Impacts of PV System Configuration, Retail Tariffs and Annual Household Consumption on Payback Times for Residential Battery Energy Storage

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Abstract

In Australia, a perfect storm of falling hardware costs and rising electricity prices have driven the rapid uptake of household photovoltaics (PV) over the last decade. As battery energy storage (BES) begins to follow the same declining price trends while retail electricity prices remain high, and much higher than feed-in-tariffs for exported residential PV, it is widely expected that an increasing number of households will also install storage. Certainly the financial case for PV and BES seems likely to strengthen in coming years.

This work investigates how the sizing of PV and BES, magnitude and profile of residential electricity consumption and retail tariff types affect the payback time of BES for Australian households. It draws upon data from over 2200 households from the Smart Grid, Smart City (SGSC) data set, measurements of PV performance from the Ausgrid 300 Solar Home dataset and a range of existing and proposed retail tariffs in the Australian National Electricity Market. Projecting current price trends for PV and BES into the future, it is then possible to estimate roughly how soon BES may become economically viable for households according to their circumstances and technology choices.

Our study findings highlight that adding a small amount of storage helps to reduce household PV exports, and increase household electricity bill savings substantially. However there are diminishing returns from the addition of storage. Somewhat surprisingly, annual savings are largely independent of the residential tariff types that were considered in the modelling.

Our modelling also suggests that the more electricity a household consumes, the sooner BES is likely to become economically viable for them. While an ideally sized PV and BES system for a large home can have a simple payback of 7.5 years or less, a sub-optimally sized PV and BES system for a home with low annual consumption could take as long as 25 years to pay for itself at present retail tariff rates. This highlights the need for appropriate consumer guidance in system sizing and configuration. On current price reduction trends for the technologies, and current retail tariffs, a PV and BES system might be economically viable for around half of all Australian households with suitable roof space in as little as three years.

1. Introduction

Since 2009, almost 9GW of PV has been installed in Australia [1], more than 85% of which has been installed by households and other small scale consumers [1]. Most is connected to the National Electricity Market (NEM), which has a total of approximately 43GW of registered generators [2], and hence represents a substantial addition of generation, albeit from installations that lie outside formal NEM arrangements. This high uptake of PV is a consequence of high State-based feed in tariffs (FITs) in the early years, deeming of additional renewable energy certificates (RECs) under the National tradeable Renewable Energy Target (RET) scheme, declining component costs and rapidly increasing electricity prices [3]–[5]. While the State FITs are no longer available for new systems [6] and multipliers and deeming periods are ramping down under the RET scheme, high electricity prices and low cost of components remain further boosted by the small scale renewable energy scheme (SRES), and consumer installation of PV in Australia has remained strong. As an example, in 2011, the Solar Bonus Scheme paid a feed in tariff to households for their generation of 20c/kWh [7]. In NSW, over 230,000 households have installed PV in the five years since the closure of the Solar Bonus Scheme, compared to 148,000 while the solar bonus scheme was open [1], [7]. Since that time, retail electricity prices have increased substantially and the economics of PV are strong enough in conjunction with the SRES to drive uptake on their own. In most States, FITs are now at fixed price levels that are close to wholesale market prices, well below retail prices which are typically the order of three times higher [6], with the exception of the Victorian FIT [8], which now has a time-varying price.

Though BES prices have been high over this period of PV deployment, and it does not yet appear to be economic for households to install storage, current price trends for PV and BES as well as retail tariffs all suggest that it is only a matter of time before storage is an economic option for many households. Thus, while the total number of installed household BES is currently less than 50,000 in Australia [9], this number is expected to escalate quickly in coming years [10]–[12].

1.1. Electricity price rises driving consumer substitution of supply

Electricity retail price increases have contributed to the economic attractiveness of installing PV and storage. In the Australian context, there have been a number of factors that have contributed to these price rises, and make it unlikely that electricity prices will decline significantly in the near future. Indeed, they may still contribute to further increases, although this is not certain.

<u>Network investment</u> – As a consequence of (incidentally unrealised) rising peak demand forecasts and high reliability requirements, distribution networks in Australia invested heavily in their regulated asset bases (RAB) over the last decade [13]–[16]. Since networks earn a regulated return on their RAB, tariffs have consequently increased.

<u>Wholesale market prices</u> – Recent wholesale market price rises have been attributed to a combination of: exercise of market power within an increasingly concentrated market, rapid gas price rises as gas export facilities have opened, retirements of ageing cheap coal generators and changing demand profiles [17]. While any specific cause is difficult to isolate, NSW wholesale prices in 2016/17 were on average 40% higher than in the preceding 5 years [18]. These cost increases faced by retailers have been passed on to consumers in the form of substantial price rises [19].

