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Domestic Photo-Voltaic installations - their contribution and practicalities

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Abstract

The roofs of domestic-scale properties used to haveone overall main function – to keep the weather out. But since the first solar-PV panels were fitted in the UK in 1994, it has become increasingly clear that, to reduce carbon emissions and thus contribute to the transition to net-zero, all suitable roofs need to be electricity generators as well as weather protection.

Based on the author's 10 years' experience of roof-mounted PV systems, this paper reports on system performance over the recent 3½ years, including part-charging an electric car. The practicalities of specifying the system , the options available and the operational considerations complete the exploration of a modern system. The paper reports in some detail on the results from 3½ years' operation.

The paper also explores financial considerations, largely in a UK context, but a framework is given for decision-making in other generation and financial situations.

Finally, the paper briefly discusses the wider implications of such systems, for example for local and national AC grids.

Keywords: Renewable energy sources; Net Zero emission transition; photo-voltaics; impact of citizen science on environmental attitudes, behaviour, knowledge.

1. Introduction

This is a practice-based paper presenting data and insights from direct experience of two domestic-scale solar-PV systems (hereafter called System 1 and System 2) alongside learnings from others' experiences, over 12 years. Although it describes and reports on some operational research on the two systems, and presents web-researched views on recent developments, it is not a conventional scientific research paper.

The author hopes it aids better-understanding of the options and practicalities of domestic PV, provides guidance to anyone considering installing such a system, and help to those seeking to operate such a system in a way that maximises use of the generated electricity and/or minimises needless import of electricity from the grid.

System 1 was installed in 2011 with12 panels (all facing within a few degrees of south), an inverter and an export meter. The system was straightforward, with little opportunity to vary the way in which the generated electricity was used, but it was, in essence, all that was available at the time. It generated about 95% of electricity usage in the house over its first 5 years, with around 70% of generation exported and a similar amount imported.

Figure 1: System 1 Panels

System 2, specified and installed in 2019, is larger because of the sub-optimal orientation of the roofs, and has more components. These were aimed at maximising utilisation of the generated energy on site, and at supplying a very significant proportion of the charge needed to run an electric car. See Figure 2.

Figure 2: System 2 Panels
Top: SE & SW-facing; Lower: NE-facing

2 System 2: details and system element selection

Building on the development of available elements since the first system, the design of System 2 was an attempt at an optimal system as at mid-2019. The aim was not only to deliver self-sufficiency for the house consumption (by regarding the grid as acting as the equivalent of a large battery) but also to supply a very significant proportion of the charge needed to run an electric car.

System 2 has 21 panels, a house battery with usable capacity of 8.8 kWh, an immersion controller that provides manual use, and automatic use of what is called excess solar, and a combined Solar Inverter/EV Charger.

None of the panels face close to due south: 8 face just south of south-east, 5 just west of south west and 8 just east of north east. This does not sound encouraging, but the L-shaped arrangement of the house enabled the inclusion of a larger number of panels than necessary for just house consumption. This not only compensates for the orientations not being close to south, but also the different orientations combine to widen the generation curve. An important final factor in the choice of this system was price reductions for elements in real terms.

The above comments on the System 2 design reflect the rapid change in system components available and their pricing. This was further highlighted by the System 2 supplier admitting, after it was operational, that although they had fitted all of the components before, System 2 was the first that the supplier/installer had supplied with *all* the elements combined. Three years later, they have supplied many 10s of such multi-element systems.

3 Overall outcomes for System 2

3.1 Power generation

Overall, System 2 has been working since mid-October 2019, 3.5 years at the time of writing. Total generation so far is 16.2 MWh, 87% of total consumption since switch-on. That consumption includes all the home charging of an electric car for 2.7 years.

Looking at performance in 2022, which is not only the most recent full year but also reflects some maturity in the way System 2 is operated, its performance was:

- Generation: 5.25 MWhrs
- House consumption: 2.85 MWhrs
- Excess of generation over house consumption: 2.4 MWhrs
- Total Car charging at home 3.0 MWhrs
- PV contribution to home car charging: 80%
- Total car charging at home and away: 3.65 MWhrs
- Overall PV contribution to car charging: 66%.

See figure 1 below.

