Thinking about getting a home solar energy system?

Useful things to know...

This article (updated in July 2023) is intended to provide some guidance about things to consider when preparing to invest in a home solar PV (photovoltaic) electricity generation system, possibly with battery storage. It draws on the authors' experiences of owning solar PV and battery systems and on conversations with other owners and prospective owners. Solar thermal domestic hot water heating is outside the scope of this article.

Please note that the authors are not solar industry professionals and do not claim to have the expertise or experience that system suppliers will have.

Some (important) terminology clarification

When looking at media reports and, especially, Internet articles, forum posts and videos it is very common to see incorrect use of terminology and confusion about the difference between energy and power. It is worth briefly clarifying these before we move on.

> *Energy* is sometimes defined as *the capability to do work*. The base unit of energy is the Joule (J), but it is a very small quantity. In the context of this article, the unit most frequently used is the kilowatt hour (kWh). Energy bills show the cost for kilowatt hours of energy supplied using a tariff cost per kWh.
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> *Power* is the *rate of doing work* i.e. how quickly the energy is being used. The base unit for power is the watt (W), but in this context the unit used is the kilowatt (kW). 1kW = 1000 watts.

An example may help to clarify:

> To heat 1l (one litre) of water from a cold tap (assume 10ºC) to boiling (100ºC) requires 0.1kWh of energy. This is a physical property of water.
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> A kettle with a power rating of 2kW will take 189 seconds to do this but a 3kW kettle will deliver energy more quickly, taking 126 seconds. Both kettles have delivered the same amount of energy to boil the water.

If you see articles quoting terms like "kilowatts per hour" or "kilowatt-hours per hour" beware, these are meaningless and demonstrate a lack of understanding.

What is your household energy use?

A good starting point is to know the electrical energy use in the home. This will help the system provider to design a suitably sized system. Two figures are useful: annual consumption in kWh and average daily consumption in kWh.

Prospective system suppliers will specify in their quotations the estimated annual solar energy generation in kWh, which can be compared with the annual home consumption. Average daily home consumption in kWh (you can divide annual kWh by 365 days) is a useful point of reference, especially with regard to the storage capacity of a battery. Sources of this information include:

- Electricity bills include the energy supplier's estimate of annual consumption, though this will vary between bills. Using actual consumption from bills from the past year or two is another option.
- The energy supplier's app or website account pages.
- A smart meter display will show information on daily, weekly, monthly and annual consumption if it has been installed for a sufficient period of time.

It is worth considering whether your energy use will be affected by changes you may be anticipating. These might include switching cooking to all electric (consider installing an efficient induction hob), plans for buying an electric vehicle (EV) or possibly installing a heat pump for heating and/or hot water.

For an EV, most home wall-mounted chargers are rated at a nominal 7kW maximum output power, though they should have the capability to adjust output power to a lower level, for example to make use of surplus exported solar power. A 13A portable plug-in charger, providing around 2kW (often referred to as a "granny charger") is usually supplied with an EV. This is more of a "trickle charger" which will take many hours to deliver a significant charge to a battery EV, but could suit a plug-in hybrid (PHEV) which will have a relatively small battery. More detail about EV charging in relation to solar PV systems is beyond the scope of this article, but we may produce a separate article covering our experiences in this area.

What benefits do you want from your PV system?

There are a variety of potential benefits from a solar PV installation, each of which will influence the system design and costs. These include:

- *Minimise electricity costs* – with a PV-only system, savings come partly from reduced grid energy consumption and partly from offsetting the income from exported surplus solar energy against the cost of consuming grid energy when sunlight is not available for generation. Adding a battery to store and use more of the generated energy will further reduce grid consumption costs, but requires additional investment. Some systems also provide the facility to put energy into the battery from the grid overnight at an off-peak rate for use during next the day to reduce daytime peak-rate consumption. A suitable time of day tariff such as Economy 7 is needed for this. The most that can be saved is the total cost of the existing energy bill, including the daily charges, though some systems are capable of producing a net annual income.
- M*inimise grid consumption* – A solar PV system only generates energy during daylight hours and the power generated depends on how much sunlight is available. Adding a battery (at extra cost) allows some of the surplus solar energy to be stored and used to power the home when solar generation is insufficient or after sunset. Some PV+battery systems can reduce consumption of grid energy close to zero from early spring through into autumn and still have surplus energy to export. In the winter months daily solar energy generation may be as low as 10%-30% of daily consumption (and nothing on some days), though a PV system can still generate a surplus to export on some sunny winter days.