Retailers have been under scrutiny recently as retail offers that are not easily comparable and high competition (customer acquisition) costs have led to extremely high margins and are the second largest proportion of price increases in the last 5 years after distribution network tariff increases [20]. Household electricity rates in NSW have increased from a flat tariff of 10.2c/kWh to 31.9c/kWh between 2006 and 2017 [19], [21].

A perceived lack of value – paying two or three times the price for a commodity that has not visibly changed – is pushing customers to investigate substitutions for the services supplied by electricity.

This has manifested in consumers investing in rooftop PV and taking advantage of greater energy efficiency [22]. The rapidly declining costs of solar and storage seem likely to continue to drive significant future uptake.

1.1.1. Payback times of PV and storage

There is a substantial body of work examining the payback times of PV and storage in Australia and elsewhere (e.g. [23]–[26]). However there is value in regularly evaluating the household savings and payback times of PV and BES, given the continuing decline in system component prices [3], [25], [27], [28], and retail electricity prices where values can change by more than 20% in a single year [19]. Payback times are likely to influence uptake rates and therefore be an important consideration in planning. The study presented in this paper contributes to the existing literature, which analyses the load data of a small number of homes [24]–[26], by analysing interval consumption data of thousands of households from the Ausgrid Smart Grid, Smart City (SGSC) project [29] to provide a probabilistic estimate of household PV and BES payback times according to different household consumption levels and system configurations.

Section 2 of this paper presents the method used to calculate payback times for households according to system size and BES operation method. Section 3 discusses the results of this modelling before the conclusions are summarised in Section 4.

2. Method

2.1. Data sources

Household load data from the SGSC project [29] conducted in the Ausgrid network area was used to model residential load. Households with a maximum of 10 missing days of data from the year (less than 3%) were used to maintain data quality, leaving a set of 2230 homes with sufficiently complete interval metered data. Household surveys indicate a considerable variety of households in terms of size, number of occupants and types of appliances, leading to a wide range of energy consumption patterns and usage ranging from less than 5kWh/day to as much as 100kWh/day.

In order to capture a level of variation in PV generation, a data set of 300 home generation systems in the Ausgrid service area, publicly provided by Ausgrid, was used [30]. This generation data is from residential PV systems in the same network service area as SGSC. Due to the relatively small geographic area covered by Ausgrid, these PV system owning households can be considered to have faced very similar weather conditions as the SGSC houses over the year of analysis.

2.1.1. Tariff Modelling

This work applies some existing and proposed retail tariffs available in Australia. There are three main tariff types: flat rate, time of use (TOU) and demand tariffs, which are also known as capacity tariffs. All tariffs considered have a fixed daily charge, and a volumetric component, shown in Table 1. The demand tariff used has been adapted from an existing demand tariff from Victoria [31] given the limited use of this tariff structure to date in the NEM. Note that there are a wide range of discounts offered to households who seek competitive market offerings, so the tariffs used in the modelling should be seen as 'worst' case. However, a considerable proportion of households still remain on these 'standard' offers.

Table 1: Tariffs used to calculate annual costs and savings

Retail Tariff	Fixed charge	Variable Charges	
Flat	$0.924/day	$0.319/kWh	
Time of use	$1.056/day	Peak (2pm-8pm weekdays)	$0.594/kWh
		Shoulder	$0.253/kWh

		(7am-2pm, 8pm-10pm weekdays, 7am-10pm weekends)	
		Off-peak (all other times)	$0.165/kWh
Seasonal Demand	$0.894/day	$0.2552/kWh	
		Summer (peak time 2pm-8pm weekdays)	$10.91/kW/month
		Winter (peak time 2pm-8pm weekdays)	$2.88/kW/month

2.1.2. Calculating costs

Households were grouped according to their annual total usage into low (<3200kWh/pa), medium (3200-7000kWh/pa) and high (>7000kWh/pa) usage and allocated PV and storage systems sized according to their group, as shown in Table 2. Each household was randomly allocated the generation from an individual system within the Solar Homes set, scaled according to Table 2.

The annual electricity bill for each household was calculated for each tariff type (Flat, TOU, Demand) in order to provide a baseline annual cost. The bill was calculated for each household in a PV only scenario, with the assumption that households were paid the average recommended NSW 2017 FIT [6] of 11c/kWh for their exported generation. Bills were also calculated under four battery tariff operation scenarios (flat, TOU, TOU shoulder (TOUSH), demand tariff), described in the following section.

