The Thermal Battery

Exploring the synergies between hot water cylinders and solar PV

hot water association

DEVELOPING HOT WATER

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Foreword

We are entering an exciting and dynamic time in domestic energy production and usage. More and more opportunities are opening up for consumers to control their usage, switch their supplier and generate their own energy.

These rapid changes are empowering consumers in ways that have not been seen before in the energy industry, but they also carry with them immense challenges for our grid infrastructure which must be factored in to decisions on our future energy system.

Having paid for their own system to be installed, owners of domestic solar PV will understandably want to make the best use of the energy they are generating. A typical household with solar PV will export the majority of the energy they produce which they will be paid a fixed rate for.

This paper, written with Stuart Elmes CEO of Viridian Solar, explores an alternative way of using excess energy generated to heat and store water, transforming a hot water cylinder into a 'thermal battery'. This innovative approach would help consumers to meet their hot water demand, offering them much better value from their system in the process. I hope you find it informative and useful.

Yours,

Isacc Occhipinti
Head of External Affairs, Hot Water Association

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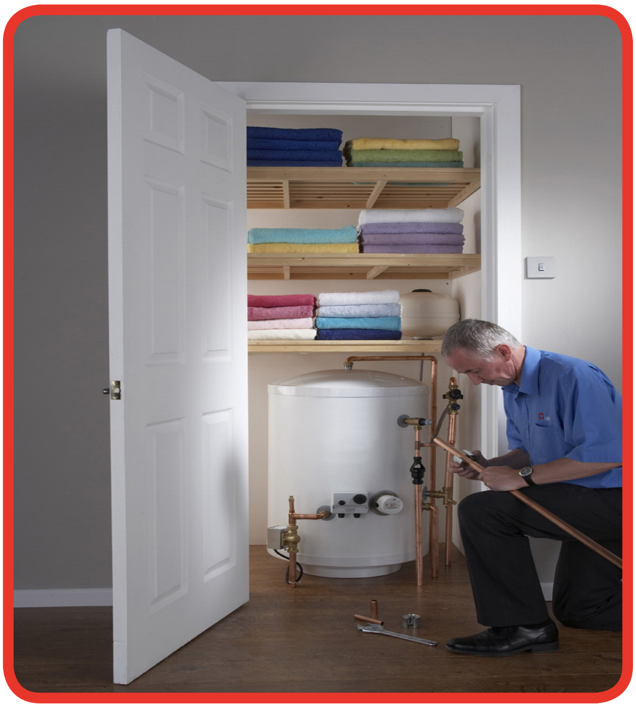
Introduction

The Hot Water Association (HWA) is a trade association with members focused in the domestic hot water storage sector. We aim to be recognised as the leading body in this sector and, through co-operation and partnerships, to support, drive and promote the sustained growth and improvement of standards within the entire domestic hot water industry.

Despite the unexpectedly rapid proliferation of solar PV since 2010, very few studies into getting the best value from an installed system have been conducted. The perceived wisdom has been that it is best for system owners to export all of their excess electricity in return for a flat rate calculated from the total generating capacity of their installation. This is now beginning to change with the development and promotion of domestic battery storage technologies which can help flatten out peak and troughs in domestic electricity demand by storing excess power, providing system owners with large savings in the process.



However, there is an alternative way of storing energy using a solar diverter alongside a hot water cylinder, technologies which are readily available and far cheaper than large batteries. This paper explores how this alternative use for excess electricity from solar PV could maximise a householder's return on their investment whilst also reducing strain on the electricity grid.

The savings have been calculated using a bespoke model that calculates how much a typical household would pay for hot water, before using solar PV generation data to estimate how much of this cost could be offset by using 'spare' electricity from their solar PV array.

The large potential savings and quick payback times are detailed to show the benefits of combining solar PV and a hot water cylinder into a thermal battery.

