A Solar Power Tutorial

This document describes my experience with Solar PV. The intention is to give the reader some facts about Solar power generation and how Solar power has reduced the amount of electricity purchased through the Grid.

Data shown here for Solar Generation, Battery Storage and Grid use is for my detatched house in Windsor. The data comes from (a) Solar PV and Electricity Grid meter readings (b) Solar PV monitors (latest version is ECO-eye Trax) and (c) data and graphics available at the PowerVault online Portal

We installed a set of 16 Solar PV panels on 29th Febraury 2012. The panels are on a South facing roof and have a nominal rating of 4 kWh. We measured an annual generation average of 3,650 kWh/year over the nine years.

The 8 kWh PowerVault battery was installed in July 2019 and is used to store excess Solar power – instead of exporting that power to the Grid.

Note – we use Gas for central heating, hot water and a lot of cooking with an occasional gas fire in the living room.

This overview chart is a good place to start.

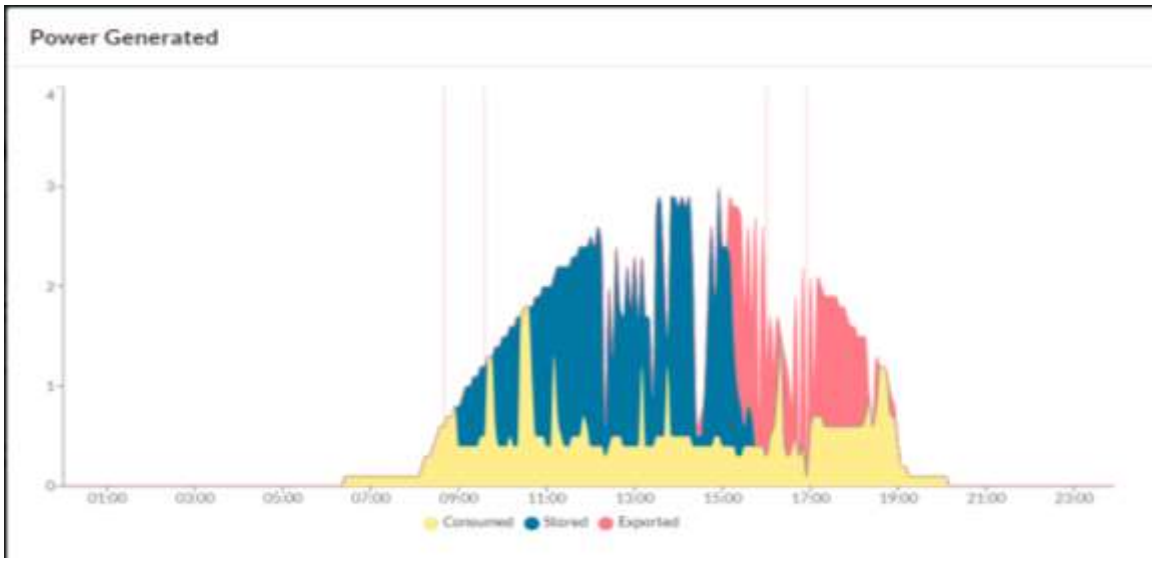
Data and graphics below come from the PowerVault Battery system.

This shows data for the 24 hours of Tuesday 20th July 2021. On RHS is summary data with a total for Solar Generated and Consumed plus Grid Export and Import and House consumed. On LHS are two graphs of Power Used and Power Generated. Yellow and Blue is good – red is bad.

On this day all but 0.3 kWh came from Solar power – either directly during the day or via the battery between 19.00 and 07.00.

Note – before the battery was installed the blue power used would be bought from the Grid and the blue power generated would be exported to the Grid.

Let's consider Power Generated during the day.