Table 2: Component sizing used according to household size and scenarios

House size	Annual usage	PV size (small / medium / large)	Battery size (small/medium/large)
Small	<3200kWh	2kWp / 4kWp / 6kWp	3kWh / 6kWh / 9kWh
Medium	3200 – 7000kWh	2.5kWp / 5kWp / 7.5kWp	4kWh / 8kWh / 12kWh
Large	>7000kWh	3.25kWp / 6.5kWp / 9.75kWp	5kWh /10kWh /15kWh

2.1.3. Battery Modelling

A generic battery based on the average characteristics of over 30 home storage battery models currently available in Australia [32] was used for this study. The characteristics used in modelling were available capacity (kWh), maximum sustained output (kW) and cycle efficiency (%). The modelling is designed to provide snapshots for a single year of operation, so battery degradation rates were not included in the modelling. Nominal capacity, taking into consideration the maximum depth of discharge was used for the modelling. Load forecasting was beyond the scope of this work, but might improve battery performance.

It is assumed that only PV system owners will install battery storage. The LCOE of PV generation is below the price of off-peak tariff rate, and is therefore the cheapest supply of electricity to supply the batteries. The FIT on offer by the dominant retailers at the time of modelling was also lower than the off-peak tariff rate charged to consumers on a time of use (TOU) tariff, and lower than the flat rate price most consumers paid, thus encouraging maximum self-consumption of PV generation. The battery is therefore only called into use after the load has been reduced by any available PV generation. Two strategies were employed for the operation of BES, depending on the tariff type. In the case of flat tariffs, there is no time-based component to the tariff. In this instance, the first deciding factor of operation is the net load after PV: if there is insufficient PV generation to supply the net load, the remaining energy will be drawn from the BES if there is sufficient charge available within the operating constraints of the battery. Otherwise, the remaining load will be supplied by drawing energy from the grid. If there is any excess generation after meeting the load, it is used to charge the BES, taking into account the overall BES efficiency.

For TOU and demand tariffs, there is at least one time-based window where prices or charges are at their peak. In these cases, this time window is when the battery must be available to minimise grid-based consumption for the household, and hence minimise costs. For TOU and demand tariffs therefore, the first deciding factor on battery operation is the time of day and week (Figure 1). During the windows of peak prices (2pm – 8pm weekdays in NSW), BES are operated similarly to the flat tariff, where the net load after any PV generation (load minus PV – LMP) is supplied by the BES where possible, otherwise by the grid. Outside these times, no charge is drawn from the BES and excess PV generation after meeting the load is used to charge the BES if possible, or exported to the grid. In the case of the time of use shoulder (TOUSH) operation strategy, it follows a similar logic to the TOU operation, but the window of operation includes the shoulder price periods (7am-10pm all days).

