BATTERY WASTAGE

Why battery storage for rooftop solar doesn't pay

Capell Aris

The Global Warming Policy Foundation

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Contents

About the author

Dr Capell Aris worked in the Electricity Supply Industry first as reactor physics specialist at Wylfa nuclear power station, and then at Dinorwig and Ffestiniog pumped storage stations in the control and instrumentation section and later with additional responsibility for information technology systems. He is a Fellow of the Institute of Engineering and Technology.

Summary

This paper assesses the cost effectiveness of installing a battery store alongside a rooftop solar panel array. It concludes that such an installation is unlikely to provide any financial benefit. The reasons for this failure are:

- Battery stores are warranted for an energy storage capacity and a number of duty cycles. The energy that can be delivered from the store is thus limited by warranty. Given the high cost of these stores, the stored energy cost exceeds present retail electricity prices.
- The savings that could flow from the installation of a battery store alongside a roof-top solar array are low because:
  - a typical household electricity bill (excluding standing charges) is £510 per annum, and any saving created by installing storage can only be a fraction of that charge
  - a rooftop solar array can reduce grid import by as much as 40% without any need for a battery store
  - consumers have convenient cost-free techniques to load shift more (perhaps as much as 7%) of their domestic load into the daily solar production peaks
  - the low level of winter solar generation means there is little possibility that a battery store of realistic size can affect grid energy import in this period.

1 Introduction

Solar battery storage is the latest renewable 'bling'. The realisation that trying to run a household on solar energy is difficult when the sun doesn't shine has driven battery development, and this now enables us to smooth out the gaps in solar energy production, reduce dependence on costly energy alternatives, and avoids the need to sell any excess solar energy to the grid.

This study assesses the benefits of installing batteries to work alongside rooftop solar panel installations. Only solar installations in the UK are considered. The study requires knowledge of solar energy production and household electricity consumption patterns over the course of a day and a year, both of which will be modelled. To determine the benefits of installing battery storage, three different scenarios will be considered:

- a household drawing all its electrical energy from the grid,
- a household with a rooftop solar panel array, sourcing electrical energy from both the grid and the solar panels
- a household with a rooftop solar panel array and batteries.

2 Modelling

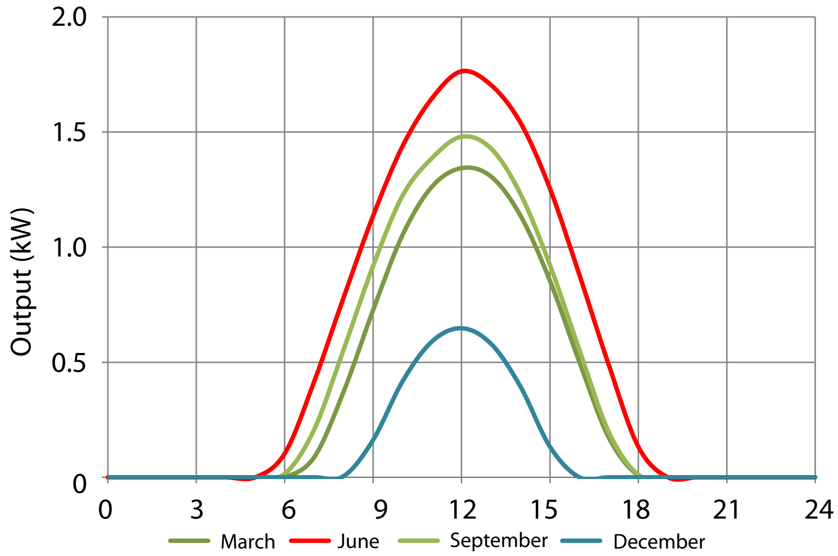
The analysis uses models of rooftop solar installations, observations of average household electricity consumption, and specification sheets provided by manufacturers of Li-ion batteries.

