Shifting domestic electric water heating to solar hours reduces battery capacity requirements by 80%: a case study in regional Victoria

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Introduction

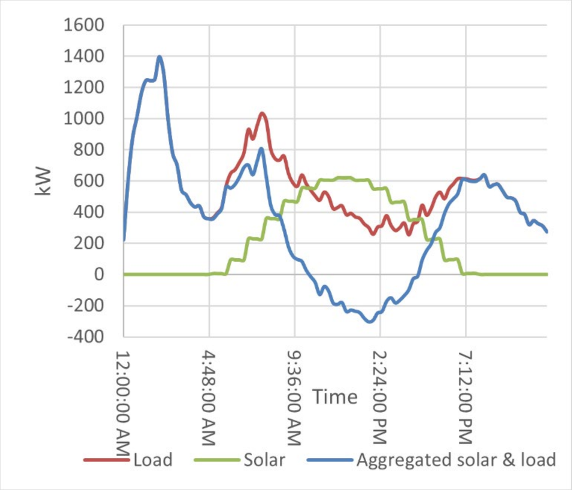
Australia has the highest per capita uptake of rooftop PV systems in the world (APVI, 2021). However, high levels of solar generation being produced within the distribution network at a different time to peak electricity demand can cause significant issues for network operators (Mahmud and Zahedi, 2016). Battery storage can address issues caused by mismatched solar generation and peak demand. Many of the benefits of batteries could be achieved through demand management strategies for a reduced cost (Houssainy and Livingood, 2021). Domestic electric water heating systems (DEWH) account for approximately 23% of residential electricity consumption and have high flexibility due to the thermal storage capacity of hot water cylinders (E3, 2012). This presents an opportunity to increase the alignment of generation and load, reducing battery capacity required.

Previous studies in Australia have demonstrated the ability of DEWH systems to provide storage for solar PV energy, lowering the electricity costs of households (Li et al., 2021, Clift and Suehrcke, 2021, Yildiz et al., 2021). The Victorian town of Yea exceeds the national average proportion of PV installations by almost 10% (APVI, 2021). The local community energy group 2030Yea has set the goal of supplying the town with 100% renewable electricity by 2030, which will require greater utilisation of local solar generation (2030Yea, 2022). In late 2021, 2030Yea commissioned a report to investigate the potential for the town to install a community battery. The report found that the maximum daily peak load was at 1am caused by DEWH timers set to coincide with off-peak pricing but also coinciding with highest-emission coal generation overnight (McConnell et al., 2022). The peak tariff period has recently changed to 3pm-9pm, presenting the opportunity to shift hot water heating from excess solar during the day and providing a cost-effective way for Yea to reduce the need for battery storage and move towards their 2030 net zero goal (Essential Services Commission, 2021).

Methods

To determine the impact that shifting the DEWH peak has on battery storage requirements, a battery optimisation was run under a range of different load conditions and battery sizes. As the main motivation for installing a community battery is to better utilise surplus solar generation, 100% self-consumption of solar was used as a point of comparison. The changing electricity cost for each scenario is also important for the feasibility of this approach as currently DEWH occurs during an off-peak period. For each scenario the aggregate cost of energy per household was calculated for the current two-part tariff (peak period 3pm-9pm) and the previous two-part tariff (peak period 7am-11pm) which was in effect prior to 01/09/2021. This can provide an insight into why this approach may not have been considered in the past.

The aggregated load for Yea throughout 2018 was provided by Ausnet. Two days were chosen to model, a high solar day (01/02/2018) with more solar exported than 95% of days in 2018 and a moderate solar day (06/03/2018) with more export 75% of days in 2018 (Figure 1 and 2). Solar export is defined as the energy flowing in the reverse direction through the HV feeder into Yea. Each day was repeated to make up 48 hours of operation and capture battery behaviour overnight. The days with the highest solar generation were chosen to provide an indication of future conditions as installed PV capacity continues to rise. Load data for each day was manipulated to shift the maximum point of the DEWH peak to the point of maximum solar generation, to replicate mechanical DEWH timers being shifted to midday. Two peak shifting methods were used; a raw shift of the peak maintaining the initial shape, and a smooth shift where the DEWH peak is distributed evenly over twice the time. The smooth shift is used to indicate the benefits of improved control methods. The load where the peak occurred prior to the shift was linearly interpolated from the pre and post-peak values with the addition of random noise with an amplitude of approximately 10% of the underlying load.



