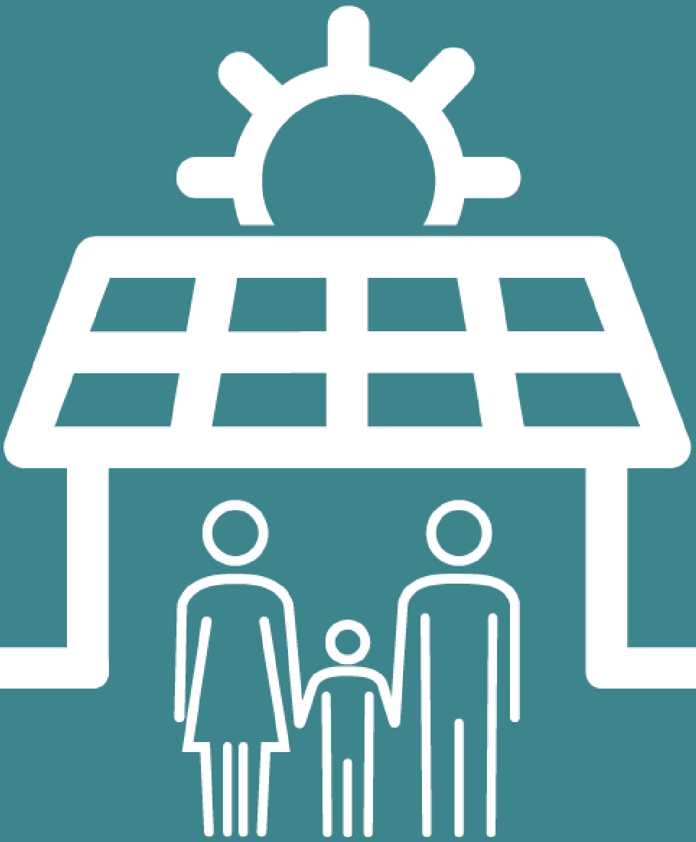
NEA

Action for Warm Homes



Increasing self-consumption of solar PV

Increasing self-consumption of solar PV:

Analysis of long-term performance of domestic solar PV installations

Paul Rogers and Michael Hamer

Background

National Energy Action is the national fuel poverty charity working across England, Wales and Northern Ireland, and with sister charity Energy Action Scotland (EAS), to ensure that everyone can afford to live in a warm, dry home. In partnership with central and local government, fuel utilities, housing providers, consumer groups and voluntary organisations, NEA undertakes a range of activities to address the causes and treat the symptoms of fuel poverty. Its work encompasses all aspects of fuel poverty, but in particular emphasises the importance of greater investment in domestic energy efficiency.

This project was carried out by the Innovation and Technical Evaluation team at NEA

January 2023

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1. Introduction

1.1. Project aims

The Increasing Self-Consumption of Solar PV project was funded by the Energy Industry Voluntary Redress Scheme and had several aims:

- Develop solar PV advice materials and distribute these to households with solar PV
- Provide training on solar PV for front-line workers
- Provide advice to households with solar PV by telephone, email and face-to-face
- Install solar PV monitors and solar immersion controllers and assess how beneficial residents find these devices
- Assess the long-term performance of domestic solar PV systems, looking at reasons for system downtime and details of the faults which developed

This report focuses on assessing the long-term performance of PV systems installed on socially rented properties and discussing issues which may cause lower performance.

1.2. Report overview

The report initially considers factors which affect the electricity generated from solar panels such as the system size, orientation, inclination and level of shading. It also discusses methods that are commonly used to estimate annual generation such as the MCS method outlined in the MCS Solar PV standard MIS 3002, the PVGIS website and PV*SOL software.

The components of a solar PV system are described and the most common faults that can develop are discussed. There are case studies from several social landlords and community energy organisations, discussing the size of their solar PV portfolios and how they monitor and maintain the systems. Among the case studies is one for Chase Community Solar (CCS), a community energy organisation that has a portfolio of 312 domestic solar PV systems on bungalows which are socially rented by Cannock Chase Council.

NEA was working with Chase Community Solar on another project funded by the Energy Industry Voluntary Redress Scheme, where 75 batteries were fitted on some of the bungalows with solar PV. As a result of this collaboration, it was possible to access anonymised data from this fleet of systems.

The long-term performance of 75 solar PV systems was assessed between 2016 and 2021. Properties were grouped in 12 different areas with similar solar PV installations. They were chosen so that PV systems in each area had approximately the same orientation and inclination. The performance of systems could be compared by looking at annual generation (kWh/kWp). Periods with lower generation were investigated and explanations were obtained where possible. These included periods where the property was unoccupied, inverter faults, meter and communication issues and problems with RCD trips or isolators being turned off. Out of the 75 properties analysed, 33 had battery storage systems fitted in 2022.

2. Factors affecting electricity generation from solar panels

The annual generation from a domestic solar PV system will depend on a number of factors:

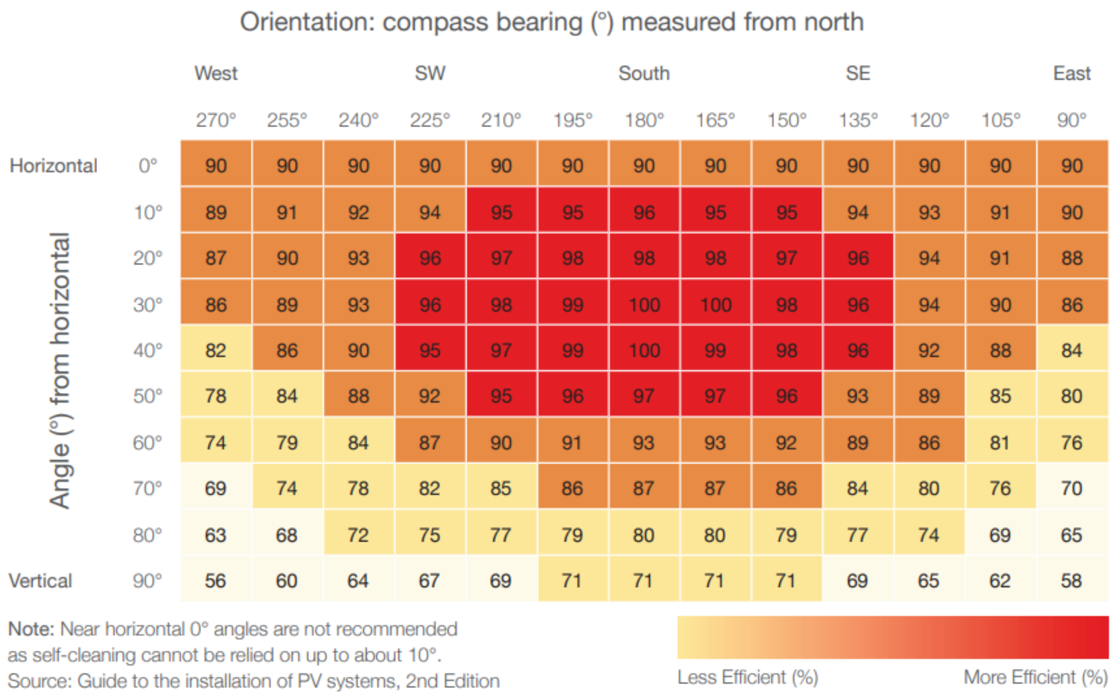
- Size of the solar PV array
- Orientation of the solar PV array
- Inclination of the solar PV array
- Shading of the solar panels
- Location
- Solar irradiance that year
- Components used for the solar PV system

2.1.1. Size and components of the solar PV array

The maximum power output of the solar PV array is one of the key factors which affect the annual generation. This is calculated by multiplying the number of panels by their rated power and depicted as kWp (kilowatt Peak). The models of solar panel and inverter used and how they interact will also affect the annual generation. Solar PV system designers can assess how different components might affect the annual generation using design software such as PV*SOL.

2.1.2. Orientation and inclination of solar array

The orientation and inclination of the solar panels affects the level of solar energy reaching the panels. In the UK, maximum annual generation will occur for a solar array that faces south on a roof inclined at about 35 degrees.



Orientation: compass bearing (°) measured from north

Angle (°) from horizontal		West			SW			South			SE			East
		270°	255°	240°	225°	210°	195°	180°	165°	150°	135°	120°	105°	90°
Horizontal	0°	90	90	90	90	90	90	90	90	90	90	90	90	90
	10°	89	91	92	94	95	95	96	95	95	94	93	91	90
	20°	87	90	93	96	97	98	98	98	97	96	94	91	88
	30°	86	89	93	96	98	99	100	100	98	96	94	90	86
	40°	82	86	90	95	97	99	100	99	98	96	92	88	84
	50°	78	84	88	92	95	96	97	97	96	93	89	85	80
	60°	74	79	84	87	90	91	93	93	92	89	86	81	76
	70°	69	74	78	82	85	86	87	87	86	84	80	76	70
	80°	63	68	72	75	77	79	80	80	79	77	74	69	65
Vertical	90°	56	60	64	67	69	71	71	71	71	69	65	62	58

Note: Near horizontal 0° angles are not recommended as self-cleaning cannot be relied on up to about 10°.
Source: Guide to the installation of PV systems, 2nd Edition

Figure 2.1 Percentage of the maximum possible yield from a solar PV system in the UK for different orientations and inclinations
(Graphic from Mitsubishi Electric Information Guide, Photovoltaic Systems, Issue 40)

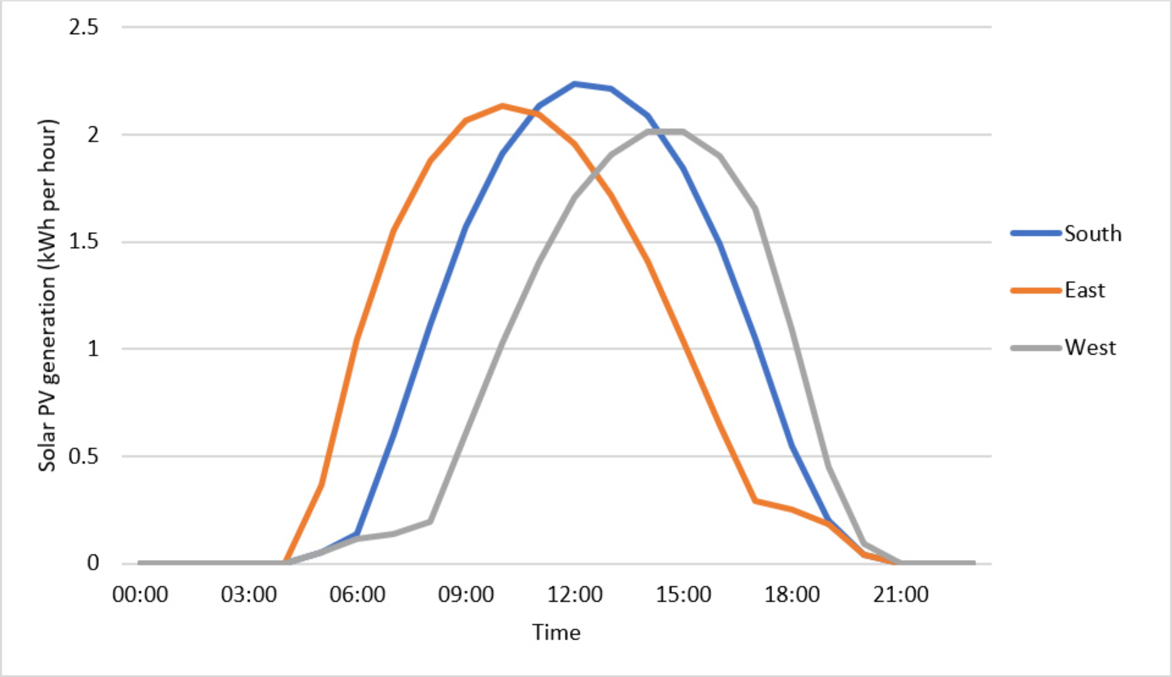


Figure 2.2 How the orientation of the solar PV array affects daily PV generation

The sun rises in the east and a solar PV array facing east will typically have a peak in electricity generation before midday. A south facing solar PV array will generate maximum electricity at about midday. The peak in generation will be higher than for a comparable sized east or west facing PV array. A west facing solar PV array will tend to generate maximum electricity later in the afternoon.

If the priority of the owner of the solar PV system is to maximise electricity generation from the solar panels, then a south facing array inclined at 35 degrees would be best. This was an important consideration when selecting sites for solar PV during the period of the feed-in tariff.

However, there are advantages in having a domestic solar PV system with panels on both east and west facing roofs. The maximum output from the PV system during the day is lower as is the annual generation. However, there is more PV generation in the early morning and late afternoon, at times when residents are more likely to be using electricity. This means the level of self-consumption of the solar generated electricity could be higher for households with an East-West solar PV array.

2.1.3. *Shading of solar panels*

Shading or dirt on solar PV panels will reduce the electricity generated.

A string inverter has the solar panels wired together in series in one or two strings. With a string inverter, if the output from one solar panel is reduced to 50% due to a shadow on the solar panel or significant levels of dirt, the output from the other solar panels linked in series on the same circuit or string will be similarly affected. There are technologies which aim to reduce the impact of shading solar PV generation. These include microinverters or optimisers which may be fitted to each solar panel. Microinverters and optimisers are a more expensive option than a string inverter and may only be chosen in situations where shading is likely to be an issue. Modern half-cell solar panels have higher tolerance to shade due to the way the cells are wired in the module. These have only been available for a few years and are not likely to have been installed with PV systems during the time of the feed-in tariff.

When estimating the annual generation for a solar PV system, the impact of shading at the site needs to be considered. Shading of solar panels might come from trees or bushes or a nearby building. It can also be caused by chimneys or other features of the property producing a shadow on some of the solar panels at a particular time of day.

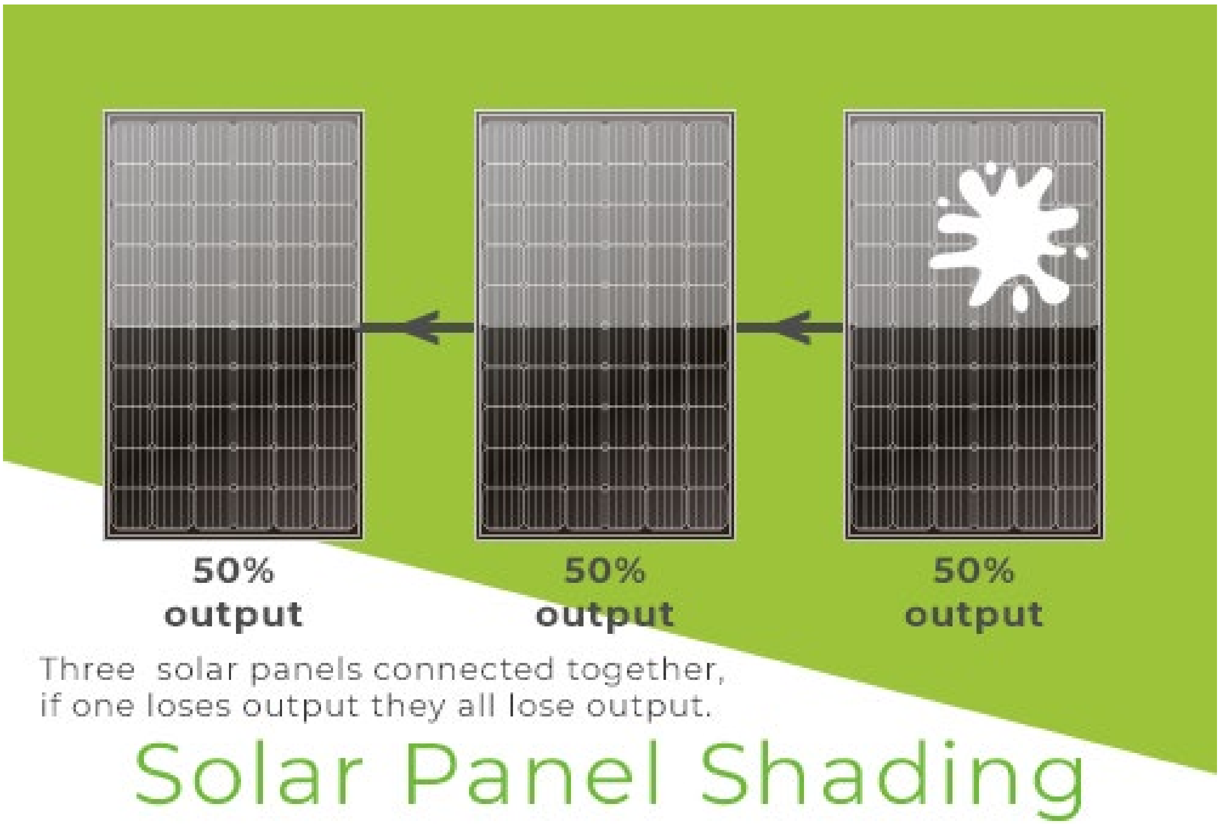


Figure 2.3 Graphic illustrating how shading or dirt on a solar panel can affect the electricity generated by other panels in the same string

(Image from Fresh Electrical Solar https://www.freshelectricalsolar.co.uk/solar-panel-optimisers/)

2.1.4. Location and solar irradiance

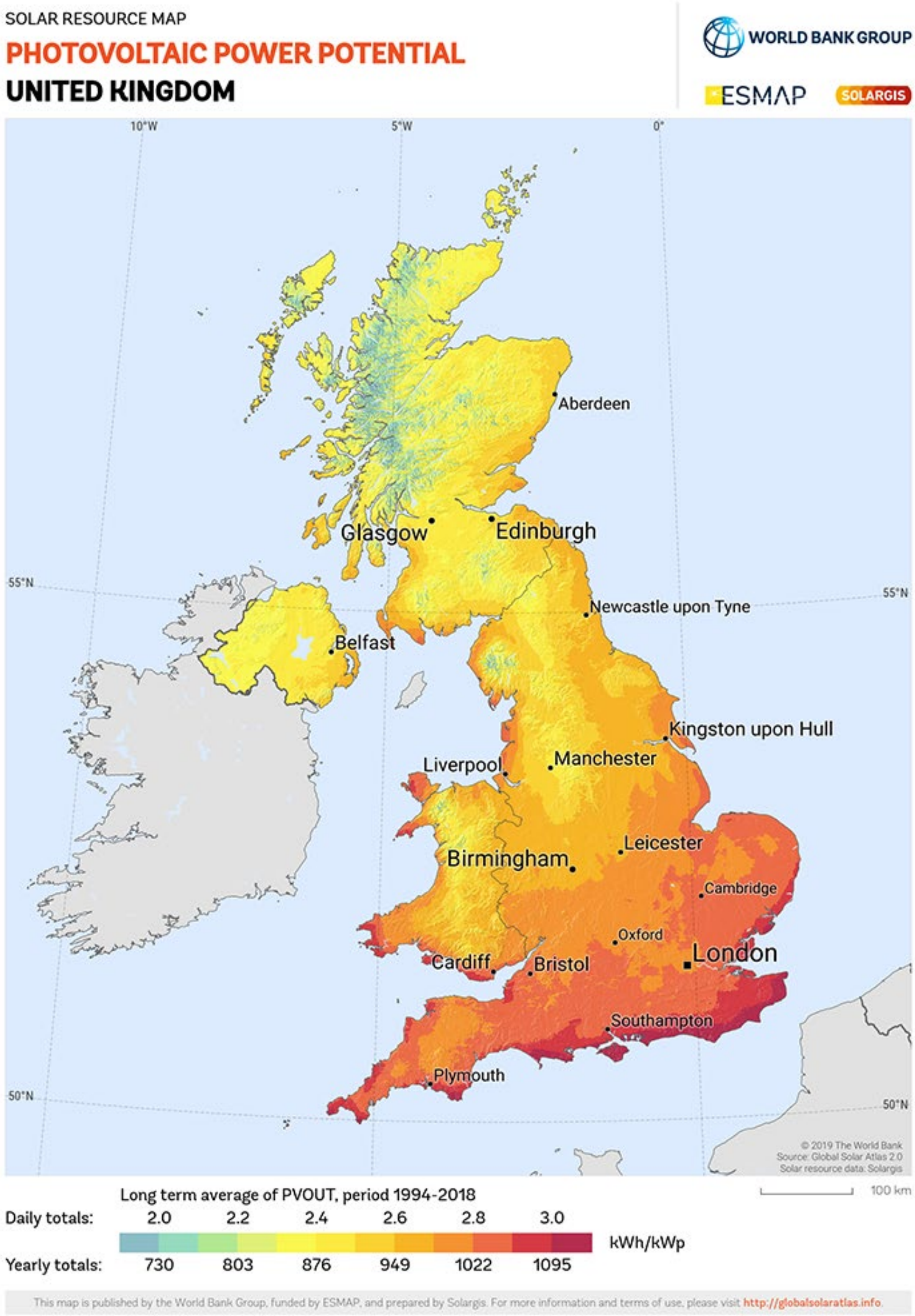


Figure 2.4 Map of Photovoltaic Power Potential (kWh/kWp) for the UK

(© 2020 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis)

Figure 2.4 shows how the average level of solar irradiance varies across the UK. A solar PV array located in the south of England will generate more electricity per year than a solar PV system of similar size and orientation in the north of Scotland. A solar PV system with optimum orientation and inclination in the south of England might generate over 1,000 kWh per kW of solar panels.

