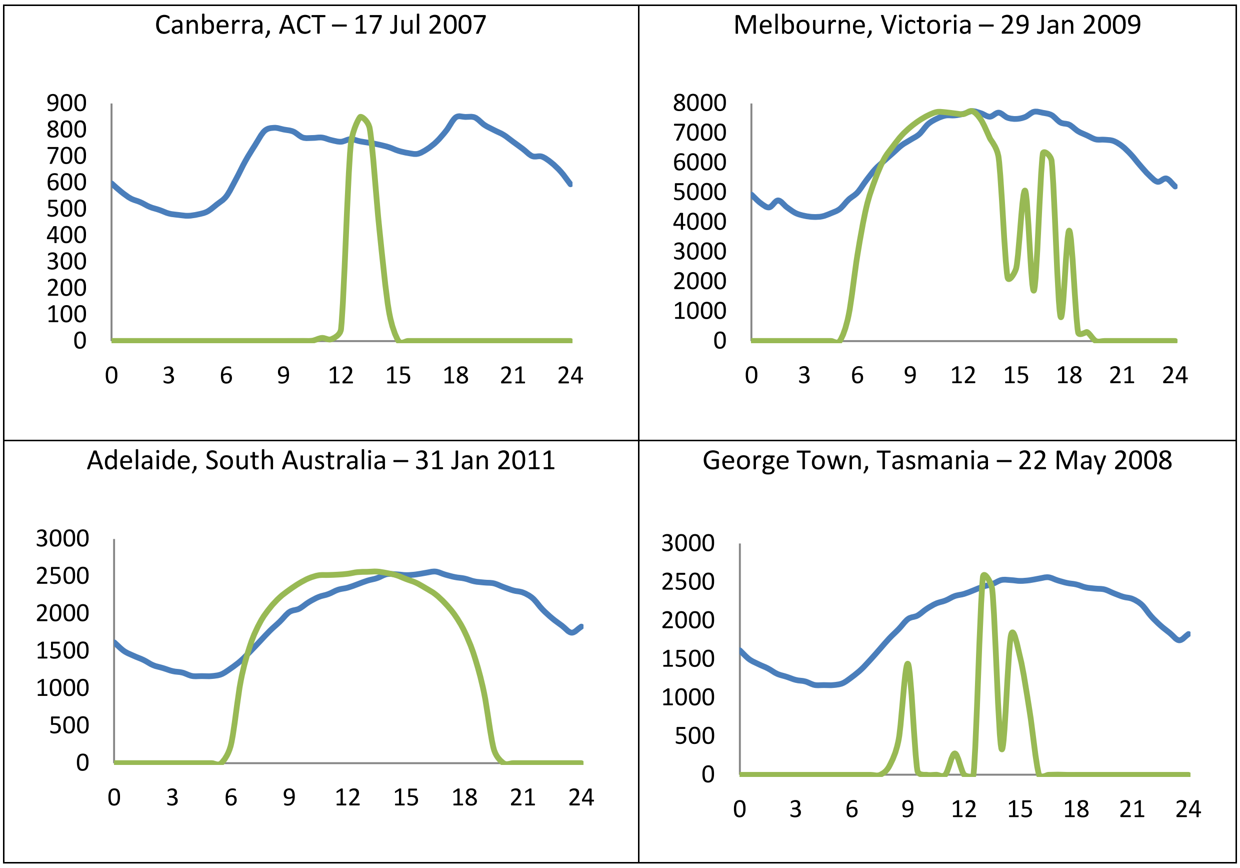


2.3 Intermittency and solar PV matching peak demand

Figure 2-8 compares the normalised direct solar intensity against the highest peak demand day over the period 2007 to 2011 for 5 nodes in the NEM. These five demand nodes in the NEM are chosen because they are the closest nodes to the only Australian weather stations that provide half hourly solar intensive reading within the NEM.

Figure 2-8 Comparing normalised direct solar intensity to the highest net peak demand day in 2007-2011 at 5 nodes in the NEM





(Sources: BoM 2012b; Wild & Bell 2011)

Table 2-1 matches the weather station with the nodes in Figure 2-8. The nodes Rockhampton, Melbourne and Adelaide and their weather stations at their local airports provide a good match. However, the node Canberra and its closest weather station at Wagga Wagga are about 200 km apart and the node George Town and its closest weather station Cape Grim are about 250 km apart. This separation must be considered when interpreting Figure 2-8.