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Policy Context

Since the creation of the Department for Energy and Climate Change and the passing of the Climate Change Act in 2008, Government subsidies for domestic renewable energy generation have driven a large uptake in the installed capacity in the UK. In particular, the growth of the domestic solar photovoltaic (PV) industry has been exponential in recent years with installed capacity under the Feed-in Tariff (FIT) scheme jumping from 1.97GW in June 2013 to 4.93GW four years later (see figure 1 below). Despite the significant drop-off in installations following the cut to FIT payments at the beginning of 2016, there were close to 37,000 solar PV installations under the scheme in the year to July 2017.

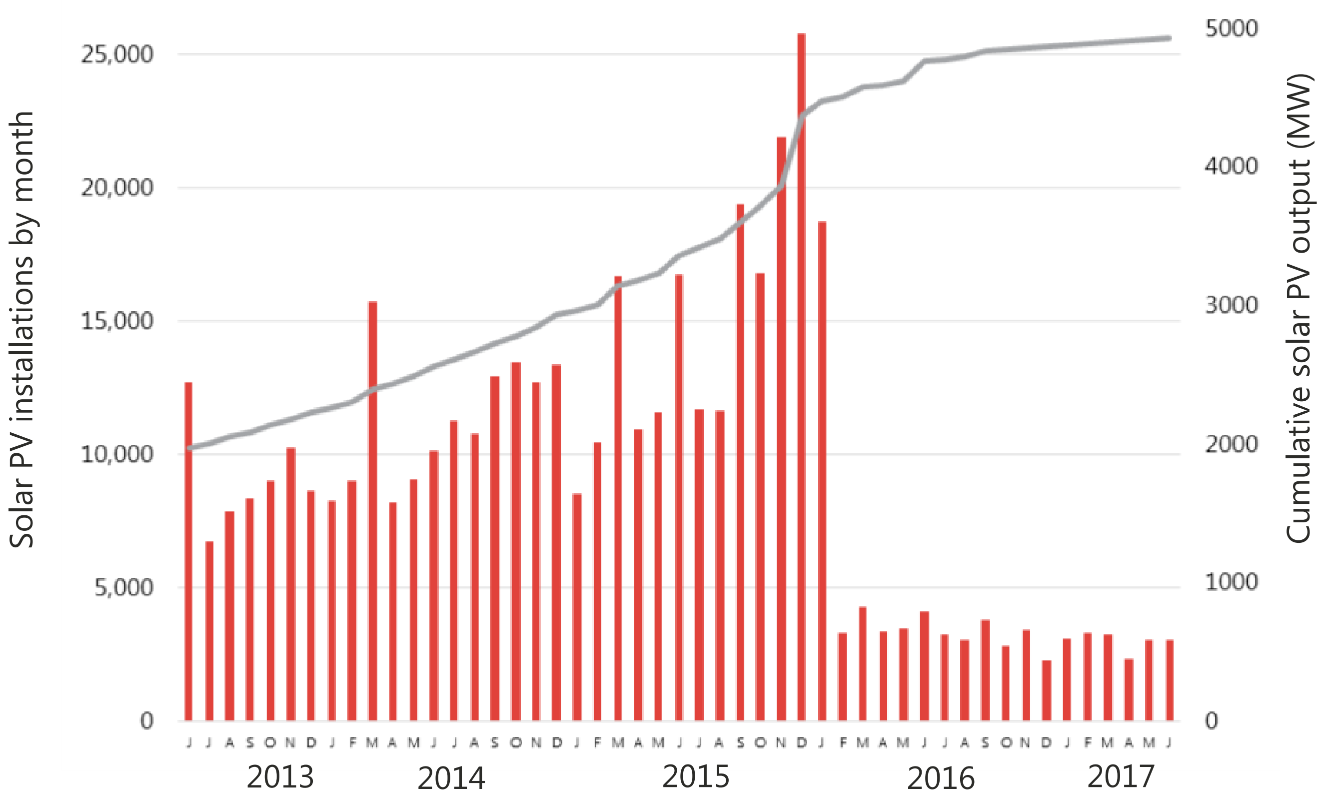

Figure 1: Solar PV deployment under the FIT Scheme[1]

With the closure of many large coal-fired power stations and the need to meet the UK's stringent emissions reduction target of 80% on 1990 levels by 2050, the Government has been keen to encourage the uptake of renewable sources of electricity generation. Small-scale solar PV installations across the country, which number nearly 900,000, are a tool for reducing peak electricity demand which in turn reduces the pressure on spare capacity margins and backup power supplies.