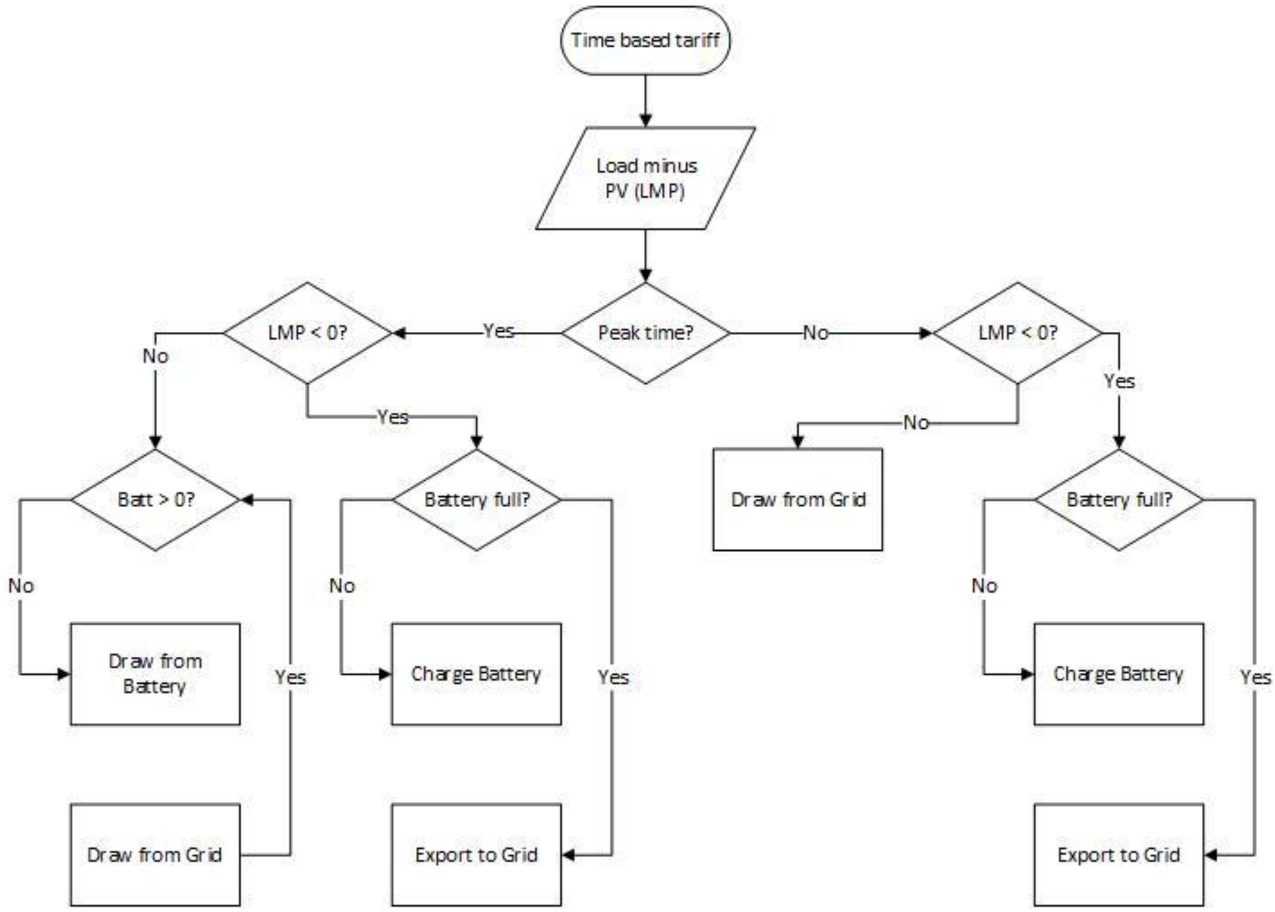

Figure 1: Decision tree for time based tariffs, including TOU and demand tariffs

The system size for each household was used to calculate system costs, with PV and storage prices obtained from SolarChoice [33], [34], using the market averages of the most recently available figures from March 2018 (Table 3), taking into account that smaller PV systems have a higher cost per kW installed. The prices used also consider the SRES benefits that system owners might receive. The battery cost used is based on the assumption that the PV system will have a battery-ready inverter. Systems that do not have battery-ready inverters would have higher costs.

Table 3: Component costs used to calculate final system costs. Values are the market average for each size range, data source [33], [34]**.**

PV Size	System Cost per kW	Battery size	Cost per kWh installed
1.5kW	$1780	1-5kWh	$960
2kW	$1700	6-10kWh	$1000
3kW	$1360	11-15kWh	$950
4kW	$1230	16-20kWh	$870
5kW	$1130		
7kW	$1150		
10kW	$1280		

2.2. Payback time

A simple payback time of 7 years was regarded as an economically viable investment, as suggested in other sources [34]. The choice was made to examine only how changes in battery prices would affect payback times, and not to examine the effects of current declines in PV costs or increases in electricity pricing. Nykvist proposed that the current learning rate for battery technology was 14% +/- 6% [35], and hence a decline in battery prices of 14% has been used in this work. While installed PV prices are still declining [3], the dominant cost in a PV/Storage system is the cost of the BES, and reductions in cost will have the greatest impact on payback times. Further to this, while electricity prices have continued to rise in recent years, it is not certain if these increases will continue, as the driving factors identified in previous inquiries [15], [16], [36] have been targeted by recent reforms that have yet to take full effect.

3. Results and Discussion

In this work, the bills and savings for over 2200 households were calculated after being allocated a PV and storage system, as outlined in the previous section. Table 4 shows the average annual bill savings for small, medium and large energy consuming households with PV and storage under different tariffs, and Figure 2 shows the distributions of these savings. While there is some overlap in the distributions, both the flat tariff and the TOU/TOUSH tariff operation strategies deliver higher savings than the demand tariff for all household sizes, the difference is more pronounced in households with higher annual energy consumption.

Table 4: Average annual savings according to each tariff type and household size in a medium sized PV and storage scenario

Tariff Type	Small Energy HH (<3200kWh/pa)	Medium Energy HH (3200-7000kWh/pa)	Large Energy HH (>7000kWh/pa)
Flat Tariff	$488.85	$730.80	$939.64
TOU Tariff	$477.55	$800.10	$1088.70
TOUSH Tariff	$508.22	$798.39	$1039.20
Demand Tariff	$457.04	$644.81	$799.31