Modelling rooftop solar production

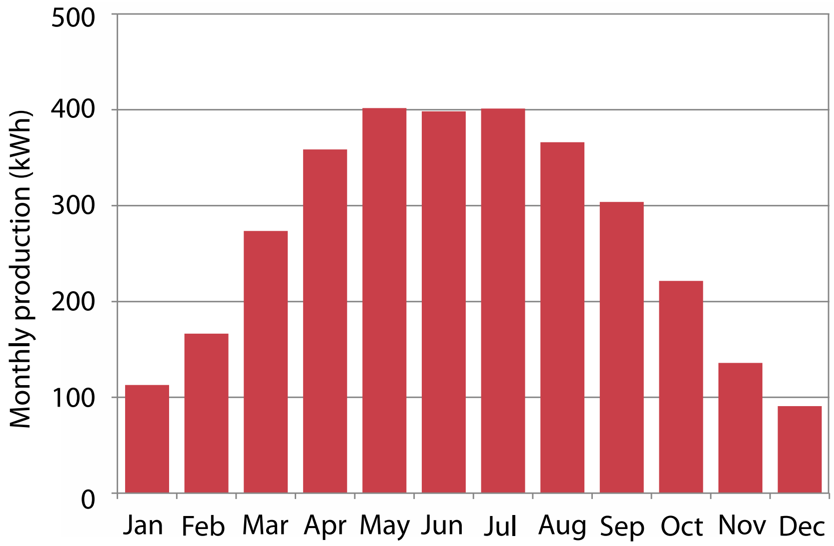
The most common solar panel array installation size in the UK is 4 kW. When new, such an installation will produce about 3,400 kWh per annum; in southern England and western Wales production might reach as high as 4,000 kWh per annum. When the sun is directly overhead, the surface receives about 1 kW/m^2.[1,2] As the sun moves over time its rays will hit the surface at different angles, and changing weather will bring clouds and other periods of reduced energy reaching the panels. These variations can be modelled and verified against observations. Data from solar panel specifications can then be used to calculate the variation of energy production with time for the solar array. Solar panel energy production is assumed to decline with age at 0.5% per annum. The solar model uses solar almanacs available from the Greenwich Observatory and NASA, insolation studies from NASA and others, and 10 years of half-hourly aviation weather reports.[3] These results are repeated to cover a 20-year period, equal to the duration of the FITs tariff schemes. Figure 1 shows the daily power output and monthly solar energy production for a rooftop solar array with a peak output of 4 kW.

Average domestic consumption

I have taken data for the average domestic electricity consumption profile from Enertek's *Household Electricity Survey: A study of domestic electrical product usage.*[4] Enertek describes three daily electricity consumption profiles: workdays, holidays and 'away from home' days. The holiday type is taken to apply to all weekends and to periods of holiday at home (such as Christmas); an 'away from home' type represents an annual holiday away from home during



(a) Daily



(b) Monthly

Figure 1: Daily solar output and monthly energy production.

Based on a 4 kWp solar array

summer. Figure 2 shows the daily profiles of the various day types. The overall consumption is scaled to bring the annual average electrcity usage to 3,900 kWh per annum.

