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The Potential for PV Self-Consumption for Hot Water Systems in Australia

Saeed Tehrani [1], Osama Bany Mousa [2], Robert A Taylor [2,3], Chris Taylor [4]

[1] Apricus Australia, Sydney, Australia

[2] School of Mechanical and Manufacturing Engineering, University of New South Wales, Sydney, Australia

[3] School of Photovoltaic and Renewable Energy Engineering, University of New South Wales, Sydney, Australia

[4] Reclaim Energy, Byron Bay, Australia

The Australian hot water market is dominated by electric and gas water heaters, but also contains a non-negligible solar share. While this ‘solar share’ came from solar thermal collectors during 2010 to 2016, solar thermal technologies (both flat plate and evacuated tubes) now seem to be losing ground to Photovoltaic (PV) systems. This trend has (ironically) been exaggerated by reductions in electricity feed-in tariffs (from 0.6 AUD/kWh in 2010 to < 0.1 AUD/kWh in 2019/2020 in both Victoria and NSW [1]). That is, PV system owners have been increasingly incentivised to use their excess PV on site—rather than export it—for economic reasons and for grid protection to ensure transformers do not become saturated due to increased voltage from exportation [2]. This study investigates the ‘best’ use cases for solar PV self-consumption for solar hot water in Australian households. To do so, we compared to conventional gas and electric heaters as well as the solar thermal and heat pump hot water systems (see Fig. 1). Although several recent global research efforts which have investigated the trade-offs between solar thermal hot water systems (including PV-driven hot water configurations), none of these have investigated these issues for Australia [2,3]. From these studies, though, heat pumps have shown to provide a much more efficient use of electricity than resistance heating elements for providing hot water in buildings. However, heat pumps have higher up-front costs and face issues around freeze/frost protection cycles, so these represent barriers to uptake. In addition, most heat pumps are not suitable for direct integration with PV as they are not compatible with an intermittent power source. With these trends as a background, this study will seek to explore the following questions: (i) What’s next for the solar hot water industry in Australia?, and (ii) Under what conditions can PV-driven solar hot water systems to be competitive against grid options?

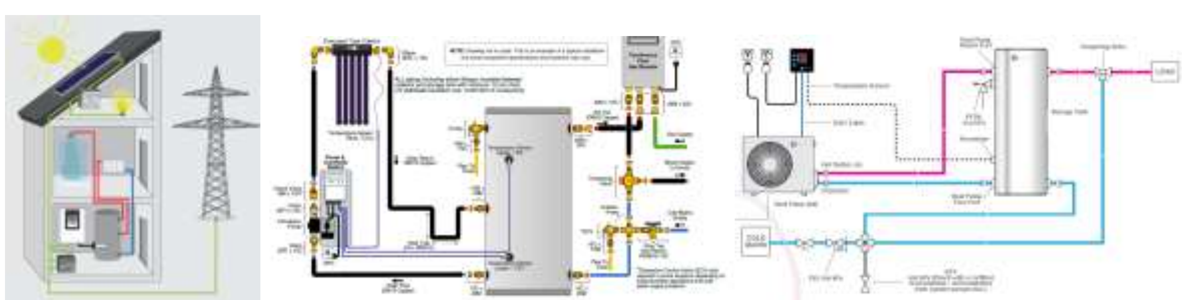


Fig. 1. Representation of typical solar PV hot water system (left), solar thermal hot water system (middle), and heat pump hot water system (right) [5,6]

To address these questions, the study uses a transient energy model, together with experimental data on household total electric load profile and PV generation, to techno-economically analyse a range of hot water solutions, as reflected in Table 1.

Table 1. Main Characteristics and the method for hot water system evaluations in this study

Type of Hot Water System	Main Characteristics	Method for energy calculations
Instantaneous gas	26 L/min gas booster, 82% Thermal Efficiency, 203 MJ/hr gas consumption	Per AS/NZ 4234 (i.e. climate zones & methodology) using TRNSYS [2, 4]
Electric hot water storage	315 L hot water tank, 2.5 kWh/day heat loss per AS/NZ 4692	
Solar thermal hot water system	Evacuated tube or flat plate with 2.78 m^2 aperture area (~5 m2 gross area on the roof), 72% peak thermal efficiency	
CO2 Heat Pump	A CO2 heat pump with 0.9 kW and 4.5 kW rated power draw and thermal capacity, respectively.	
Solar PV electric boosted hot water system	5 kW PV system + 315 L electric tank (~25 m^2 roof area)	Experimental for 3 case studies in NSW 2337 & NSW 2278 (Zone 3), VIC 3113 (Zone 4)