As the Internet of Things enables households to control their energy demand in ways not previously possible, the idea of a smart connected home which is flexible and, to a large extent, self-sufficient is quickly gaining traction. This fits into the vision of a varied, flexible electricity grid which is the goal of the Government and Ofgem as the sector regulator. In order to contribute to this, the Government recently unveiled[2] a £246 million fund to boost the development of high-capacity battery technology. There is a high level of interest in the potential for domestic battery storage to flatten out a household's energy demand by storing electricity in periods of low demand in order to lessen peaks in demand.

1 BEIS statistics: Monthly feed-in tariff commissioned installations

However, a large growth in renewable energy generation can produce challenges for electricity grid infrastructure, especially at a local level. With the vast majority of households with solar PV opting to sell their excess electricity to the grid, the level of exported electricity entering the grid can be high when overall demand is low. Without significant upgrades to grid infrastructure, certain areas could breach their capacity, according to electricity distribution companies[3].

Add to this the presumed levels of electric vehicle deployment over the next ten to fifteen years as well as the ever-increasing need for more houses to be built and it becomes clear that a large number of solar PV systems exporting all of their excess generation could exacerbate a major issue facing grid infrastructure.

Seeking a future energy system which is more decentralised with self-reliant households is one of the reasons that the Government are keen to support the development of battery storage technology.

What needs to be acknowledged, however, is that there is more than one way of storing energy. Solar thermal systems already demonstrate that solar energy can be harnessed to meet a significant proportion of a household's hot water demand. In this respect, hot water produced from solar energy can be classified as a thermal store which can be accessed at a later time when the hot water is needed.

However, unlike high-capacity battery storage technology, the measures explored in this report are readily available at a relatively low cost. They can be accessed by system owners and easily added to their existing installation. This means that the benefits for them and the electricity grid can also be realised faster and more cheaply.

3 BBC article: Cornwall renewable energy schemes 'strain electricity grid'

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Considerations for system owners

Installing a solar PV system represents a significant investment for any householder. The relatively large initial outlay, even if paid incrementally with an interest-free loan, is a barrier for many homeowners who may consider installing a renewable energy system in their home. Therefore, making the most of solar PV is essential for system owners and the electricity grid. This is particularly the case for those who have installed their system since the cut to FIT payments at the beginning of 2016 which saw incentives for householders reduced by 65%[4].

Another consideration for householders is meeting their hot water demand as well as their electricity demand. An unmodified system will not produce hot water, meaning that their demand will have to be met by their primary source of heating, typically a mains gas boiler. Combined installations of PV and solar thermal panels are more complex and costly to install as well as being clearly less flexible given the two separate technologies each supplying a separate form of energy. A solar PV system, fitted with a diverter which will use excess electricity to power an immersion heater, can perform both functions thereby increasing the flexibility of the system to cater to the owner's needs.

Using as much of the energy produced by a solar PV installation within the system owner's home also provides environmental benefits as the energy is used to offset subsequent grid energy demand. This reduces the inevitable transmission losses which occur when exporting and importing energy to and from the home. This is a consideration which may influence some system owners, particularly those who have installed a system since the reduction in FIT payments and may therefore be more motivated by environmental considerations than financial.

System owners should also consider the reduction in their energy bills which would result from using more their own energy. Hot water demand for kitchen and bathroom use is fairly consistent throughout the year which means that during the summer months with longer periods of sunlight, most households would be able to meet the vast majority of their demand using their solar PV system.