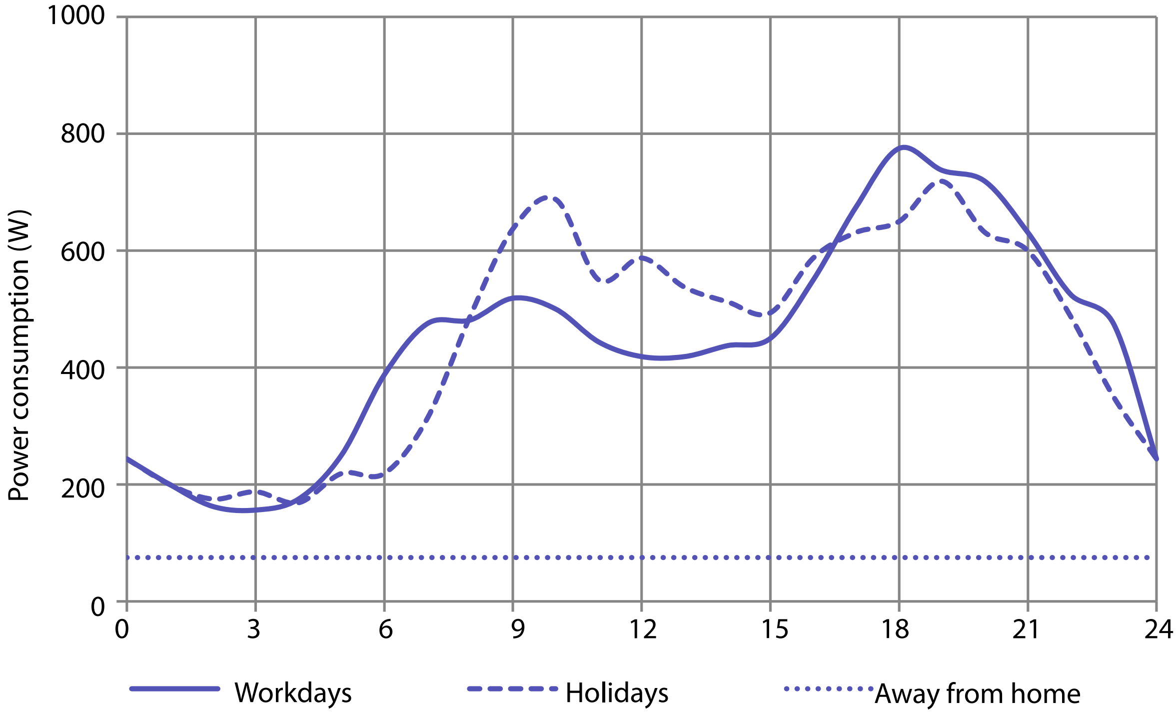


Figure 2: Average household daily energy consumptions for workdays and holidays.

Battery store specification sheets

Manufacturers state the useable energy storage, the cost of their batteries, and provide warranties for a number of duty cycles and expected life; see Table 1 for typical values.

The capacity to store energy falls with each full storage (or duty) cycle a battery experiences, and they also age with time. In this study the warrantied life is taken as 10 years, at which point the battery storage capability is assumed to have deteriorated to 70% of installed capacity; this rate of decay is continued to extend the model study to 20 years.

Like all batteries, Li-ion batteries lose, or waste, energy as they are being charged or discharged. Typically, they have a turnaround efficiency of between 85 and 95%. For the purposes of the model, a turnaround efficiency of 88% was used, divided into storing and draining efficiencies of 93.8%.

Modelling a domestic solar generation system, with and without an energy store

Without any solar production, domestic energy consumption will be taken from the grid. Add solar panels to a home and the domestic consumption divides between energy drawn from the solar system and energy drawn from the grid. Typically, 40% of the energy used is from the solar rooftop array.[5] A sizeable fraction of the solar energy is therefore exported

Table 1: Typical manufacturers' data for battery stores.

Battery chemistry	Capacity (kWh)	Manufacturer's warranty		Installation price £ (ex VAT)
		Full cycles covered	Years	
Lead acid	4	1200	5	3,410
Lead acid	4	2500	NS*	3,980
Lithium	3.84	4000	5	4,240
Lithium ion	6	2500	5	8,140
Lithium ion	4	3000	5	3,386
Lithium ion	4	4000	5	4,055
Lithium iron phosphate	3	6000	5	4,430
Lithium iron phosphate	13.5	Unlimited	10	6,250
Lithium iron phosphate	6	10000	10	7,390
Lithium iron phosphate	8	10000	10	8,645

*None stated. Source: Adapted from Cornwall Solar Panels.[1]

to the grid because it is generated at times when the solar panel production exceeds the consumption of the house. Adding an energy store allows later use of this excess and a reduction of solar energy export. Passing energy into and out of the store will entail some wastage of energy. All of these movements of energy can be modelled for each half hour of the study period. The results are discussed below.

3 Energy flows

Figure 3 provides an overview of the energy flows in the three modelled configurations:

- No solar rooftop array, domestic consumption 3,900 kWh/annum.
- With 4 kW solar rooftop array, producing 3,400 kWh/annum when new. The 20-year average solar production is reduced to 3,230 kWh per annum due to solar panel ageing.
- With a solar rooftop array and energy store of 4 kWh capacity.