3.1.1. Savings according to tariff

The differences in savings are partially dependent on the tariff at the time that consumption is offset. Solar and storage delivers the greatest savings for households under the TOU/TOUSH tariff, because they can minimise household grid demand at times when electricity prices are 59.4c/kWh – substantially more than the flat tariff of 31.9c/kWh at the same time. The demand tariff has the lowest price per kWh during afternoon and evening hours – when much of demand can be met by PV and storage, depending when the storage is discharged. The demand charge is applied for each household to the period of highest demand in each month. If demand is not offset by PV or storage during this period – as may happen after one or two cloudy days –high demand charges will be set for the month, reducing the certainty of savings compared to other tariffs

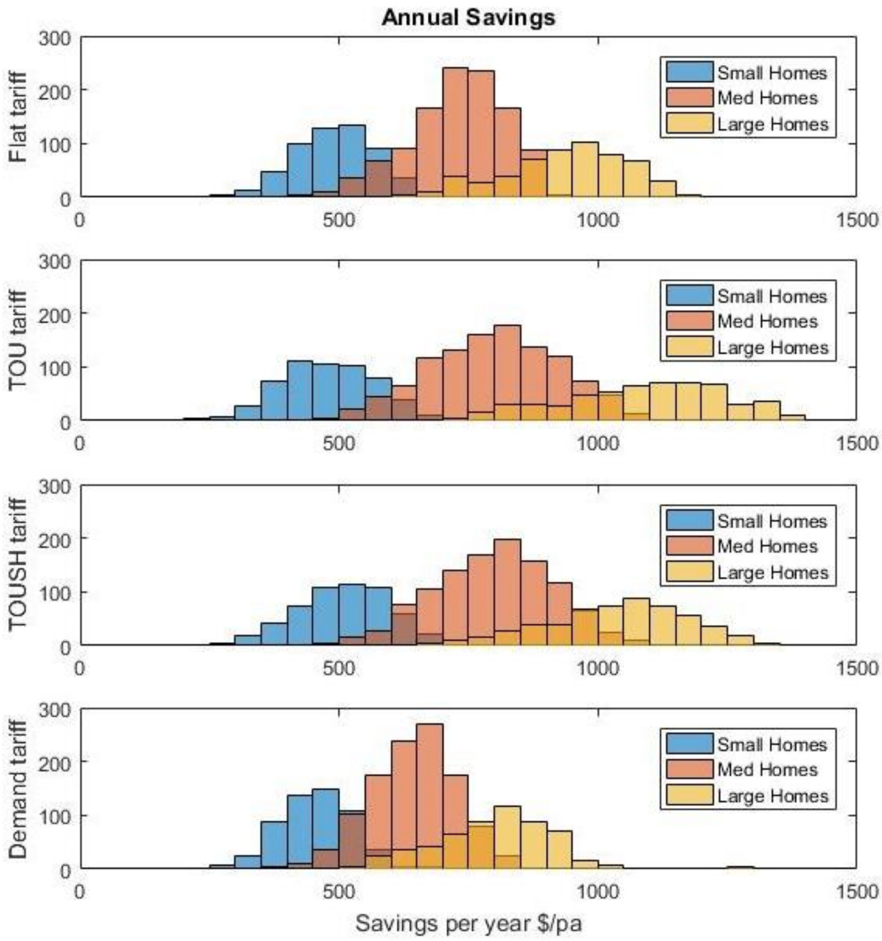

Figure 2: Savings per annum for medium PV and medium storage scenario, with overlap in distributions visible

3.1.2. Exports

Figure 3 shows the percentage of PV generation exported in a scenario where all households have a small PV system, scaled according to their annual usage, and in all but the 'PV Only' scenario, the same homes also have a small amount of battery storage (as per Table 2), again scaled to the size of the household annual consumption. Where households have no storage, a substantial proportion of PV generation is exported.

On average across a large range of user demand profiles, homes with low energy demand show the highest proportion of exported generation, while homes with larger energy demand export the lowest proportion of their generation. In the cases of smaller households, while larger PV size does result in a higher proportion of generation being exported, it is still clear that storage makes a substantial difference to the amount exported. In these cases, the battery operation strategy becomes more important – the flat and TOUSH operation strategies have far wider operation windows, meaning that the battery is more fully cycled each day. This allows for a higher proportion of generation to be captured. Interestingly, once the reductions in volumetric charges and the value of FIT for exports has been incorporated into the bill savings, Figure 2 showed that there is very little economic difference between operation strategies.