The Solar PV panels are generating (in the summer) from around 6.30am until 8pm. On a good day this graph would be a smooth curve rising in the morning, peaking in the early afternoon then declining as the sun moves to the west and sets. *Note – the peak around 2pm shows the 4 kwH rated panels generating 3.0 kWh.*

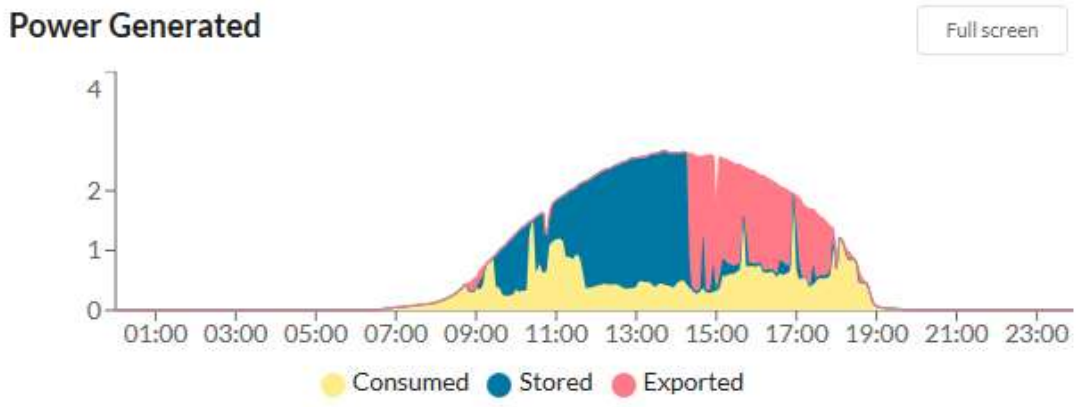
The Yellow part of the chart shows Solar Power that is used immediately as it is generated.

The Blue part shows power that is stored in the Battery. From 9am to 3pm any excess Solar generation is stored in the Battery.

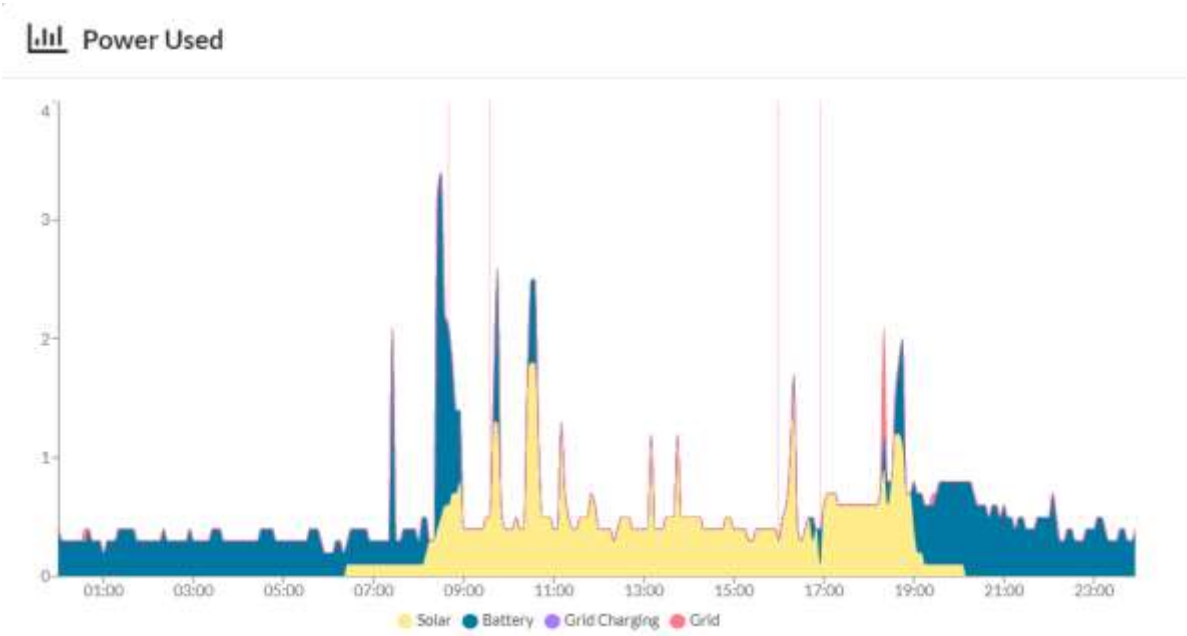
Soon after 3pm the Battery is full – so any excess Solar power is exported to the Grid. Red is bad in this case – we couldn't use it. A bigger battery would store more of the red – but to limited additional value for a higher capital cost.