Table 2-1 Matching the NEM nodes and weather stations that provide half hourly solar data

Node	Weather station
Rockhampton, Queensland	Rockhampton Aero
Canberra, ACT	Wagga Wagga
Melbourne, Victoria	Melbourne Airport
Adelaide, South Australia	Adelaide Airport
George Town, Tasmania	Cape Grim

3 Discussion

Figure 2-5 shows that non-scheduled generation goes some way to explain the reduction in net demand since 2007. This effect will be more pronounced in 2012 as the install of solar PV has substantially increased. The CER is still receiving data on installation for 2012. Additionally, **Figure 2-5** shows a reduction in demand between 2007 and 2011 in the early hours of the morning and late evening. This period is when electric hot water heaters use off peak power. Modelling increase in installations of solar hot water heater could explain much of this decrease in demand.

Renewable energy is having a major effect on the net demand curve and helps explain some of the apparent decrease in demand. Introducing the concept of gross demand helps frame the discussion of changes in demand on the NEM in a clearer fashion. There are degrees to the extent that net demand could be grossed up by including the following factors:

1. Non-scheduled generation;
2. Solar hot water; and
3. Energy efficiency.

These are given in order of ease of calculating the direct effect on the demand. As in this paper the wind speed and solar intensity can be used directly to calculate power generated at a specific time, which can then simply be used to gross up the net demand curve by adding the power to the net demand curve. The effect of solar hot water heating on net demand is not as simple a relationship. The solar hot water replacing electric hot water heater is an indirect relationship, which would require calculating the power that would have been used by the displaced electric water heaters. This displaced power could be used to gross up the net demand curve. Finally, the effect of energy efficiency on net demand is the most difficult to calculate. There is a two per cent turn over in housing stock every year, which will improve the efficiency of electricity use in buildings generally. In addition, there is the more rapid turnover of electric appliances. Attributing energy efficiency effects to the time of the day is left for further research.

Peak demand drives the requirement for new network infrastructure. The analysis of Figure 2-6 and Figure 2-7 shows the misleading conclusions that can arise from failing to incorporate non-scheduled SGU in analysis of peak demand. Misleading conclusions can manifest in two ways by:

- underestimating the effectiveness of non-scheduled SGU in addressing peak demand by focusing on the remaining net demand peaks; and
- misattributing the effectiveness of non-scheduled SGU to other factors.

Figure 2-8 compares solar intensity with net peak demand days. Bear in mind that the net demand curves are shown here, so solar PV has already shaped these curves. In the summer months solar provides quite a good match with net demand. However, there are two considerations that make the match less than ideal:

- intermittency; and
- the mismatch between the peak solar intensity around midday and peak demand in summer around 3 to 4 pm.

This mismatch and intermittency can be addressed with energy storage but there needs an incentive for non-scheduled SGU to install energy storage. Time of supply payment would provide such an incentive. This issue is discussed in detail in Bell and Foster (2012). Additionally, time of use charges would encourage people to shift demand from peak periods.

4 Conclusion

The paper has two conclusions.

Firstly, a requirement for policy to target the growth in peak demand via time of supply feed-in tariff for small generation units and time of use charges. The time of supply feed-in tariffs are intended to promote the adoption of storage technologies, which in turn, will help with intermittency. Time of use charges and time of supply payments encourage demand side participation and management.

Secondly, modellers of electricity demand consider both net and gross demand in their forecasts to improve forecasts and insight into the dynamics operating in the electricity market. Modellers considering both net and gross demand are required to model non-scheduled generation. Meeting this second conclusion has the following requirements:

- more comprehensive solar intensity data be provided by the BoM, and
- AEMO provide data in GIS format of each demand region's shape using the Australian Statistical Geography Standard developed by ABS to enable easier integration of large quantities of geographic data from a number of sources.

The applicability of these finding become more relevant to other countries as unscheduled generation becomes more wide spread.