Figure 2.5 shows that significantly more electricity is generated on a sunny day than on a cloudy day with less direct sunshine. Figure 2.6 shows there are high levels of solar PV generation between March and September. The monthly generation can however vary significantly between years. A sunny June can be followed by a damp and cloudy June the following year. There may be less variation in the annual generation than in the monthly generation as weather patterns can even out over a year.

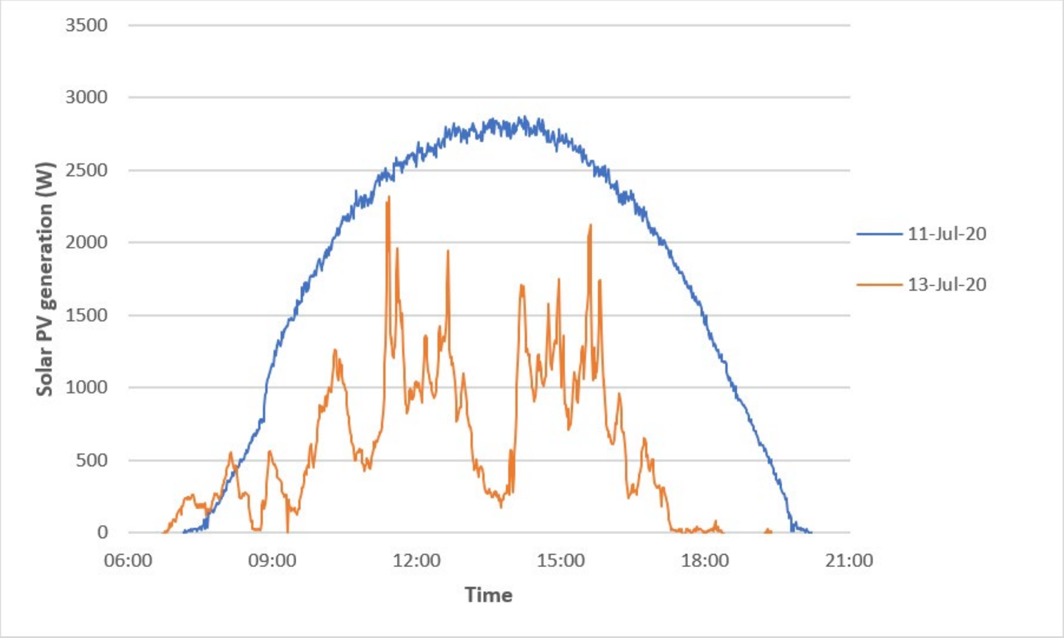


Figure 2.5 Graph showing PV generation on two days in July 2020, illustrating the impact of weather on electricity generated

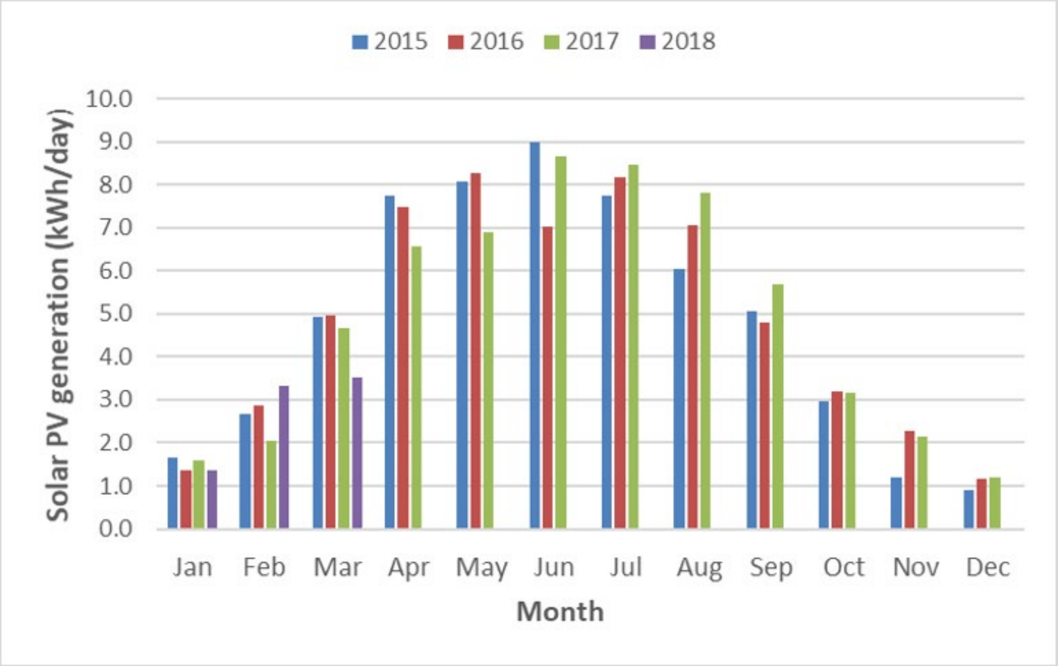


Figure 2.6 Variation in solar PV generation between 2015 and 2018 for a 2.35kW solar PV system in London orientated 60 degrees from south

3. Estimation of annual generation

3.1. MCS Method for estimating annual generation

Solar PV installers and system designers should produce an estimate of the annual generation for a domestic solar PV system. The standard method used is described in the MCS Solar PV Standard, MIS 3002[1]. This uses the following equation:

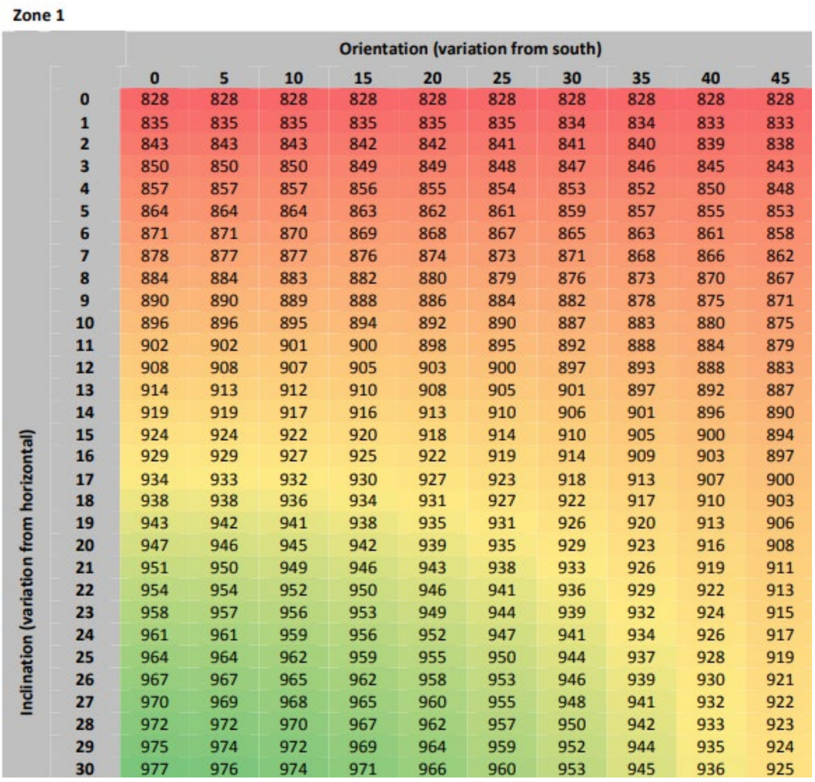
$$Annual\ AC\ output\ (kWh) = kW_p \times K_k \times SF$$

kW_p is the sum of the rated power outputs from each of the solar panels in the array.

K_k is influenced by:

- Angle of orientation of the array
- Angle of inclination of the array
- Location of the installation in the country

Tables have been produced which show the value of K_k for different angles of orientation and inclination. Figure 3.1 shows an example table which is for the region around London. Overall, the UK has been divided into 21 different regions (figure 3.2) which each have their own table for determining K_k.



Zone 1

Inclination (variation from horizontal)	Orientation (variation from south)									
	0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**
0	828	828	828	828	828	828	828	828	828	828
1	835	835	835	835	835	835	834	834	833	833
2	843	843	843	842	842	841	841	840	839	838
3	850	850	850	849	849	848	847	846	845	843
4	857	857	857	856	855	854	853	852	850	848
5	864	864	864	863	862	861	859	857	855	853
6	871	871	870	869	868	867	865	863	861	858
7	878	877	877	876	874	873	871	868	866	862
8	884	884	883	882	880	879	876	873	870	867
9	890	890	889	888	886	884	882	878	875	871
10	896	896	895	894	892	890	887	883	880	875
11	902	902	901	900	898	895	892	888	884	879
12	908	908	907	905	903	900	897	893	888	883
13	914	913	912	910	908	905	901	897	892	887
14	919	919	917	916	913	910	906	901	896	890
15	924	924	922	920	918	914	910	905	900	894
16	929	929	927	925	922	919	914	909	903	897
17	934	933	932	930	927	923	918	913	907	900
18	938	938	936	934	931	927	922	917	910	903
19	943	942	941	938	935	931	926	920	913	906
20	947	946	945	942	939	935	929	923	916	908
21	951	950	949	946	943	938	933	926	919	911
22	954	954	952	950	946	941	936	929	922	913
23	958	957	956	953	949	944	939	932	924	915
24	961	961	959	956	952	947	941	934	926	917
25	964	964	962	959	955	950	944	937	928	919
26	967	967	965	962	958	953	946	939	930	921
27	970	969	968	965	960	955	948	941	932	922
28	972	972	970	967	962	957	950	942	933	923
29	975	974	972	969	964	959	952	944	935	924
30	977	976	974	971	966	960	953	945	936	925

Figure 3.1 Table of values for Kk in Zone 1 around London[2]

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[1] Appendix B, MCS MIS 3002, Issue 4.0, The Solar PV Standard (Installation), https://mcscertified.com/wp-content/uploads/2021/10/MIS-3002_Solar-PV-Systems-V4.0.pdf (Accessed 27 Jan 23)

[2] Zone 1 – London, Irradiance datasets spreadsheet, MCS Solar PV Installer standards, https://mcscertified.com/standards-tools-library/ (Accessed 27 Jan 23)

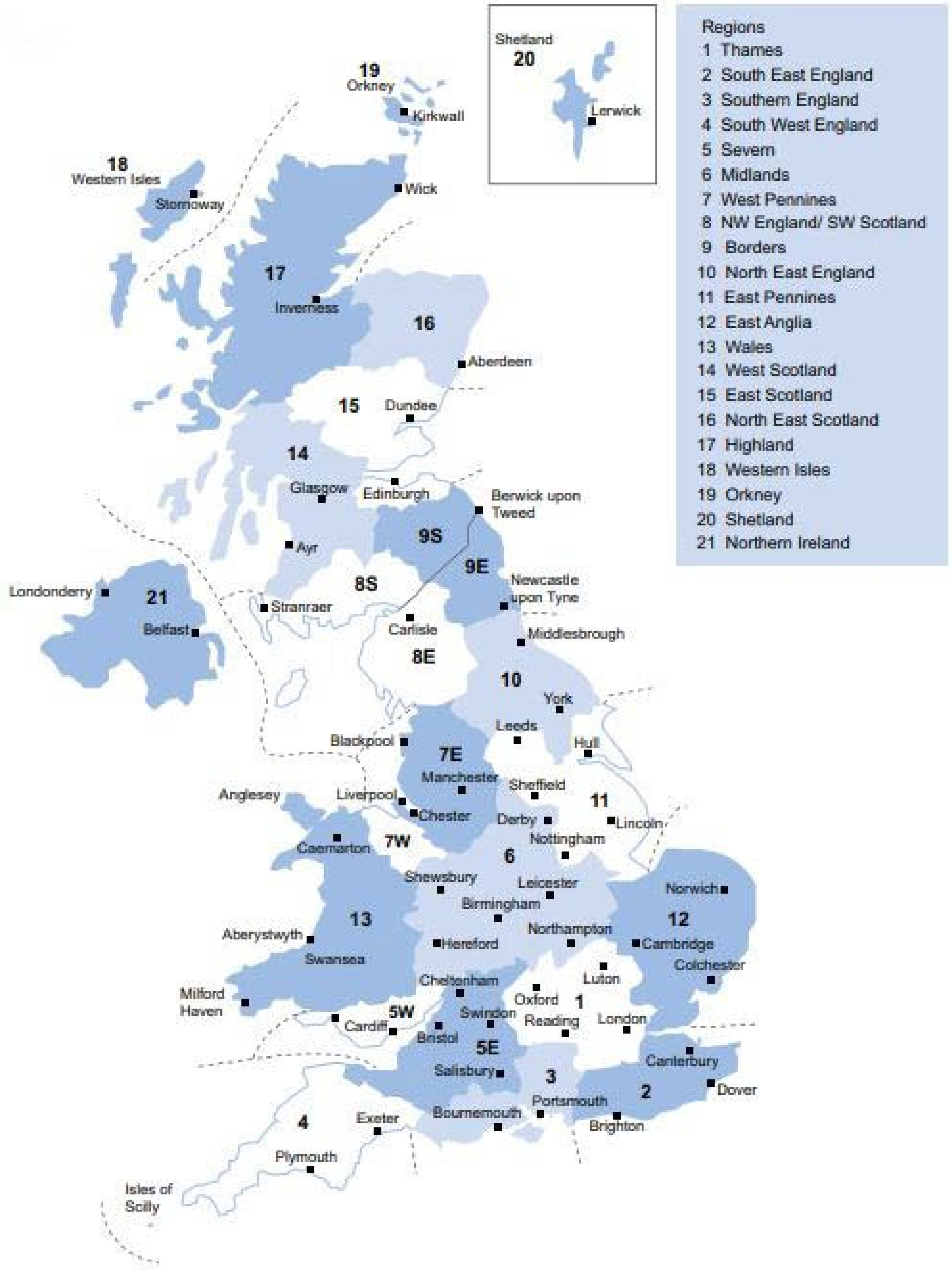

Figure 3.2 Map showing the 21 regions of the UK with tables for determining the value of Kk (From MCS MIS 3002 The Solar PV Standard)[3]

SF in the equation for estimating PV generation is the Shade Factor. This has a value of between 0 and 1. SF has a value of 1 if there is no apparent shading.

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[3] Appendix B, MCS MIS 3002, Issue 4.0, The Solar PV Standard (Installation), https://mcscertified.com/wp-content/uploads/2021/10/MIS-3002_Solar-PV-Systems-V4.0.pdf (Accessed 27 Jan 23)

If there is shading of the solar array by trees, bushes or buildings, an assessment should be made of the impact on the level of generation. MCS recommend using a sun path diagram to assess the proportion of incident solar energy which could be blocked by obstructions at different times of the day and year. This can be from objects which are close to the PV array or further away towards the horizon.

Figure 3.3 shows an example sun path assessment. The diagram has 84 segments which each have a value of 0.01. In order to calculate SF, you first count the number of segments which are affected by the object. In the case of figure 3.3, this is 11 segments.

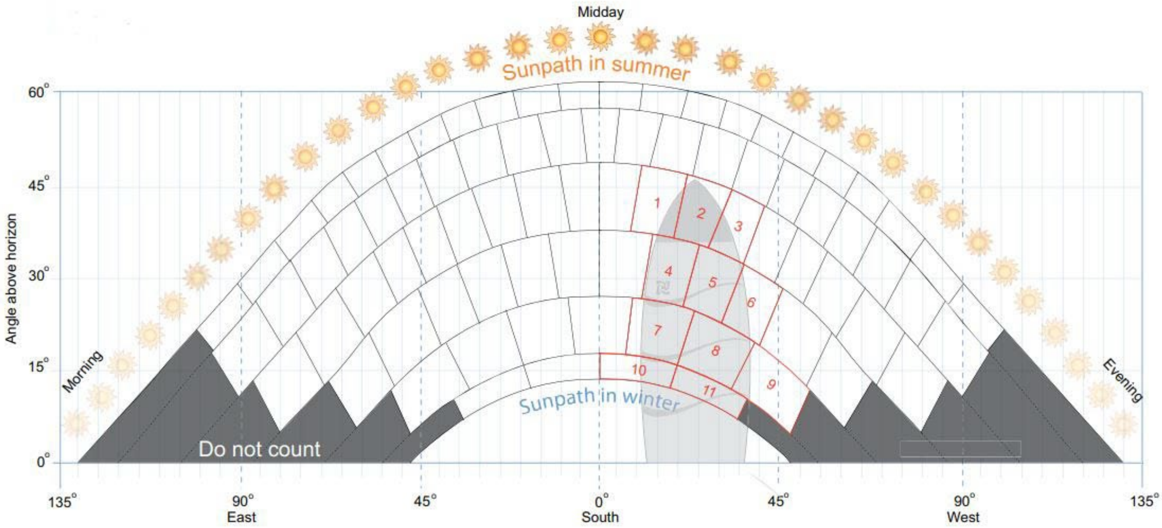

Figure 3.3 Sun path diagram showing an example shading assessment
(From MCS Solar PV Shade Evaluation Procedure)[4]

For figure 3.3,

$$SF = 1 - (0.01 \times segments\ affected) = 1 - (11 \times 0.01) = \mathbf{0.89}$$

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[4] MCS MGD 005 Solar PV Shade Evaluation Procedure, A method to determine Shade Factor, https://mcscertified.com/wp-content/uploads/2021/10/MGD-005-Solar-PV-Shade-Analysis-V1.0.pdf (Accessed 27 Jan 23)

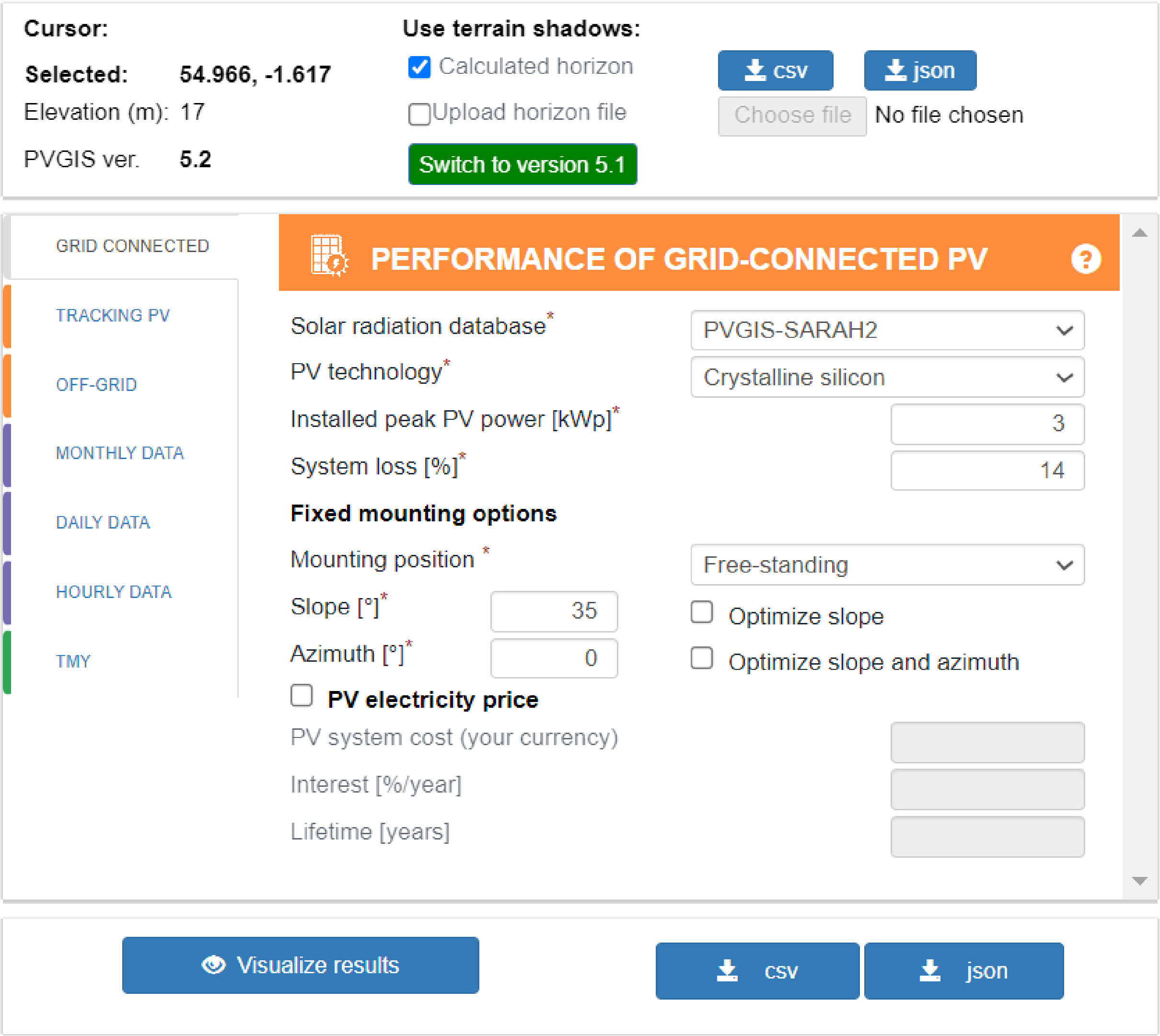
3.2. Other methods to assess annual generation

3.2.1. PVGIS Photovoltaic Geographical Information System

PVGIS is a free web application hosted by the Joint Research Centre (JRC), the European Commission's science and knowledge service. It provides estimates of solar radiation and potential electricity generation for solar PV systems for locations around the world.