- *Minimise return time of the investment* – optimise the system design so energy cost savings pay back the system cost in the shortest time.
- *Minimise system cost financial impact* – optimise the system design so that energy cost savings offset the cost of a loan used to finance the installation, i.e. the system might be "cost-neutral" for the duration of the loan.
- *Anticipating future uses* – the system may be "oversized" in anticipation of a future use, such as the installation of an electric vehicle charger. It may be more cost-effective to oversize initially and benefit from the extra generating capacity than to add new capacity and upgrade some system components later.
- *Reduce carbon footprint* – many energy suppliers claim to supply 'green' energy, so this might be considered moot. However, the UK still uses fossil fuel generation for a significant proportion of energy generation, so self-consumption and export of surplus energy from home solar generation will help to reduce the amount of fossil fuel generation required in the national mix. See comments on carbon reduction later in this article.

Solar PV panels

As well as the estimated annual energy generation (in kWh), a solar PV system quotation will specify the peak power output in kW (kWp) that it it is capable of generating. Solar PV panels are produced in a range of physical sizes and using different technologies. The efficiency of a panel (the percentage of light energy that it converts to electricity) can range typically from around 15% to 22%. Higher efficiency panels which generate more power for a given panel size are usually more expensive.

PV Panels currently have a rated peak power output ranging from around 250W to 420W. The array of ten high efficiency 400W panels shown in Figure 1 has a peak generation power of 4kWp which is about the typical power rating for a PV system in the UK (see also Connecting to the Grid).

Figure 1: Typical rooftop solar panel array

Panels are usually installed on the house and/or garage roof, so the number of panels that can be installed is limited by the roof area and shape, less any space that will be excessively shady. Trees are a notable cause of shading, though it may be possible to reduce this by thinning and shaping which can be done by a tree surgeon. It is commonly assumed that a south-facing roof is required, but east and west-facing aspects can also work well. South-facing panels provide a steady rise to peak power around midday before falling away towards sunset. East/west-facing systems have a wider, flatter power generation curve as they face the sun more directly early and later in the day while the angle of the panels to the sun is steeper in the middle of the day. East-west facing systems can typically provide 80%-85% of the energy that would be produced by a south-facing system.

Figure 2 shows the actual measured power generation profile for sample days in December and June for a south-facing 6kW system. In December, generation starts around 09:30 and stops around 15:00. In June power is generated from around 06:00 through until 20:00. In the December plot, a couple of sunny periods are visible in the power output and in the June plot the effects of passing clouds can be seen.

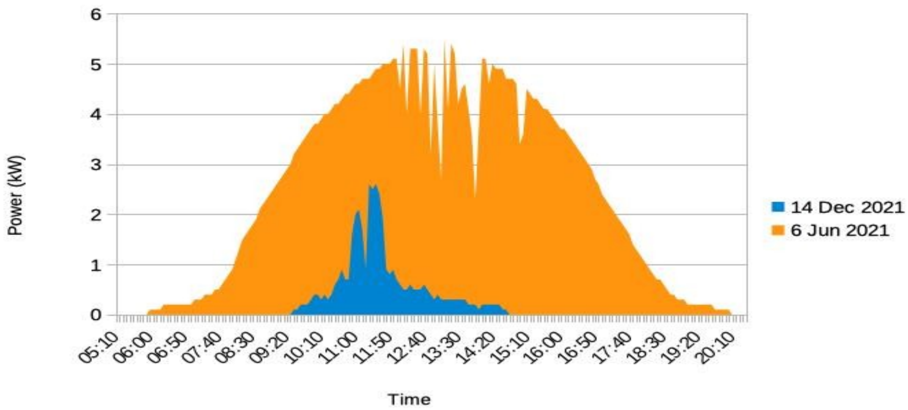

Figure 2: Solar generation summer vs winter (6kWp south-facing system)

It is possible that the power demand in the home will be at its highest when the solar generation is low or has finished, especially in the winter as illustrated in Figure 3 for a sample December day.