Solar production could displace 82% of the grid electricity if production and consumption were concurrent, but that is not the case; typically, solar production displaces 38% of grid consumption with no store. With a 4 kWh store this rises to 56% (Figure 3).

Increasing the size of the store will further increase the amount of solar energy consumed at home and reduce the energy spilt to the grid, but how well this works is influenced by variation of solar energy during the day, and over a year. A 16 kWh battery store allows 60% of domestic consumption to be drawn from the solar installation, a modest increase on the performance of the 4 kWh store. Figure 4 explores the performance of increasingly large energy stores on the profile of annual electricity import. The scarcity of solar production in winter (Figure 1b) will make avoidance of grid import only possible with energy stores of massive capacity, or larger solar array size.

(The proportion of household electrical energy required for 'washing/drying' is 14%.[4] Because most washing machines and dishwashers are fitted with timers, it is cost-free and

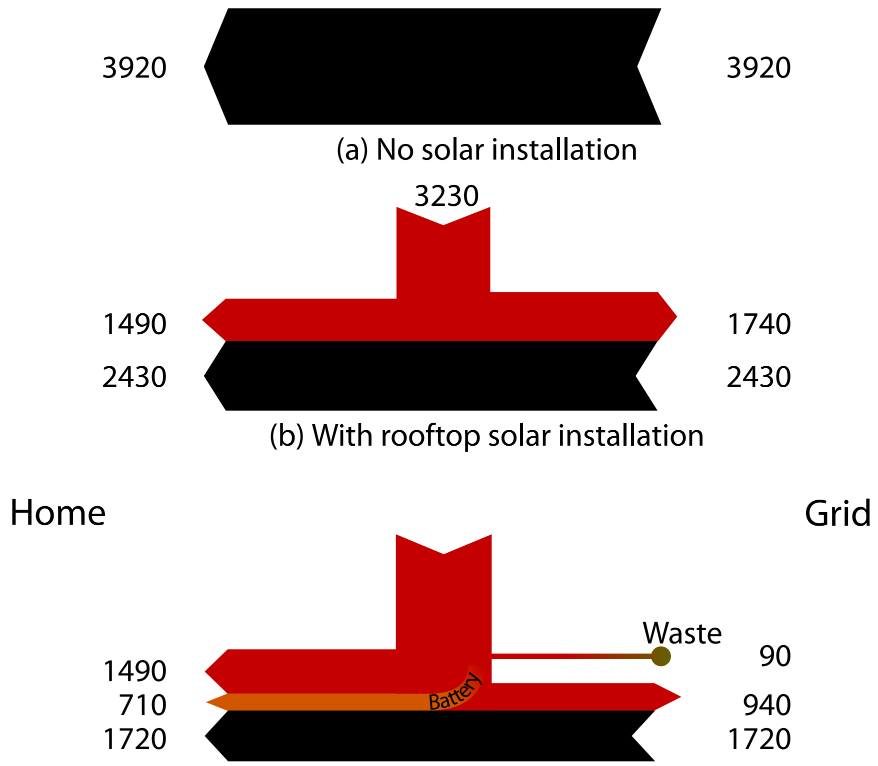


Figure 3: Modelled energy flows for various methods of domestic electricity supply.

Numbers are energy flows in kWh/annum. Arrow widths are scaled to the size of energy flows.