You can enter details of the location of the installation by inputting the postcode or the latitude and longitude. You also enter the solar PV system size (kWp), inclination of the panels (slope) and azimuth (orientation) as shown in figure 3.4. The azimuth is the direction relative to due south, with east being -90 degrees, south 0 degrees and west +90 degrees.

The application can take into account shading from local hills or mountains which block the sun for periods of the day. The default calculation does not take into account shading from nearby objects such a trees and buildings. However, it is possible to upload horizon information so shading from such objects can be corrected for. By clicking on 'Visualise results', estimates of the energy production by the solar PV system are produced.



Cursor:
Selected: 54.966, -1.617
Elevation (m): 17
PVGIS ver. **5.2**

Use terrain shadows:
☑ Calculated horizon
☐ Upload horizon file
No file chosen

PERFORMANCE OF GRID-CONNECTED PV

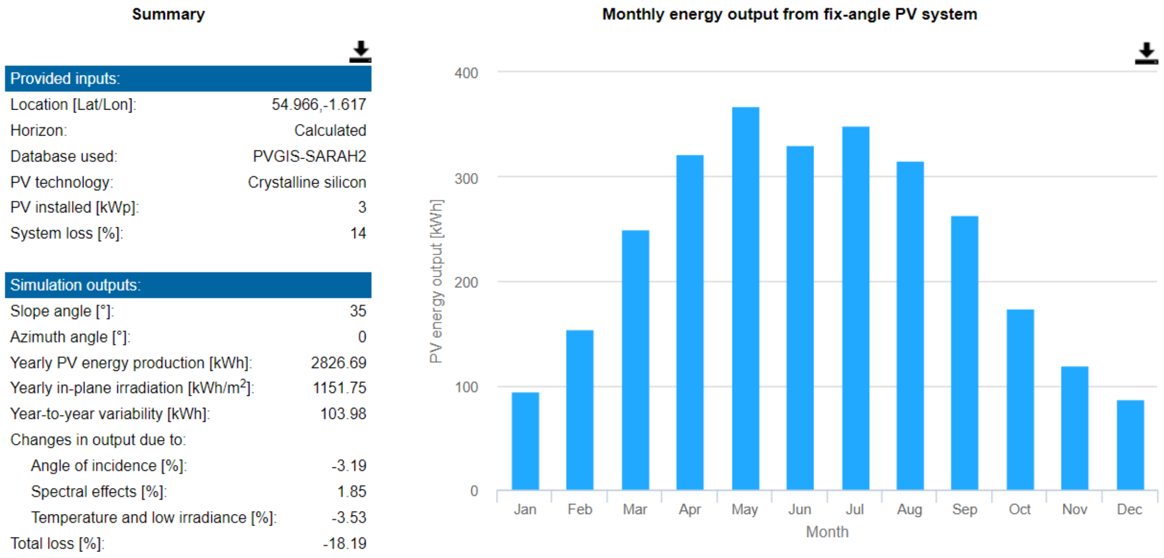
Solar radiation database* PVGIS-SARAH2
PV technology* Crystalline silicon
Installed peak PV power [kWp]* 3
System loss [%]* 14

Fixed mounting options

Mounting position * Free-standing
Slope [°]* 35
Azimuth [°]* 0
☐ Optimize slope
☐ Optimize slope and azimuth

☐ **PV electricity price**
PV system cost (your currency)
Interest [%/year]
Lifetime [years]

Figure 3.4 Data entry for PVGIS calculation
(From https://re.jrc.ec.europa.eu/pvg_tools/en/ Accessed 27 Jan 23)



Summary

Provided inputs:	
Location [Lat/Lon]:	54.966,-1.617
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed [kWp]:	3
System loss [%]:	14

Simulation outputs:	
Slope angle [°]:	35
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	2826.69
Yearly in-plane irradiation [kWh/m^2]:	1151.75
Year-to-year variability [kWh]:	103.98
Changes in output due to:	
Angle of incidence [%]:	-3.19
Spectral effects [%]:	1.85
Temperature and low irradiance [%]:	-3.53
Total loss [%]:	-18.19

Monthly energy output from fix-angle PV system

Figure 3.5 PVGIS analysis showing annual and monthly generation from solar PV system
(From https://re.jrc.ec.europa.eu/pvg_tools/en/ Accessed 27 Jan 23)

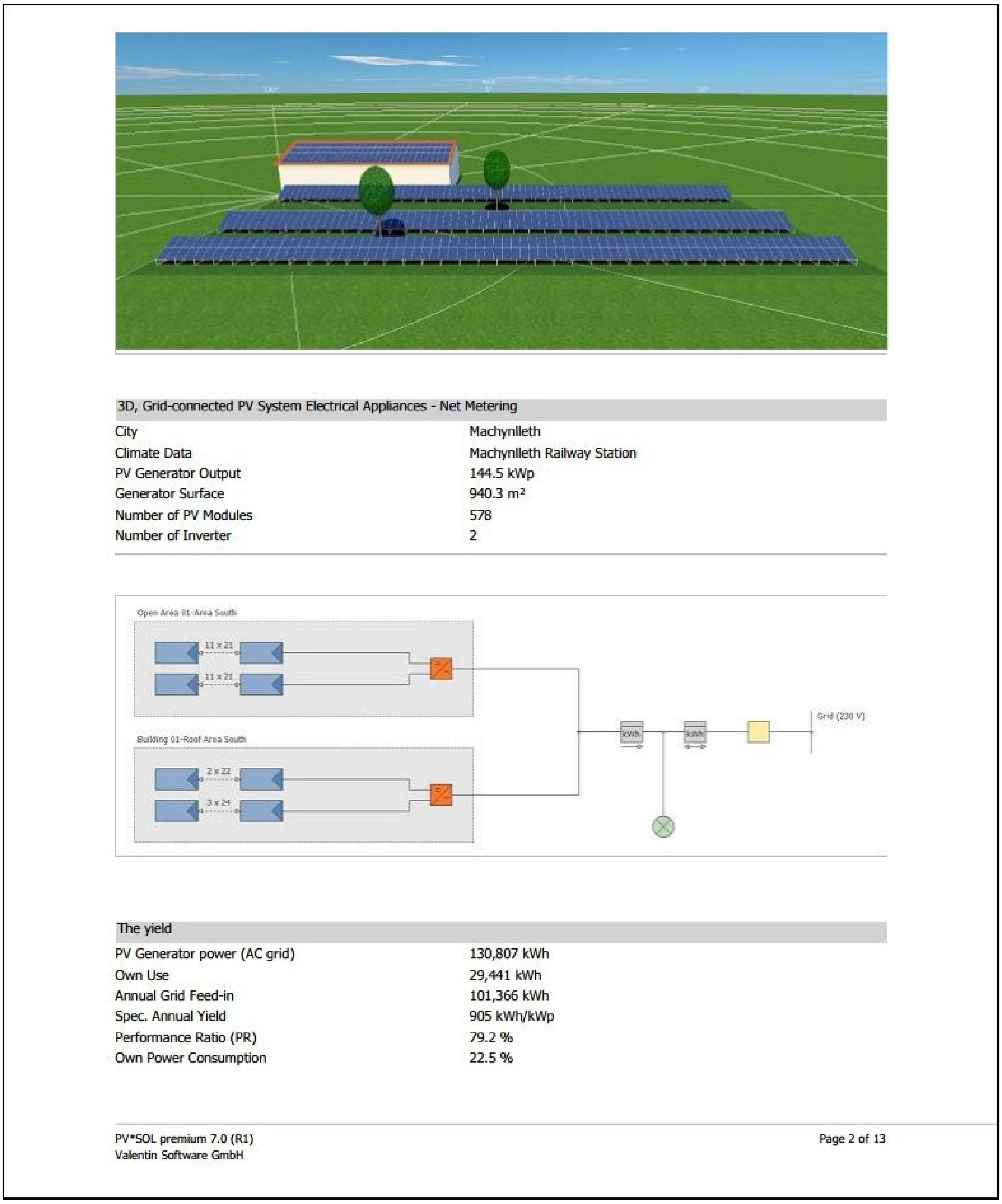
The summary table in figure 3.5 includes an estimate of the annual energy production by the solar PV system in kWh. It also shows the likely variability from year to year.

A chart is plotted showing the monthly energy output from the solar PV system. The monthly values can also be obtained by downloading a PDF version of the results.

The monthly values of generation can be useful for comparing actual generation with estimated generation. A significant drop in PV generation which has not been caused by a cloudy and wet month could be an indication of issues with the solar PV system.

*3.2.2. PV*SOL*

PV*SOL is an advanced software package that is used by solar PV system designers. It will take into account the effect of location of the solar PV installation, its orientation and inclination on generation. It will also check the suitability of combinations of solar panels and inverters and show their impact on annual PV generation. There are advanced tools to assess the impact of shading. These include import of horizon profiles or modelling of buildings and objects in 3D. It can also import electricity consumption profiles and determine the likely level of self-consumption of the solar generated electricity.



3D, Grid-connected PV System Electrical Appliances - Net Metering	
City	Machynlleth
Climate Data	Machynlleth Railway Station
PV Generator Output	144.5 kWp
Generator Surface	940.3 m²
Number of PV Modules	578
Number of Inverter	2

The yield	
PV Generator power (AC grid)	130,807 kWh
Own Use	29,441 kWh
Annual Grid Feed-in	101,366 kWh
Spec. Annual Yield	905 kWh/kWp
Performance Ratio (PR)	79.2 %
Own Power Consumption	22.5 %

PV*SOL premium 7.0 (R1)
Valentin Software GmbH

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Figure 3.6 Image of a PV*SOL premium project report

(From The Solar Design Company https://www.solardesign.co.uk/pvsol-premium.php, Accessed 27 Jan 23)

4. The Feed-in tariff and growth of solar PV installations

The Feed-in Tariff (FiT) for renewables was introduced on 1 April 2010. Prior to this, few homes in the UK had solar PV systems.

Under the scheme, payments were made for every kWh of electricity generated. There was also a payment for electricity exported to the grid (deemed to be 50% of the generation). Households also were able to make savings by using any of the electricity generated by the solar panels for free.

The feed-in tariff for a domestic solar PV installation (under 4kW) was 41.3p/kWh when the scheme was introduced in April 2010 and the export tariff was 3p/kWh. At the time, the typical installation cost for a 4kW solar PV system was about £13K. The scheme led to a rapid growth in installations and significant reductions in manufacturing and installation costs. By September 2011 the cost of a 4kW system had fallen to about £6K, while the feed-in tariff rate had increased to 43.3p/kWh. This led to an improved return on investment[5].

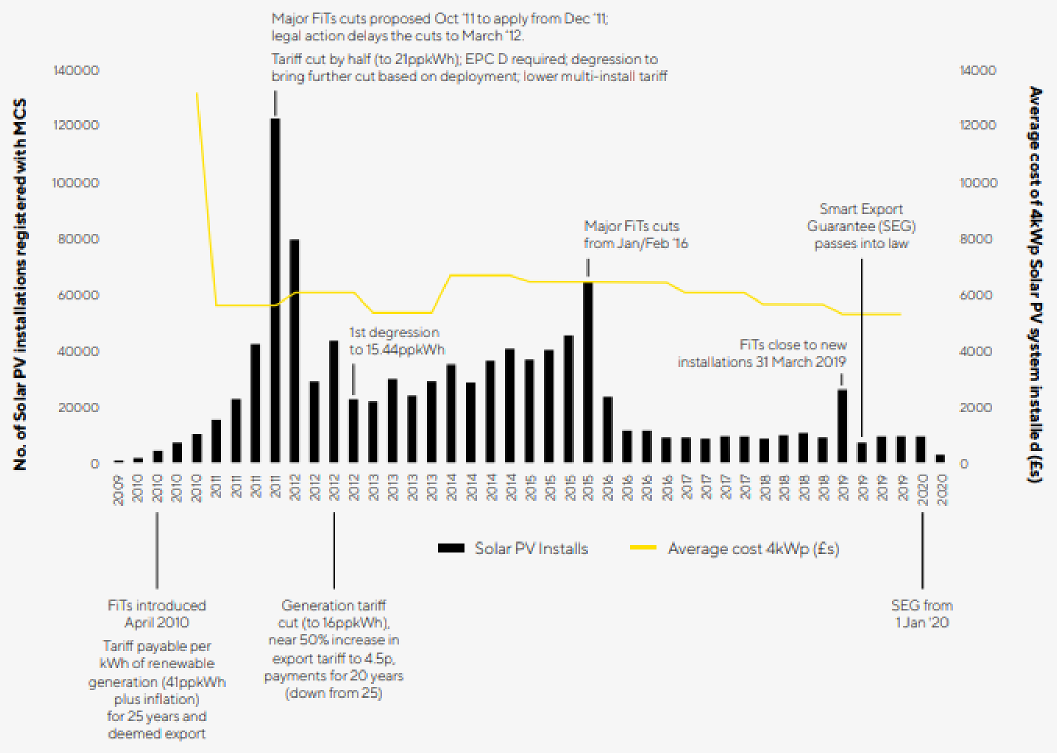

Figure 4.1 Variation in number of MCS registered solar PV installations during the Feed-in tariff[6]

Rates of the feed-in tariff also decreased following high numbers of installations and the fall in system installation costs. In August 2012, the feed-in tariff rate fell from 21p/kWh to 16p/kWh and the period over which it was paid fell from 25 years to 20 years.

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[5] UK Domestic Solar Panel Costs and Returns:2010-2014, Green Business Watch, https://greenbusinesswatch.co.uk/uk-domestic-solar-panel-costs-and-returns-2010-2014#rhiintroduction (Accessed 27 Jan 23)

[6] MCS Renewing Britain report, https://renewingbritain.com/#:~:text=MCS%20has%20pioneered%20the%20installation,over%20the%20last%2014%20years (Accessed 27 Jan 23)

The economics for solar PV between 2010 and 2015 were sufficiently attractive that many social landlords had large programmes of solar PV installations on their housing stock.

In 2012, the London Borough of Waltham Forest funded the installation of about 1,000 solar PV systems on homes managed by their then arms-length social landlord, Ascham Homes[7].

For social landlords who could not afford solar PV installation programmes, the rates of return allowed 'rent a roof schemes' which were developed by businesses or community energy organisations.

Mid-Devon Council participated in a 'rent a roof scheme' in partnership with Anesco Ltd. The council received some rental income and the tenants could use any electricity generated by the solar panels for free. By 2015, solar PV had been installed on 1,175 homes, about 38% of the council's housing stock[8]. The MCS Renewing Britain Report noted that by the end of 2020, that 4,143 households in Mid-Devon had solar PV. At 12.2%, this was the 3rd highest percentage in the country. The local authority with the highest percentage of homes with domestic solar PV was Peterborough with 12.8% (9,851 households), with many of these 'rent-a-roof' installations on social housing.

Sunderland is an urban area with a high percentage of solar PV installations. By the end of 2020, there were 9,310 domestic solar PV installations on 7.5% of the homes in the Sunderland.

The Sunderland based social landlord, Gentoo has 5,330 homes with solar PV. Empower Community acquired 2,327 existing solar PV installations on Gentoo social homes in 2014 and continues to manage these. The refinancing enabled Gentoo to fund a further 3,000 domestic solar PV installations.

Chase Community Solar is a Community Benefit Society in the West Midlands. In 2015, they raised over £1m through a community share issues and loan. This enabled them with the support of Cannock Chase Council to install solar PV systems on 314 of the bungalows which are socially rented by the Council.

Energise Barnsley is also a Community Benefit Society. It was set up with Barnsley Metropolitan Borough Council with the aim of delivering community owned renewable energy and heating projects in the borough. They raised £800K in 2016 through the 'Barnsley Solar Bond' which enabled 321 homes owned by Berneslai Homes to receive to receive free solar PV installations. Over 75% of the houses were bungalows with residents over 55 years and 25% were on pre-payment meters. The solar PV systems are managed by Generation Community Ventures.

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[7] Solar Photovoltaic Installations on Council Housing, London Borough of Waltham Forest meeting, 9 Dec 2011
https://democracy.walthamforest.gov.uk/documents/s17231/Solar%20Panels%20Revised%20281111%20final.pdf
(Accessed 27 Jan 2023)

[8] Mid Devon District Council Draft Housing Strategy 2015-2020, p.19
https://democracy.middevon.gov.uk/documents/s3650/MDDC%20Housing%20Strategy%20v4%20kd%2006102015%20Decent%20and (Accessed 27 Jan 23)

5. Components of a solar PV system

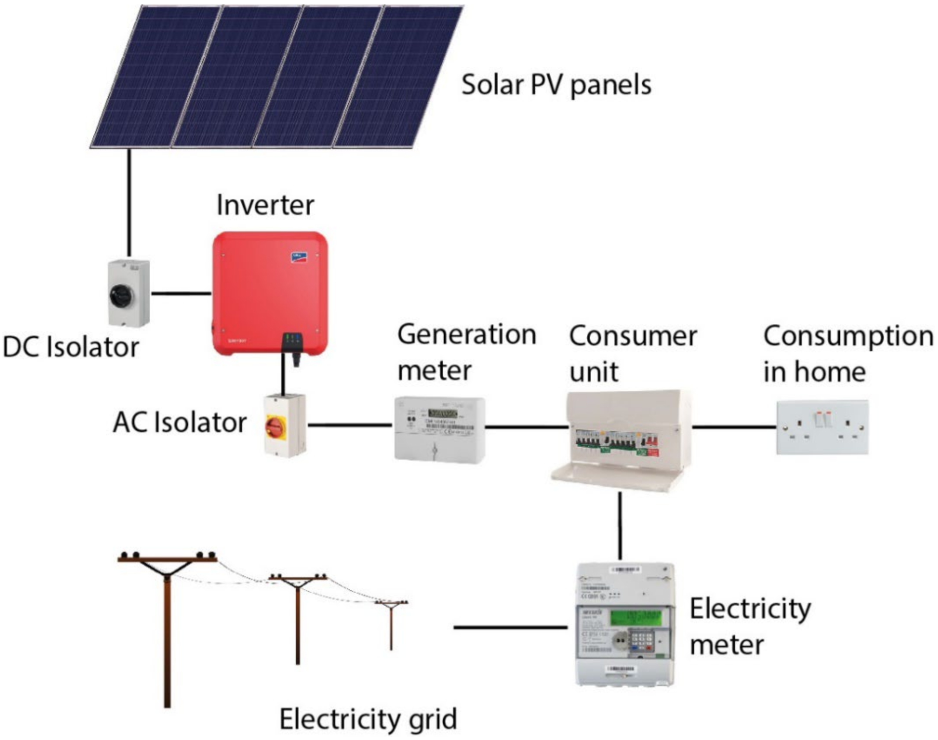

Figure 5.1 Schematic diagram of components in a solar PV system

Figure 5.1 is a schematic diagram of the components making up a solar PV system and shows how they connect into the home electrical system.

Solar panels generate direct current (DC) electricity. They are fitted on the roof with a mounting system that comprises of roof hooks, rails and clamps. There is a junction box on the back of the solar panel with wires coming out. The solar panels are wired together by plugging a male MC4 connector on one panel into the female MC4 connector on another panel.

Figure 5.2 Male and female MC4 connectors which are used on solar panels

Solar panels are expected to operate for at least 25 years. Most have a product workmanship warranty of 5-15 years and a performance warranty with the panels expected to generate 80-85% of the rated power after 25-30 years.

Damp getting into the MC4 connectors is a more likely cause of a fault than the failure of the panels themselves.