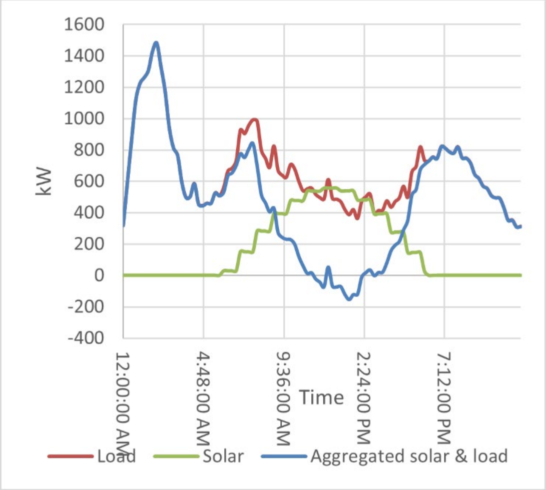


Figure 1: PV generation & load for 01/02/2018 **Figure 2: PV generation & load for 06/03/2018**

The open-source linear optimiser, echo, developed by the ANU Battery Storage and Grid Integration Program was used to determine the battery capacity required for 100% solar self-consumption, with an objective function of minimising cost to the consumer and minimising grid imports and exports (BSGIP, 2022). The cost of electricity imports was set to match the current pricing for Yea, with peak prices occurring between 3pm and 9pm, and off-peak for all other times. The optimization was then carried out for batteries from 0 to 1040 kWh in 10 kWh increments. The discharge rate of the battery was set so each capacity could be discharged in 1 hour from full. 100% self-consumption was deemed to have been achieved when the total solar export is 0 for the 48-hour period.

As only the aggregate load for the entire town is provided, any solar generation being shared between households was not measured. To include the cost of this shared electricity between solar and non-solar households, the solar generation was estimated. This was done using NASA CERES irradiance data for each day and typical assumptions of PV system sizes and losses. It was assumed that all the load in Yea is residential, and each household has the same electricity consumption. As approximately 40% of the town's households have solar installed, any contribution of solar to the load above 40% was assumed to be shared to a non-solar household and charged at the current tariff rate.

Results & Discussion

Figure 3 shows that, while a 100kWh battery in the control and raw shift scenarios operates in a similar manner, the smooth shift battery is utilised much less. Figure 4 shows the battery capacities required for 100% self-consumption under each scenario. This shows that the battery capacity required for the raw shift is only 18.3% of that required for the control capacity and the smooth shift only requires 5.8% of the control capacity. This highlights the importance of DEWH load shifting to achieve 100% self-consumption. Figure 5 shows a day with moderate solar under control and raw shift scenarios. As there is less solar, battery capacities required for 100% self-consumption are much smaller. On the moderate solar day, the raw shift results in no solar export and does not require a battery for 100% self-consumption. As this day still has more solar that 75% of days in 2018, this shows that even a raw shift of the DEWH peak will eliminate the need for a battery during all but the highest solar generation days.