On this day peak generation was not achieved between 11.30 and 17.00 partly due to cloud but mostly due to high tempreatures in the loft where the Inverter sits. The Inverter is set to run at reduced power if the air around it gets above a certain tempreature. Maybe an air-conditioning unit beside the Inverter would enable full Inverter operation for longer 😉

This example on a cooler and sunny day in August 2019 shows the point –



Let's look at Power Used.



The chart shows all electricity used in the house for 24 hours.

As before, Yellow is power sourced directly from the Solar PV. Blue is power taken from the Battery.

On this day there is a small amount of Red at 6.30pm – power taken from the Grid. Red is bad as we have to buy that electricity 😉

From midnight till 7am and again after 10.30pm there is a steady use of between 0.3 and 0.4 kWh per hour. This same use is actually there for the whole 24 hours – so we have base power use of 24*0.33 = 8 kWh a day.

The 24 hour base power use is from appliances on standby, clocks in applliances, the phone and internet systems. The bursts of power are when the fridges and freezers are cooling. The PowerVault battery also uses power to drive its computer and run the cooling fans.

During the day other devices are switched on. For example –

- At 7.30am the kettle for tea.
- At 830am the fan oven for bread making
- At 9.30am and 10.30am the dishwasher is doing its wash and dry.
- From 9am to 9pm the base load rises to 0.45 kWh as many other appliances are used – eg. Computers, phone charging, lights in kitchen/garage, radio/TV etc
- At 11am. 1pm twice and 4pm its the kettle again
- At 7pm the microwave twice
- Not sure what the 0.8 kWh load is around 8pm – maybe an old 250W halogen light in the living room? I can't find a suitable LED replacement.
- Security lights (LEDs) run from around 8.30pm to 11pm.

Here is an example from a near perfect generation day.

At 3am the battery was empty – because the previous day had been cloudy and the battery had not been fully charged. From 3am to 9am power was purchased from the Grid

What about a cloudy/rainy day?

See the chart below. The 29th and 30th June were cloudy/rainy days. The battery was empty at midnight, little power was generated during the day and the battery was empty again by 8pm. Therefore before 7am and after 8pm all electricity came from the Grid – essentially this is how it would be without the battery.

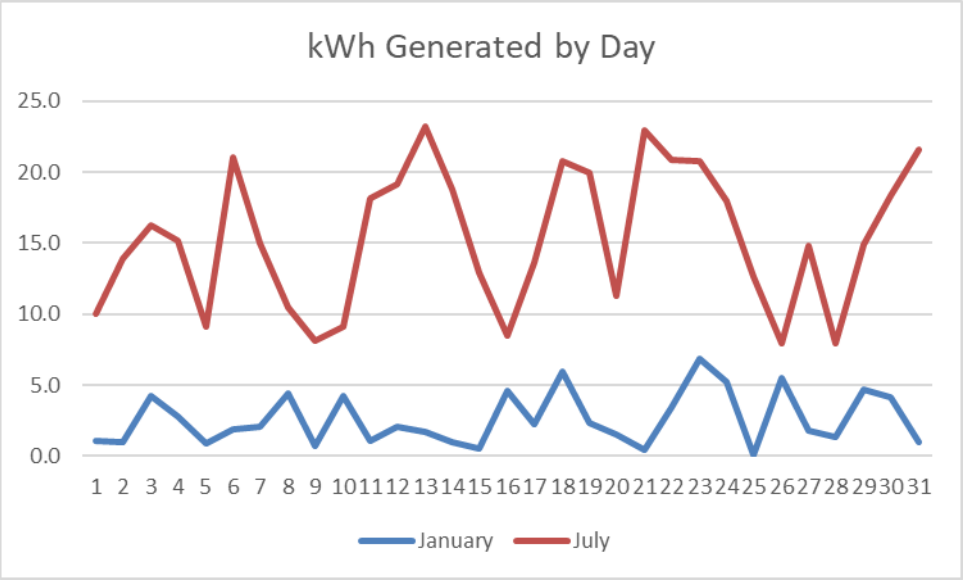
Other monitoring data from the PowerVault portal.