The **inverter** converts DC electricity from the solar panels into AC (alternating current) electricity which can be used in the home. Most solar PV inverters are string inverters. These have the solar panels wired in series in one or two strings. Each string of solar panels can behave independently. This means an inverter with two strings is more tolerant of shading.

Alternative options to string inverters are microinverters or optimisers. These have the advantage that each solar panel can operate individually and shading on one solar panel does not affect the performance of others. Microinverters and optimisers are more expensive than string inverters and so are less common. In situations where there is significant shading, the better performance with microinverters or optimisers can justify the extra cost.

The warranty for string inverters is usually between 5 and 10 years. It is possible with many manufacturers to pay extra and extend the warranty to 15 or 20 years. Solar Edge has a 12-year warranty on their inverters and a 25-year warranty on the optimisers that go with them. An Enphase microinverter has a 25-year warranty but must be kept online during that period.

The **DC isolator** is a black rotary switch which can isolate the inverter from the solar panels and allow an electrician to safely work on the inverter. The **AC isolator** is a red rotary switch which is installed between the inverter and the consumer unit. This is switched off when an electrician wants to switch off power from the mains and the solar panels and carry out electrical work in the home.

A **generation meter** is fitted between the inverter and the consumer unit. This shows the amount of electricity which has been generated by the solar panels since they were installed. The reading from this meter is used to determine the feed-in tariff payments for a solar PV system.

Social landlords may have hundreds of solar PV systems. They normally have installed smart generation meters to save regularly visiting homes to take meter readings for the feed-in tariff. This data can be accessed via a monitoring portal with readings on a daily or half-hourly basis. These meter readings can be used to determine faults or issues with the PV system.

In social housing, the inverter and generation meter are often fitted in the loft. The inverter is also often fitted in the loft for owner-occupiers. The roof space usually gets hot in summer and this can reduce the lifespan of the inverter. There may be few alternative locations for the inverter in the house, but an outhouse or garage might be suitable if electrical requirements around DC cable lengths and their routes can be satisfied.

Figure 5.3 shows an example of a SolaX inverter fitted in the loft of a socially rented home. On the left of the inverter is the DC isolator and on the right is the AC isolator with the smart generation meter above it. Much of the cabling has been fitted in plastic trunking.

Figure 5.3 SolaX inverter with the DC isolator, AC isolator and smart generation meter

6. Owner-occupier survey of most common problems with solar panels

The consumer organisation Which? has carried several surveys of solar panel owners looking at the most common technical faults which occur. A survey was carried out in June 2021 of their Connect panel with 1,116 solar panel owners. Out of these, more than 7 in 10 had not experienced a technical fault despite some respondents having owned the PV systems for a decade[9].

The most common faults were with:

- Inverter (over 10%)
- Electrical problems (6%)
- Generation meter (2%)
- Solar panels, under generation (2%)
- Solar panels, no generation (2%)
- Poor electrical connections (2%)
- Solar panels, cracked or broken glass (1%)
- AC or DC isolator (1%)

They also noticed other problems associated with the solar PV system

- Nesting birds or squirrels (15%)
- Accumulation of dirt on the panels (14%)
- Shading from trees or buildings (7%)
- Damaged or loose roof tiles (3%)

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[9] Solar panel problems and how to solve them, https://www.which.co.uk/reviews/solar-panels/article/solar-panels/solar-panel-problems-and-how-to-solve-them-aJP018k6yC6E (Accessed 27 Jan 2023)

7. Case studies on solar PV in social housing and common issues affecting PV generation

During this project, NEA has worked with a number of partners and gained an insight into the performance of solar PV in social housing. Social landlords and other organisations who owned and/or managed the solar PV systems were interviewed.

The most common cause for a system being offline for an extended period was due to a change in tenancy and the landlord carrying out upgrades to the property during this void period. The electricity supply to the property is normally turned off until the new tenant is about to move in. When the electricity supply is turned off, the solar PV system also shuts down.

When maintenance is carried out on the electrical system of the property, the AC isolator for the solar PV system will be turned off so the electrician can carry out work safely. This shuts down the solar PV system. In some cases, the electrician may forget to turn the AC isolator back on after completing the work. On some occasions the tenant may also turn off the AC isolator.

Faults can also occur with the solar PV system and these may for example be with the smart generation meter or communications with the meter, failure of the inverter or can be due to wiring on connector issues on the roof.

The following case studies describe the PV systems a series of organisations manage, their methods of monitoring the performance and the common issues they have to deal with.

7.1. Case Study - Empower Community

Figure 7.1 Photo of solar PV installations in Sunderland

Empower Community is a social enterprise that was established in 2011. It has used investment from capital markets to develop or purchase solar PV installations.

Empower Community manages about 2,300 roof mounted solar PV systems hosted on socially rented homes owned by Gentoo in Sunderland. It also manages two solar parks which are each 5MW in capacity.

It has established a profit-sharing programme with local stakeholders to build local resilience. The Empower Sunderland Local Community Fund was set up by Gentoo and Empower Community Foundation to provide grants generated by the Empower Community funded solar PV installations in Sunderland to local voluntary and community groups.

Gentoo direct labour and external contractors carry out repairs and maintenance for the systems. Gentoo staff also provide operational day-to-day support. This includes a Sustainability Officer focused on support for solar PV.

The systems in the Empower Community portfolio were installed during 2012 to 2013, with the majority in 2013. The portfolio includes inverters from 5 to 6 different manufacturers that were available at the time. A single manufacturer has been identified for replacing all inverters that fail which provides efficiency in maintenance.

The solar PV systems have the inverter and generation meters in the loft. The generation meters are fitted with modems to daily transmit generation meter readings. Performance of the systems is monitored using the Meter Manager online portal[10] as well as ACTIS, a software package specifically adapted for monitoring roof mounted solar PV systems

Typical faults which develop include modem and inverter failures along with occasional generation meter failures. To date, after 9-10 years, 90% of the inverters have had no failures. One inverter performed less well with a greater number of failures, but is no longer available on the market.

For safety reasons, Gentoo switches off electricity and gas supplies in void properties. This and varying solar irradiation affect generation output to the property.

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[10] Meter Manager, https://metermanager.co.uk/ (Accessed 30 June 2022)

7.2. Case Study – Northampton Partnership Homes (NPH)

Northampton Partnership Homes (NPH) is an arms-length management organisation (ALMO) that manages West Northamptonshire Council's housing services. NPH manages 11,380 homes across the Borough of Northampton.

NPH manages about 1,700 domestic solar PV systems across council owned housing stock. Approximately 1,300 of the systems are council owned, while 400 are third party owned through rent-a-roof schemes.

The portfolio was installed over 4 phases.

- Phase 1 – Installation of about 62 third-party owned PV systems from 2012
- Phase 2 – Installation of 1,233 council owned PV systems from 2016
- Phase 3 – Installation of 330 third-party owned PV systems in 2017/18
- Phase 4 – Installation of 70 new council owned PV systems which is ongoing in 2022

The average system size is about 3kW, but systems range from 2kW to 4kW. Very few of the installations are on homes with electric heating. This may be as low as 1%.

The solar PV systems have smart generation meters which communicate on 2G/3G networks. The council owned portfolio is monitored via a solar PV maintenance contractor on a web portal. The third-party owners also use web portals which NPH have access to. The portals used include Meter Manager, ASL and an E.ON platform.

Faults are identified very quickly via monitoring carried out by the third-party owners and their solar PV maintenance contactor. NPH receives quarterly reports from their maintenance contractor, but they do not check the performance against expected generation.

Typical faults include communications failure and inverter failures. The portfolio of 1,233 solar PV installations unfortunately used a bad batch of inverters. About 1,000 of these needed to be repaired within a couple years.

It is difficult to assess the typical lifespan of the inverters as the third-party owned systems are normally repaired without NPH being involved. The council-owned portfolio had failure of inverters due to a bad batch rather than typical failures.

Faults are repaired either by third-party owners or the specialist solar PV maintenance contractor. If there is unexpected lower generation, inspection by the maintenance contractor should uncover any faults with the system which is remedied as appropriate. The time for a repair might range from a couple days to a couple of months depending on the type of issue.

When tenants move out of a property, the electricity supply is turned off and so the solar PV system is also turned off. About 10% of properties become void per year and the void period on average is about 2 weeks. Apart from during voids, systems are turned off during Electrical Installation Condition Report (EICR) inspections and other maintenance of household electrics and there can be reconnection issues associated with this activity.

There have been issues around high levels of shading from overgrown trees. This is difficult to resolve, in some cases due to the responsibilities for tree maintenance and also a conflict in priorities. Is it appropriate to remove a tree to help a solar PV system work better?

There are lots of complaints due to pigeons roosting underneath and around the solar panels. This is proving to be a serious problem and some tenants have requested for the solar panels to be removed, which is generally not possible.

The residents can only monitor the performance of the solar panels via the generation meter. If a resident thinks their solar PV system is not working correctly, the query will come to the NPH Sustainability Manager. He would check the monitoring portal to see if the system is performing as expected and liaise with the resident to find out why they think it's not working. Normally explaining how the system works is sufficient. Sometimes an inspection by the maintenance contractor helps to reassure the resident. If the system is not working, the Sustainability Manager would notify the maintenance contractor or third-party owner.

7.3. Case Study - London Borough of Waltham Forest

Figure 7.2 Solar PV installation in Waltham Forest

The London Borough of Waltham Forest has 1,108 solar PV systems. Nearly all of these were installed in the early stages of the feed-in tariff, between January and March 2012 and in July 2012. There are relatively low numbers of solar PV installations in London and at the end of March 2019, the council owned systems made up over 70% of the domestic solar PV systems in the Borough that were installed under the feed-in tariff scheme (total of 1,551)[11]. The average size for the Waltham Forest solar PV systems is 2.4kW.

The Borough Council appointed Aston Group as their Mechanical and Electrical (M & E) Contractor and they monitor and maintain the solar PV systems. Monitoring is carried out via the Orsis Sunrise portal which receives data from smart generation meters. The portal is checked on a daily basis and there are daily email reports from Orsis with notifications of any alarms. It is usually possible to determine if a fault has occurred within a few days.

Insulation resistance faults are one of the more common issues causing unexpected shutdowns and can be due to damaged or poorly installed MC4 connectors and DC cabling. The damage can be caused for example by bird droppings degrading the components. Sometimes an insulation resistance problem can lead to no generation, but it other cases, there can be low generation which may only occur in rainy weather. Other faults more commonly experienced include relay faults within the inverter. If there is a fault with a system, the M & E contractor would carry out the repair. The typical lifespan for inverters has been of the order of 5 years. SMA inverters have performed better than Eversolar/Zerversolar.

The time taken to receive a warranty replacement inverter has increased since Brexit from 10 days to sometimes more than a month. During this period the PV system is not running

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[11] December 2019 Subregional Feed-in Tariff Statistics, BEIS, https://www.gov.uk/government/statistical-data-sets/sub-regional-feed-in-tariffs-confirmed-on-the-cfr-statistics (Accessed 19 Jan 23)

and is costing the Council money and the resident facing higher electricity bills due to the absence of solar PV generated electricity for use in the property.

Other issues which can cause reduced annual generation include when there is a void/empty property. commonly, when a property is void, the main switch to the distribution board will be switched off until the property is reoccupied. This also leads to shutdown of the solar PV system. Occasionally, the Council has had tenants that believe the solar PV system is costing them money and switched it off as a result. In such a situation, the Council's Digital and Environmental Energy Office would either phone or visit the household and provide a better understanding of how the system works and the benefits it provides to them. The residents do not have access to any monitor for solar PV generation,

7.4. Case Study - North Devon Homes (NDH)

North Devon Homes is a not-for-profit social landlord with over 3,330 domestic properties in North Devon. It currently has 116 homes with solar PV. An estate in Barnstaple was redeveloped between 2012 and 2015 and 114 of these new build homes included solar PV. The systems typically had 6 or 7 solar panels, with a maximum output of 1.5 or 1.75kW.

NDH investigated a large scale retrofit programme of solar PV on its properties during in the early years of the feed-in tariff. Cuts to the FiT rates significantly impacted the business case for installations and the retrofit programme did not go ahead. 2 homes have more recently had solar PV installed as part of the ZEBCat (Zero Energy Buildings Catalyst) programme for Energiesprong retrofits.

The solar PV installations on the new build homes in Barnstaple had the inverters fitted in the loft. The AC isolator and generation meter was fitted in the consumer unit or in a separate enclosure next to the consumer unit (figure 7.3).

The generation meters that were fitted were not smart. This requires collection of meter readings via the residents with a 3 monthly cycle of PV meter reading collection. Text messages are initially sent to customers with PV systems requesting a meter reading. If there is no response to the text message, these are followed up with phone calls and letters. If none of these have been successful, a visit would be organised to try and collect the final outstanding readings.

Figure 7.3 AC isolator and generation meter in an enclosure above the consumer unit

The lack of online monitoring means it can take longer to detect faults if they occur. NDH has a maintenance contractor for the systems and residents can contact them if they think the system has stopped working. There is also an annual service check from the contractor.

NDH will be retrofitting solar PV systems to 18 homes in 2023 and these are likely to have Orsis smart generation meters fitted with monitoring of the generation via the Orsis portal.

7.5. Case Study - Stockport Homes

Figure 7.4 Example of Solar PV installation in Stockport

Stockport Homes is an ALMO (arms-length management organisation) that was set up in 2005 to manage housing stock across Stockport on behalf of Stockport Council. It manages over 12,000 properties for the Council and Private Landlords.

They look after 2,807 solar PV systems. This includes managing 4 rent- a-roof solar PV systems which are on schools. Their programme of solar PV installations commenced in July 2011. The average size of their solar PV systems is 2.19kW.

Monitoring is carried out using the Orsis Sunrise portal. This provides access to half-hourly data transmitted by the Orsis S2-M SmartGen meters which were used as generation meters. Annual performance of systems is recorded on a spreadsheet and those which are under-performing are investigated.

The Sunrise portal is checked around 3 times a week and issues identified. Reports from the system are run each month but may also be produced on an ad hoc basis when needed. Expected generation compared to the actual generation can be plotted on the portal and also included in the annual generation spreadsheet.

If a property has been identified as not generating, staff would first check if the property is void or having repairs or programmed work carried out. They will also consider if there are signal issues from the generation meter or if the customer is in emergency credit with their electricity supplier.

Stockport Homes used to get a separate email of alarms, but no longer receives this. Instead, they run a 'no data' report to show properties which are not generating. The report is run as often as required.

If a fault is identified, the repair would normally be carried out by an electrician from the Stockport Homes Repair Team. Repairs normally took 14 days in summer and 28 days in winter to complete before the COVID pandemic. During summer 2022, the landlord was dealing with a backlog due to all non-essential visits having been concealed during the pandemic.

They have replaced around 90 original inverters to date and were looking at a further 14 at the time of writing. The inverters had a 5-year warranty. Some have been replaced with new inverters with 10- or 20-year guarantee chosen.

Apart from inverter failures other issues which occur include signal issues with an older-style generation meter. If a system has been underperforming, a visit would be arranged to look at the cause. The solar panels may also be cleaned.

If a resident reported that they thought the solar PV system was not working, it would be referred to a member of the Environmental and Energy team. They would check the portal and the level of PV generation and feedback the details of the system performance to the customer. Stockport Homes customers with solar PV system can have free access to the Orsis Sunrise portal to monitor generation from the PV system. Each customer was provided with a login at the start of the programme, but the landlord has no idea how many of their customers are currently using the system.

Occasionally a solar PV system will go offline because the customer has switched off the solar PV system because they thought it was costing them too much money to run. In such a situation, an energy advisor would contact the customer to outline the savings they could receive by keeping the solar PV system switched on. They would also receive more wide-ranging energy advice.

When a resident moves out, the electricity is not turned off and neither is the solar PV system while the property is void. This is in contrast to some other landlords. The solar panels are displayed on the portal as 'not generating' in situations where there is debt on the prepayment electricity meter.

7.6. Case Study - Energise Barnsley

Figure 7.5 Example of Energise Barnsley solar PV installation

Energise Barnsley is a community benefit society that was launched in 2015 with the aim of delivering community owned renewable energy and heating projects across the borough[12].

The initial project installed over 1.4 MW of solar PV with 321 systems on residential properties and 16 on community buildings. Ignite provided a £2m underwriting facility to Energise Barnsley to enable the project to go ahead. In 2016, the Barnsley Solar Bond Series I was launched and raised £790,000. The residential systems were installed in the final quarter of 2016, while the non-domestic systems were fitted in the first half of 2017[13].

Barnsley Metropolitan Borough Council (BMBC) is the key partner and custodian trustee of Energise Barnsley. It owns the properties where the solar PV is installed, including the 321 council homes which are managed by its housing company, Berneslai Homes. Generation Community Ventures initiated, developed and delivered the solar PV project and provides asset management services. British Gas was the solar PV contractor. They also carry out operations and maintenance and provide a performance guarantee and warranty for the PV installations.

The average size of the domestic PV installations is 2.8 kW and 35 kW for the installations on community buildings. Generation Community Ventures monitors the PV systems using the ASL portal and they have their own asset management system.

They interrogate weekly status reports and check performance against the local weather station, relative to all the other systems and any red flag events. There are alarms and action is taken after 2 weeks to allow for any communications or electrical works to be completed.

Since installation in 2016, 10% of the residential inverters have been replaced and 3 of the inverters on non-domestic installations. The inverters which have been replaced are of a model that is no longer manufactured. The typical inverter lifespan is expected to be 10 years.

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[12] Energise Barnsley website https://www.energisebarnsley.co.uk/ (Accessed 20 Jan 23)
[13] Energise Barnsley Case Study, Energy Hub, https://www.gsenetzerohub.org.uk/wp-content/uploads/2020/05/Energise-Barnsley.pdf (Accessed 20 Jan 23)

Other common causes of reduced generation are SIM card communication issues with the generation meter, third part contractors turning off the isolation switch while working in the property and not turning it back on again and void properties. If there is a fault with a PV system, the operations and maintenance contractor would carry out the repair. If there was unexplained low generation, this might be due to an issue with a string of the solar panels, shading or bird fouling. All of these would require a visit to determine the cause and rectify the issue.

If a tenant moves out and a property becomes void, there is a requirement to keep the electricity connected which allows the solar panels to keep generating. While the electricity should be left on, there are occasions when it has been turned off. The property is likely to be void for around 3 weeks and about 3 – 5% of properties become void in a year.

At the time the domestic PV systems were installed, residents were provided with an OWL monitor for the solar PV. It is likely that few still have this now. If a resident thinks the solar PV system may not be working, a tenant liaison officer would report this to Generation Community Ventures to investigate. If there is a fault, it should be repaired in under 2 weeks, but it can sometimes take a month if an inverter needs replacing.

7.7. Case Study - Chase Community Solar (CCS)

Figure 7.6 Examples of locations with CCS solar PV installations

Chase Community Solar (CCS) is a Community Benefit Society and installed 314 solar PV systems on bungalows owned by Cannock Chase Council in 2015. The bungalows had a variety of different designs, with roof pitches from about 25 to nearly 40 degrees. Most were semi-detached, but some were terraced.

Since 2015, the number of solar PV systems has reduced to 312 after 2 systems were removed after the tenants purchased their homes under right-to-buy. A total of 1,556 domestic solar PV systems were installed with funding from the Feed-in Tariff in the Cannock Chase Local Authority area, with the CCS portfolio representing about 20% of the total[14].

The systems range in size from 2.25 to 4kW with an average size of 2.88kW. Afore inverters were used throughout, with most being single string with a single MPP tracker. A few of the larger sized PV systems had inverters with two strings and MPP trackers.

The generation meter used was a Revenco meter with an attached communications unit. Half-hourly meter readings are recorded and uploaded daily to the Sunrise Portal hosted by Orsis. In recent years, the CCS installations have been monitored and maintained by Dave Price, a local solar engineer.

CCS uses automated reports sent by the Orsis Sunrise portal as the primary method to determine whether a system may have a fault. The portal sends two daily reports:

- No data – list of sites where no data has been received for a set period of time
- Generation status – list of sites with no or reduced generation for a set period of time

The No data period was set to 96 hours and the No Generation period was set to 48 hours to reduce nuisance call outs when the Orsis portal fails to collect data in a timely fashion.

The most common issue that occurred was failure of the signal between the communications unit of the generation meter and the portal. Initially when Dave Price took over managing and repairing the PV systems, there were about 30 systems which were not establishing a

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[14] December 2019 Subregional Feed-in Tariff Statistics, BEIS, https://www.gov.uk/government/statistical-data-sets/sub-regional-feed-in-tariffs-confirmed-on-the-cfr-statistics (Accessed 19 Jan 23)

good signal acquisition and required installation of a more sensitive antenna. There have been a few meter failures and a flurry of SIM card failures.