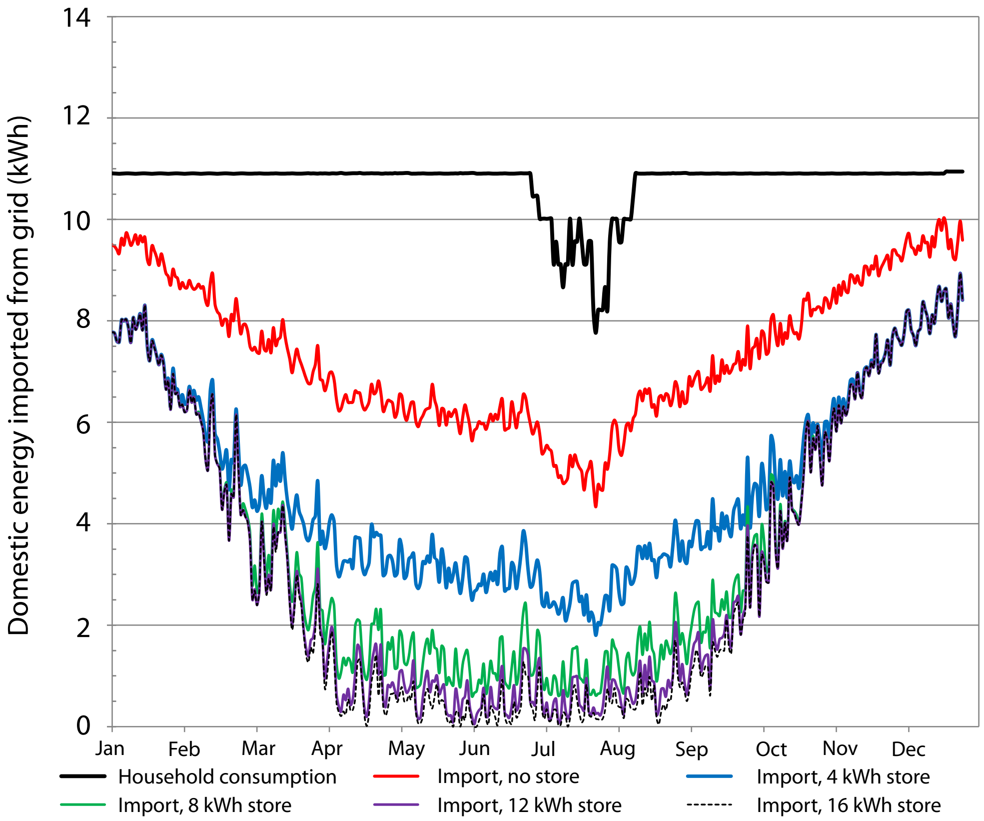


Figure 4: Impact of increasing storage on domestic electricity energy import.

Yearly energy import variation with and without solar and store

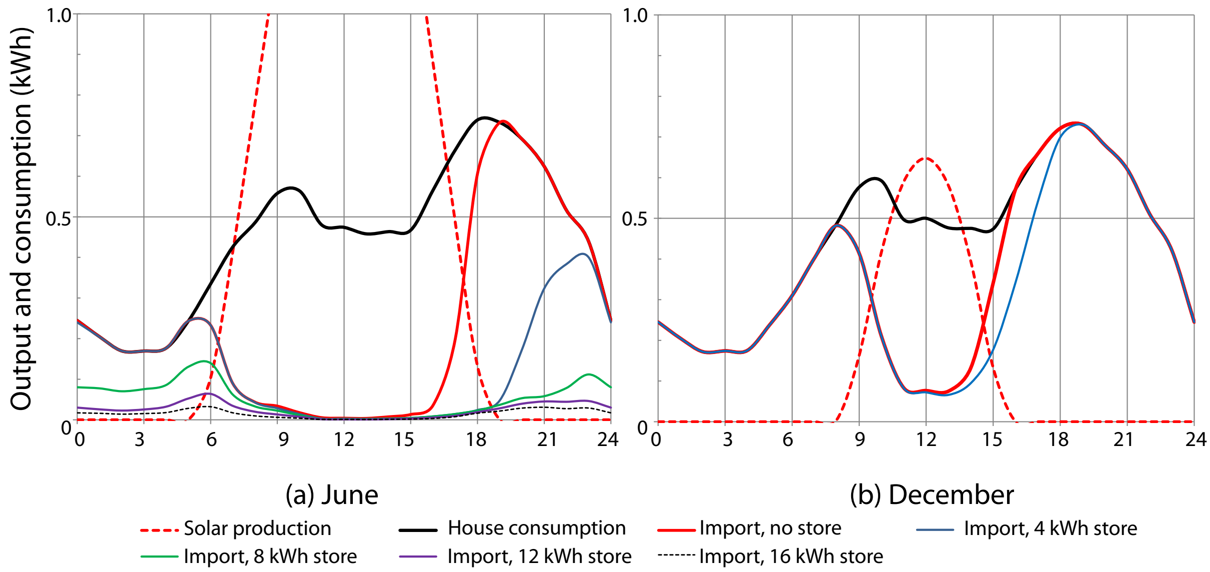


Figure 5: Daily energy flows in June and December.