This chart shows the live statistics. Here we can see that for this instant that the Solar PV is generating 2.1 kWh and that power is being used by three things -

- The house is consuming 0.93 kWh.
- The Battery is being charged at 1.26 kWh.
- The excess of 0.09 kWh is being exported to the Grid.

How does Solar Generation vary in a month?

We have looked at individual days and will later look at monthly and yearly averages. Not every day is the same – sun, rain, snow all impact the Solar PV efficiency.



Note – in July 2021 we used between 10 and 14 kWh (12 average) of electricity every day. Excess generation above this was exported to the Grid. Daily electricity use in January would be higher than the summer 12 kWh average as we have lights on for longer, heat the greenhouse (frost free) and have outdoor Christmas lights on.

Would a larger array of Solar PV panels help?

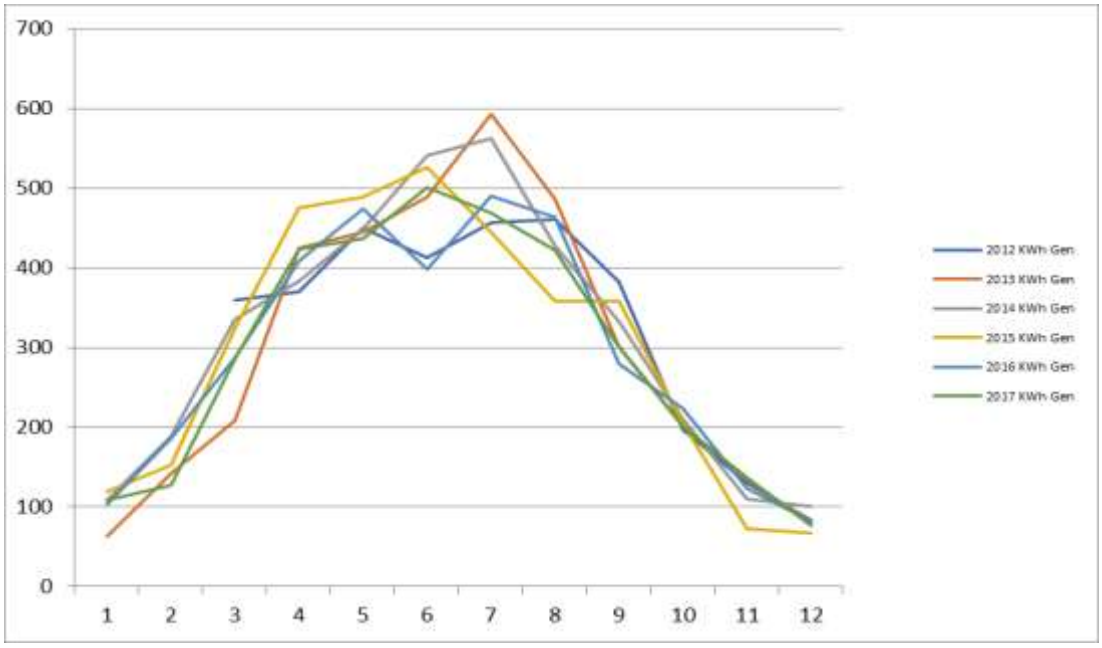
We have a 4 kWh set of panels – what if we doubled it to 8 kWh? Lets look at the data above – kWh generated by day.

In the July example above there are only about 10 days when 15 kWh or less is generated. Yes - 8 kWh panels would double the power generated enabling most days to use 100% Solar power but most of the extra power generated would be exported to the Grid. However the Grid import savings and any Export income obtained would mean that the Capital cost of the extra 4 kwH panels would take many years to recover.

In the January example an 8 kWh set of panels would only generate 10 or more kWh of power a day on 5 days out of 31. Generating less than 10 kWh a day means that for most days in the month the battery is little used. 10 kWh/day is less than the average use per day of 12-14 kWh and so Grid import of power remains significant in the darker months.