Inverters started failing after the first couple of years and the incidence of failures is increasing. At present they are averaging at about one per month. The inverters came with a 10-year warranty. There have also been wiring and termination failures.

After a tenant moves out of a property, the electricity supply is turned off and the gas isolated. The solar PV system is shut down during this period. The typical period for a void can range from 21 to 35 days. The Council has about 400 voids per year out of 5,300 properties.

There have been issues where contractors have switched off the solar PV while working on the property and not switched it back on when leaving. In one case a tenant was regularly turning off the PV system themselves. When a prepayment meter runs out of credit, the PV system will also stops working.

Long-term low generation can be caused by shading and soiling of the panels.

Tenants do not have access to monitoring of the solar PV generation. If tenants think there is an issue with their solar panels, they can call Dave Price directly. He also gets referrals after tenants have contacted the council. Repair times vary depending on the nature and severity of the fault. In some cases, the issue can be addressed within 2 hours of the problem being reported, but it is more typically within 2 days.

In 2021, Chase Community Solar partnered with Beat the Cold to make a successful application to the Energy Industry Voluntary Redress scheme for the project ‘Smart solar in Cannock’. During the spring and summer of 2022, the project installed 75 battery systems in some of the 312 homes with solar PV systems.

Afore hybrid inverters were used for the installations, replacing the previous Afore inverters. Battery storage with hybrid inverters is normally DC coupled. Ofgem guidance requires a bi-directional generation meter on such systems which claim the feed-in tariff. Since the Revenco generation meters were not bi-directional, they were replaced with new meters.

Data from the new meters was uploaded to the Afore monitoring portal rather than the Orsis Sunrise portal. Using the portal, it is possible for CCS and Beat the Cold to monitor generation from each of these solar PV systems as well as electricity consumption of the households and charge/discharge of the batteries. The aim was also for tenants with smart phones to also able to use the Afore portal to monitor their own system, using a simplified version of the full tool. This has taken longer to develop than was expected.

NEA was selected to carry out the monitoring and evaluation for the Smart Solar in Cannock project. CCS were also happy for NEA to assess the long-term performance of 75 of their solar PV systems for the ‘Increasing Self-Consumption of Solar PV project’. This included 33 of the households that received battery storage.

8. Assessment of the long-term performance of 75 domestic solar PV installations on socially-rented homes

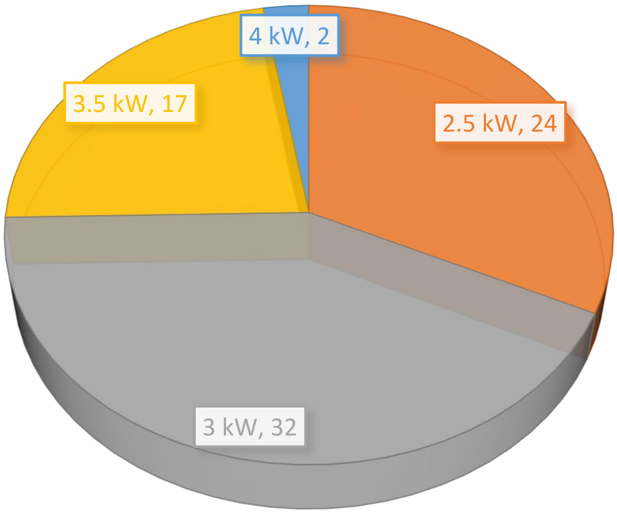


Figure 8.1 Chart showing the sizes of the 75 CCS solar PV systems studied

The project investigated the long-term performance of 75 of the 312 solar PV systems that make up the current portfolio of PV installations for Chase Community Solar (CCS). This was just under a quarter of the total number. All the systems were involved socially-rented bungalows which were either semi-detached or terraced. The angle of inclination of the bungalow roofs varied from about 25˚ to nearly 40˚. There were 24 systems analysed that were 2.5kW, 32 systems that were 3kW, 17 systems that were 3.5kW and just 2 were 4kW. The average system size among the 75 installations was 2.98kW.

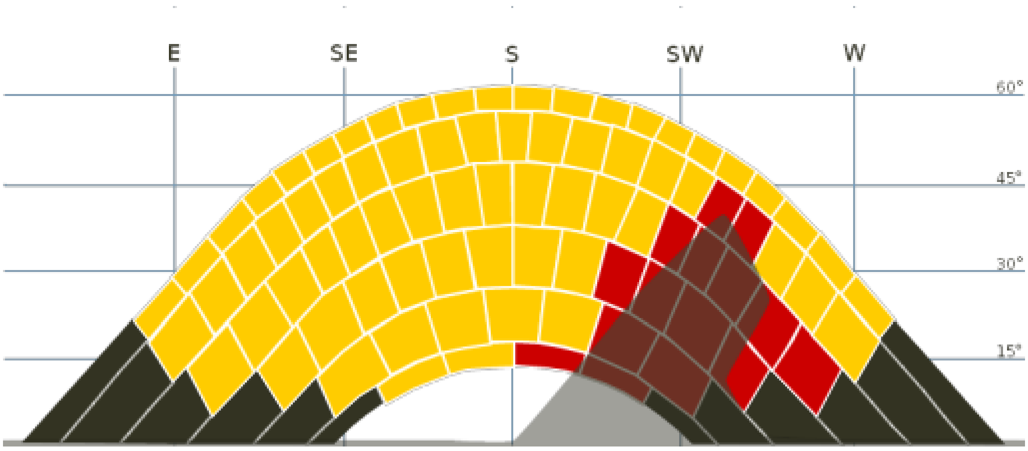
The installer produced system designs which included roof layouts, schematics and inverter compatibility and electrical checks. They also estimated the annual generation according to the MCS method, including a shading assessment (figure 8.2). This was used by CCS as the expected output to compare actual annual generation against.

Over the original 314 installations, not every system that was fitted was identical to the system design. CCS had noticed that 4 installed PV systems did not match the system design, with a smaller number of panels fitted. This might have been due to there being less roof space than had been anticipated or installer error.

During the analysis carried out by NEA, a further 3 installations had different systems sizes to those recorded on the CCS database. There may have also been mistakes over the course of over 300 installations in the estimates of the annual generation, which may account for significant differences with the typical generation produced by some systems.

Inverter 1: HNS2500TL-10 2.5Kw inverter

Input 1



A: Installation data	
Installed capacity	2.5 kWp
Orientation	10°
Inclination	27°
B: Calculations	
kWh/kWp (kk)	920
Shade factor (sf)	0.85
Estimated output	1955 kWh

Figure 8.2 Shading assessment and estimate of annual generation for example CCS installation

Select Date: 2022

● Generations ○ Tariffs

Feed in Tariff

Earnings to Date [redacted]

Earnings this month [redacted]

CO_2 Saved

Saved to date 2,889,041.78 Kg

Saved this month 5,238.63 Kg

Energy Data

Generated 5,728,388.52 KWh

Exported 0.00 KWh

Figure 8.3 Orsis Sunrise portal for Chase Community Solar (CCS)

The Orsis Sunrise portal was used to download generation data from 75 PV installations over a period of 6 years. The 75 systems analysed were selected from 12 distinct areas with all the solar PV systems located in a particular area and having approximately the same orientation and inclination (same design of bungalow). This meant comparisons of performance were easier. The impact of different system size was accounted for by comparing the PV generation per kW of solar PV. The main factors affecting annual generation were therefore:

- Annual solar irradiance
- Voids – periods with no occupant
- System faults - PV system and metering
- Shading

Monthly generation data was downloaded from the Orsis portal with 'Expected v Actual' Reports for the years 2016 to 2021. These provided the expected annual and monthly generation, based on the estimate made by the installer as well as the actual generation recorded by the system. By comparing expected against actual values over a number of years or with several comparable systems, it was often possible to identify periods with unexpectedly low generation. Where a period with apparent low generation was identified, a Calendar Analysis report was often downloaded for the period with generation from individual days. This allowed the days with zero generation during the issue to be identified.

In addition to the predicted generation by the installers, NEA made estimates of the annual generation using PVGIS. This was a desktop-based exercise, making estimates of the orientation and roof pitch of properties using Google Earth and Streetview. It was not possible to make estimates of the impact of shading with the online assessment. Often the PVGIS SARAH2 Solar irradiation database overestimated the generation compared to the MCS method. However, it was useful to make these estimates to sense check the estimates of annual generation by the installers and show instances where there was significant error in the original estimate.

8.1. Performance of PV systems in CCS Area A

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
A-01	908.6	937.0	829.5	853.6	887.7	855.2	895.3	823.7
A-02	924.0	937.0	917.5	877.8	871.6	871.6	925.5	878.1
A-03	914.3	937.0	939.9	902.3	948.1	918.7	942.1	890.7
A-04	925.7	937.0	942.3	917.6	965.5	937.5	958.4	908.6
A-05	820.0	937.0	869.3	816.0	905.7	874.7	898.7	846.8
A-06	890.0	937.0	914.6	877.6	919.2	868.5	917.1	873.8
A-07	903.3	937.0	809.1	788.0	771.5	855.8	865.1	823.4
A-08	903.3	937.0	922.2	885.5	925.7	902.2	924.1	880.9
A-09	862.9	937.0	920.8	886.5	930.3	902.9	926.4	882.2
A-10	908.6	937.0	900.3	860.6	900.9	870.9	906.5	867.3
A-11	902.9	937.0	938.1	897.7	935.0	912.8	935.2	887.2

Table 8.4 Annual generation between 2016 and 2021 for properties in CCS Area A

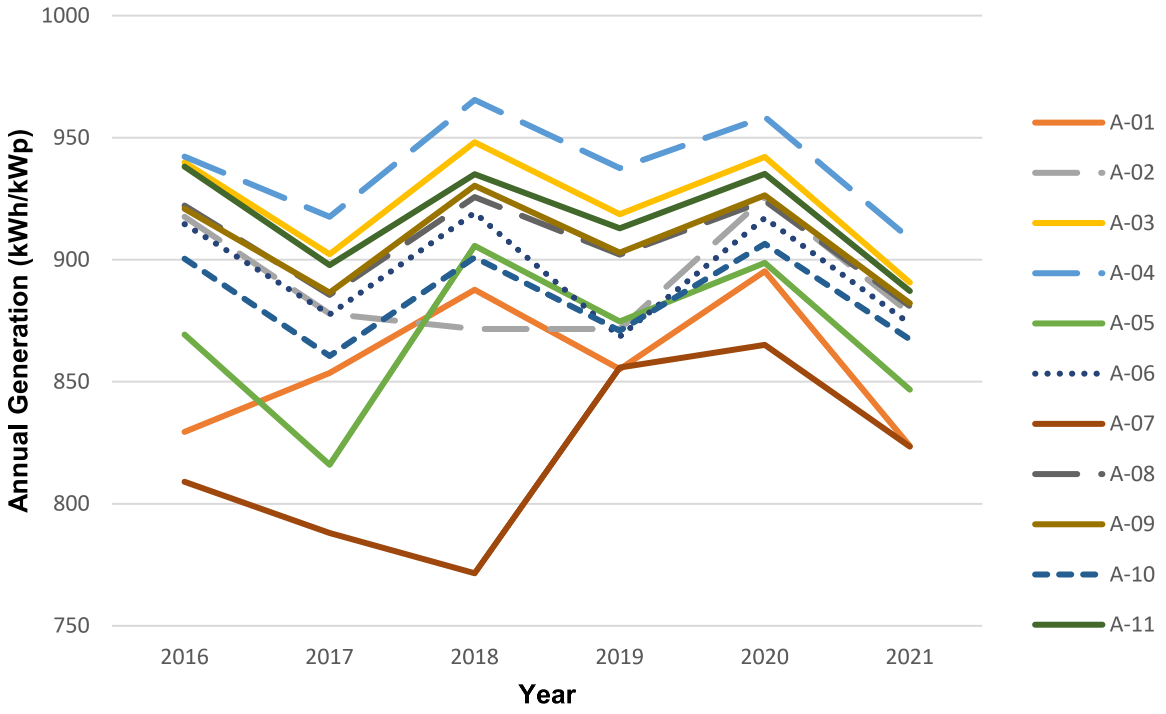


Figure 8.5 Graph of annual generation between 2016 and 2021 for properties in CCS Area A

Area A had solar PV installations on parallel terraces of bungalows with up to 6 installations on a terrace. Given the same orientation and inclination as well as the close proximity, it might be expected that performance should be similar. In practice there were notable differences.

Figure 8.5 showed several patterns in the annual generation. Firstly, there is the variation due to differences in the annual solar irradiance, which caused the broadly common undulating lines of the graph. There is also the impact of shading on the generation. The undulating lines were typically parallel with each other, but sites with greater shading were shifted to lower generation. Finally, there is the impact of the PV system not being operational. This caused dips in generation and a deviation from the parallel undulating lines.

8.1.1. Impact of system issues and occupancy in Area A

Installation A-07 was the poorest performing system in Area A, with the annual PV generation line in figure 8.5 significantly below the other sites in 2016 – 2018. The issues with the system were primarily related to the generation meter and communications. In 2016, there were sporadic days with zero generation. This included 5 days in July, which would not be expected. From 9 Dec 16 through to 8 Jan 17, there was a consecutive period with no generation. There were a further 5 days in June and 7 in July 2017 with zero generation. These were likely to be due to a loss of communications to Orsis for an extended period. There were further sporadic days with zero generation in 2018, with 7 each in July and August. From 15 Dec 18 to 7 Jan 19, there was frozen Orsis meter. Other issues at the site included a circuit breaker which tripped causing several days of generation to be lost.

There were issues with installation A-01 during 2016, with only 829.5kWh/kWp. The loss of generation was due to a period when the property was unoccupied, and the electricity turned off. This was between the end of October and early January 2017. Other issues at this site included an RCD that had tripped.

Installation A-05 recorded low generation in 2016 and 2017. There was a period of zero generation between 7 Jan 16 and 3 Feb 16 and particularly low generation between 1 Nov 17 and 29 Nov 17. These may be due to meter and coms issues with the meter failing in January 2016 and some output data lost.

The generation from installation A-02 closely followed that for A-06 apart from in 2018. From 7 Mar 18 to 27 Mar 18, the property was unoccupied and the electrics turned off. The generation from installation A-06 was normally only slightly lower than from installations A-08 and A-09. In 2019, this difference was larger due to a loss of generation for A-06 between 14 Jan 19 and 8 Feb 19. This was likely to be due to the failure and replacement of an inverter.

Other issues at the sites included a SIM card failure at A-08 in 2019 where no readings were acquired for a while. This was remedied after fitting a new SIM and a high gain antenna. At least 2 of the sites had pre-payment meters which kept running out of credit and losing power to the property. As a result, the PV system went offline.

8.1.2. Impact of shading in Area A

The installations in Area A were on terraced bungalows with the systems close together. There was some shading from trees and this caused a difference in solar PV generation of between 5 and 10 % between the trend for the best and worst performing systems.

Estimates were made of the annual generation by the installer using the MCS method (predicted generation) and a desktop estimate was made with PVGIS not taking shading into account. The installer estimates were always lower than with PVGIS. Where there was shading, the predicted generation typically underestimated the actual generation.

Figure 8.6 shows a graph of half-hourly PV generation against time for 5 of the installations on 29 Mar 21. Although there was a strong generation peak in the middle of the day, the sun was still relatively low in the sky and so there were greater shading issues. In the morning there was reduced generation from installations A-01 and A-10, while in the afternoon, generation from installation A-05 decreased earlier than for the other systems.

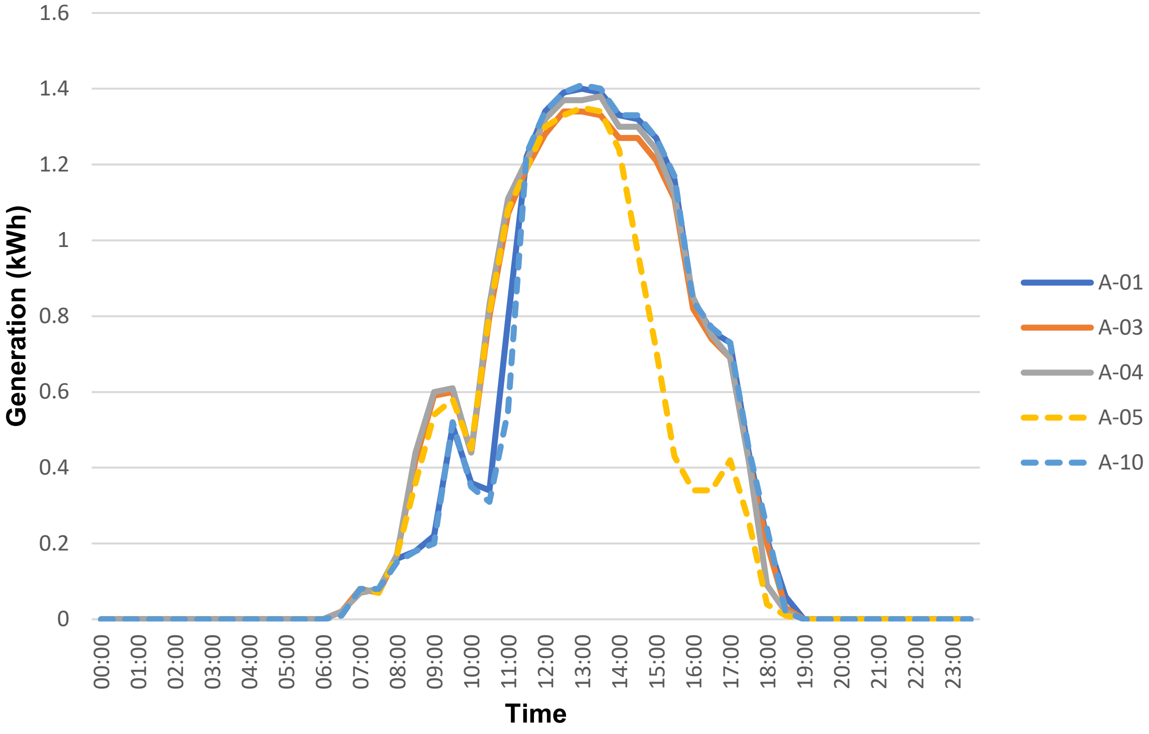


Figure 8.6 Graph of Solar PV generation on 29 Mar 21 for households in CCS Area A

Installations A-01 and A-10 were on the eastern end of the terrace and were affected more severely by shading from trees along a road to the east of the bungalows. There was a tree near to installation A-05 on the western side of the terrace and the tree caused greater shading of this installation as the sun went down in the afternoon.

A graph of half-hourly solar PV generation against time for 5 households in Area A is shown in figure 8.7 for 16 Jun 21. With the sun higher in the sky, there was less impact from shading in June. In the afternoon/evening, as the height of the sun in the sky decreased and the solar generation fell, the level of generation was similar for all 5 installations. In the first half of the morning, the rise in generation for installation A-01 was still delayed due to shading from trees, but the generation from all 5 systems was comparable by 09:30.

