# 3

# Rooftop Photovoltaics: Distributed Renewable Energy and Storage (or Low-Cost PV Changes Everything)

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## Introduction

Since 2008, the consumption and generation of electricity in Australia has been going through a period of unprecedented change (Fig. 3.1). In 2008, total electricity demand stopped increasing for the first time, then fell and in 2015 it began to slowly rise again. Much of this fall was to do with sharp electricity price increases, predominately driven by expenditure on "poles and wires" to ensure the system could meet peak demand. In response, many consumers used electricity more efficiently as discussed by Mark Diesendorf in Chapter 2. Further decreases in demand (from a grid point of view) came from the uptake of rooftop photovoltaic (PV) systems—predominantly by households. Starting from essentially zero rooftop grid connected systems in 2008, installed capacity of household rooftop systems (<10 kWp) reached approximately 5.5 GW, with total installed capacity of PV in Australia reaching just over 7 GW

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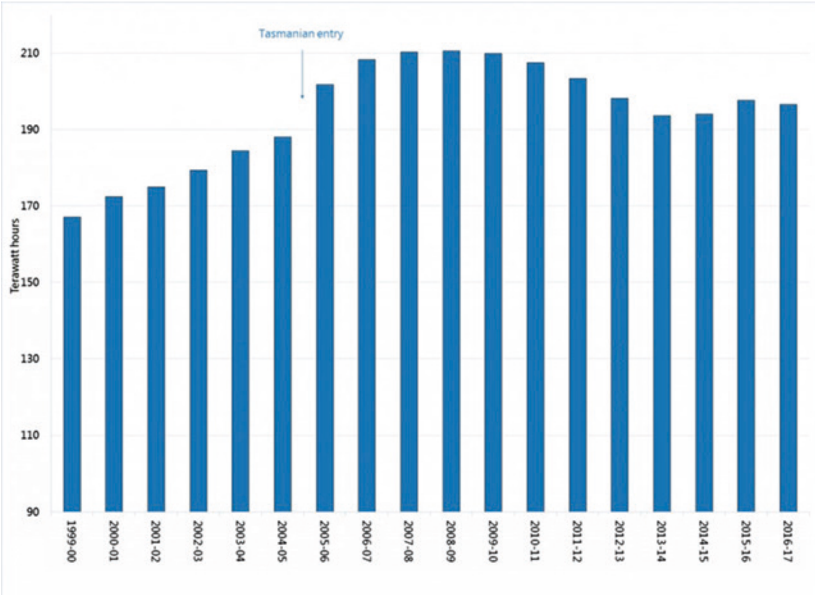


**Fig. 3.1** National electricity demand, Australia, 1999–2017 (*Source* https://www.aer.gov.au/wholesale-markets/wholesale-statistics/national-electricity-market-electricity-consumption)

at the end of 2017 and producing about 4% of Australia's electricity. Over this period the cost of installed rooftop PV systems has decreased by about 9% per annum from $2300/kWp in 2012 to $1300/kWp in 2018 (including an Australian government financial incentive which reduces the price to consumers by about $600/kWp) (https://www.solarchoice.net.au/blog/solar-power-system-prices). Without government incentives—the cost of a rooftop PV system in Sydney, installed at $1900/kWp, will produce electricity over its 25-year lifetime at a levelised cost of $0.08/kWh. In comparison, current electricity tariffs in Sydney for residential customers are significantly higher.

PV used to be one of the costlier options for dealing with carbon emissions reduction in the built environment. An installed PV system on the rooftop of an Australian home is now the lowest cost approach for delivering energy into a home. In comparison to conventional electricity, the levelised cost of rooftop PV electricity is now about one-third of the domestic tariff, one-fifth of the peak tariff and about half the off-peak tariff. Furthermore, PV is now cheaper for residential and small businesses than natural gas in many locations in Australia.