The solar thermal and heat pump systems savings are calculated based on TRNSYS modelling of Apricus Australia/Reclaim Energy products based on the minimum savings values set by the clean energy regulator through the method outlined in AS/NZ 4234 [7] . According to AS/NZ 4234, all solar thermal/heat pump hot water systems should reach a minimum of 60% annual energy savings in Zone 3, for which most products in the Australian market are designed. A minimum of 60% is also expected for solar PV driven hot water system. The study was conducted by considering a 315 L/day hot water delivery or the daily peak demand of 42 MJ/day (~ 12.2 kWh/day) for hot water, based on the relevant Australian standard (AS/NZ 4234) [7]. Given the fact that solar PV hot water system performance is sensitive to the production and demand profiles, the system was experimentally evaluated by data available by Reclaim Energy solar PV installations using the Solar Analytics monitoring device as shown in Fig. 2 [5,8]. This initial study is limited to three solar PV installations, but more variations—including system size and load profile—will be considered in the future study using additional case studies across Australia in all four climatic zones (as per AS/NZ 4234) to generalize the results of this study.

Fig. 2. Solar Analytics installation for a solar PV hot water system: Left, device installation at switchboard and (right) online monitoring platform [5,8]

A daily production and load profile for a 5 kW solar PV system is shown in Fig. 3. In the absence of electric battery systems, an electric storage hot water tank is a potential candidate to increase the household self-consumption by diverting the excess solar PV to the resistive element with (ideally) 100% efficiency (i.e. 1 kW electric input = 1 kW thermal output). A month by month analysis was conducted for the year between Jun 19- Jun 20, as shown in Fig. 4 for the three case studies. While the monthly solar generation is similar from one case to another, there are significant differences in solar PV contributions to the household electricity loads. While the data might include some outliers (i.e. un-occupied residents, power disruptions, etc.), a 5 kW solar PV system has successfully reached 100% solar contribution to the hot water demand for many months in all three locations. For the three case studies, the annualized solar PV hot water contribution varies between 77-96%, while the annualized solar PV on-site use alters between 16-26%.

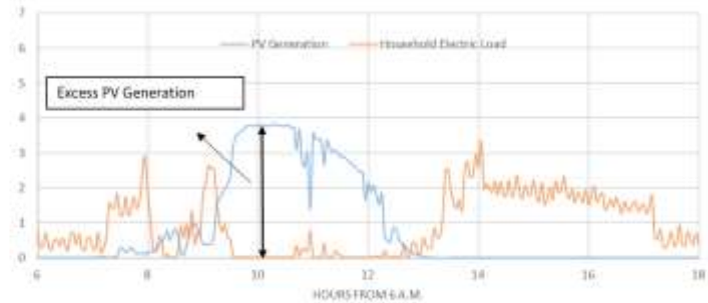
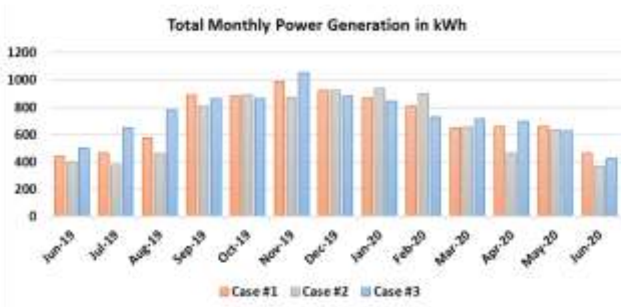
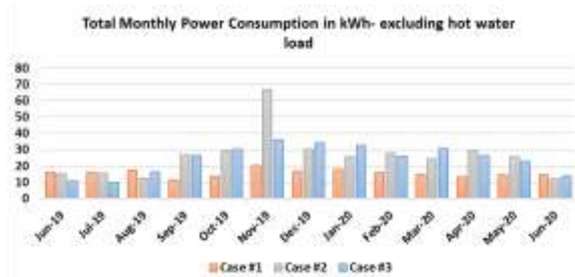


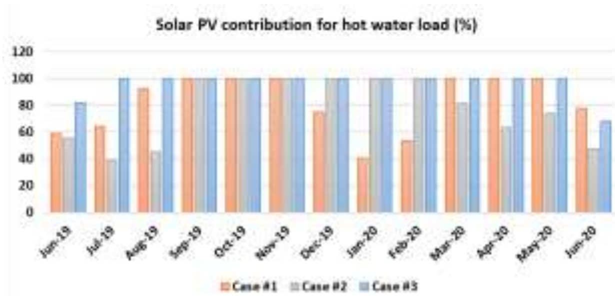
Fig. 3. Excess generation in kW for a representative day in June 2020 (NSW 2337)



