THE CONTINUING PROFESSIONAL DEVELOPMENT PROGRAMME

Fundamentals CPD

Photovoltaics and Batteries

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Some of the key issues relating to the installation of photovoltaic (PV) arrays and batteries in domestic and small non-domestic buildings will come under scrutiny in this article. Under the spotlight will be small-scale PV arrays, e.g. less than 1MWp output capacity, but not utility scale installations.

PV cells convert solar radiation into electricity. The technology has been in use in the UK for decades, but there was a significant rise in its application following the introduction of the feed in tariff (FiT) in 2010 which continued until 2019, when the FiT scheme closed. Installations in the year to February 2020 were 43 per cent lower than in the previous year[1] when the FIT was available.

PV cells typically comprise silicon crystals doped with phosphorous or boron to increase the movement of free electrons and subsequent power generation. Polycrystalline and monocrystalline are the most common types of PV cell with polycrystalline cells being typically cheaper, but less efficient than monocrystalline cells. Amorphous silicon PV cells have lower costs, but have only a little over half the efficiency of monocrystalline cells.

The energy management hierarchy places high priority on reducing electricity demand before considering the generation of electricity from renewable sources. Energy efficiency measures should be implemented to reduce a building's electricity demand before a PV array is installed. This will reduce the capacity of the PV array needed to meet a building's electricity needs. The return on investment on a PV array can be optimised by sizing it to meet the lowest daytime electricity demand. Energy efficiency measures can contribute to this optimisation by prioritising the minimisation of energy waste at these times.

Maximising total output

The location of a PV array affects its ability to generate electricity. The ideal location for maximising total annual electricity output in the UK is an unshaded position in a south-facing orientation at an inclination from the horizontal of about 30°. Shading by trees, buildings, pylons, roof geometry and furniture can have a significant impact upon the power generated by a PV array. The excitement of electrons within the semiconductor material of a PV cell is significantly reduced by shading. However, where one shaded cell is in a circuit with unshaded cells, the flow of electricity from the whole circuit can be reduced, further reducing the power generated by the array. Even a small degree of shading can have a significant effect upon power output of an array.

Both the direction a PV array is facing and its angle of tilt relative to the sun are important factors in optimising electrical output. A south-facing orientation will be ideal through the majority of the day in the UK, whereas east and west orientations will only optimise direct sunlight in the morning and evening, respectively. While the ideal inclination from the horizontal varies with latitude, time of day and season, the optimum for a fixed-axis system in many parts of the UK is 30˚. A system in the north of Scotland will need to be set up differently from one in Cornwall, and even under optimum conditions, the level of insolation received annually in Scotland will be less than that in Cornwall.

Once a building's electricity demand has been reduced, grid connected PV arrays are sized to take account of a number of factors, including residual peak and minimum power demands; the area available to accommodate a PV array; the building owner's appetite for financial risk; occupancy patterns.

The power generated by PV arrays varies throughout the day according to light levels, intermittent shading and other factors. Power demand in buildings also varies in line with occupancy patterns and activity levels. There are few applications where these two are aligned. Consequently, if a PV array is sized to meet a building's peak demand, a significant proportion of the electricity it generates at times of non-peak demand is likely to be exported from the building to the electricity supply grid. However, means of managing consumption, electricity storage and export can be introduced to optimise self-consumption, carbon emissions and costs.

Battery storage can be incorporated into a building's energy strategy, for example, to:
• improve security of energy supply;
• reduce the export of electricity from a building's PV array;

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"A small number of electricity suppliers in the UK sell solar panel and storage packages"

For off-grid applications a PV array can help to reduce the use of fossil-fuel stand-by generators

- optimise the site's electricity carbon intensity; and
- optimise the site's electricity cost.

A battery storage system can be installed to improve security of electricity supply. Specialist systems, commonly known as Uninterruptible Power Supplies (UPS), have been in existence for many decades and are commonly associated with supporting the continuous availability of information and communication technologies and other business-critical systems. However, not all PV-battery systems are designed to provide protection against power interruption, and it is important to clarify this functionality before procuring a system.