This means that all conventional wisdom about how to achieve carbon emissions in the built environment is radically altered. As an example: natural gas for hot water and domestic space heating used to be the lowest cost option with lower carbon emissions than using electricity. However, PV is now able to provide hot water and space heating (as well as cooling) cheaper than gas (which has increased recently in price by factors of 2–3)—utilising highly efficient heat pumps/reverse cycle air conditioners or even resistance heaters! As such, the hierarchy of what measures should be undertaken to minimise carbon emissions needs to be drastically re-evaluated. For example, for residential customers in Sydney gas is charged at ~\$0.04 per MJ or \$0.144 per kWh. Currently it is now more cost effective to heat your home in Sydney by utilising daytime PV electricity through a resistance heater (with PV electricity at \$0.08/kWh) rather than burning natural gas in an 80% efficient heater (costing ~18 c/kWh)—more than twice the cost of PV heating. Utilising a high-efficiency heat pump with a coefficient of performance (COP) of 4 reduces the PV/electric option further to 2 c/kWh!

In fact, buying green power from the grid is now cheaper than buying fossil fuel electricity and gas from the grid. This is evidenced by the University of NSW (UNSW) signing a 15-year power purchase arrangement for 100% solar supply. This option was the lowest cost option on offer when negotiated in 2017—cheaper than black electricity—and no subsidies were required (the City of Melbourne undertook a similar arrangement in November 2017 for a 10-year renewable electricity supply from Pacific Hydro sourcing wind energy). As such, the built environment can now look to decarbonise their emissions through low-cost PV—via onsite or offsite generation.

To compete, any energy efficiency measure needs to be evaluated purely on cost. If it is not competitive with rooftop PV, then it is not justified in terms of carbon emission reductions. For example, increasing the star rating of a residential building to 7 or 8 stars or beyond is probably not economically competitive in comparison to PV combined with reverse cycle air conditioning systems—if the driver is to lower carbon emissions. Energy efficiency measures that are bespoke solutions will not succeed as typically this approach will be too costly. Of course, there may be other reasons for implementing measures that bring another benefit to a building. There now needs to be a greater analysis and emphasis placed on the importance of energy efficient buildings in terms of other factors such as peak electricity demand, resilience to weather extremes, thermal comfort and occupant health and productivity.

## Rooftop PV in Australia

The Australian electricity network has an installed capacity for all technologies of about 56 GW (http://apvi.org.au/wp-content/uploads/2018/07/PViA-2018-AU.pdf). The cumulative installed PV capacity in Australia is shown in Fig. 3.2. Note that before 2008, the installed grid connected PV capacity in Australia was essentially zero from the perspective of contributing to Australia's electricity supply. The uptake of PV in Australia since 2008 has predominantly seen the installation of small, household rooftop systems of less than 10 kWp (see Fig. 3.2). This is reflected in part by the various incentive schemes in place from either the State or Federal governments which encouraged residential rooftop systems via guaranteed feed-in tariffs or upfront financial incentives such as the Renewable Energy Certificate scheme. In conjunction with, at times overly generous financial incentives, the underlying price of PV systems has continued to fall as mentioned previously at about 9% per annum. As a result, today, it is estimated that there are over 1.8 million PV systems installed in Australia of which about 1.75 million are rooftop systems—predominantly less than 10 kWp.

Because of these rooftop PV systems, their combined impact on electricity demand is now starting to become visible in the Australian electricity network. Shown in Fig. 3.3 is the National Electricity Market (NEM) electricity data for a 7-day period in 2018 (10/9/18–17/9/18). Rooftop solar systems over this period are providing about 5% of the electricity required in the NEM while utility scale PV—(a more recent phenomena