4 Guardian article: UK solar power installations plummet after government cuts

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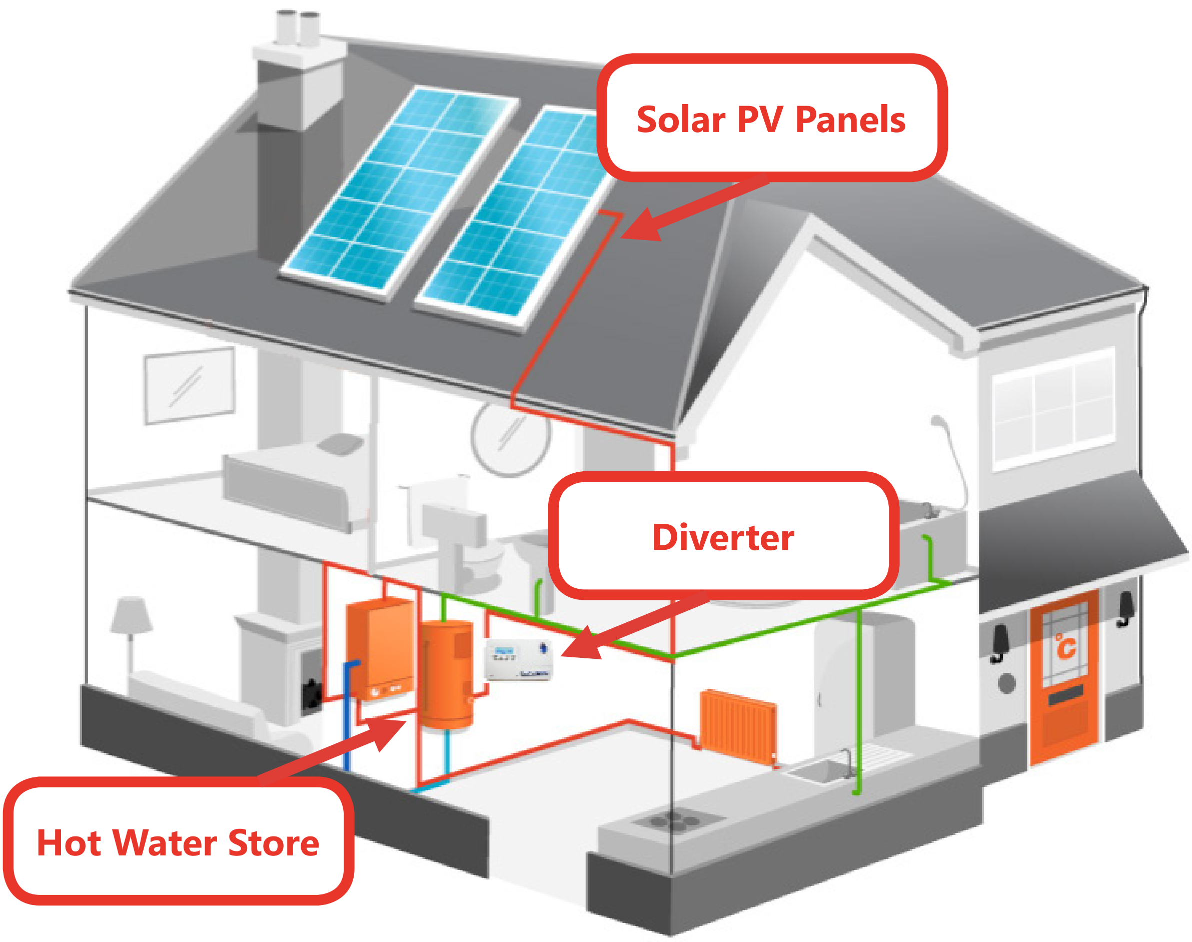
Solar PV and HWS

Below is a simplistic diagram of how the solar PV and diverter system works in conjunction with hot water storage.

Essentially, the solar PV system generates electricity. When an excess is being produced the diverter kit prioritises the electricity to power the immersion heater in the hot water cylinder. This in turn heats the water for use later on.