Batteries can also be used to store electricity generated at times of day when generation exceeds demand. The stored electricity can then be discharged for use at night and other times of no/low PV power output.

For off-grid applications, a PV array-battery combination can help to reduce the use of fossil fuel standby generators.

For grid-connected applications, a small number of electricity suppliers offer systems that store electricity to batteries when grid electricity is less carbon-intensive, allowing it to be used later, when grid electricity is more carbon-intensive. This approach can support organisational carbon reporting, reducing reliance upon carbon offsetting to achieve net zero operational energy. However, it should be noted that although the most widely adopted and authoritative organisational carbon emission reporting methodology, the Greenhouse Gas Protocol, supports the organisational reporting of emissions using market (or contract) based carbon conversion factors, the protocol also requires organisations to report using their location-based carbon conversion factors for electricity, which would not benefit from this time of day variation in grid carbon intensity[2].

A small number of electricity suppliers in the UK sell solar panel and storage packages, offering discounts in return for helping them to balance the grid. This allows suppliers to aggregate a network of small batteries to access grid balancing schemes and associated payments for addressing peaks and troughs of electricity supply and demand.

Time of day tariffs offer lower cost electricity at night and higher cost during the day, or at peak periods, such as between 16:00 and 19:00. These systems can be used with batteries alone, whereby the battery is charged during low-cost periods (e.g. overnight) and discharged during peak periods. The effectiveness of this strategy can be enhanced by the combination of a PV array and battery designed to charge the battery either through self-generation or grid-supplied electricity when it is at low cost. Supplying electric vehicle charging within this context can offer further value for money.

More complex, real-time pricing is available, even at a domestic scale. This is more nuanced than banded time-of-day pricing and requires more automation to optimise value from it. However, the current global gas and electricity market price surge has led to wholesale electricity prices being consistently high, making this a risky option at the time of writing.

Real-time pricing is also available from a small number of suppliers for electricity exported from a PV array. The Smart Export Guarantee tariff is designed to pay for excess renewably generated electricity. These tend to be a fixed rate of the order of 5p/kWh. However, higher rates are available from the small number of suppliers that offer real-time pricing of exported electricity.

Framework for certification

The Microgeneration Certification Scheme (MCS) is a quality assurance scheme, supported by the Department for Business, Energy & Industrial Strategy (BEIS). It provides the framework for the certification of microgeneration technologies used to produce electricity and heat from low carbon sources. MCS operates a Battery Storage Standard (MIS 3012) which outlines the installation requirements for MCS certified Installers to supply, design and install battery storage systems. It both equips installers to roll out energy storage installations and provides consumer protection.

It should be noted that the financial case for PV-battery combinations is not always clear – especially during this time of high wholesale electricity prices. The business case for installing a battery alongside a PV array is likely to be stronger when non-financial considerations, such as security of electricity supply and optimising self-supply are valued. However, other environmental impacts associated with batteries that are not addressed by this article should also be taken into account. This could include impacts such as chemical toxicity and pollution caused during materials extraction and manufacturing processes and the embodied carbon of the selected battery technology.

Renewable energy generators, such as solar PV and wind significantly reduce annual greenhouse gas emissions arising from electricity generation and use compared to electricity generated by coal and other fossil fuels[3].

PV arrays installed in countries with areas of plentiful sun and with a high proportion of coal in their grid electricity energy mix (such as Australia and China) will save a considerable amount of carbon each year compared to the alternative of sourcing grid electricity.

However, what of the energy and carbon emissions arising from making, transporting and installing the PV arrays? The Embodied Carbon of a PV array is the carbon footprint taken to make it. It can be calculated using Life Cycle Assessment. Manufacturers can carry out a Life Cycle Assessment of their products and produce an Environmental Product Declaration (EPD). However, there is currently a dearth of EPDs for PV panels. A review of Life Cycle Assessment references for PV panels, based on monocrystalline cells carried out by Circular Ecology[4] came to the conclusion that a reasonable value to take is 2,560 kilograms of carbon dioxide equivalent per kW of rated output capacity of a PV panel (2,560 $kgCO_2e/kWp$).