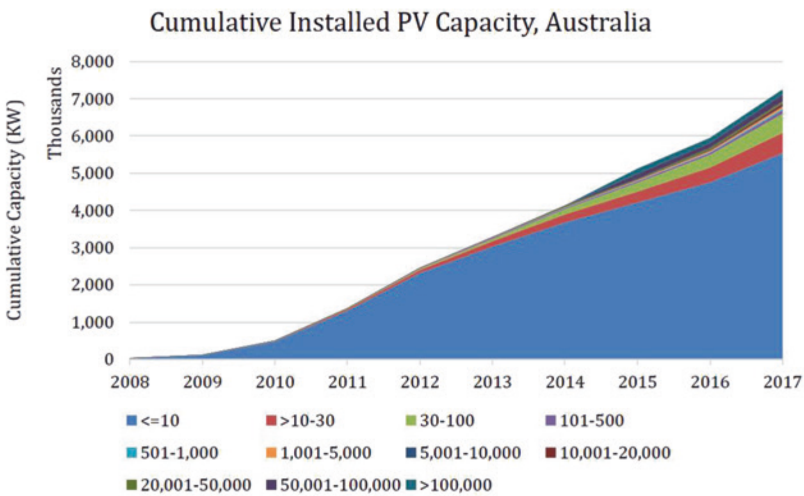


**Fig. 3.2** Cumulative installed PV capacity Australia 2008–2017 (*Source* APVI http://apvi.org.au/wp-content/uploads/2018/07/PViA-2018-AU.pdf; accessed from WikiMedia Commons https://wikivisually.com/wiki/Solar_power_in_Australia 3 January 2019)

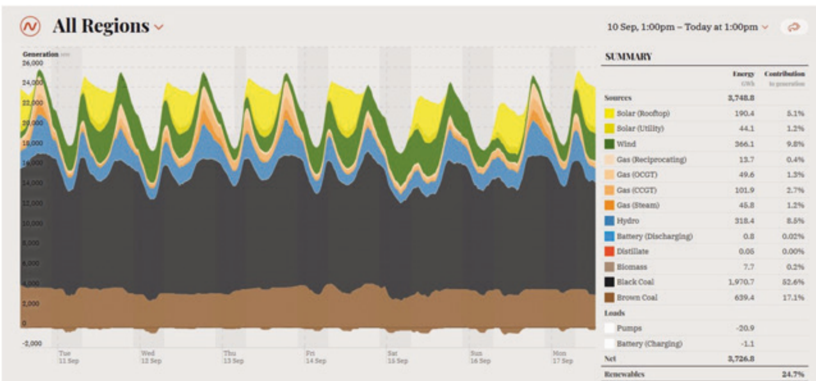


**Fig. 3.3** Open NEM data (*Source* https://opennem.org.au/#/all-regions)

in Australia) is supplying about 1%. From this snapshot it is clear that the 1.75 million rooftop PV systems, distributed across the country, when aggregated, supply a significant fraction of daytime electricity demand.

Rooftop PV on residential buildings face some challenges, however. Some critics would point out that as more PV is installed in the low voltage distribution network (i.e. 240 V AC network) then there is the potential of too much power being generated on sunny days when few people are at home and demand is low. This could lead to over-voltage issues on the grid and there is much discussion about the possibility of curtailing PV systems to avoid this problem (https://www.afr.com/news/solar-power-could-have-to-be-curtailed-to-avoid-grid-disruption-20181003-h1675d).

However, without resorting to batteries, which are costly at present, there are many other options that could be implemented in a cost-effective way that already exist to address this issue. For example, as previously discussed, PV is now cheaper than off peak electricity, so it would make economic sense for residents to use their excess PV power to heat their hot water. At present in many parts of Australia this is achieved using off-peak electricity in the middle of the night—typically from power stations burning coal. For example, in the state of NSW residential off-peak hot water is of the order of 2–3 GW. Shifting this load to the middle of the day would allow a significant further increase in installed PV capacity on the low voltage, residential distribution network. This could be achieved in several ways. Some companies are exploring the option of customers installing devices to divert excess PV production to hot water tanks. The challenge here is that this can be an expensive option—as the best way to do this to minimise grid imports is to utilise a solar diverter that essentially is a DC to AC inverter. Alternately, the grid operators could utilise off-peak signals to switch on hot water tanks when sections of the grid have "too much" PV power in the middle of the day. Off-peak periods could then occur in the middle of the day rather than the middle of the night—as is presently the case. This is a paradigm shift that may take electricity utilities some time to accept—that PV power in the middle of the day has created the situation where off-peak is now a daytime issue rather than in the middle of the night.