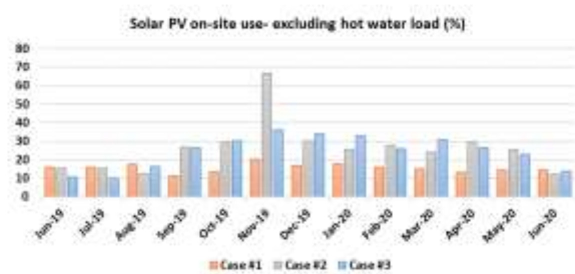
(a)



(b)



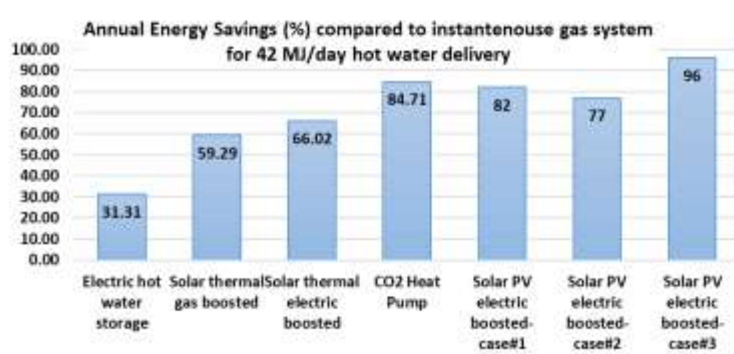
(c)



(d)

Fig. 4. Monthly analysis of three PV system installations: (a) Monthly power generation, (b) Monthly power consumption, (c) Monthly solar power contribution in hot water load, (d) Monthly solar PV on-site use

The annual total energy for delivering of 315L/day hot water with gas and electric systems are 22-24 and 15-16 GJ/yr, respectively, in Zone 3/Zone 4- i.e. Sydney/Melbourne- (as per AS 4234 [7]), respectively. Comparing with these baseline values, the annual energy and cost savings of different hot water alternatives are shown in Fig. 5.



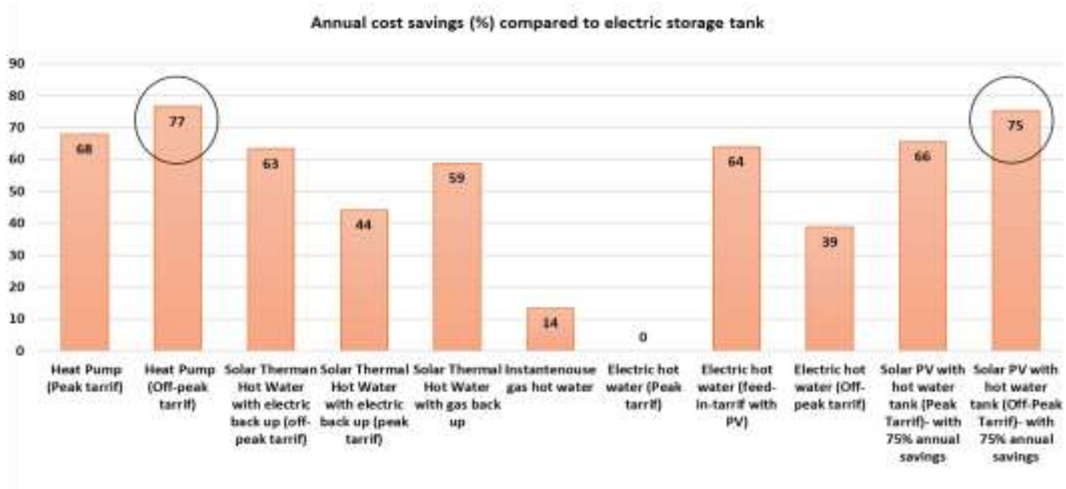


Fig. 5. Annual savings results: A. Annual energy savings (%) compared to instantaneous gas hot water system and, B. Annual cost savings (%) compared to electric storage hot water system

The following conclusions can be draw from this comparison and study:

- While heat pumps are the leading technology for energy efficiency and long-term cost-effectiveness, solar PV hot water systems can achieve a competitive savings (i.e. 100% versus 80% in energy) with almost the same operating costs and at least one-third of the capital cost. This is, however, for a 5 kW PV system which has a lot of excess capacity for self-consumption throughout the year.
- By using electric hot water tanks integrated with solar PV, the solar PV on-site use can be at least tripled to ~60% (from ~ 20% for each location). This is based on the assumption that the electric tank is equipped with a 5 kW element and is capable of absorbing as little energy as 0.1 kWh.
- Given heat pumps are about 4-5 times more efficient than electric resistive storage tanks, if they become compatible with intermitted solar PV resources (to take the excess PV generation direct) and with upcoming grid protection regulations such as demand response capability, they should be a preferable option to capture excess PV compared to resistive elements.

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