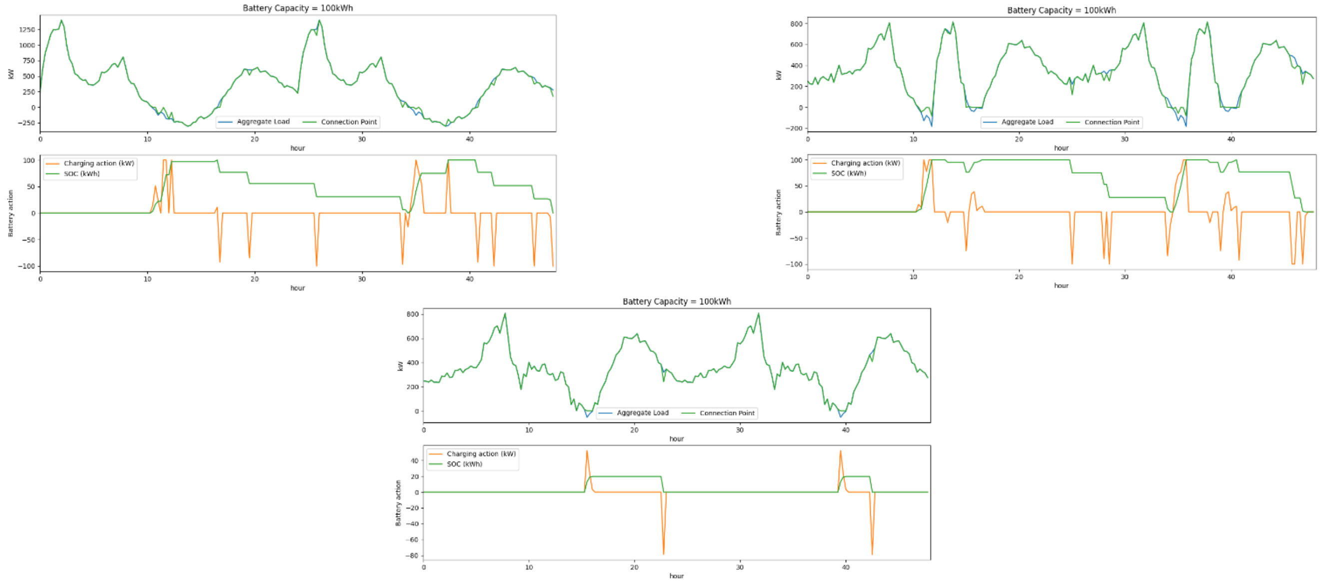


Figure 3: Battery optimisation for 100 kWh battery capacity under control (left), raw shift (right), and smooth shift (bottom) scenarios for a high solar export day (01/02/2018)