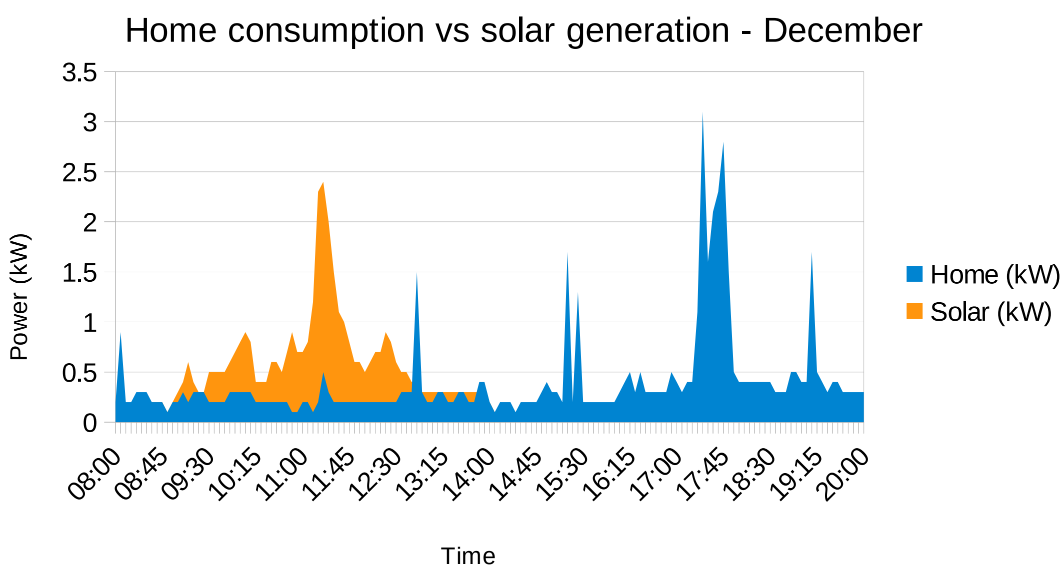

Figure 3: Solar generation vs home power consumption in December

The blue area shows power consumption for one of the author's homes between 08:00 and 20:00. It has a PV+battery system. For much of the day until late afternoon the power consumption is between 100W and 300W. The amber area is the period of solar power generation, running from about 09:00 until 14:30. During this period there is a surplus of solar power, except for a spike in home consumption around 13:00. The surplus is used to charge the battery and any remainder is exported. Outside of the solar generation period, the home power is provided by the battery and then by grid import if the battery charge runs low. You can see that the peak period of power consumption is from late afternoon into the evening. The profile of energy use in your home may be different. If you have a smart meter, the energy supplier's website or smartphone app may have an option to view the profile of energy consumption during a day.

PV panels usually have a long warranty against failure, possibly 20-25 years. Power generation capability can decline by up to 20% during their lifetime. Both of these figures are specified by the manufacturer and are worth checking. We have been asked about cleaning panels. Guidance we have seen is that panels do not require regular cleaning but that it can be done, with care, if required. The system supplier will be able to advise on this.

The inverter

The inverter is a device that converts the DC power produced by the solar panels into mains voltage AC. Inverters are available in a range of power outputs and the system designer will choose one that is most appropriate. In some systems the inverter also controls DC-connected battery storage (see Battery storage below). The warranty for an inverter may be ten years or longer and this should be specified in the quotation.

Battery storage

A battery is primarily used to store surplus solar energy to power the home when solar generation declines or stops due to lack of sunlight. In winter a battery may more than double the amount of solar energy that can be consumed.

Factors to consider:

- What is the battery's *usable* energy storage capacity? Some manufacturers quote a capacity in kWh, but place constraints on the minimum and maximum levels of charge so the usable capacity will be lower, possibly 85%-90% of the headline value. System suppliers may quote the gross capacity rather than the usable capacity so this is worth checking. Look at this in the context of the average daily house consumption. The size of the proposed PV system will also be a factor in battery sizing. Battery systems we have experienced or seen range in usable capacity from around 4kWh to 13.5kWh, though higher capacities are available. Some battery products are modular, so it is possible to add capacity later.
- Does the proposed system provide the capability to add charge to the battery from the grid overnight to take advantage of off-peak electricity tariffs such as Economy 7? This is particularly useful during the winter months when solar generation is limited by shorter daylight hours and lower light levels than in the summer (see Figure 2). If it does, how is this controlled?
- What is the *usable* maximum power output from the battery system? This may not be stated in a system quote, which may focus on the energy storage capacity, so is worth checking. For reference, a fan oven may consume 2.5kW-3kW when heating (much less when up to temperature), a microwave oven might consume 1kW-1.5kW and a kettle

around 2.5kW. These high power loads are usually transient, being present for a period of minutes. The more power the battery can supply will reduce the required grid energy import. We have seen battery systems specified with power outputs ranging from 2.5kW to 5kW, though systems with higher power output are available. Note that in some designs the battery system delivers power at mains AC voltage separately from and in addition to the solar PV system output, while in other designs the battery system is integrated with the solar PV system which limits the total power available to the maximum output of the inverter. See also the section below on battery backup power.