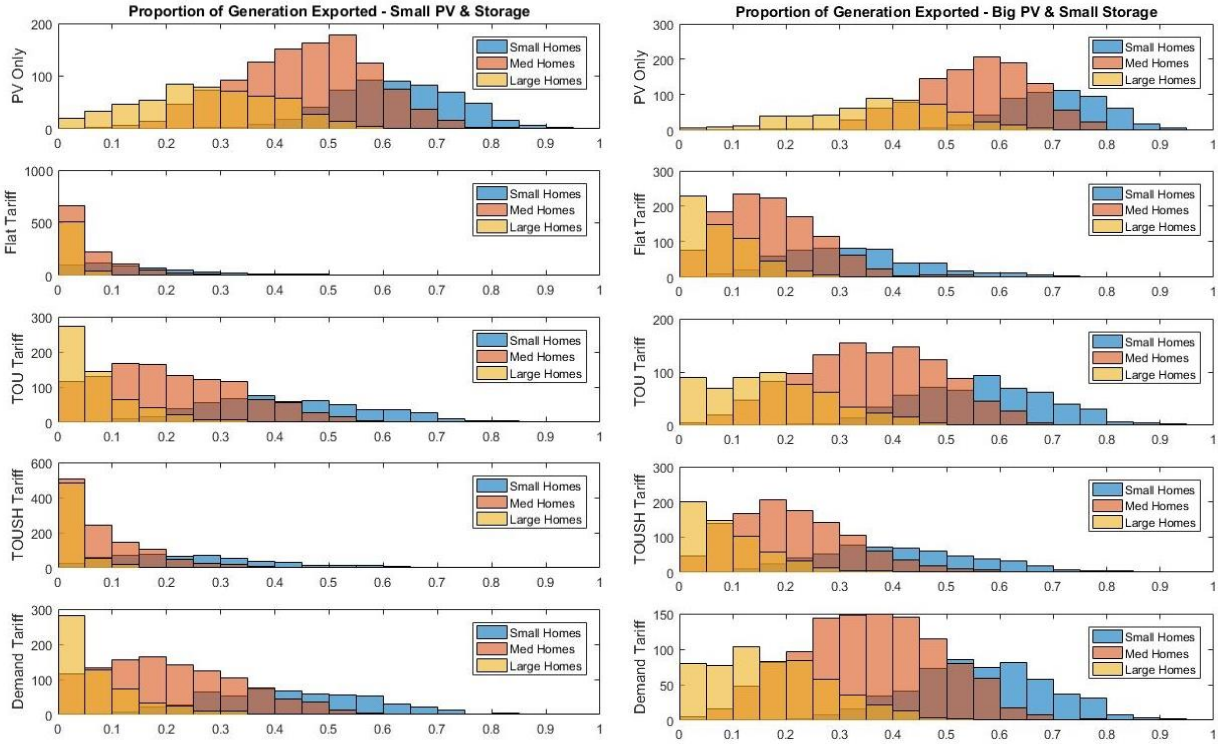

Figure 3: Distribution of percentage of PV generation exported by small, medium and large households under different BES operation methods in a small PV and BES scenario (left) and a large PV and small BES scenario (right)

In all small battery scenarios, with either small or large PV systems (Figure 3, left and right), the majority of households with high levels of energy consumption typically exported less than 20% of their generation. This suggests that these high consumption households have the most to benefit from adding a small amount of storage, and that in so doing, they can maximise the value of their PV generation.

3.1.3. Simple payback according to household demand and system size

To clearly articulate the effects of component size and household size on simple payback times, this section focuses on the payback times under a TOU tariff, seen in Table 5. The payback times are marginally longer under other tariffs, but the trends are the same.

Table 5: Average simple payback time in years according to scenarios for homes on the TOU tariff

Scenario	Small Homes		Medium Homes		Large Homes	
	PV Only	PV with BES	PV Only	PV with BES	PV Only	PV with BES
Sm PV/ Sm Batt	5.91	11.45	5.07	9.3	4.38	9.09
Sm PV/ M Batt		18.74		15.03		13.96
Sm PV/ Lg Batt		25.82		19.76		17.57
M PV/ Sm Batt	6.31	10.98	5.29	8.76	4.51	8.15
M PV / M Batt		17.47		13.72		12.06
M PV / Lg Batt		23.97		17.76		15.04
Lg PV / Sm Batt	6.51	10.77	5.56	8.56	4.71	7.58
Lg PV / M Batt		16.63		12.75		10.72
Lg PV / Lg Batt		22.52		16.58		13.54

From Table 5, in a PV only scenario for households, the larger the system is, the longer the payback time. This is because more generation is exported to the grid, at little benefit to the household. The value of the FIT given to households is only 11c/kWh, substantially lower than the import price of electricity under all tariffs, and greater than the levelised cost of energy from a PV system [37]. Thus while the FIT does provide some benefit to households, it is not currently at a level that would encourage over-sizing household PV.

Also, as evident in Figure 1, the savings are substantially higher for households with high energy consumption, because there is a greater probability that more of the PV generation will be used to offset household consumption. The effect of this is evident in Table 5: high consumption homes have by far the lowest payback times of all households. Further to this, the smaller the system, the more likely that little or no generation is exported.