In addition to hot water, there are several energy loads in the residential sector that could be shifted to the middle of the day when PV systems are supplying low-cost electricity. Residential space heating in the winter and cooling in the summer are ideal candidates. This approach would work best if houses are reasonably well insulated and not leaky in terms of air infiltration. However, this approach would be beneficial to minimise energy usage in homes anyway, as it is the build-up of heat in a home over the day that drives large consumption of electricity for cooling when residents return home in the evening. Even if a home is not thermally efficient, pre-cooling in summer or pre-heating in winter using PV and reverse cycle HVAC systems (now installed in 70–80% of homes in Australia) makes sense. Retrofitting of homes to make them thermally more efficient would be a good approach as well but would need to be sure that only cost-effective approaches that improve the building performance are implemented that are cheaper than installing more PV. Such approaches could include things like: sealing of homes against draughts, improving the performance of HVAC systems (particularly ducted systems) or possibly external shading of west facing windows. The recent ASBEC report *Built to perform* (https://www.asbec.asn.au/research-items/built-perform/) however, found that very few additions to new homes beyond 6 star were cost effective—only PV and LED lighting showed benefit/cost ratio better than 1.

Other loads that are easily shifted into the daytime are pool pumps, dishwashers and clothes dryers. In such cases, residents can minimise their loads by installing more efficient equipment (Fan, MacGill & Sproul 2015). For pool pumps there are several options including 3 speed or multispeed pumps or retrofitting a variable speed drive to run pumps at lower speed and save up to 80% of the pump energy (Zhao et al. 2017). Clothes dryers are also significant residential loads. Increasingly heat pump systems are entering the market, however, at present their higher initial price may make it a costly pathway to reducing electrical demand. Hence, households with PV systems and resistance clothes dryers or even resistance heaters for space heating could usefully utilise PV electricity from their own rooftop systems if the alternative is curtailment of their use or purchasing electricity from the grid at a later time.

## Non-Residential Buildings and Rooftop PV

In contrast to the residential sector where demand occurs predominantly out of sync with PV generation, non-residential buildings such as commercial office buildings, shopping centres, schools, universities

**Fig. 3.4** Tyree Energy Technology Building, UNSW 6 star Greenstar building with a 150 kWp PV array (*Source* School of Photovoltaic and Renewable Energy Engineering, UNSW)

and hospitals—all typically have peak demand that coincides with peak PV power production. As such these types of buildings are ideal for the uptake of PV rooftop systems. At present in many parts of Australia there is no feed-in tariff on offer for larger scale non-residential systems. As such these systems are typically sized to only supply sufficient power to the internal loads of the building on a sunny day in order to minimise export of electricity for which the owner of the PV systems receives no compensation.

An example of this sort of system can be seen in Fig. 3.4 which shows the 150 kWp PV system installed on the rooftop of the Tyree Energy Technology building at UNSW.

Illustrated in Fig. 3.5 is the electricity demand for the building over a typical weekly period (Monday to Friday, September 2nd–6th, 2013). The total electrical demand for the building peaks at approximately 500 kW, typically in the middle of the day—coinciding very well with PV generation that on a sunny day peaks at about 100 kW. Due to the energy intensive nature of the research laboratories in the building this system can produce at best about 20% of the buildings demand—due to the limitation of roof space. Interestingly the TETB is a 6-star Greenstar building and was originally designed and built to include an 800-kW electrical generator powered by natural gas—which also had 400 kW of heat recovery and an absorption chiller. Unfortunately,

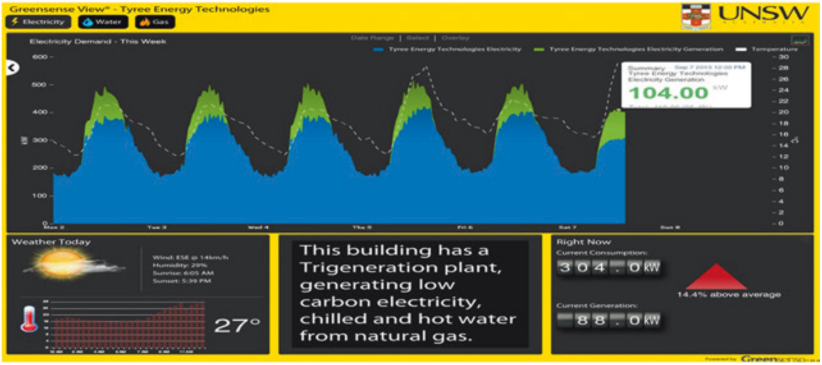


**Fig. 3.5** PV generation (green) and remaining electricity demand (blue) TETB, UNSW (Monday to Friday, September 2nd–6th, 2013) (*Source* Drawn by author from data accessed via https://www.estate.unsw.edu.au/live-energy)

the recent price rises in natural gas now mean that this trigeneration system rarely runs except on days when the UNSW Energy Management team are wanting to bring online the 800-kW generator to avoid peak demand charges. Meanwhile, the PV system continues to operate reliably and economically and with no need to be concerned about rising fuel prices.