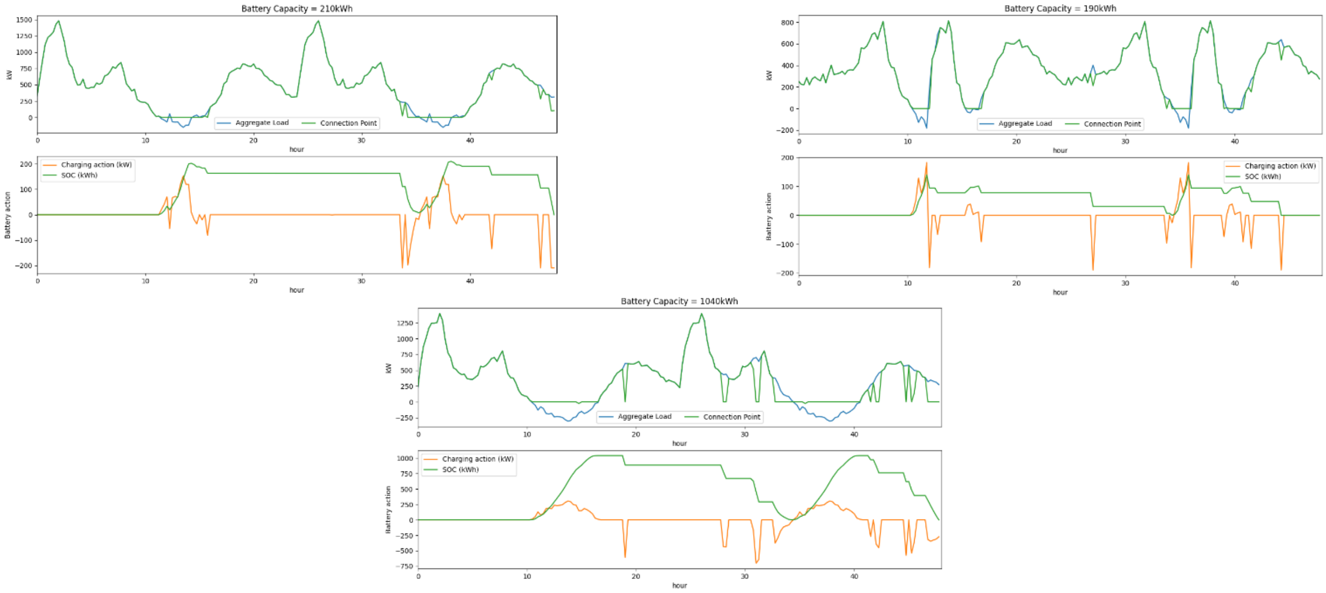


Figure 4: Battery optimisation for battery capacities required for 100% self-consumption under control (left), raw shift (right), and smooth shift (bottom) scenarios for a high solar export day (01/02/2018)

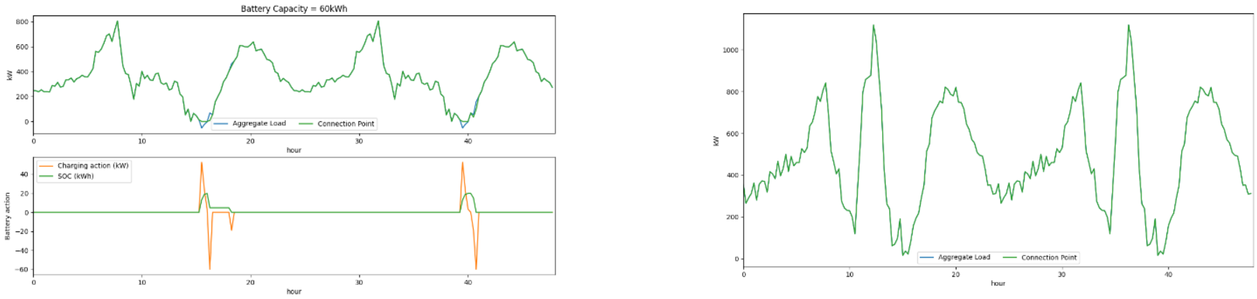


Figure 5: Battery optimisation for battery capacities required for 100% self-consumption under control (left) and raw shift (right) scenarios for a moderate solar export day (06/03/2018)

Figure 6 shows how the cost of energy changes with shifted DEWH under current and past tariff structures. The cost estimates from the optimisations comparing the daily average energy cost per household in Yea show that under current two-part tariffs, shifting DEWH is cheaper. For the high solar day under both tariffs the shifted DEWH results in lower electricity costs. For the lower solar day, shifting DEWH was more expensive under the old tariff structure, yet cheaper with the new one applied. This demonstrates there is now an incentive for homeowners to heat hot water with solar which previously did not exist.

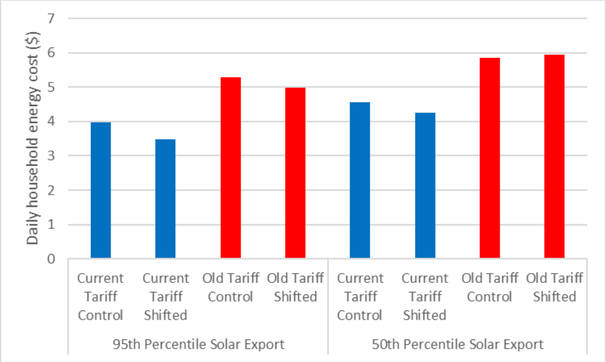


Figure 6: Average daily energy costs for high (95th percentile solar export) and moderate (50th percentile solar export) daily PV generation under current tariffs (peak period 3pm-9pm) and old tariffs (peak period 7am-11pm). Control scenario refers to DEWH load occurring at 1am and shifted scenario moves DEWH load to 12pm.

Conclusions and Implications of findings

Our results demonstrate the cost efficiency and reduced battery storage requirements when shifting residential hot water heating to solar hours. Shifting hot water peak can significantly reduce the total size of battery required for 100% PV self-consumption by up to 81.7% under the raw shift scenario (maintaining initial DEWH peak shape). This results in an average reduction of $0.5 in household energy costs for a high solar day. A key limitation of the study was only analysing two days. Further research should model an entire year to determine seasonal impacts.

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