While the payback time for a household PV system without storage increases as the PV size increases, if households install storage, under any tariff, the payback time will decrease as the PV size increases. However, at no time does this offset the cost of storage – the average household system with storage has a longer payback time than a PV only system for all component sizes, but for some homes, storage may still be a good option. The cost of battery storage is still the dominant cost component of any home energy system, and the additional savings garnered do not offset the additional cost for any storage system. Moving from a small battery to a medium battery (e.g. 4kWh to 8kWh) increases annual savings by approximately 4%, depending on the tariff, far less than the cost increase caused by the larger storage size.

3.1.4. Change in payback time as battery prices decline

From Table 5, the PV and BES configuration with the shortest payback time on a TOU tariff is that with the largest PV size and smallest battery size.

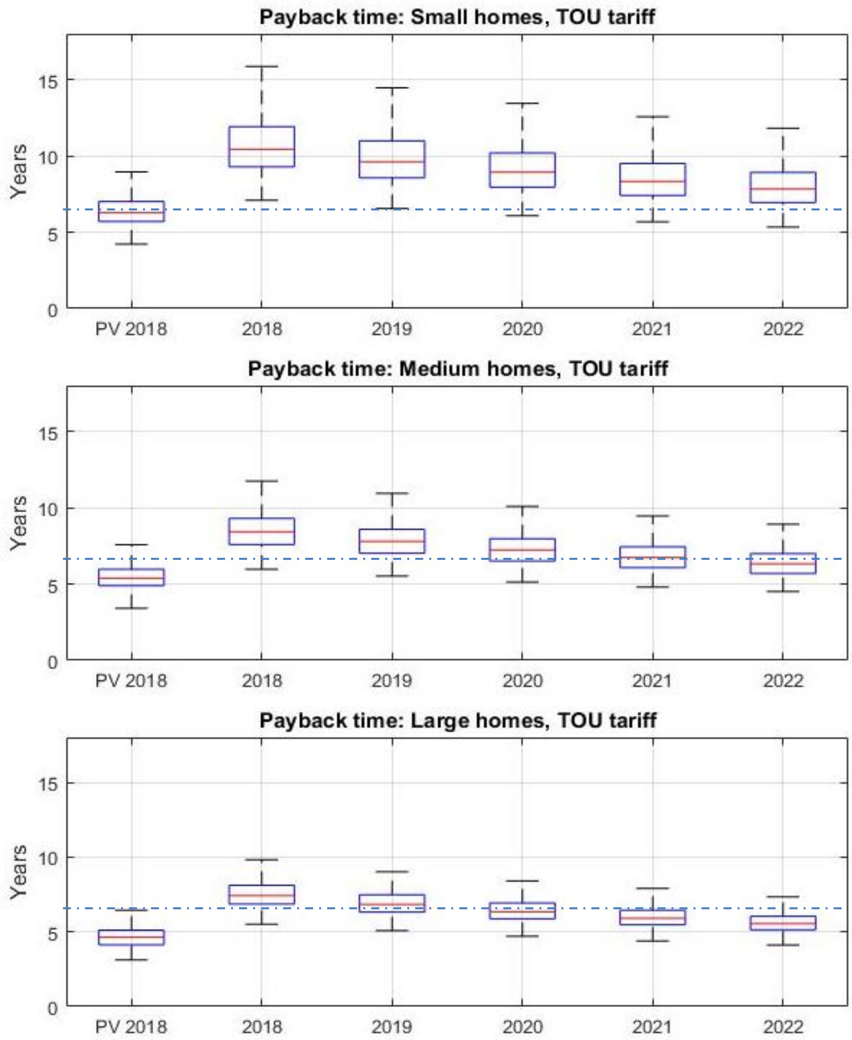

Figure 4~~Figure 4~~ illustrates payback times for this system and tariff configuration for households in NSW.

As previously noted (Table 5), for all household consumption levels, a large PV system will pay for itself in less than 7 years in the majority of cases. The mean payback time for a large PV, small storage system for large energy using households is 7.58 years. A large PV system and small battery will pay for itself within 10 years for all households with high energy consumption levels. As previously discussed, industry analysis suggests that a seven year payback time is considered to be sufficient for storage to be attractive to households. Based on this work, slightly less than half of all of the high consumption households have already reached this payback threshold at the time of writing.