This calculation takes account of the fact that the manufacture of PV cells is an electricity-intensive process. Cells made by energy-efficient processes will use less energy to make than those made under less well controlled processes. Silicon-based PV cell technologies are more energy intensive to make than the less common Cadmium Telluride (CdTe) cells, which have a higher 'energy return on investment'[5]. Furthermore, cells manufactured in countries with carbon-intensive electricity grids will have higher embodied carbon than those manufactured with electricity sourced from largely decarbonised grids. The majority of the silicon-based PV modules are manufactured in Asia (about 80 per cent), with China alone accounting for 62 per cent of total global production; European manufacturers about 10 per cent; and the USA 4 per cent[6]. The majority of global installed PV capacity is also in Asia (57 per cent), with over a third of total global capacity residing in China[7].

China and India have electricity grid carbon intensities of approximately 1$kgCO_2e/kWh$[8]. This suggests that, in broad-brush terms, the global PV market is having a significant climate change mitigation impact by displacing China's high-carbon intensity grid electricity with PV. By comparison, the carbon intensity of the UK grid is less than a quarter of China's (0.23 $kgCO_2e/kWh$ in 2021)[9].

Annual electricity output

To simplify the comparison between the carbon intensity of electricity generated by a PV array with that of the UK electricity grid, some assumptions can me made about the annual electricity output and the life of the PV array. Assuming an electricity generation of 1,000kWh/kWp and a useful life of 20 years, the carbon intensity of each kWh generated by a PV array could be estimated as: -

PV array capacity (kWp) x {Embodied carbon per kWp / (Annual electricity generation (kWh/kWp) x Useful Life)}

Assuming a 1 kWp PV array, the lifetime carbon intensity of electricity generated by a PV array becomes:

1kWp x {2,560$kgCO_2e/kWp$ / 1,000kWh/kWp x 25 years}
= 2,560 /25,000$kgCO_2e/kWh$
= 0.10$kgCO_2e/kWh$

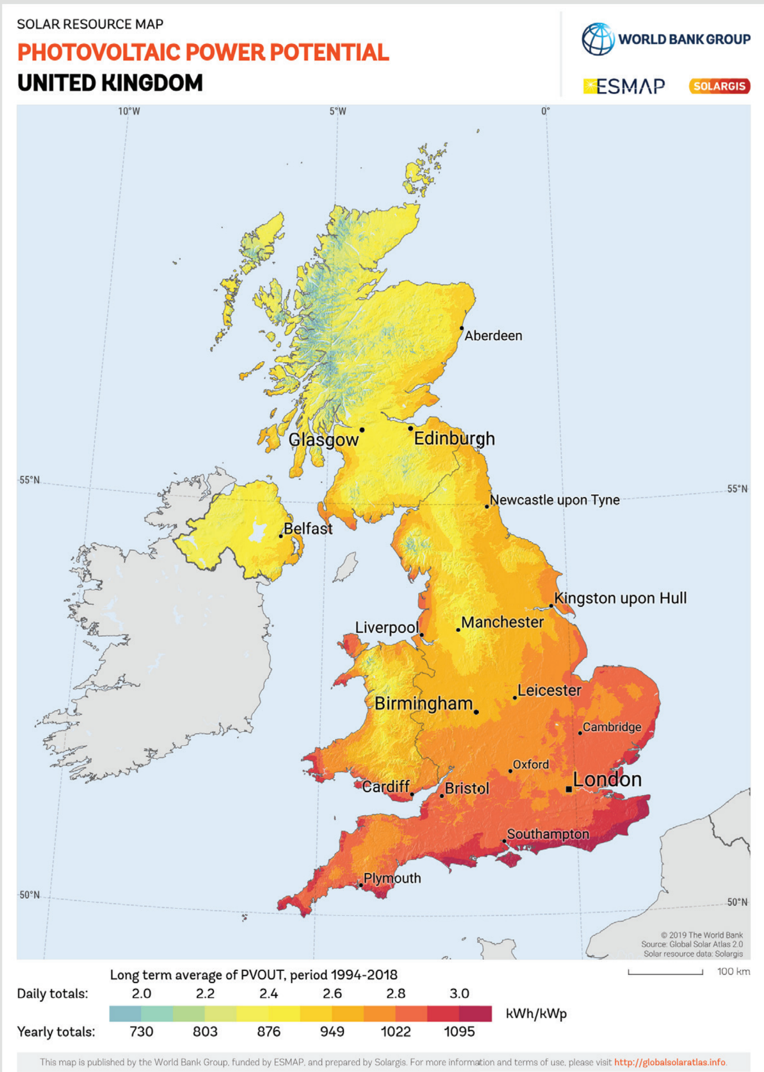
Even allowing for reasonable degradation in the output of a PV array over its life and other real world factors, the carbon intensity of electricity generated by a PV array installed today will be considerably less than the grid intensity of the 2021 UK grid electricity conversion factor of 0.23$kgCO_2e$/ kWh.