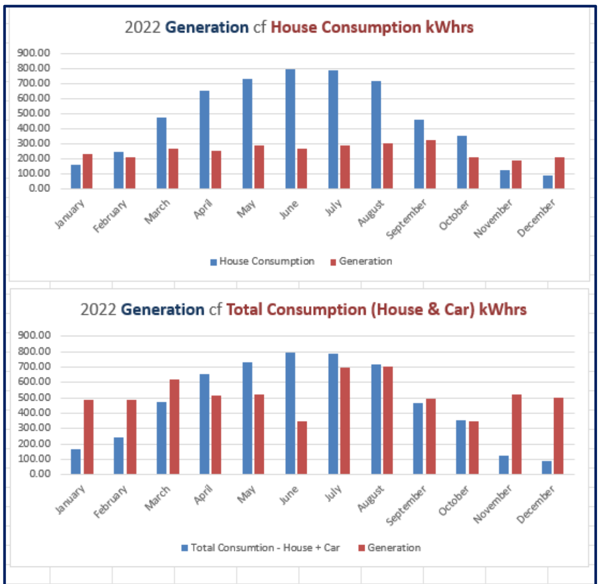

Figure 1 :2022 Generation cf House Consumption and House + Car Consumption kWhrs

3.2 Embodied Energy payback

On the issue of energy payback, which is in the author's view a very important aspect for prospective buyers, it is regretted that it is not possible to provide clear data. There is one primary stumbling block – the absence not only of embodied energy data for the overall System, but also the absence, at least in the public domain, of consistent data for each system element. What data is available implies that the embodied energy in System 2 could range from 4 MWh to 16 MWh. These then give embodied-energy payback times of 0.8 to 3.5 years.

3.3 Embodied carbon payback

The same issues of data availability and consistency apply here too but even more so, because of the added problem of not being able to determine the energy mix used in the manufacture of system elements. In addition, there remains a debate in carbon assessment circles on whether any component made using entirely renewable energy should be counted as having no carbon content, or having a carbon content based on the average carbon emissions per kilowatt-hour for the country in which manufacture takes place. This paper is not the place for a contribution to that debate, only to acknowledge it.

On the plus side, Solar Edge (www.solaredge.com) provide, in the App for controlling System 2, two items of data under the heading of Environmental Benefits:

- CO2 Emissions Saved (so far) = 3,345 kg, and
- Equivalent Trees Planted = 202,

which feel very positive. However, so far, it has not been possible to secure details of the algorithm on which these two numbers are based, which do not include payback of embodied carbon.

3.4 Do these payback estimates matter anyway?

The expected life of modern systems is at least 25 years, and many commentators suggest we should not become too fixated on the embodied energy and carbon payback periods (Stack Exchange, 2020 & 2022). Why? Because, with the above range, System 2 should supply at least 21 years of generation after paying back the planet for the energy consumed in creating System 2.

Efforts to drive down the embodied energy should be pursued, and assessment techniques refined, but the overall view from web research is that renewable energy as a whole is much better for us environmentally and economically than any form of fossil-fuel-based power.

3.5 Finance
Here too, the assessment is not quite as straightforward as one might wish. Why? Because, whilst the data from the Apps provided by system suppliers and from Smart Meters is extensive, in the author's experience it would still a) need to be complete (there are often gaps), and b) require very time-consuming gathering and manipulation-by-hand of data from the App or Smart Meters. However, using annual data and some estimation, for example of the total consumption over the year in the period from midnight to 7pm each night for which a lower rate is normally paid, some useful indicators can be derived.

First of all, some fundamentals.

- At the time of System 1, the UK Government were actively encouraging homeowners to instal PV systems by providing what they called a Feed-In Tariff (Ofgem, 2020), where owners were paid for all of the electricity they generated, including what they used. This was a mechanism for paying owners for becoming generators, rather than just a reasonable return on capital employed (ROCE).
- Since April 2019, the basis of investing in UK PV systems has changed to earning a return through saving on electricity from the grid and, increasingly, from the Smart Export Guarantee (Ofgem 2023), with payments by energy suppliers to system owners for exported electricity.
- In System 2, none of the payments to System 2's owner relate to paying back the capital, Instead, the savings are considered as the equivalent of interest on a capital sum, but one that you will *not* have returned to you until the property is sold. Even then, it will not be possible to identify any part of the sale price as payment for the system.
- The headings in which savings or income can arise in relation to house consumption include:
    - reduced importation of grid electricity equal to overall generation less the total exported
    - reduced gas consumption in summer by using excess solar electricity in an immersion tank
    - payments for exported electricity.
- If an electric vehicle is added to the mix, then savings will arise from home charging compared to public chargers and, depending on the costs of each, possible savings compared to petrol or diesel.

In terms of practicality, the ease of identifying the data needed to measure and calculate these savings will depend on the data-gathering features of the PV System control & monitoring App, and the data available from the grid electricity supplier.

One also has to check the accuracy of the App measurements: note that the figures quoted about System 2 have been adjusted down from those provided by the PV System App because the officially certified generation meter shows that the System 2 App over-reads generation by around 6%. As to the financial amount of the savings, a key element is of course the price paid by a system owner for imported electricity and gas.
For System 2 in 2022, the Return on Capital Employed, when the import prices were less than the variable market rates because of a two-year price fix from July 2021, was around 3.5%, much larger than conventional interest rates available at the beginning of 2022. If the generation and consumption numbers for 2023 are similar to 2022, then the current domestic prices of electricity and gas suggest that the 2023 ROCE will be about 5.5 to 6%.

4 Practicalities

4.1 System design and level of complexity
Not all potential buyers or owners of domestic-scale PV require the most comprehensive specification that is now possible. It seems that many suppliers are now offering a house battery as a 'standard fit' and an integrated car-charger also as standard fit for houses with off-street parking. However, the straightforward nature of System 1, of just panels, an inverter and export metering, works for many owners with low consumption of electricity. Such owners are content with the balance of lower capital costs and the need to import more electricity than would be the case if, for example, a battery were to be added. What is needed is the ability to add features later.