- What is the expected lifetime of the battery? Some systems specify useful life in terms of the number of charge/discharge cycles, while others specify it in years, typically ten years.
- How does battery capacity (in kWh) reduce over time? All batteries experience a reduction in capacity over time, but some types of battery degrade more than others. We have seen specifications ranging from 65% to 80% of the initial capacity remaining after ten years.

Some people we have spoken with have expressed a view that one battery product is “expensive” compared with another. One metric that can used for comparison is the cost per kWh of *usable* capacity, but also consider expected lifetime and any additional system capabilities.

Power backup

A solar PV only system is designed to shut down in the event of a grid power failure. This is because the system is connected to the grid and cannot be allowed to feed power back into the network when engineers are working to effect repairs. Many solar PV installations that have batteries will also shut down for the same reason.

However, some solar+battery systems provide the capability to isolate from the grid temporarily and provide full or partial backup power to the house. How long the system can provide backup power depends on the amount of energy stored in the battery and the energy demand from the house. The maximum power that the battery system can supply is also a factor. If the house attempts to draw more power than the battery can deliver, the system will shut down. Some systems include backup as a standard feature, but in other systems additional components are required. Note that momentary dips in grid supply voltage (known as brownouts) can still cause lights to flicker and may reset appliance clocks and computers, etc.. If you want your system to provide power backup, you will need to check with the potential system supplier whether they can provide this capability and whether it is sensible for your situation.

System Monitoring and Management

PV and battery systems usually provide facilities to monitor and manage their behaviour. In some systems this is done using panel displays on the equipment, which is best installed in a convenient location so the controls are accessible. For other systems management is done using smartphone apps and/or website interfaces. In this case, the equipment will require connection(s) to the internet using the home broadband to upload data (usually a real-time feed), download software updates and, possibly, to provide for remote diagnostics in the event of a fault. Connection to the home broadband router may be via WiFi or wired ethernet. For this to work the broadband connection should remain turned on continuously.

If the idea of system management sounds onerous, it need not be. Once some system settings have been configured (usually by the installer), the system can usually be left to run with minimal need for changes. For those who are curious or like to tinker to optimise their system's behaviour, the displays and apps can provide a wealth of information about how the system is performing and facilities to modify its behaviour.

Using surplus solar for water heating

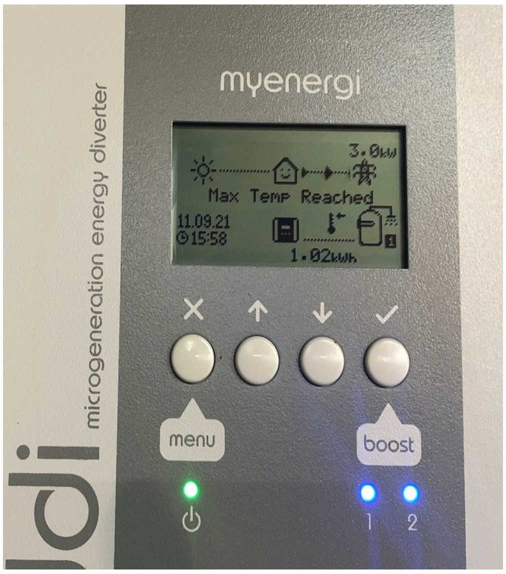

Figure 4: Power Diverter screen

An additional component that may be proposed by the solar system provider is a 'Power Diverter'. Example products are the Immersun and myenergi Eddi. This device monitors the home power feed for surplus power being exported and can divert it to (usually) feed an immersion heater if the house has a hot water tank with an immersion heater fitted. If the thermostat on the immersion heater is closed (water is below temperature) and there is surplus solar, the energy is used to heat the water. When water reaches the target temperature, export of any surplus solar resumes. Heating also stops if there is insufficient solar power to export. Figure 4 shows the screen of an Eddi diverter. Water has reached temperature, 1.02kWh has been diverted and export of surplus solar power has resumed at 3.0kW

Energy metering and export tariffs

You may need to consider changing your electricity energy supplier to get the best benefit from a solar PV generation system.