Output and domestic consumption for a 4-kV solar panel, illustrating the scarcity of solar production in winter.

convenient to shift these loads into peak solar production times. If we assume half of this load is shifted, then this could result in a saving of approximately 270 kWh per annum on grid import, without any requirement for a battery store).

Figure 5 shows the daily energy flows with and without battery stores in December and June. In December, the addition of a 4 kWh battery store captures the whole of the midday solar energy export. No further increase in battery size can possibly reduce the size of grid import in winter months; only an increase in the size of the solar array will accomplish this goal. In July, there is a large spill of solar energy, and increasing battery capacity captures more and more of this peak, but there is very little difference between a 12 kWh and a 16 kWh store.

Figure 6 illustrates this reducing return on cutting grid import as battery capacity is increased, but also explores the effect of increasing the size of the solar array. With a 4 kWp solar array, increasing the battery store appears asymptotic to reducing the grid import by 1,300 kWh per annum, lifting the solar component of domestic consumption to 71%. If the solar array size is increased to 8 kWp (which will require a large roof area), the import saving approaches 1,800 kWh per annum, and the solar component rises to 84 % of domestic consumption

4 Cash flows

From this consideration of the energy flows, the costs and benefits of adding a battery store to a solar panel installation can be determined.

Domestic electricity prices vary between 9 and 17p/kWh.[6] If we take a median price of 13p/kWh, then we can modify Figure 6 to show the 20-year cost savings achieved by adding a battery store, together with commercial battery store costs (Figure 7). This reveals that if the cost of some of the battery stores was halved then they would be cost neutral over the

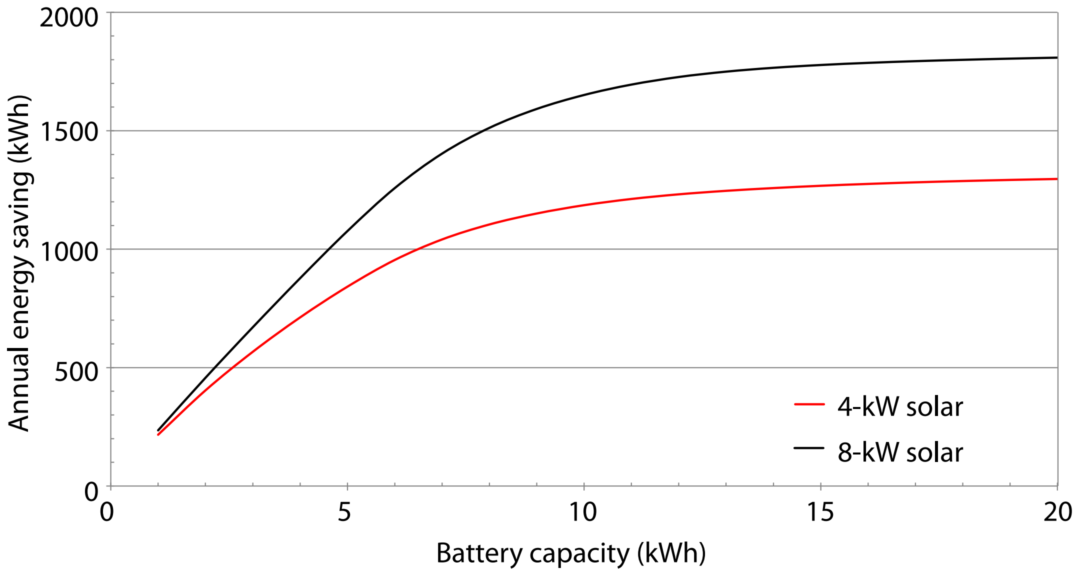


Figure 6: The diminishing energy saving experienced with increasing battery capacity.

Annual household electricity savings due to inclusion of battery storage.