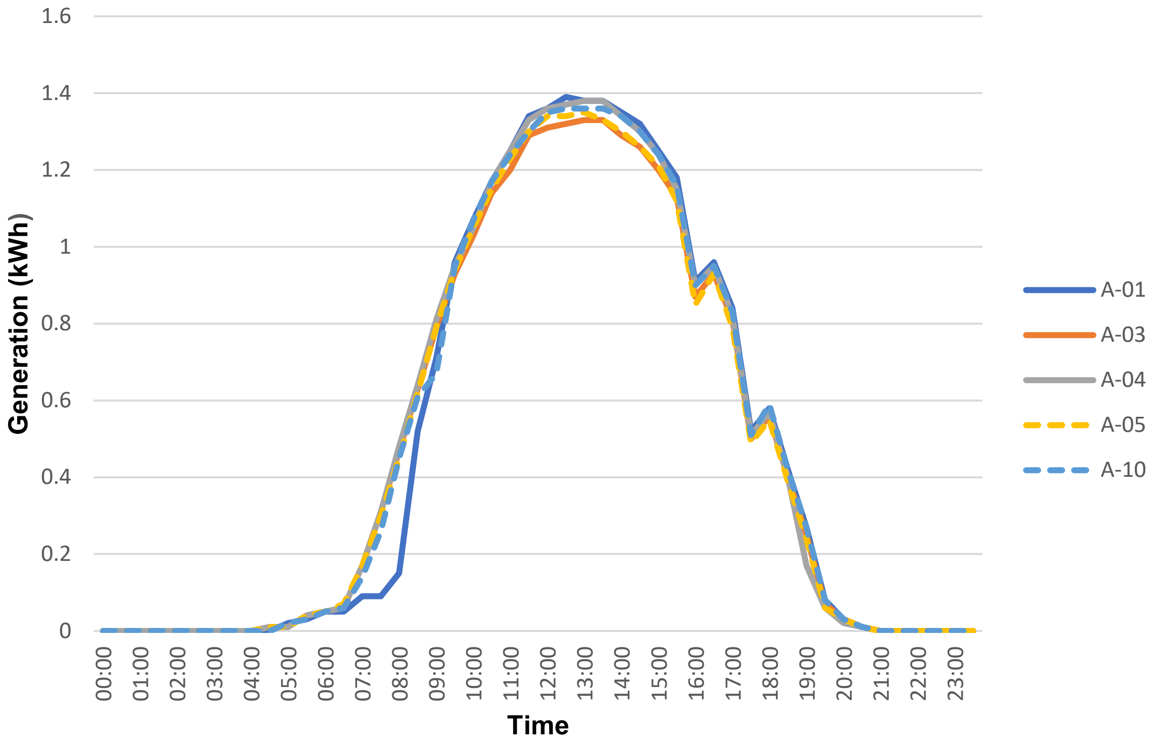


Figure 8.7 Graph of Solar PV generation on 16 Jun 21 for households in CCS Area A

8.2. Performance of PV systems in CCS Area B

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
B-01	836.0	931.3	936.0	867.3	928.9	963.1	964.3	925.2
B-02	832.0	931.3	921.7	852.6	911.4	885.0	931.0	894.5
B-03	800.0	931.3	945.6	869.9	953.1	758.6	941.8	892.9
B-04	848.0	931.3	926.4	843.9	911.8	883.4	919.6	548.7
B-05	860.0	931.3	913.9	846.3	907.9	764.4	849.3	869.5
B-06	800.0	931.3	968.7	899.9	967.7	941.1	978.7	930.3
B-07	819.6	931.3	910.2	840.5	900.2	875.0	920.2	880.1
B-08	816.0	931.3	905.1	831.7	903.7	866.0	925.0	833.2
B-09	780.4	931.3	784.4	727.2	818.8	773.0	815.0	754.8
B-10	784.4	931.3	859.1	785.5	874.5	831.7	835.7	822.5

Table 8.8 Annual generation between 2016 and 2021 for properties in CCS Area B

Area B was in an estate of semi-detached bungalows. Over half of the bungalows faced approximately south (Azimuth of 12˚), while the others had roofs which faced approximately east/west. The bungalows facing approximately south had PV systems installed by CCS. Systems were not fitted on the bungalows with east/west roofs due to the lower annual generation, which meant the sites were less economic under the feed-in tariff. There were a number of trees on the estate which led to varying levels of shading of the solar PV installations. The PVGIS estimates which did not take into account shading were generally closer to the actual generation than those predicted by the installer. The predicted generation was closer for installations B-09 and B-10 where there was more shading.

8.2.1. Impact of system issues and occupancy in Area B

The Orsis meter registered for installation B-01 was discovered to have been fitted at installation B-03. This had to be referred to Orsis for correction and led to a change in the relative performance between these systems.

There was a drop in generation in 2019 from installation B-03. This was due to an inverter failure and the AC isolator being turned off at one point for an unknown reason.

In 2016, installation B-04 required a high gain antenna to be fitted on the Orsis meter. There was a period of 90 days where the system was offline in Spring 2021 and this was likely to be due to the property being unoccupied and the electrics turned off.

There was an inverter failure at installation B-05 in Spring 2019 and the system was offline for about 25 days. There was also low generation in December 2019/January 2020 and in June 2020 which was likely to be due to the property being unoccupied.

Installation B-08 had a period of low generation for a week in June 2021. This may have been due to signal failure. Installation B-10 was offline for just over 3 weeks in October 2020. This may have been due to a period when the property was unoccupied, but it was also a known area where shading and signal failure could be a problem.

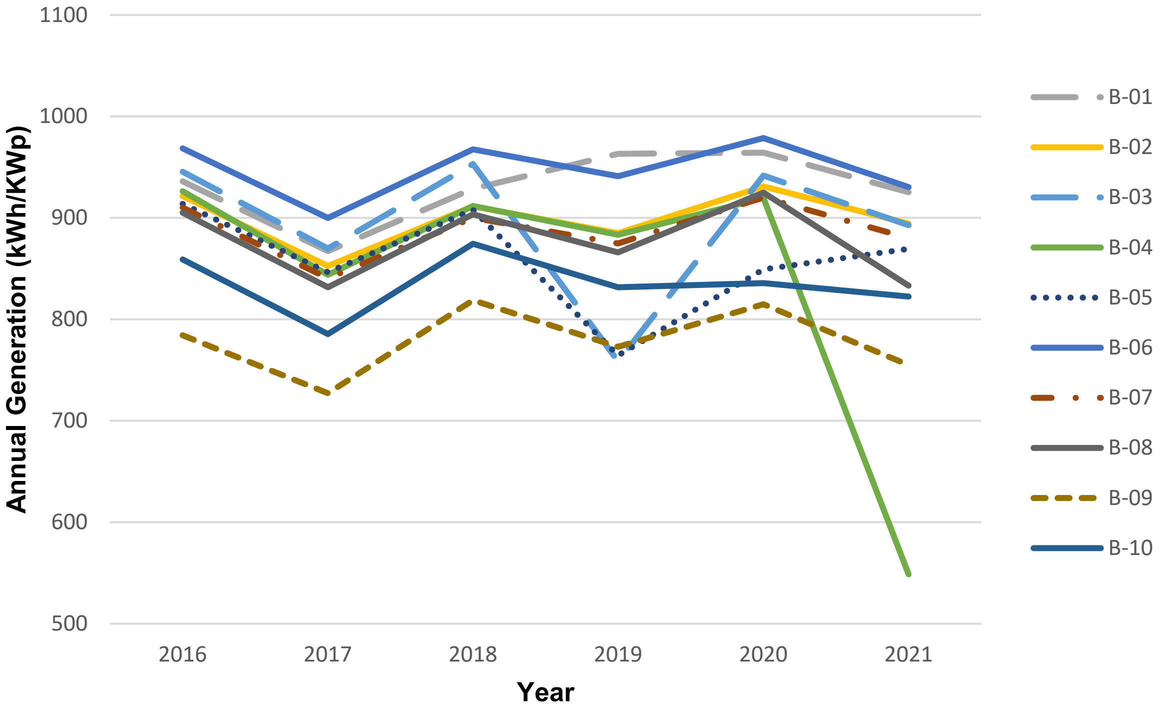


Figure 8.9 Graph of annual generation between 2016 and 2021 for properties in CCS Area B

8.2.2. *Impact of shading in Area B*

Installations B-01 and B-02 were on a pair of semi-detached bungalows. There was a tree in the garden of the property of B-02 which led to the lower performance of that installation.

One of the best performing systems was B-06. Installation B-05 was next door and typically generated 50-60 kWh/kWp less than B-06 when neither system had any issues. The cause of this lower generation was likely to be due to shading from a nearby tree and telegraph pole.

There were a number of larger trees in Area B. The level of shading was greater for installations B-09 and B-10, with B-09 particularly badly affected due to being closer to one of the trees.

As a result of the shading issues, installation B-09 was the worst performing system in the area, with B-10 also underperforming compared to the other systems.

8.3. Performance of PV systems in CCS Area C

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
C-01	845.7	917.4	823.5	757.4	811.0	795.3	813.1	736.5
C-02	820.0	917.4	820.0	765.0	813.4	800.9	836.1	779.5
C-03	820.0	917.4	860.0	788.3	848.2	837.2	876.8	812.8
C-04	862.9	917.4	779.1	716.1	771.3	765.4	614.0	751.1

Table 8.10 Annual generation between 2016 and 2021 for properties in CCS Area C

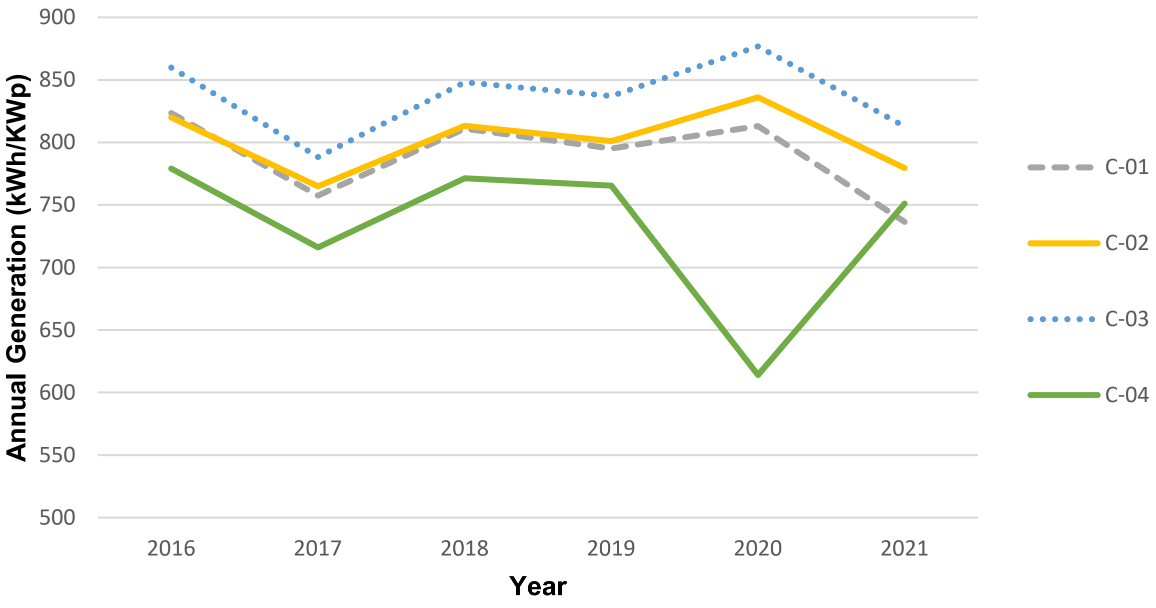


Figure 8.11 Graph of annual generation between 2016 and 2021 for properties in CCS Area C

The installations in Area C were on two pairs of semi-detached bungalows. These were in the same road and were orientated at about 20˚ from south. There was shading from trees and bushes on the other side of the road, which led to lower generation. Due to the shading, the PVGIS generation estimates were poor. The installer estimate predicted the generation from installation C-04 would be the highest when it was in fact the lowest.

Installation C-01 had a few days offline in 2020 and 2021. These might have been due to the residents turning the electricity off for a few days while away, such as over New Year. Installation C-04 was offline for half of May and the whole of June 2020. This was likely to have been due to a void or extended period when the property was unoccupied.

Installations C-01 and C-02 were on one pair of semi-detached bungalows and had typically similar performance. Despite installations C-03 and C-04 being close together on the other pair of semi-detached bungalows, there was a significant difference in performance. C-03 was the best performing system and C-04 was the worst performing system with a typical difference of 70 to 80 kWh/kWp per year. The cause of this performance difference was likely to have been shading. Most of the trees along the other side of the road were evergreen, but those opposite installation C-03 were not and this may have reduced the impact of shading from Autumn to Spring.

8.4. Performance of PV systems in CCS Area D

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
D-01	872.4	941.3	914.1	849.8	903.9	891.0	784.6	860.2
D-02	872.4	941.3	914.5	850.9	905.3	673.9	932.1	869.1
D-03	908.0	941.3	880.0	813.1	837.6	859.5	889.1	833.9
D-04	872.4	941.3	919.9	853.6	912.1	881.9	913.4	850.3
D-05	844.0	941.3	934.2	871.1	917.7	909.7	942.3	872.7
D-06	897.4	941.3	909.5	841.4	893.2	884.5	911.9	844.3
D-07	907.0	941.3	795.0	828.7	434.8	856.6	889.2	813.3

Table 8.12 Annual generation between 2016 and 2021 for properties in CCS Area D

The installations in Area D were on a group of semi-detached or terraced bungalows with the same orientation, about 20˚ east of south. There was more limited shading from trees and bushes in this area compared to others.

There was a period with low generation for installation D-01 between the end of May 2020 and beginning of July 2020 which was likely to be due to the property being unoccupied.

Installation D-02 was offline between mid-April and mid-June 2019, most likely due to the property being unoccupied. There was some underperformance of installation D-03 in 2018, but there were no apparent periods offline.

The meter for installation D-07 was not initially registered with Orsis and started recording data from 16 Mar 16. The site also had a history of power cuts tripping the circuit breaker and poor reception for the generation meter. A high gain antenna was fitted externally. Between early February and early July 2018 no generation was recorded. This might have been due to generation meter issues or the property being unoccupied.

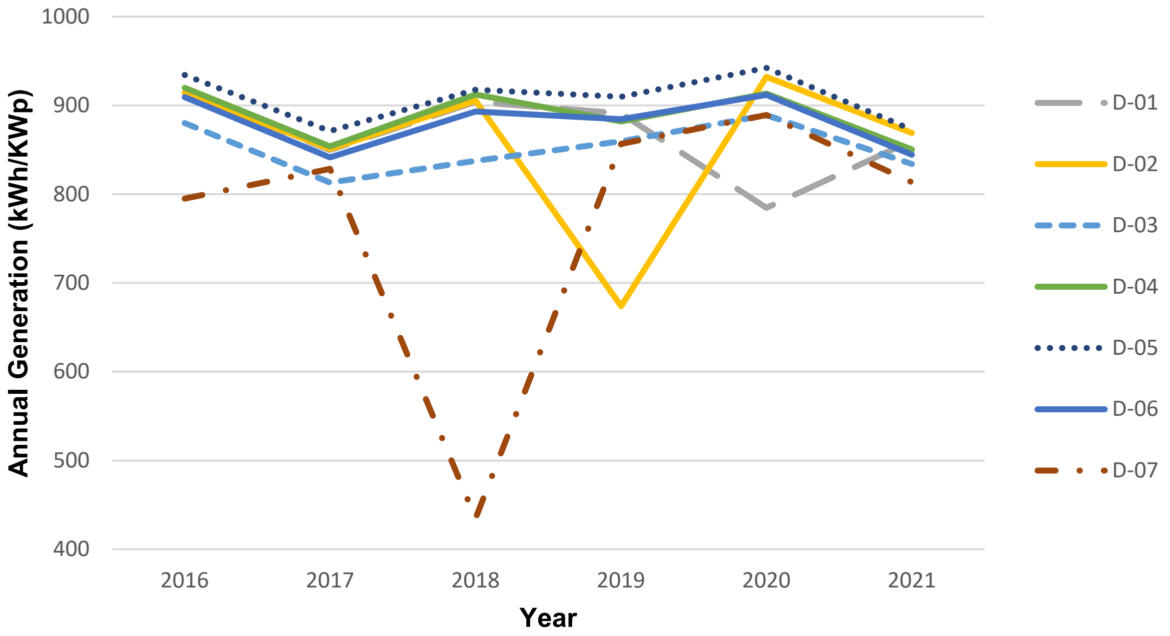


Figure 8.13 Graph of annual generation between 2016 and 2021 for properties in CCS Area D

8.5. Performance of PV systems in CCS Area E

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
E-01	883.3	946.0	903.9	835.7	666.3	879.3	912.5	871.7
E-02	1084.0	945.9	940.3	865.8	931.4	902.1	946.2	897.5
E-03	873.3	946.0	852.3	835.0	924.3	899.2	934.6	885.8
E-04	890.0	946.0	955.0	843.7	901.1	864.9	883.0	812.1
E-05	920.0	945.9	965.2	878.9	947.5	925.1	940.2	829.9
E-06	910.0	946.0	931.6	855.7	920.7	678.4	921.1	846.4

Table 8.14 Annual generation between 2016 and 2021 for properties in CCS Area E

The installations in Area E were on a row of 3 pairs of semi-detached bungalows which were orientated approximately 20˚ east of south. There was limited shading, with installation E-01 likely to be most affected with some impact from shadows from a larger tree and the next-door building. The predicted generation by the installer was generally good apart from for E-02 where the recorded system size was too large.

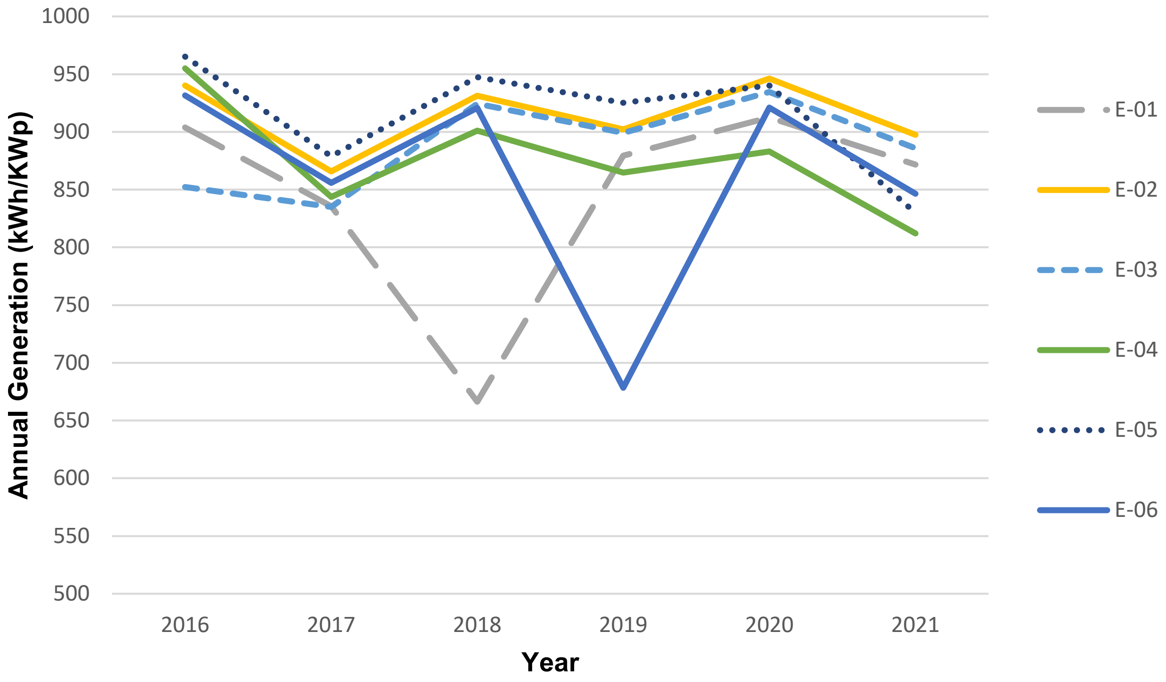


Figure 8.15 Graph of annual generation between 2016 and 2021 for properties in CCS Area E

There was a drop in generation for installation E-01 in 2018 due to the property being void between the end of July and end of October. Installation E-03 was offline for 38 days in February/March 2016. Notes for the property indicate a circuit breaker tripped at some point for an unknown period with no fault found. It may have taken longer to resolve this due to access issues or a period when the property was unoccupied.

There was a gradual decrease in performance of E-04 compared to the other installations after 2016. There were no clear periods offline and the site did not appear to be affected by shading which became worse. Likewise, there was a decrease in the relative performance of installation E-05 in 2021 with no periods offline apparent. Neither of these changes in performance can be explained from the information available.

The significant drop in generation for installation E-06 in 2019 was due to major building works. The property was unoccupied between the end of February and early May 2019.

8.6. Performance of PV systems in CCS Area F

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
F-01	907.0	926.2	949.5	871.4	947.3	927.3	948.9	888.4
F-02	867.0	949.1	935.8	853.3	495.5	905.2	934.5	861.6
F-03	883.6	949.1	924.9	841.1	909.5	891.6	923.0	863.6
F-04	886.7	949.1	921.6	853.9	927.2	906.1	936.6	865.2
F-05	896.3	949.1	915.6	848.9	923.8	905.9	931.1	819.6

Table 8.16 Annual generation between 2016 and 2021 for properties in CCS Area F

Area F had 6 pairs of semi-detached bungalows and there were 5 solar PV installations on properties which were close to south facing. Installation F-01 was facing approximately 30˚ east of south, while installations F-02 to F-05 were facing about 10˚ east of south. There were some taller trees to the south of installations F-02 to F-05, but these were not evergreen, so there was less of an impact from shading between Autumn and Spring when the sun was lower in the sky and the trees had lost their leaves.

The property at installation F-02 was unoccupied between mid-April and mid-July 2018 which led to the reduced generation that year. There was a period of about 2 weeks of very low generation with installation F-05 in May 2021 and this was due to an Orsis meter signal issue and a high gain antenna was fitted.