To explore future payback times for battery systems, this work uses a learning rate of 14%pa for battery system prices, without considering possible electricity price rises or the ongoing PV system cost declines, both of which could decrease the payback time further. Even without including these additional factors, the mean simple payback time for medium energy consumption homes for the best system modelled (large PV and small storage) declines to 7 years by 2020 – less than 2 years away. Within 5 years, the mean payback time for small energy consuming homes also reaches 7 years. This suggests that in the near future, close to half of homes that install PV might also install storage and in the medium future, it is likely that the majority of homes that install solar might also install storage, because it is economically viable for them to do so.

The return on investment (ROI) for the first year after installation was tested for the optimal configuration on all household sizes, but showed that the ROI for PV + storage was unlikely to out-perform the ROI of PV only systems within the next 5 years. Hence, it is still not yet economically logical for most households to install storage in addition to PV.

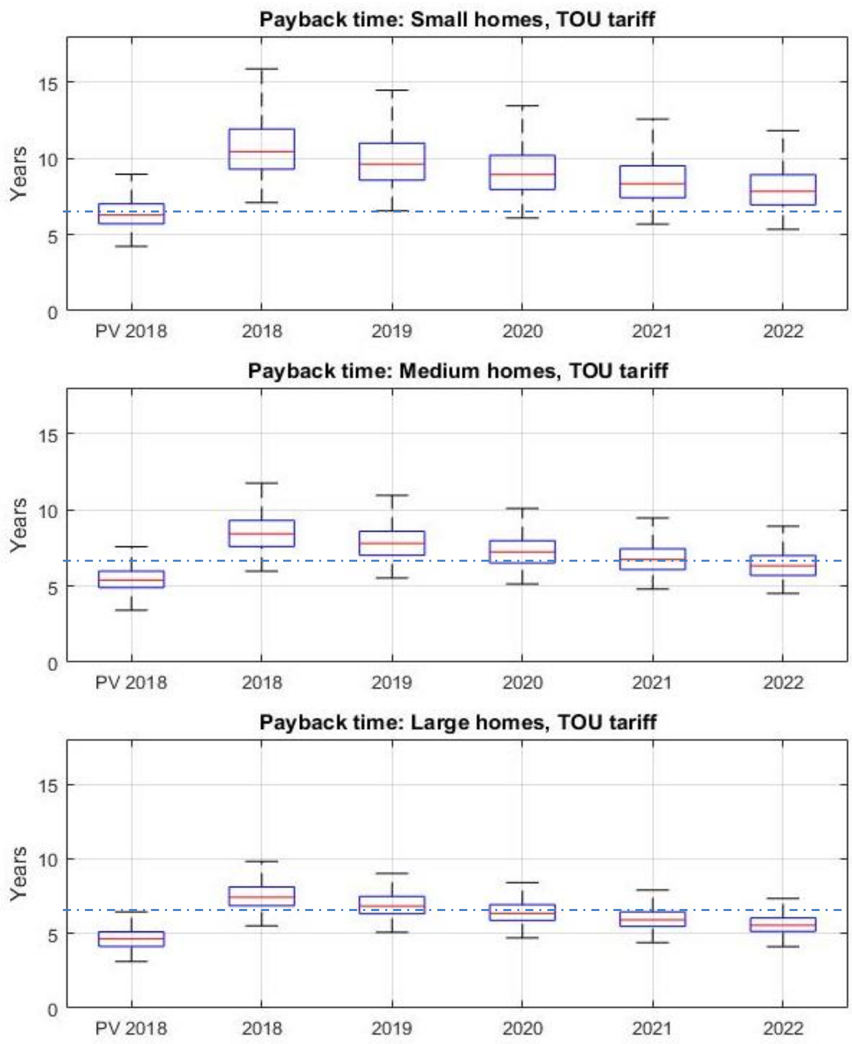

Figure 4: Payback times for homes on a TOU tariff with a large PV system and a small battery

4. Conclusions

The first aim of this work was to establish the economic incentive for households to install solar and investigate the current and future economic viability of household storage. Based on a seven year simple payback, solar is already economically attractive for all homes, and storage with PV is currently economically viable for approximately 15% of homes, and half of homes with high energy consumption levels. If current trends continue, PV and storage will be economically viable for approximately 50% of homes in the next two years, and for all homes in the next 5-6 years. These findings highlight the importance of using tariffs to encourage appropriate battery operation.

The second aim of this work was to establish outcomes for households with battery operation strategies under existing and proposed retail tariffs. The results suggest that there is very little difference in economic benefit for households between under Flat, TOU and TOUSH operation strategies given opportunities to change BES operation accordingly, suggesting that all of these strategies need to be included in modelling of household battery operation. While the demand tariff modelled typically delivered less savings for households, this is the tariff that distribution service operators are looking to introduce in coming years as part of a move towards more cost reflective tariffs, and therefore also needs to be included in future modelling.

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