4.2 Maximising self-consumption and minimising imports
It is of course possible for any system to be run with minimal intervention by the system owner. In those circumstances, demand is met from the PV or the grid as demand and generation vary. This is likely to result in more grid import and more export (which means greater net cost) for any given overall demand.

By contrast, active management of demand by home-owners, as has been applied to System 2, can be used to increase what is called Solar Self-consumption (Solar Southwest, 2023). This is typically given as a percentage and refers to the total amount of PV energy consumed, either directly in the property or via a house battery, in relation to the total amount of energy generated. This approach generally leads to reduced import levels and reduced export levels for any given overall demand.

There are many sources on the web about how to do this (e.g. Solar Southwest, 2023). Most guides focus on changing usage, of which these are three examples.

- Users can ensure that combinations of power use that take the needed supply above the rated inverter capacity (normally between 3.6 and 4 kW) are not run together (e.g. oven and water heater);
- Users can lower the instantaneous power rating of individual and frequent uses – for example buying a lower-powered kettle to prevent import being triggered in times of low generation;
- One can also actively manage the charging of a car direct from roof generation. For example, using a 10-amp charger from a domestic socket, on partly cloudy days when the house battery is partly full, will enable generation above 2.4kW to flow into the house battery and when generation is below 2.4kW to be topped up from the house battery. This is often better than using an autocharger because that starts only when excess solar is above a trigger level (1.4 to 1.5kW), which means some power is exported as the excess solar level grows, and because the charger stays connected when

generation falls below the trigger level), meaning that unwanted imports are brought in.

However, note that the price paid by the network operator for exported electricty can sometimes exceed the cost of overnight imported electricity, in which case it is better financially for the PV system owner to divert energy consumption that can be done at night from direct solar.

5 Future prospects for domestic-scale PV

5.1 Growth opportunities and motivations

Once again, the data from public sources is generalised. In the UK, it has been estimated that 1.2 million houses (approx 4%) have solar PV systems, but data on the total capacity of those systems has not been identified. By contrast, for Greece, there is an estimate of total domestic capacity (370MW) but no data on the number of houses with PV systems (for example, The Eco Experts, 2023).

Not all houses are suitable, or orientated in any helpful direction. In addition, and especially during the present extreme pressures on the cost of living, only a modest number of house owners will have the resources needed to fit a PV system. Nevertheless, modest take-up so far amply demonstrates substantial opportunity for growth in numbers of systems, generation and carbon saving.

As for the motivations for owner-occupiers to invest in solar PV systems, these range from ‘doing the right thing’ through an active decision to reduce carbon emissions to securing an attractive rate of return from available capital. UK local government is also assisting in this area by facilitating purchases of PV systems by groups of owners in a geographical area, at prices discounted from those for individual installations. (Solar Together, 2023)

5.2 Could national grids cope?

The UK National Grid Company says it is coping now but “strategic investment in the whole energy system is urgently required to keep pace with Net Zero ambitions and strengthen energy security” (National Grid, 2022).

In Germany in 2020, Green Tech Media asserted that “Northern Germany can’t use all the renewable energy it’s making. Neither can its neighbors”. In 2022, EURACTIV reported “German electricity grid upgrade ‘will be expensive’, experts warn” because at that time “Germany’s power grid” was “in dire need of upgrade to ensure stable supply in a country aiming to source 80% of its electricity from intermittent wind and solar by 2030”.

In Greece, renewable energy sources (RES) are a major focus of the Greek National Energy and Climate Plan (Hellenic Republic, Ministry of the Environment and Energy, December 2019, updated January 2023), which acknowledges that “management complexity and time lags due to external factors are the main challenges to the setup of such plants, and there is a need to address the congestion of the power grid in order to allow for setting up new RES capacity in areas with a high potential.”
So, in summary, some grids are coping, some are not, some struggle; some will need minor upgrade, some major. Overall, however, it is clear that the present and coming challenges are known by national authorities, and they have plans to cope in order to deliver on promises of net-zero carbon emissions by no later than 2050.

6 Conclusions

- Existing domestic-scale PV systems are beneficial.
- New systems will be even more effective because of improvements in the technologies involved – panels, inverters and control systems.
- The potential markets are very large compared to systems supplied so far, and the motivations of potential owners vary, as does the capital required.
- Extensive practical information and guidance on operating modern systems effectively is available.
- No consensus on whether they increase house value has been found. Views range from “they don't provide an increase in house value”(Money Saving Expert 2023) to “suggestions range from 4% to 14% on average” (Yopa, 2023). However, there is some consensus that “they are unlikely to detract from the value of your home (Yopa 2023).
- The extent to which national grids have coped and are coping with growing supply from widespread modest-scale inputs is varied. However, it seems clear that national authorities are actively working to provide the necessary system upgrades

So, for anyone with some capital for which a good return is desired and who can cope with that capital becoming illiquid, then it could be a positive option to consider.

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