This system ensures that homeowners can store excess electricity and benefit from the additional value of this. **Electricity is roughly 3 times more valuable that exported electricity. Electricity costs homeowners around 14p per kWh whilst the export tariff is currently 5p per kWh.**



Daily hot water energy requirements were estimated using the Building Research Establishment's Domestic Energy Model (BREDEM) 2012 methodology. For a given number of occupants, this methodology uses an estimate of the number of showers and baths taken each day to calculate how much hot water would need to be produced to satisfy the needs of these occupants. For the purposes of this calculation, it is assumed that the property is home to 2.4 occupants.

By taking into account the temperature of incoming water[5] and the temperature to which it is heated, the energy content of the heated water can be calculated for each day of a representative year. In addition to this, water heating system losses (in the form of distribution, storage and primary pipework losses) impose a further energy requirement upon the hot water system. It is assumed that the property has a 180L hot water storage cylinder.

Adding the above together provides the following estimate of daily energy requirements for hot water in each month:

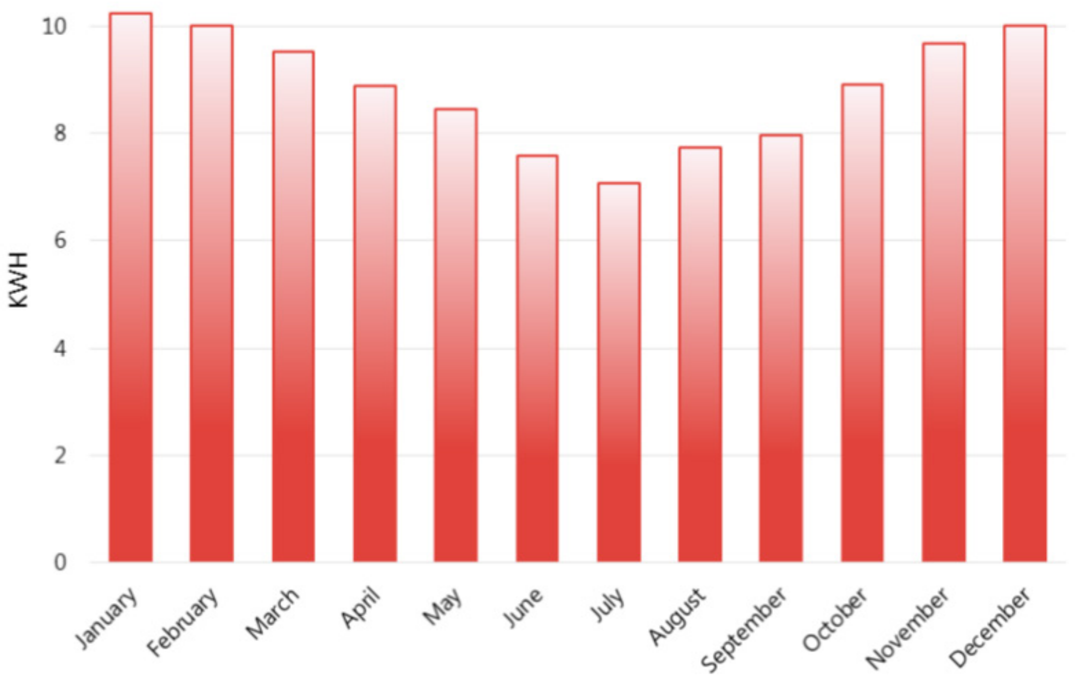


Figure 2: Average Daily Hot Water Requirements

5 BREDEM assumes the temperature of incoming water is higher in summer which explains the drop in energy demand for hot water at that time of year. Most new cylinders installed will be mains pressure and therefore the water feed at more constant (and lower) ground temperature. This may mean there are greater savings to be made with unvented systems.

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Solar PV generation data

Generation data for a UK solar PV installation was provided to the HWA by Viridian Solar. The data related to the 44.5 kWp installation on Viridian's factory roof[6] and detailed the amount of electricity generated from this installation on each day between 1st January 2013 and 31st December 2015. A 44.5 kWp installation is far larger than the typical domestic PV installation, so these generation data were scaled to indicate the output from a 4kWp installation.