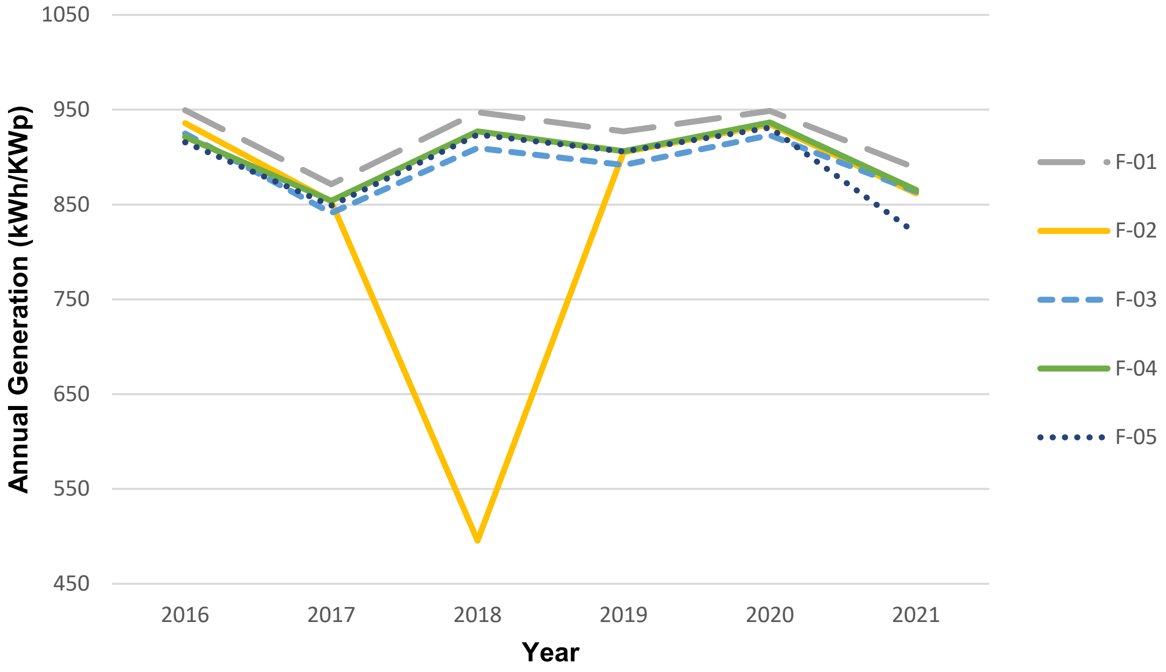


Figure 8.17 Graph of annual generation between 2016 and 2021 for properties in CCS Area F

8.7. Performance of PV systems in CCS Area G

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
G-01	930.5	944.4	975.8	895.8	970.5	951.0	984.3	920.7
G-02	870.0	944.4	981.8	912.7	997.9	925.9	993.4	924.5
G-03	872.4	944.4	996.6	921.6	982.1	955.5	980.7	935.3
G-04	924.4	944.4	991.3	909.9	978.9	746.0	991.8	926.6
G-05	924.4	944.4	975.8	896.0	951.1	937.8	964.9	882.3

Table 8.18 Annual generation between 2016 and 2021 for properties in CCS Area G

The installations in Area G were on 3 pairs of semi-detached bungalows which were facing about 15˚ west of south. There was little or no shading of the solar PV arrays. The values for the predicted generation were generally too low, but this was particularly true for installations G-02 and G-03. The PVGIS desktop estimate was generally closer to the actual generation.

There was underperformance of installations G-02 and G-04 in 2019. The system for G-02 was offline for over 2 weeks in February 2019 due to the circuit breaker tripping after a power cut. During August and September 2019, installation G-04 was initially generating less than 1kWh/day, but after 4 weeks fell to a negligible amount. This was due to a meter failure which was subsequently replaced.

There was poorer performance of installation G-05 in 2021. The system was offline for 3 days in November, probably due to the electrics or PV system being turned off. There were access issues around this time which limited the ability of CCS to investigate other performance issues.

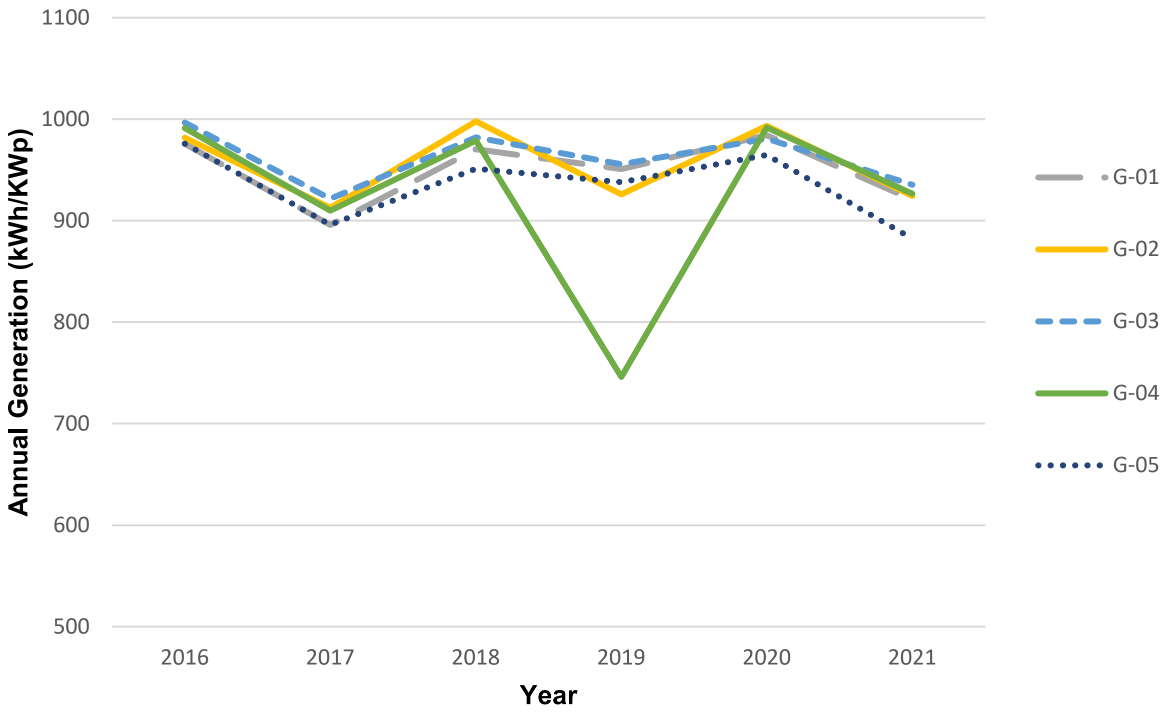


Figure 8.19 Graph of annual generation between 2016 and 2021 for properties in CCS Area G

8.8. Performance of PV systems in CCS Area H

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
H-01	874.3	904.7	937.3	872.0	351.5	924.5	959.1	896.0
H-02	891.4	904.7	926.7	865.4	929.0	908.2	942.7	878.8
H-03	874.3	904.7	913.1	852.5	916.4	897.3	926.7	865.9
H-04	840.0	904.7	847.5	878.6	949.3	928.0	963.1	897.8

Table 8.20 Annual generation between 2016 and 2021 for properties in CCS Area H

The solar PV installations in Area H were on 2 pairs of semi-detached bungalows which faced south-east. There was no apparent shading of the PV arrays by trees. The PVGIS estimates were better in a sunny year and the predicted generation better when there was lower solar irradiation such as in 2021. The predicted generation for H-04 was too low.

There was a significant drop in generation from installation H-01 in 2018, with the system not recording generation for several months. This was due to a faulty meter and it took multiple visits before Orsis authorised a replacement.

Installation H-04 recorded low generation between 14 Sep 16 and 22 Oct 16. There was a new tenant in October, but also communications issues around this time which required a high gain antenna to be fitted.

There was a lower difference in the performance of the installations in this Area compared to some others, with the difference between the best and worst performing systems normally between 30 and 35kWh/kWp. This compares to Area C where shading was more of an issue and the difference was 70 to 80kWh/kWp between the best and worst performing.

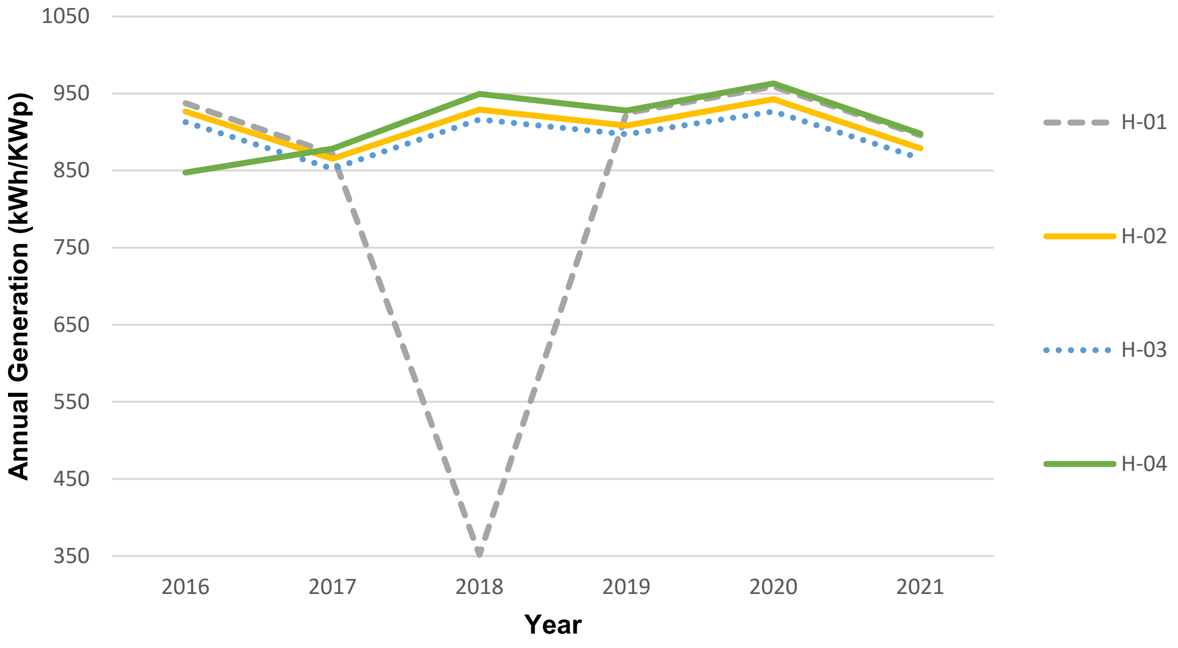


Figure 8.21 Graph of annual generation between 2016 and 2021 for properties in CCS Area H

8.9. Performance of PV systems in CCS Area K

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
K-01	893.3	921.0	871.4	827.3	877.4	838.1	850.5	631.2
K-02	863.7	921.0	849.6	821.2	891.8	851.6	864.3	810.8
K-03	709.7	921.0	629.3	656.6	902.0	862.0	889.0	835.9
K-04	779.7	921.0	818.0	790.4	855.1	817.1	833.6	774.4
K-05	807.0	921.0	839.4	801.0	688.1	813.9	827.6	762.0

Table 8.22 Annual generation between 2016 and 2021 for properties in CCS Area K

The PV installations in Area K were on 3 pairs of semi-detached bungalows with the roofs facing close to south-east. There were several trees close to the installations which are likely to have affected the level of generation due to shading. The PVGIS estimates of generation were poor as the desktop analysis did not take shading into account. The predicted generation by the installers was fairly accurate and they correctly indicated that installations K-01 and K-02 would have higher generation. The low generation for K-03 might have reflected the level of shading at the time.

There was a gradual decrease in the performance of installation K-01 compared to K-02 next door between 2016 and 2020. This might have been due to growth of a tree which led to greater shading of installation K-01. There was a period of over a month in the summer of 2021 when the installation K-01 was offline. This was due to a circuit breaker having been turned off. It was not possible to deal with the issue more rapidly as CCS were not able to access the property for a period.

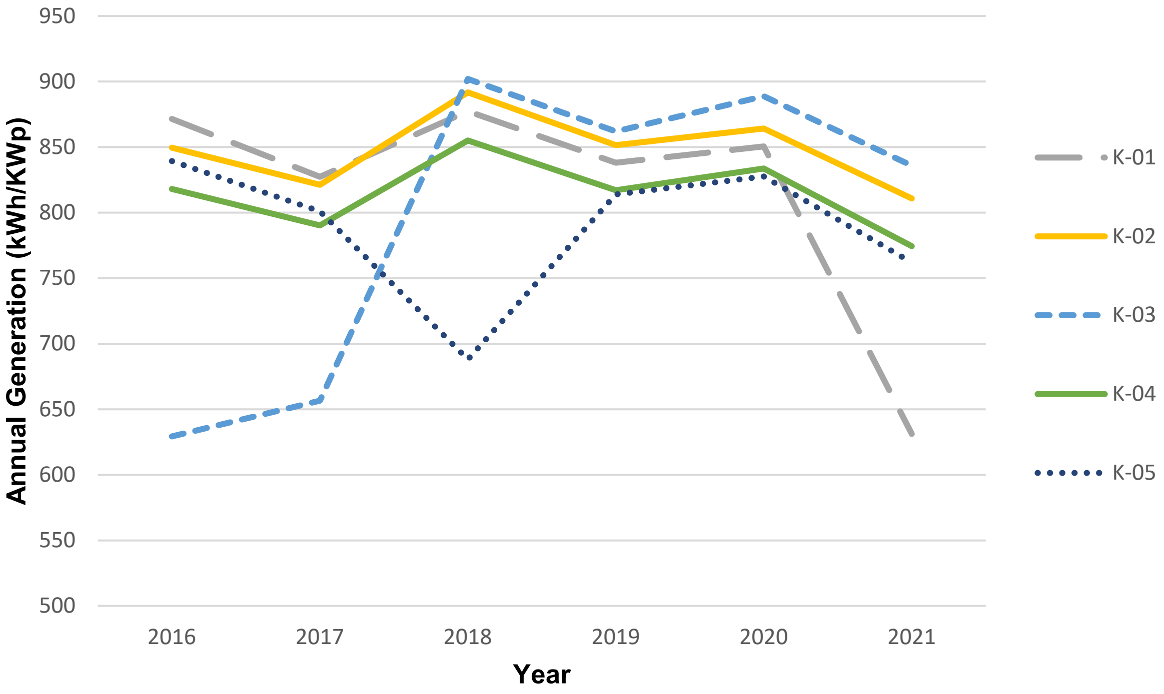


Figure 8.23 Graph of annual generation between 2016 and 2021 for properties in CCS Area K

There was lower generation than might be expected for installation K-03 during 2016 and 2017. This appeared due to general lower performance rather than periods offline. The maximum daily generation in 2016 was 13.1kWh and 15.2kWh in 2017, but increased to 19 to 21 kWh in subsequent years. This might be due to a tree being cut back reducing shading at this site. CCS did not have access to the site during this period.

Installation K-05 was offline for about a month in May/June 2018. This was likely to be due to a period when the property was unoccupied, and the electrics were turned off.

8.10. Performance of PV systems in CCS Area M

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
M-01	642.9	900.4	909.9	847.0	916.5	897.3	926.4	863.5
M-02	879.7	900.4	907.5	851.5	913.8	890.9	929.0	862.3
M-03	879.7	900.4	891.7	830.4	891.6	876.7	914.2	851.7
M-04	871.7	900.4	919.2	856.5	923.4	901.0	916.6	853.1
M-05	882.6	900.4	924.5	864.6	927.1	903.9	935.9	876.6
M-06	883.3	900.4	931.9	864.6	769.9	896.2	942.1	878.5

Table 8.24 Annual generation between 2016 and 2021 for properties in CCS Area M

The installations in Area M were on 4 pairs of semi-detached bungalows that were facing south-east. There was limited shading and the installations were not far from those in Area H, which had similar orientation.

The estimates for annual generation were generally quite good, apart from for the predicted generation for installation M-01. This was due to a larger PV installation having been fitted than was recorded. The actual generation was closer to the generation predicted by the installers using the MCS method on years with lower solar irradiance and closer to the PVGIS desktop estimate for sunnier years.

Installation M-04 had periods of a few days with no generation in December 2020, January 2021 and November 2021. There were likely to be caused by signal issues with the smart generation meter. A high gain antenna was fitted as a result.

The lower generation of installation M-06 in 2018 was due to a period when the system was offline between late July and mid-September. This was likely to be due to the property being unoccupied and the electrics turned off. CCS was unable to gain access and there was no response to letters.

Installation M-03 typically had lower generation than the others in Area M. This was likely to be due to shading of the PV array in the morning by the building next door.

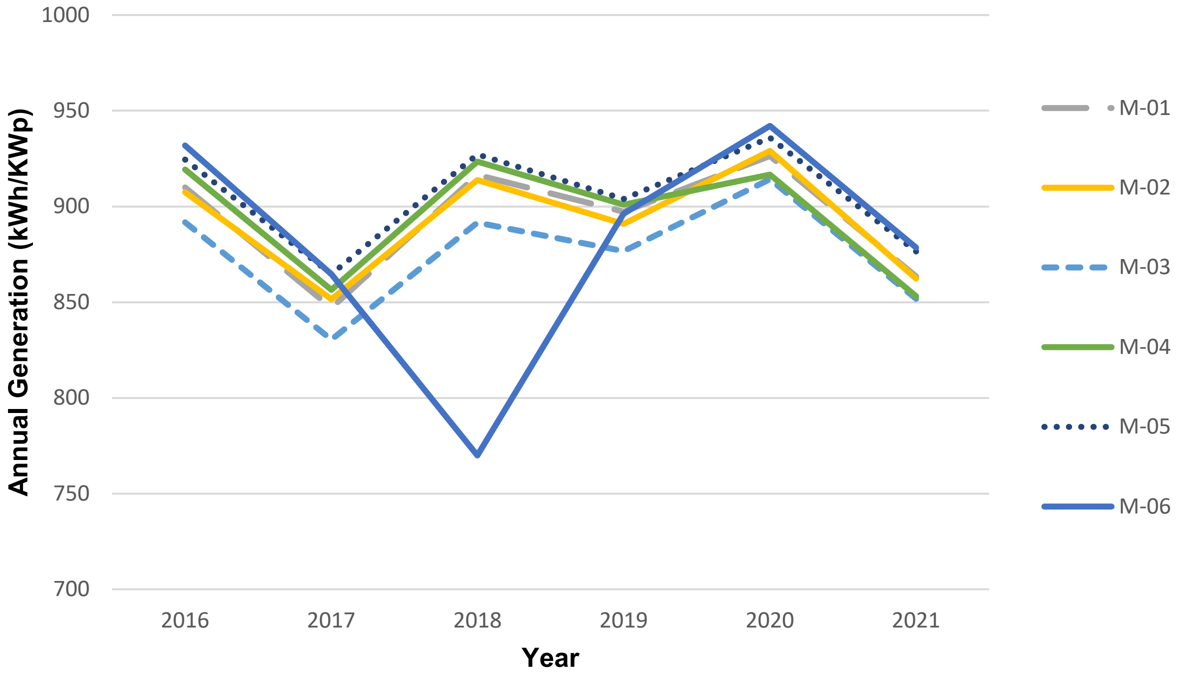


Figure 8.25 Graph of annual generation between 2016 and 2021 for properties in CCS Area M

8.11. Performance of PV systems in CCS Area S

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
S-01	804.0	886.4	815.9	735.0	786.9	765.2	786.1	376.0
S-02	986.7	886.4	898.8	843.4	914.8	889.7	918.5	871.2
S-03	796.0	886.4	770.0	717.3	758.8	725.0	746.2	710.4
S-04	893.3	886.4	901.3	844.7	802.9	876.9	913.0	869.7
S-05	840.0	886.4	847.7	780.2	842.6	624.8	860.8	637.4
S-06	893.3	886.4	897.1	808.2	871.2	840.7	831.3	821.5
S-07	796.0	886.4	788.0	730.1	773.3	742.6	764.3	716.5
S-08	893.3	886.4	893.8	835.9	904.2	871.2	897.5	852.5

Table 8.26 Annual generation between 2016 and 2021 for properties in CCS Area S

The PV installations in Area S were on a terrace of bungalows and semi-detached bungalows which faced approximately south-west. The predicted generation estimated by the installers was generally quite close to the generation in 2016. These estimates predicted that installations S-01, S-03 and S-07 would have the lowest generation. The predicted generation for S-02 was unusually high. This was due to records indicating a 3.5kW system was fitted when in fact it was 3kW.

Installation S-01 experienced a drop in generation in 2021. The PV system was offline from early March until the end of June. This had the characteristics of a void. CCS records indicated that there were significant signal issues in the area and a high gain antenna was fitted for the generation meter. Several of the sites in the area required installation of a high gain antenna or change in data provider due to the signal issues.