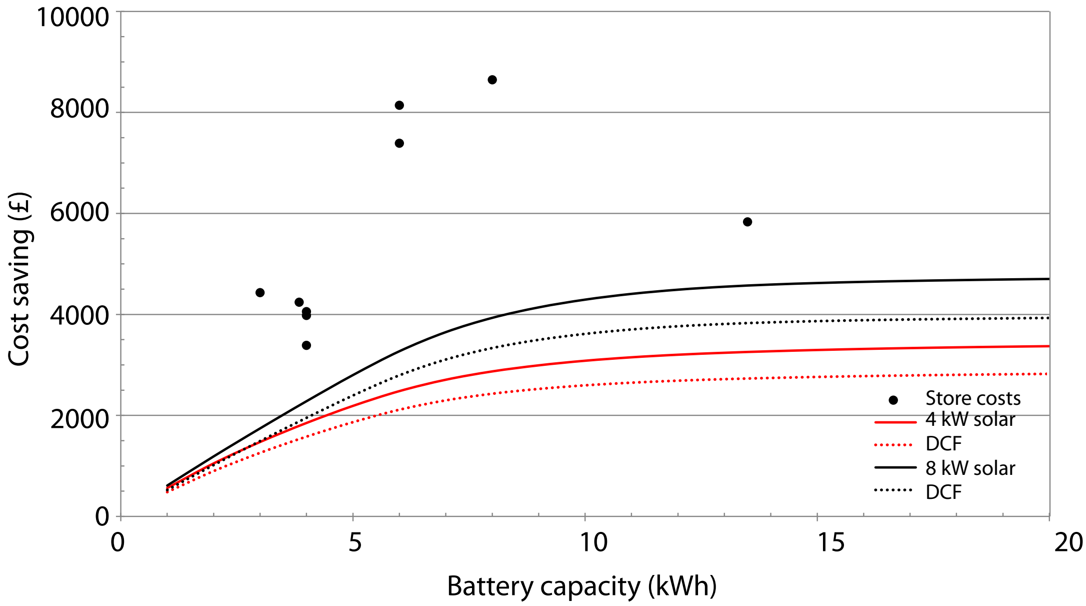


Figure 7: Cost savings on domestic electricity over 20 years generated by inclusion of battery storage alongside rooftop solar panels, and the present cost of various battery stores.

The dotted plots use discounted cash flows to determine the project savings over the 20-year period of operation. DCF: discounted cash flow.

life of the solar system. Battery costs need to more than halve if they are going to deliver any financial benefit to the electricity user.

Because the period covered by this project is quite long (20 years) the simple payback analysis described above should really be replaced by a discounted cash flow analysis. This is similar to the simple payback analysis, but the returns are discounted to their present value. If the discounting rate is r, and the annual returns are described as R_y, where y is the year number, then the value V of the project is given by

$$V = \frac{R_1}{(1+r)^1} + \frac{R_2}{(1+r)^2} + \frac{R_3}{(1+r)^3} + \dots \frac{R_{20}}{(1+r)^{20}}$$

(If r is set to zero the payback and discounted cash flow valuations become the same).

Figure 7 shows the discounted cost savings with a discount rate of 2% per annum (dotted lines). The discounting rate chosen should reflect the interest rate the investor requires of the project, and an allowance for the risks taken with a project of this nature (such as engineering failure, or a change in political attitude towards energy subsidies or generator responsibilities).

5 The battery manufacturers' warranty conditions

We can calculate an approximate cost for the electricity delivered by the energy stores from the manufacturers' specification and warranty periods (Table 1). If we assume each of the warrantied cycles delivers the full useable energy capacity then we can derive the warrantied energy delivery for each store, and then the unit cost of energy delivered under warranty (see Table 2). It is clear from these results that the development from lead-acid through lithium-ion to lithium-iron phosphate technology is reducing the cost of energy storage. However, this calculation ignores the statement of a warrantied lifetime. Operating with

Table 2: Costing battery storage from manufacturers' warranty statements.