The following line graph demonstrates how daily solar generation varies from day-to-day throughout the year. As would be expected, a highly seasonal pattern emerges:

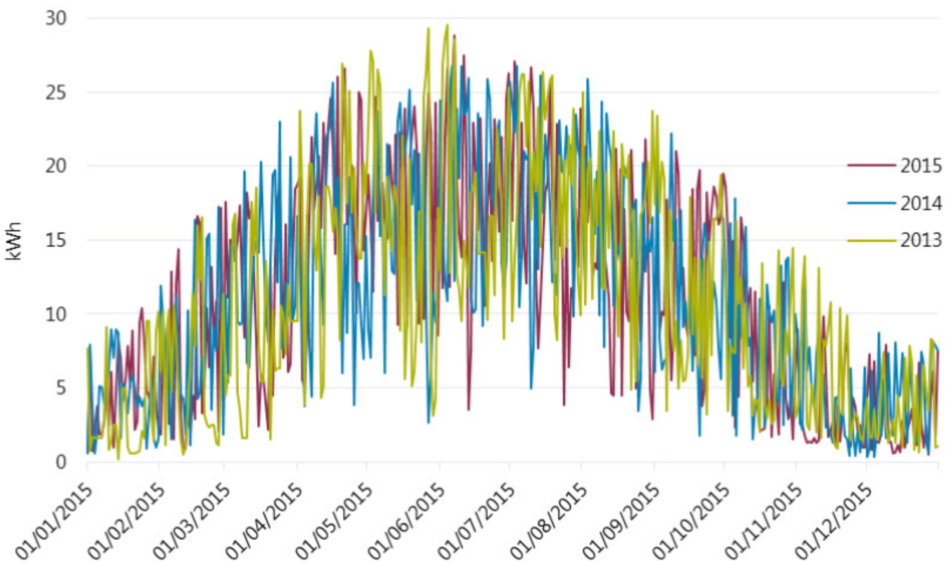

Figure 3: Average Daily Solar PV Generation

The following histogram shows the frequency of different levels of daily generation:

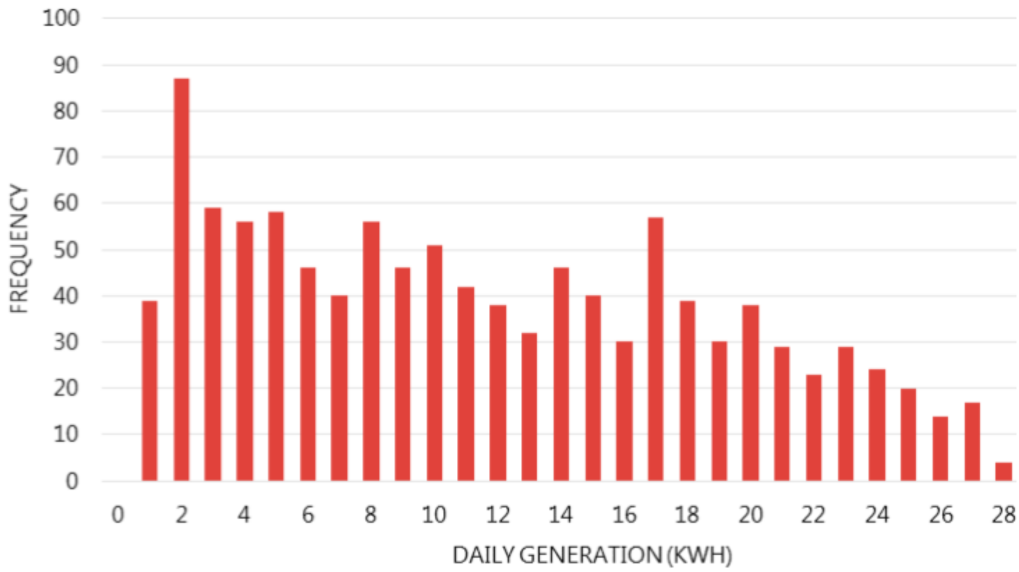

Figure 4: Histogram of Daily Generation (4kW installation)

6 Southwest facing, tilt angle 35 degrees, no, or very little, shading.

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Estimating export fractions

Although Feed-in Tariff export payments are currently paid on the basis that 50% of generated electricity is exported, this is unlikely to be true in reality. It stands to reason that a higher level of generation should result in a higher export fraction, since household electricity consumption is largely intransigent to solar irradiation (this may not be true in hotter countries where domestic air conditioning is more prevalent).