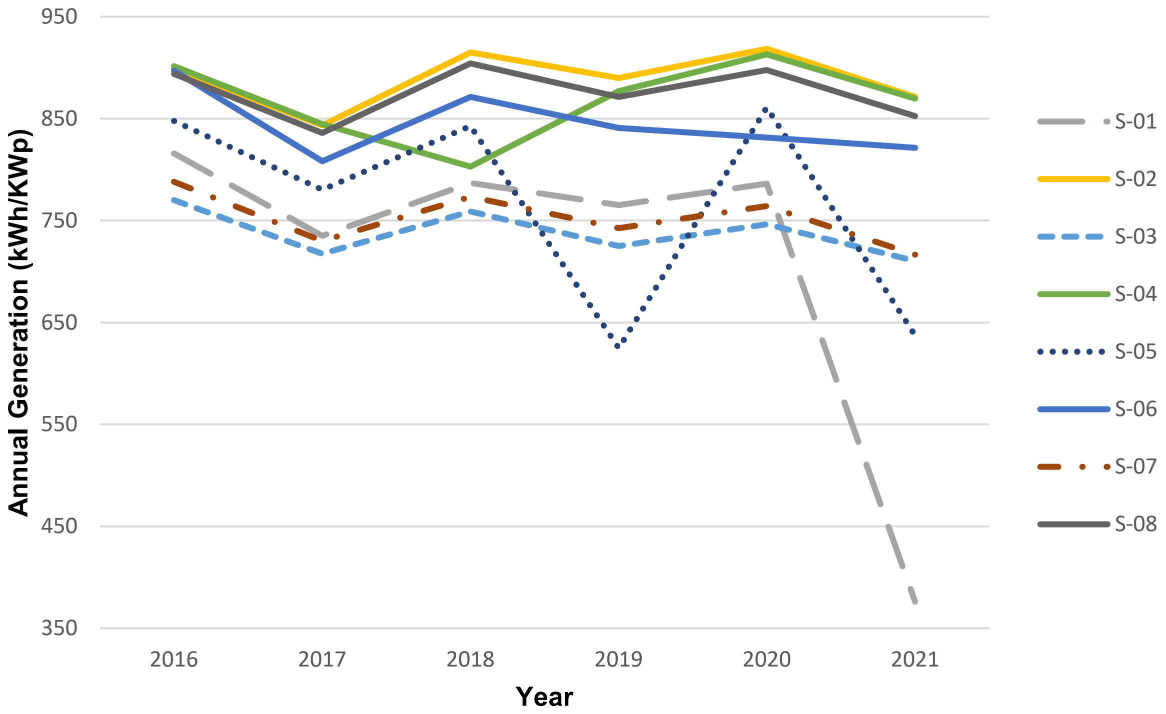


Figure 8.27 Graph of annual generation between 2016 and 2021 for properties in CCS Area S

In 2018, there was a period of reduced generation for installation S-04 between late January and the beginning of April. Most of the time, the generation was less than 0.1kWh/day. However, there were 2 periods of 4 days with generation between 0.2 and 6 kWh/day, suggesting the system had been turned back on or was working more normally again. CCS records indicated that there were shading issues at the site and panel cleaning undertaken.

Installation S-05 had lower generation than expected in 2019 and 2021. The system was offline from 31 Jul 19 to 1 Oct 19, although there were 2 days in late September when generation was recorded. The system was also offline between 29 May 21 and 8 Jul 21. CCS records suggest that the causes were signal issues and a high gain antenna being fitted to the generation meter as well as a problem following a power cut.

Initially the meter for installation S-06 had been associated with another site. During March 2020, installation S-06 was offline for just over 2 weeks. This was due to an AC isolator being left off after electrical works on the site.

The annual generation (kWh/kWp) was typically similar for installations S-02, S-04 and S-08. These installations were on the terrace of bungalows and had similar lower levels of shading.

Installations S-01, S-03 and S-07 typically had lower levels of generation. For example, the annual generation for installation S-03 was between about 125 and 175 kWh/kWp lower than for S-02. This significant difference in performance was likely to be due to a couple of tall trees which shaded installations S-01 and S-03 in particular. It was difficult to address the shading issue as the trees were in the curtilage of another property.

8.12. Performance of PV systems in CCS Area T

Property Code	Predicted Generation (kWh/KWp)	PVGIS Estimate (kWh/kWp)	2016 (kW/kWp)	2017 (kW/kWp)	2018 (kW/kWp)	2019 (kW/kWp)	2020 (kW/kWp)	2021 (kW/kWp)
T-01	836.3	791.0	796.7	745.7	806.7	784.9	808.4	761.0
T-02	763.3	791.0	737.3	692.5	751.5	730.1	746.1	701.3
T-03	843.0	791.0	745.8	681.8	739.0	721.8	729.1	494.2
T-04	750.0	791.0	719.5	657.4	713.5	687.9	692.1	628.5

Table 8.28 Annual generation between 2016 and 2021 for properties in CCS Area T

The solar PV systems installed in Area T were on 2 pairs of semi-detached bungalows. These were facing nearly due East. There was a large tree nearby which affected installation T-04 the most. The PVGIS estimate which did not take into account shading and was fairly close to the actual generation for T-01 which experienced little shading, but the other estimates were too high.

The predicted generation by the installer correctly indicated that installation T-04 would have the lowest generation, but the values estimated were too high. The estimate for T-03 was about 100kW/kWp too high with the estimate for T-04 about 50kWh/kWp too high. The value to installation T-02 was close and was about 10-20kWh/kWp too high.

There was lower generation than expected for installation T-03 in 2021, with the PV system offline between the end of July and beginning of October. This was likely to have been a period when the property was unoccupied, and the electrics turned off.

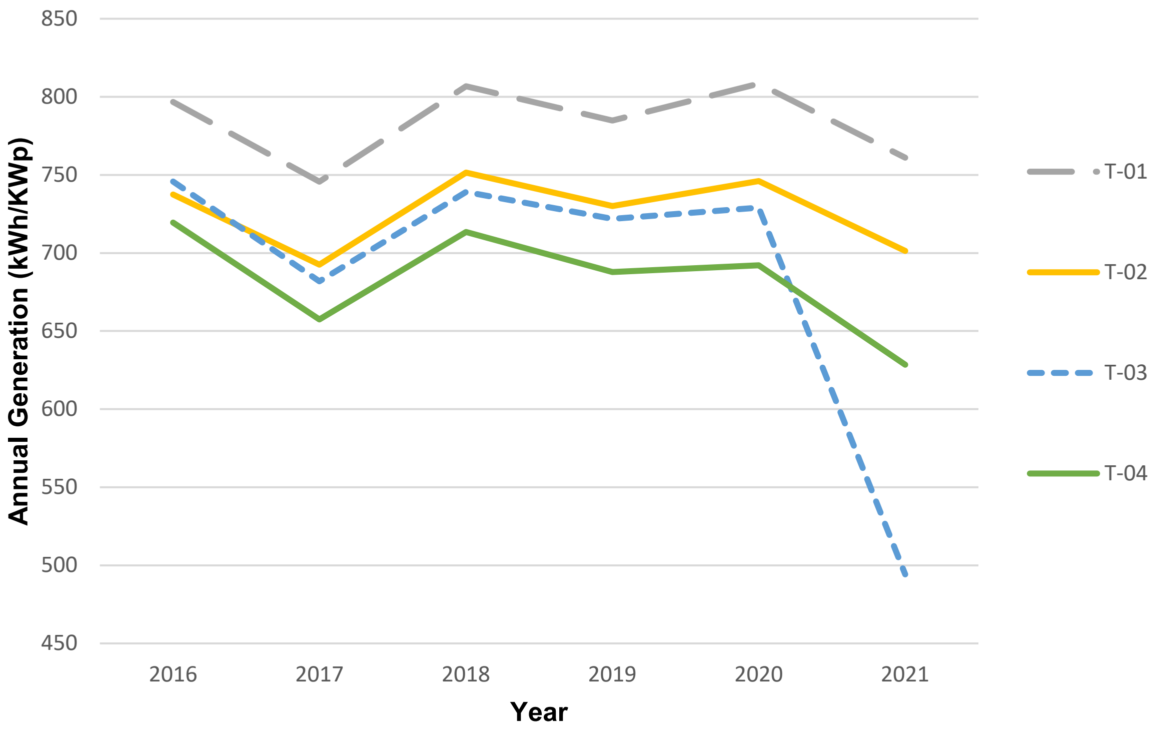


Figure 8.29 Graph of annual generation between 2016 and 2021 for properties in CCS Area T

The annual generation from the properties in area T was typically lower than for those in other areas where the PV installations were orientated closer to south and generated more over the year as a result. There was also a significant shading impact in Area T from the tree close to installation T-04. The difference in the annual generation between installations T-01 and T-04 increased from 77.2kWh/kWp in 2016 to 132.5kWh/kWp in 2021, suggesting the shading impact may have become worse over the analysis period.

Figure 8.30 shows a graph of the half-hourly solar PV generation on 26 Mar 18 for the 4 installations in Area T. The sites first started to record PV generation from 06:30, but generation from installation T-04 was significantly below the others until 09:30 due to the shading effect of the tree. Peak generation occurred at 10:00 to 10:30 and there was rapid decrease in generation after 12:00, with levels of generation between the 4 systems comparable as the generation fell in the afternoon.

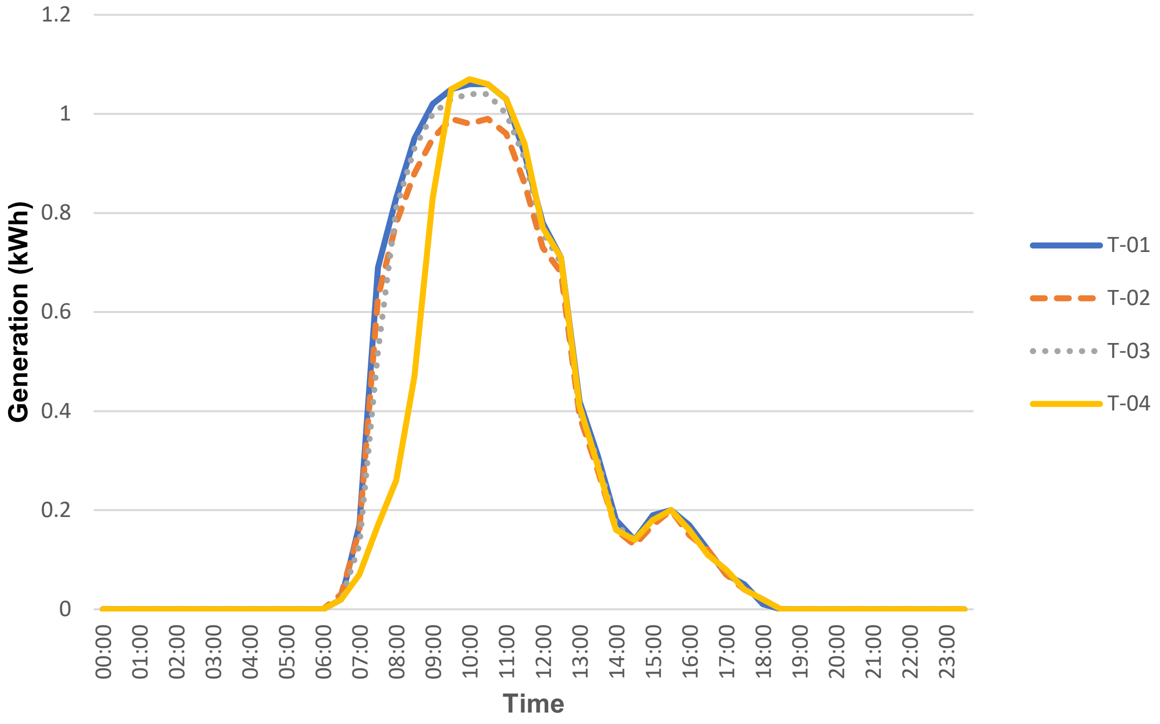


Figure 8.30 Graph of Solar PV generation on 26 Mar 18 for households in CCS Area T

A plot of half-hourly PV generation on 26 Jun 18 is shown in figure 8.31 for the installations in Area T. With the sun rising earlier in the morning, PV generation was recorded from about 05:00. There was a rapid rise in generation for installations T-01 and T-02 which were not affected by shading. However, there was lower generation from installations T-03 and T-04 until about 08:00 due to shading from the tree when the sun was lower in the sky.

Peak generation was again at about 10:00 and the level a generation was comparable for the 4 systems as the generation decreased in the afternoon. There was low generation after 15:00 despite it being the middle of the summer. This was due to the roofs facing east and little direct sun on the PV arrays in the afternoon. Such a property should have solar panels on both the east and the west facing roofs if there is to be PV generation throughout the day.

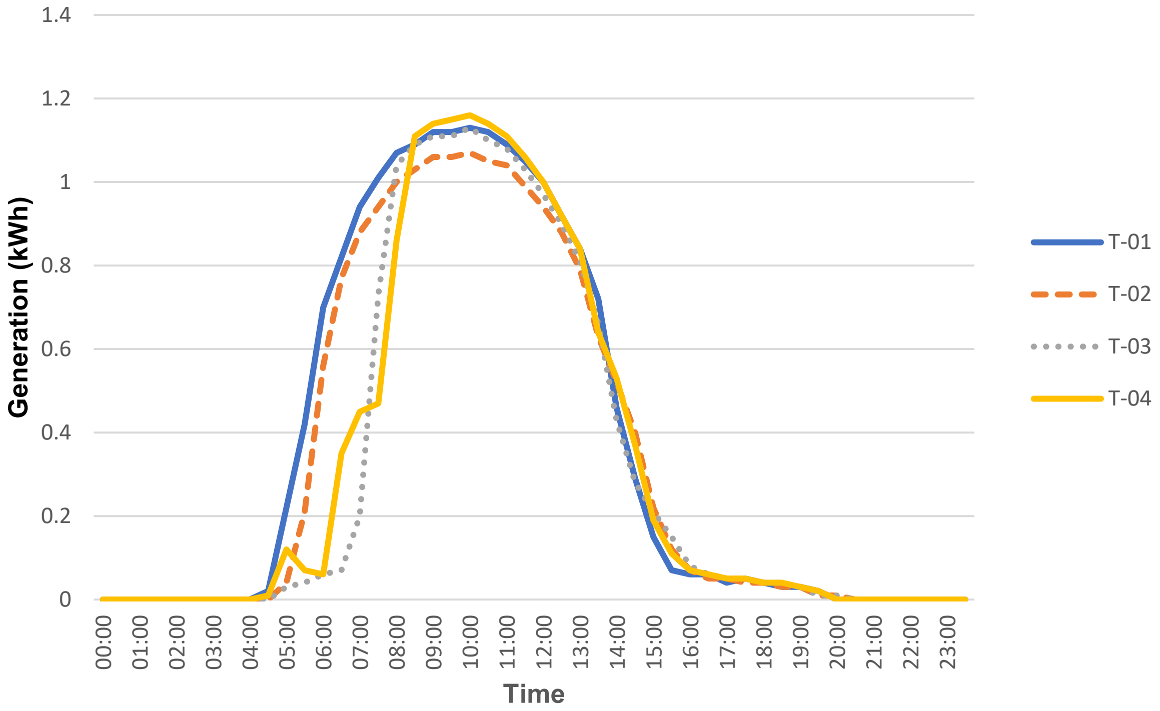


Figure 8.31 Graph of Solar PV generation on 26 Jun 18 for households in CCS Area T

Installation T-02 had lower peak generation than the other systems in this area. It is possible that this might have been due to PV components rather than shading. The annual generation for installation T-02 was typically greater than for T-03 because T-03 was more impacted by shading in summer.

9. Summary

In this report which looked at the long-term performance of domestic solar PV installations, factors which affected the electricity generation from solar panels were initially considered. These included the size, orientation, inclination and shading of the solar panels as well as the solar irradiance that year. Ways to estimate the annual generation from a domestic solar PV system were described such as the MCS Method, PVGIS and software like PV*SOL which is used by installers.

The different components of a solar PV system were discussed and the likelihood of faults. Although solar PV is often described as a fit and forget technology, landlords with significant numbers of systems will have to regularly deal with systems going offline or component failures. It is therefore important to regularly monitor performance of systems, so it is possible to quickly react and resolve an issue. This reduces the potential for higher bills for residents and loss of income from schemes such as the feed-in tariff.

Case studies were provided for 4 social landlords and 3 community energy organisations. These discussed the portfolios of PV installations the organisations were responsible for, how they monitored the performance of systems and the most common issues that occurred.

One of the community energy organisations was Chase Community Solar (CCS). NEA worked with CCS and analysed the performance of 75 solar PV systems on bungalows which were socially rented by Cannock Chase Council.

Larger portfolios of installations normally used smart generation meters. System owners typically monitored performance of installations using monitoring portals from either Orsis, Meter Manager or ASL. Some social landlords like Northampton Partnership Homes (NPH) and the London Borough of Waltham Forest used a third-party maintenance contractor to monitor and maintain their solar PV systems. Others like Stockport Homes monitored the systems themselves and used their own electricians to carry out repairs.

The monitoring portals have alarms which can inform system owners of installations which have lost connection or have no or reduced generation. These alarms can be sent by email or it is possible to run regular reports to determine any installations with issues.

System owners have found that some inverters models are more reliable than others. Empower Community and Energise Barnsley both found that one inverter model accounted for most of their inverter failures with this model no longer on the market. NPH also had a bad batch of inverters where most of them needed repairing within a couple years. While Empower Community initially used 5 or 6 inverter manufacturers, they are now replacing all inverters that fail with a model from a single manufacturer to provide efficiencies with maintenance. The London Borough of Waltham Forest experienced delays in getting replacement inverters since Brexit.

Many social landlords switch off the electricity in a property and isolate the gas supply when a tenant moves out, creating a void property. The solar PV system also cuts out when the electricity to the property is switched off. As a result, this is a major cause of lost solar PV generation and will affect income from systems installed with the feed-in tariff. While landlords might aim for a property to be void for only 3 to 4 weeks, it can last for several months, particularly if there are significant refurbishments to be carried out. Not all social landlords turn off the electricity during unoccupied periods. Stockport Homes keep the electricity and solar PV turned on and Energise Barnsley has an agreement that the electricity remains connected, allowing the solar panels to keep generating.

Another major issue with systems can be problems with metering. This can include communications issues due to a poor mobile signal. This might be resolved by switching mobile network or installing a high gain antenna. Out of the CCS solar PV portfolio, about 10% had poor signal acquisition and required installation a more sensitive antenna. Other metering issues include meter failures and SIM card failures. These are often not straightforward issues and might need several visits to resolve.

When electrical work is carried out in properties, the AC isolator for the solar PV system is often left turned off. This can happen during Electrical Installation Condition Report inspections, installations of smart meters and other maintenance of household electrics. Residents may sometimes turn off the electrics when going away from home for a period.

Insulation resistance faults can lead to PV systems tripping out. This might be due to damaged or poorly installed MC4 connectors and DC cabling. Residents can complain about birds nesting underneath the solar panels and this can also be a cause of damage to cabling.

In portfolios of several hundred solar PV systems, errors can be made in records for systems. The system that was installed may not always be the same as the original system design. This can mean the PV system size might be larger or smaller than that recorded. Sometimes Google Maps or Streetview can assist in identifying discrepancies. Mistakes can also be made in the records for the location of generation meters. This can mean 2 or more meters at the wrong sites.

Installers are required to make an estimate of the annual generation for a domestic solar PV system. This is straightforward at sites with no shading. However, in situations where there is shading, these estimates can be quite variable in accuracy. Installers can struggle to make an accurate estimate and over time, the level of shading from trees and bushes can change. When there is a large programme of installations, the likelihood of errors in the estimates of annual generation is larger.

The 75 Chase Community Solar (CCS) installations were grouped into 12 distinct areas where all the installations in an area were close and had similar orientation and inclination. The annual generation (kWh) per kW of solar PV was calculated, making it easier to compare PV systems which ranged in size between 2.5kW and 4kW. Graphs of the annual generation (kWh/kWp) were plotted for the years 2016 to 2021 for each area which had installations with similar orientation and inclination.

The graphs had a broadly common undulating line due to the variation in solar irradiation between years. The impact of shading was apparent with the undulating lines parallel to one another, with those installations experiencing greater shading shifted to lower levels of generation. In years where there was a period when a solar PV system was not operational for some reason, there was a dip in generation and a deviation from the parallel undulating lines.

For some installations, it was easy to identify periods when a system had been offline - due to a significantly lower level of annual generation. However, it was not always easy to determine years of poor generation due to the natural variation in annual generation. The graphs made it easier to pick out anomalous performance than looking at the raw data. This technique of comparing PV systems in the same area with similar orientations could be useful for assessing any changes in performance over time due to issues such as shading or perhaps system components.

The analysis showed some areas where there was greater variation in annual generation between nearby installations due to shading. It may be worth considering tree pruning in these areas to improve PV system performance.