Life	Size	Warranty	Cost	Energy delivery under warranty		During warranty period			
						Poss no. duty	Energy cost	**Prob no.** duty	Energy cost
	kWh	cycles	£	kWh	p/kWh	cycles	p/kWh	cycles	p/kWh
5	4	1200	3410	4800	71	1200	71	600	142
	4	2500	3980	10000	39	2500	40	600	166
5	3.84	4000	4240	15360	27	1825	61	600	184
5	4	3000	3386	15000	28	1825	46	600	141
5	6	2500	8140	12000	54	1825	74	600	226
5	4	4000	4055	16000	25	1825	56	600	169
5	3	6000	4430	18000	24	1825	81	600	246
10	13.5	Unlimited	6250	37800	16	3650	13	1200	39
10	6	10000	7390	60000	12	3650	34	1200	103
10	8	10000	8645	80000	11	3650	30	1200	30

Source: Cornwall Solar Panels.[1]

a rooftop solar array, battery stores will be subject to, at most, one duty cycle per day. If we assume the warranty is for the warrantied duration or the warrantied number of cycles, whichever is reached first, then a battery with a five-year warranty can only deliver 1,825 duty cycles under warranty; one with a ten-year warranty could only deliver 3,650 cycles. We must therefore adjust the warrantied energy delivered, and recalculate the warrantied, possible cost of energy delivered from the battery.

But the assumption that the batteries are subject to a full duty cycle every day is clearly incorrect. In winter months there is very little for the store to do because there is so little generation. The operational model described in Section 2 shows that, for a 4 kW rooftop solar array coupled with a 4 kWh battery store, only 1,200 full duty cycles occur over 20 years; 60 per annum. To calculate the warrantied stored energy cost we need know the exact number of duty cycles accomplished during the warranty period; that would require a calculation for each installation. In Table 2 I have assumed a probable figure of 120 duty cycles per annum, and calculated a probable cost of energy delivered from the energy store.

Table 2 confirms the need for considerable cost reductions before battery stores compete with the cost of grid-delivery electrical energy.

6 Conclusions

Most of the UK is too far north for typical rooftop installations to completely displace household consumption. Solar electricity generation is poorly matched to average household consumption patterns, both diurnally and annually (Figure 1). Rooftop solar generation can displace approximately 40% of household electricity consumption without any need for a battery installation. Simple time shifting of laundry and dishwashing loads using appliance timers could shift another 7% of household load to solar supply. Solar production in winter is so low that only a small percentage of winter consumption can be diverted to solar supply, unless the size of the rooftop installation is much larger than usual, and/or a large battery store is included. The scope for further reductions in grid energy import by installing larger batteries is pinched between what is achieved without any store, and the difficulty of tackling the winter solar scarcity.

Given the low rate of financial return from battery stores, their costs will have to continue to fall. Operating with typical rooftop solar installations of 4–5 kW, the number of duty cycles over a period of 20 years is unlikely to exceed 4,000, which Li-ion phosphate batteries seem to achieve. The warranty period is more important: there can be little confidence that the capital cost of the battery will be recovered if this is below 10 years. Once operation of the battery store is outside the warranty period then the discounting rate (Section 5) should be increased to reflect the increased risk of plant failure.

The discounting rate applied in Section 4 is uncommonly low – little more than the return on Premium Bonds. Given the presence of alternative financial investments with higher returns, the risk of plant failure outside warranty, and that the subsidy or (especially) the export tariff rates may change, a much higher discount rate should be assumed. That would make the use of battery storage supporting a rooftop solar installation an even more unattractive financial investment.

Notes

1. Cornwall Solar Panels http://www.cornwallsolarpanels.co.uk/battery-storage/
2. Mackay, DJC (2009) *Sustainable Energy without the Hot Air*, Chs 6 and D. https://www.withouthotair.com/
3. Solar power in Britain http://www.iesisenergy.org/agp/Aris-Solar-paper.pdf.
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5. Insight Report: Domestic Solar PV Customers http://www.networkrevolution.co.uk/wp-content/uploads/2015/01/CLNR-L090-Insight-Report-Domestic-Solar-PV.pdf.
6. http://www.theecoexperts.co.uk/kwh-electricity-prices

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