A second data set supplied by Viridian Solar provided information from real household solar installations on the level of solar generation and the percentage that is exported. Using these it was possible to construct a model that allowed the estimation of the export fraction for a given level of generation. The graph below shows the relationship between generation and the export fraction.

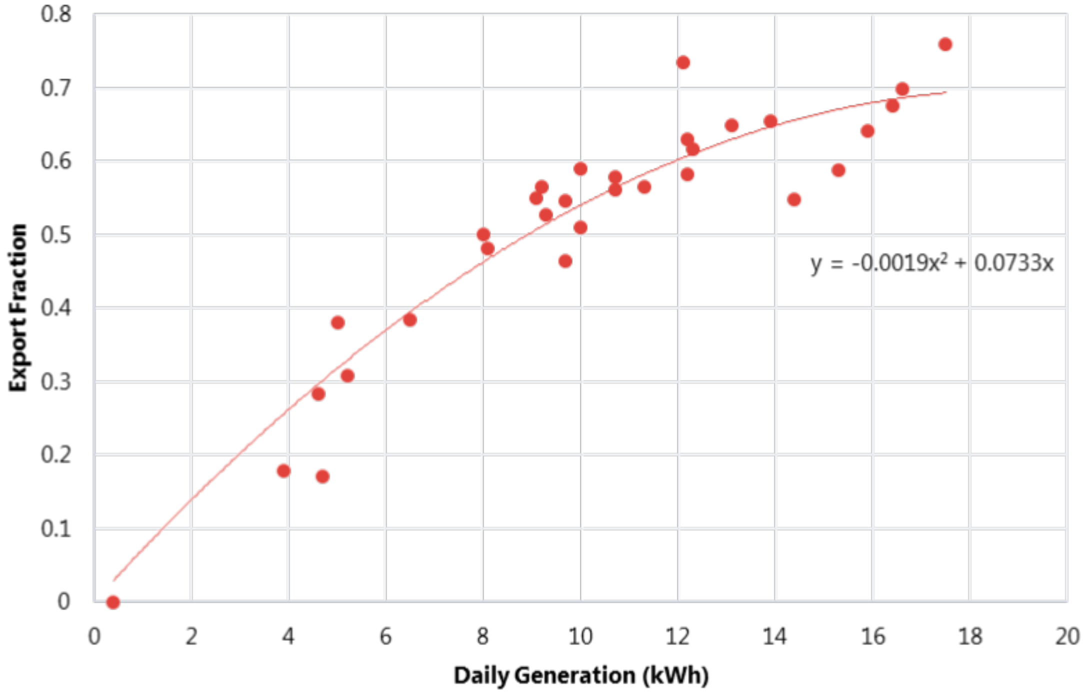

Figure 5: Relationship between generation and export fraction

A quadratic line of best fit was then fitted to these data (with the intercept set to zero). Using the formula associated with the line of best fit, it is possible to estimate the export fraction for any given level of generation. This is demonstrated in the table below:

Generation (kWh)	Export fraction
0	0.00%
2	13.90%
4	26.28%
6	37.14%
8	46.48%
10	54.30%
12	60.60%
14	65.38%
16	68.64%
18	70.38%
20	70.60%

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Estimated savings

Using a solar diverter, it is assumed that any electricity that would have been exported is used to instead meet the household's hot water demand.