How does the Solar power generated per month change over the year?

The graph shows kWh generated per month during the year. The data covers the 6 years - 2012 to 2017.

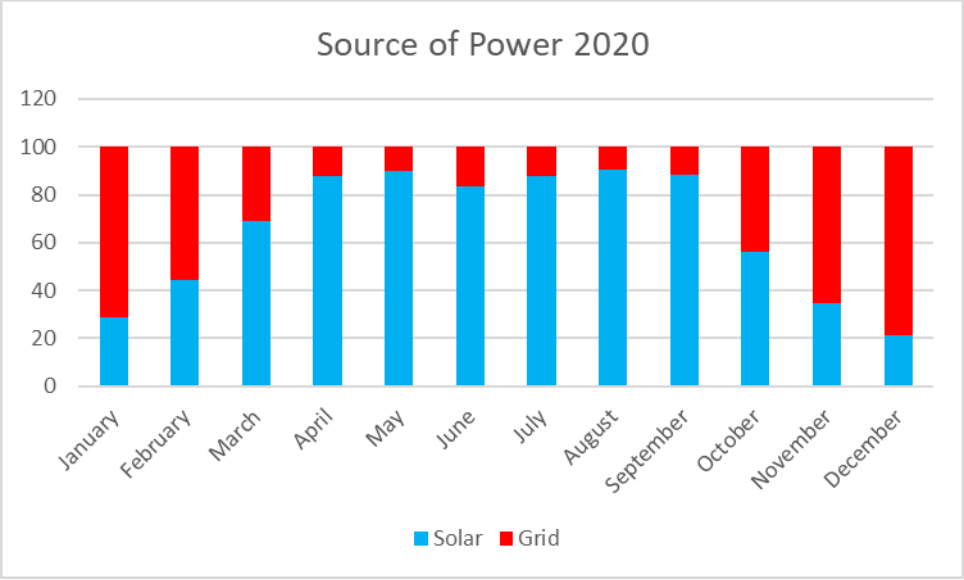


The prevailing weather conditions (sun, cloud, rain, snow) impact the kWh generated.

In this 6 year period the peak generation month was 592 kWh in July 2013 (the lowest July month was 444 kWh in 2015). The worst month was 63 kWh in January 2013 (snow) with the highest January at 120 kWh in 2015.

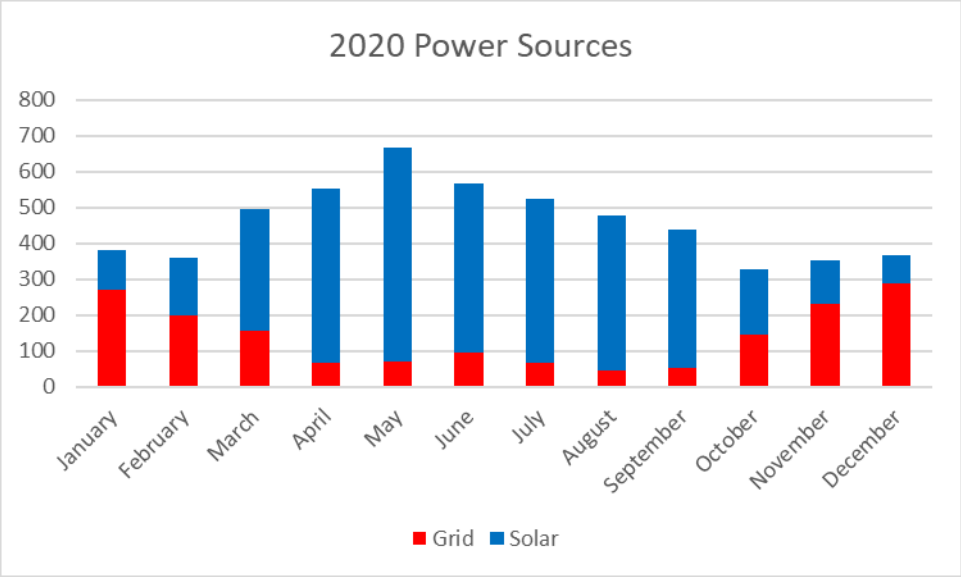
How does the Solar plus Battery benefit change during the year?