Another useful building typology for the utilisation of PV systems are school buildings which have peak demand during daylight hours. In fact, this is now becoming so clear a pathway that both political parties in NSW have announced funding commitments to instal PV systems in conjunction with air conditioning systems on public schools across the state of New South Wales.

Behind the meter PV is in fact becoming so cost effective that even industrial plants—that typically pay among the lowest tariffs for electricity—are finding that PV is a cost-effective option. For example, the company Sun Metals Corporation—installed about 100 MW of PV to allow their Zinc refinery to continue to operate its daytime shift (closed due to high grid prices during the day!) (https://www.afr.com/news/sun-metals-goes-solar-to-cut-energy-costs-20171220-h083ym).

Large commercial buildings with few storeys such as Sydney Markets are ideal locations for rooftop PV (Fig. 3.6). Demand is high during

**Fig. 3.6** View of part of the 2.2 MW PV rooftop system on Sydney Markets (*Source* Autonomous Energy (used with permission of Matthew Linney))

the day—particularly if the facility has loads such as refrigeration. Importantly PV systems can shade the rooftops—minimising heat loads in summer on the building as well as supplying electricity to the facility.

## Conclusion

The era of low-cost PV has arrived—probably far more quickly than most living and working in the built environment expected. The conventional approach to buildings in terms of low carbon has always been: efficient building envelope, efficient appliances and lighting—preferably daylighting, and lastly onsite or offsite renewable energy generation. Today for most buildings this hierarchy is becoming less meaningful. Rooftop PV or PV or Wind purchased via a power purchase agreement (PPA) is becoming the simplest and most cost-effective pathway to deliver a low energy building. For any buildings with reasonable solar access and less than say a few storeys high, then the rooftop of the building can be covered with PV (or as much as the local electricity authority will allow for now!), as city maps of PV installations clearly illustrate (Newton & Newman 2013). Ideally, PV electricity generated on site is best consumed straight away by the building loads. For residential customers, in Australia any export of electricity should be rewarded with a Feed-in Tariff that at least covers the unsubsidised Life Cycle Cost of that electricity. At present that would be approximately $0.08 per kWh. This is in fact as pointed out earlier—the cheapest electricity that can be generated in Australia at present—approximately the wholesale price of electricity. However, it has the benefit of being available right where most customers need it—without transmission and distribution losses. Hence electricity authorities would be best to purchase this electricity from the PV systems owner and on-sell it, rather than curtail it.

At present, residential PV power is often being exported to the grid at a time that coincides with peak power tariffs—hence it would make far more sense economically for all concerned that this low-cost PV electricity is utilised and not curtailed. Hence it would be best if PV electricity generated in the middle of the day, if exported and sold at off peak rates, would encourage electricity demand to occur when the cheapest electricity in the network is most available. If cloudy weather reduces generation—then loads such as hot water, HVAC pre-heating or cooling or pool pumps can be scheduled for other times when cheaper electricity is available. The worst thing to do would be to switch off the cheapest source of electricity on the grid—and it is only getting cheaper. To ignore rooftop PV makes no sense economically or environmentally. It needs to be embraced—it is only going to get cheaper so we need to find more uses for low-cost PV electricity in the middle of the day. The more loads that soak up this cheap electricity—and preferably efficiently the better, as the electricity systems need greater capacity given that another important energy transition is rapidly approaching—the move to electric vehicles. Making buildings zero energy via rooftop PV, and efficiencies that makes sense economically, will free up other sources for electricity in the network to charge electric vehicles. Many people are focussing on batteries going into buildings or onto the grid. However, at present time prices for such systems remain high in comparison to grid electricity prices—especially rooftop PV. However, when compared to the price of petroleum—batteries for electric vehicles—recharged by renewable electricity—make a lot more sense from an economic perspective. As the battery industry grows and prices fall—batteries may well find a place in the stationary energy sector. However, it would seem that their first application should be in electric vehicles.

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