5 Further research

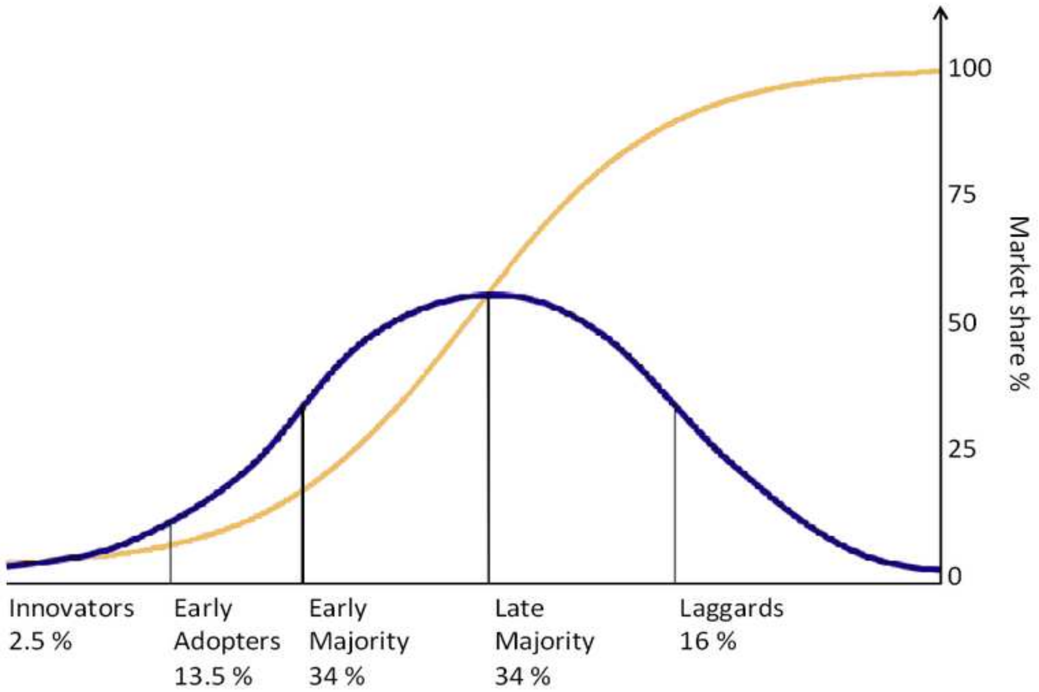
5.1 Solar hot water, small hydro and energy efficiency

This paper is instrumental to a range of further research. Other sources of non-scheduled generations should be considered to form a more comprehensive concept of gross demand, for instance, solar hot water and small hydro. Replacing electrical hot water heaters with solar hot water heaters reduces the overnight demand, which may provide a considerable transformative effect on net electricity demand. In addition, energy efficiency is meeting demand for electricity; incorporating energy efficiency would form an even more comprehensive concept of gross electricity demand and could help improve longer term electricity demand projections.

5.2 Sensitivity analysis of increases in solar PV and wind generation

This paper's modelling uses the increases of solar PV and wind for the year 2007-11. The number of solar PV installations is rapidly increasing. Bell and Foster (2012) discuss how all new technologies follow S-shaped diffusion curves that can usually be tracked by a nonlinear logistic or a Gompertz function, see **Figure 5-1**. Sensitivity of net demand to increases in solar PV and wind generation can be evaluated where the diffusion of innovation follows a Gompertz function. This can be simplified by evaluating the sensitivity of net demand to various penetrations of solar PV.

Figure 5-1 Diffusion of innovation



(Adapted from: Rogers 1962)

5.3 Improving the use of the limited solar intensity data

There are only five weather stations with half hourly solar intensity data in the NEM. However there are many more weather stations with daily global solar exposure data. Using both datasets could improve the modelling of the half hourly solar intensity at other locations. This can be achieved by using the latitude of a location between two half hourly solar weather stations in a weighted average and the resultant average scaled by the total daily solar intensity of a nearby weather station of similar latitude.

In the longer term, the Australian Renewable Energy Agency (ARENA 2012) project titled "Australian Solar Energy Forecasting System" (ASEFS) awarded to CSIRO will go some way to addressing this issue. In a similar vein, for wind generation there is the AEMO's (2011) "Australian Wind Energy Forecasting System" (AWEFS) project awarded to ANEMOS Consortium.

5.4 Using GIS to improve weather station, post code and node matching

This paper uses the longitude and latitude of the weather stations, demand nodes, and the weighted centres of ABS statistical areas to match entities. The weather stations are points, so the longitude and latitude method is appropriate. However, the demand node and the ABS statistical areas are unevenly shaped regions. This will create inaccuracies in matching entities. For instance a demand node region could be long and thin, so the weather stations lying closest to the centre of the demand node region may well be outside the region. This problem also affects population by statistical area.

Using a geographic information system (GIS) would eliminate this problem. The ABS population data already comes in GIS format and the small generation name plate values by postcode regions can be transformed into ABS statistical regions. However, the demand node regions are publically unavailable in GIS format. These maybe privately available within individual network service providers or retailers but a comprehensive publically available GIS format mapping of the demand node regions is lacking. Provision of such information is a near public good and better provided by the ABS or AEMO. Provision is a near public good because provision lacks rivalry of use, as many people can use the same information without exhausting supply, but people can be excluded from provision. Provision of the data would add to the intellectual infrastructure of Australia.

5.5 Clarify semi-scheduled generation's role in gross and net demand

Gross demand includes transmission and distribution losses and is met from all sources of generation including, SGU and larger scale non-scheduled, semi-scheduled or scheduled generation. Semi-scheduled generation role requires clarifying whether it is included within net demand or only within gross demand.

6 Acknowledgements

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