Surplus solar energy is exported to the grid. The quote from your prospective system supplier will estimate how much will be exported. To generate an income for this energy you will have to set up an SEG (Smart Export Guarantee) tariff with an energy supplier. SEG replaced the FIT (Feed In Tariff) scheme that ended for new installations some years ago. A SMETS 2 type smart meter is required to record the exported energy as well as the imported energy and communicate the values back to the energy supplier. You can ask your energy supplier to install a smart meter if you do not have one. Early smart meters were a SMETS 1 type that usually did not retain smart functions when moving suppliers and will need to be replaced with a SMETS 2 meter. To set up an SEG tariff, the energy supplier has to arrange for an export MPAN (Meter Point Administration Number) which will be associated with your smart meter for export. It will already have an associated MPAN for your energy import (shown on your energy bill). To do this you (or your PV system supplier) will have to submit some documentation which the PV system supplier produces. This process can take several weeks to complete.

Many energy suppliers offer SEG tariffs, but the amount they pay (per kWh) and the constraints they place vary quite widely so it is worthwhile researching the market. Factors to consider when choosing your export supplier:

- What rate (in pence per kWh) does the SEG tariff offer?

- Does the SEG energy company insist on being the import energy supplier too (some accept export only, but may pay a lower rate)?
- Some energy suppliers offer their own solar PV and battery products and their SEG tariff may be lower if they do not provide the system.
- Does the energy supplier allow a home battery system (some don't)?

Connecting to the Grid

PV systems with a peak generating capability above 3.68kW (16 amps at 230V) require permission from the local power Distribution Network Operator (DNO) for the system to be connected to the mains power grid. The PV system provider will have to submit the relevant Application to Connect forms to the DNO before the system can be installed. The DNO may in response place a constraint on the maximum power that can be exported, especially for larger systems. For example, one of the authors has a system rated at 6.4kWp, but the DNO required that power export be limited to 5.4kW. Thus the system design had to include a module (at extra cost) that throttles the inverter output when required to stay within the 5.4kW limit. The DNO for the authors' locations in Suffolk is UK Power Networks (UKPN).

The solar system provider may also recommend or require that the main electricity supply fuse be replaced by a higher rated one. Older houses may have a 60A (amp) main fuse, but the modern standard is 100A (maximum). In this case the you will have to contact the DNO to request a fuse upgrade. This may just involve a DNO technician exchanging the existing fuse for one of the higher value. However, in some properties the supply cable from the road to the premises cannot support 100A, but can support 80A. This should be acceptable in most cases, otherwise a new power supply cable and 100A fuse will need to be installed by the DNO.

House wiring

Regulations for house wiring standards change over time. Notable among these is those that apply to the mains consumer unit (often still known as the "fuse box"). The solar PV and battery system will be connected to the consumer unit. If the consumer unit has no spare slots to connect the PV/battery system or the wiring installation is sufficiently out of date, the PV system supplier may specify an upgrade to the consumer unit as part of the installation to bring it up to modern wiring code.

Carbon reduction

Quotations from prospective system suppliers will usually include an estimate of annual carbon emissions reduction in kg of CO_2. This figure will probably be produced by the system design software that the supplier is using which applies a CO_2 intensity factor of kg CO_2 per kWh of generation. This number may be optimistic. The actual factor varies from day to day, depending on the mix of power generation sources (wind, solar, gas, etc.) operating at the time for different geographic regions. These figures, including averages over a period such as a year are available from online sources. One useful source is on a website mygriddb (see resources). For example, one author's PV system quote used a factor of 0.43kg/kWh, but the average factor from mygriddb at the time was somewhat less at 0.236kg/kWh. For a typical 4kWp solar PV system, which might generate around 3800kWh per year, the CO_2 savings could be 1634kg or 897kg respectively using these two factors.

System suppliers

We cannot make specific recommendations for suitable system suppliers. There are a number of suppliers in our area and it is worth approaching several to discuss your needs. It has been interesting for the authors to see the different approaches that suppliers take to their designs. Your local authority may offer a group buying scheme with a selected local supplier and, as mentioned previously, some of the energy supply companies also offer solar energy products.

Resources

There are many sources of information on solar PV and battery systems online, as you would expect.

One resource of note is the Energy Savings Trust site, where can be found a very useful calculator that you can use to estimate annual solar energy generation by providing a few simple pieces of information: Energy Savings Trust calculator: https://www.pvfitcalculator.energysavingtrust.org.uk/

For estimated annual CO_2 savings, the estimated annual energy generation in kWh from the solar PV system is multiplied by the 'CO_2 intensity' factor. This factor varies from day to day and by geographic region depending on the mix of power generation sources in operation (wind, solar, gas, etc.). A useful source for this information is at: https://www.mygridgb.co.uk

The Martlesham Climate Action website: https://martleshamclimateaction.onesuffolk.net (where you probably found this article) has further useful information, including case studies of solar, battery and heat pump heating systems installed in members' homes. The site also has contact information for the group.