What changes between Summer and Winter? Percentage of power used is shown.



In the darker winter months (Nov to Feb) only 20 to 40% of the power used is produced by the Solar/Battery combination. Therefore 60-80% of the power used is purchased from the Grid.

In the peak summer months (Apr to Sept) the Solar/Battery provides around 90% of power used. Even in the peak summer months we still have to buy about 10% of our power requirements as rainy/cloudy days lower the Solar generation efficiency.



The above charrt shows kWh Solar generated or purchased from the Grid for the months of 2020. On average, the house uses 30*12 kWh = 360 kWh per month.

Sizing the Battery

A very large battery might seem desirable but it is unaffordable. How much energy is generated per day on average? How does this vary between Winter and Summer?

The charts below show a 9 year average of power generation by month. The months are colour coded to show the 4 seasons – winter, spring, summer and autumn.

	Average 2012:20		
Month	KWh Gen/mth	Days/mth	Average Gen/day
January	102	31	3.3
February	170	28	6.1
March	294	31	9.5
April	408	30	13.6
May	486	31	15.7
June	482	30	16.1
July	505	31	16.3
August	439	31	14.2
September	342	30	11.4
October	209	31	6.7
November	118	30	3.9
December	82	31	2.7
Total	**3638**		**10.0**

Note – from October to early March the average generated per day is less than the 8 kWh capacity of the battery. We also use an average of 12 kWh per day of electricity.

We have a base appliance use load per day of 8 kWh - even if we are away and not using the other appliances. So in the winter all power that is generated is used immediately and only on really sunny days is there enough power to charge the battery for some overnight use.

Of course, daily averages hide a significant variance in annual generation by season. This is weather dependant e.g. Spring 2020 was exceptionally sunny, summer 2013 was the best, winter 2012/13 was worst due to snow!

Seasons	2012	2013	2014	2015	2016	2017	2018	2019	2020
Winter Mths		288	379	373	357	319	365	396	363
Spring Mths	1179	1078	1167	1289	1169	1147	1069	1173	1423
Summer Mths	1330	1567	1530	1329	1351	1392	1531	1443	1364
Autumn Mths	708	636	653	634	626	638	764	665	692
TOTAL		3570	3729	3626	3504	3495	3728	3677	3842

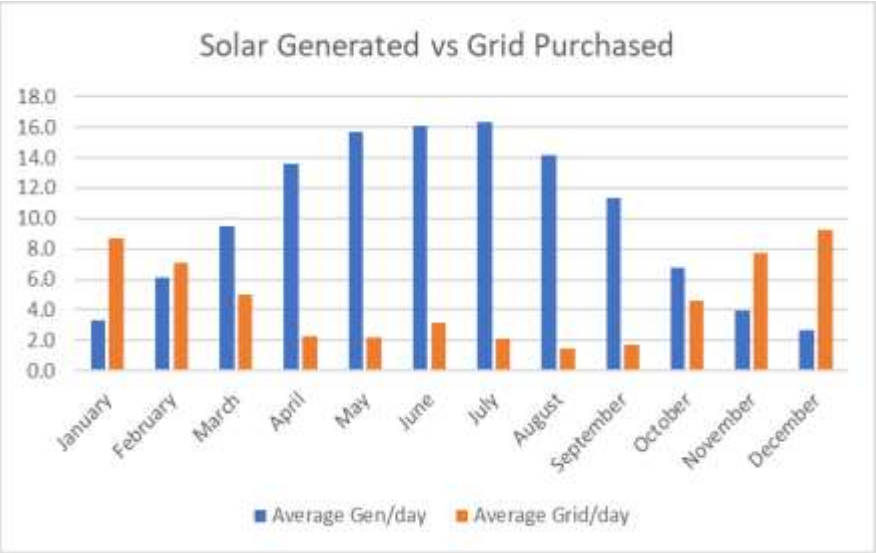
2020 was the best year so far = Global Warming?