On some days, excess solar electricity is sufficient to meet all of the energy requirements for hot water. On others, the existing heating system has to meet some of the additional energy requirements. The graph below shows the average proportion of the hot water energy requirement that could have been met by each energy source in each month over the three years for which the solar generation data were available:

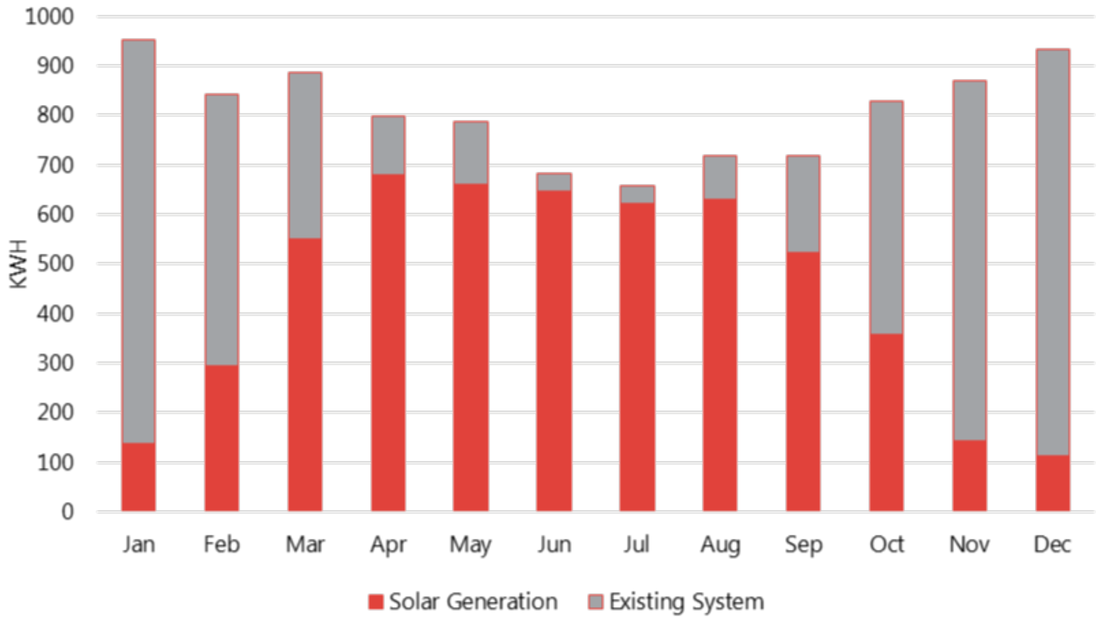

Figure 6: Hot water energy requirement by source (2013-2015)

In the first instance, the cost of meeting hot water demand using a gas boiler or an electric heating system (boiler or immersion heater) is calculated. For a household using a gas boiler the following assumptions are made:

Hot water efficiency of 80%
Gas price of 4.18 p/kWh

For a household using electric heating, the following assumptions are made:

Efficiency of 100%
Electricity price of 13.86 p/kWh7

In the second instance, the cost of meeting hot water demand using a solar PV array and power diverter alongside the existing heating system is calculated. The table below demonstrates the costs of each situation and the resulting savings:

		2015	2014	2013
Gas	Original cost	156.53	156.53	156.53
	Cost with PV and Diverter	67.63	65.61	71.33
	Savings	**88.91**	**90.93**	**85.21**
Electricity	Original cost	415.22	415.22	415.22
	Cost with PV and Diverter	179.38	174.03	189.20
	Savings	**235.84**	**241.19**	**226.02**

For households using gas to heat their hot water, a saving of approximately £90 could have been made in each of the last three years. For those using electricity, the saving would have been between £220 and £240.

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Estimated savings

In this report, we have outlined how combining a solar PV installation with a hot water cylinder to create a thermal store for excess energy is cost effective and beneficial for both system owners and the electricity grid at large.

The demonstrable savings and quick payback times from installing a diverter offer an attractive way for system owners to make the most of the electricity they are generating whilst also reducing their dependence on the grid and fluctuating energy prices.

The indirect benefits for grid infrastructure could also be significant, especially given the unexpectedly rapid deployment of solar PV in the UK over the last five years.

More information about the membership and work of the Hot Water Association can be found at www.hotwater.org.uk.

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