Note Solar PV panels and the Inverter are supposed to be less productive as they age – so we have a 9 year old and supposedly less productive Solar system generating more power!

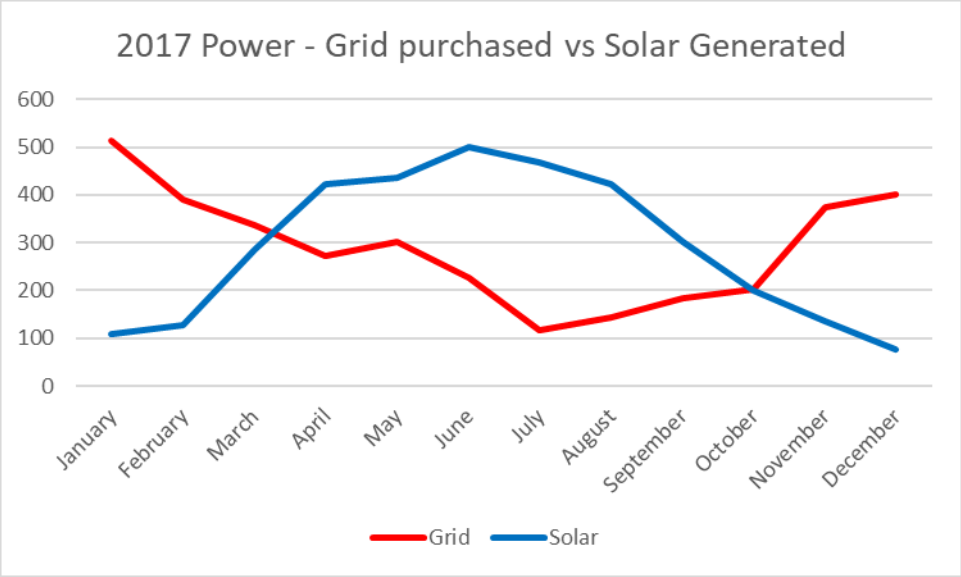
How does the power generated compare to power purchased from the grid?

The chart below shows kWh per day by month. Solar data is 9 year average (2012 to 2020). Grid data is for 2020.

Note – 2020 was the first full year of Battery use – hence imported power from the Grid is reduced vs prior years.



The chart below shows a graph for 2017 – prior to the battery being installed. Data is kWh/month.



BOTTOM LINE - By how much did Solar PV and a Battery reduce the Electricity used ?

Looking at smart meter data for Grid power purchased we can see what happened –

- **100%** - before Solar (2006-2011) we were buying about 5,000 kWh a year (6 year average
- **64%** - after Solar (2013-2018) we bought around 3,200 kWh a year (6 year average)
- **37%** - after adding the Battery in 2019 we are buying around 1,850 kWh a year (2 year average)

But this is not really a fair comparision as between 2012 and today we have made a number of changes along the way which have reduced our base electricity consumption including –

- LED lighting in frequent use areas of the house
- New A** Fridge/Freezer in the garage.
- New A Freezer in kitchen
- New LED flat screen TV

CONCLUSION

There are a lot of variables when considering what size of Solar PV and Battery Storage System to purchase.

A Battery is clearly a useful addition to the Solar PV as it provides stored energy for use overnight – when the sun doesn't shine!

Generating too much power in the summer and simply exporting it to the Grid is not a great idea. The Grid only pays less than 5p per kWh for that energy exported (and that now has to be metered) – whereas a larger SolarPV system increases the capital cost.

Sadly in the winter the sun doesn't shine as much and when it snows you generate zero. Nor can you store excess summer sun for use in the winter.

When you need power during the coldest months to drive hot water and heating systems then Solar cannot provide. Therefore you have to buy expensive power from the Grid.

A huge Solar PV system of enormous size can never generate 100% of the required power during the winter months – fact!

It is a juggling act to size the Solar PV and Battery for an optimal cost balancing for the required power demands of the building. A mix of Solar and Grid supplied power will be needed – and possibly retaining some gas (or later hydrogen) heating.

Peter Norris, July 2021