The carbon intensity of the electricity grid in the UK rapidly decreased in the period 2015 to 2020, due in large part to the deployment of additional renewable generation capacity. This included rapid growth in solar, but was predominantly due to growth in offshore wind capacity and a decrease in fossil fuel capacity. 2020 was the first full year in which the UK generated more electricity from renewables than from fossil fuels[10,11]. This trend is set to continue – and must if the UK, Welsh and Scottish Governments' net zero targets of 2050, 2050 and 2045 are to be met.

Continued grid decarbonisation will mean that the relative carbon emissions benefit of generating electricity from solar will decrease each year, unless PV panels of lower embodied carbon are sourced, e.g. by using technologies of lower carbon intensity, such as cadmium tellurium, or if the manufacture of PV cells prioritises locations supplied by grid electricity of lower carbon intensity – a development which is already mature in the data centre market.

However, it should be noted that the grid intensity figures provided by BEIS do not include the construction embodied carbon of new generating plant or grid reinforcement activities, the inclusion of which would improve the case for self-generation by PV.

Renewable electricity generated by licensed suppliers is assigned a Renewable Energy Guarantee of Origin (REGO) certificate for each MWh of electricity generated. However, there is a market for REGO certificates and separation of the renewably generated electricity from its certificate is a common occurrence. Renewably generated electricity can be the lowest priced electricity available under certain conditions – e.g. when wind or sun are strong and electricity demand is low. A supplier focused solely on price might purchase this low-cost electricity, but forego its REGO certificates to avoid their small additional cost. The outcome is that these REGO certificates are separated from their renewable electricity and become available to be sold separately. Electricity suppliers can buy such REGO certificates at a rate of approximately a few pounds for the equivalent of a year's supply to a typical household and claim to have a renewable tariff, when it is the same mix of sources as is available across the grid to anyone who buys electricity without the REGO certificate. By contrast, suppliers that buy both the renewably generated electricity and the REGO certificates that accompany them directly from generators (such as solar farms) using a Power Purchase Agreement are able to demonstrate that the electricity they sell is renewable. Electricity sold under such arrangements tends to attract a premium cost. However, with the scepticism directed at 'greenwash' claims, organisations with reputational value at stake may consider this to be a cost worth paying. ■



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Please mark your answers below by placing a cross in the box. Don't forget that some questions might have more than one correct answer. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet, return it to the address below. Photocopies are acceptable.

Questions

1. What term is commonly used to refer to electricity storage systems used to provide security of electricity supply for information and communication technologies?

☐ Uninterruptible Power Supply
☐ Unilateral Power Service
☐ Unit Power Supply
☐ United Parcel Service

2. How does the efficiency of a monocrystalline PV cell compare to that of a polycrystalline PV cell?

☐ Equal
☐ Higher
☐ Lower
☐ Not comparable

3. When was the Feed in Tariff introduced in the UK?

☐ 2000
☐ 2005
☐ 2010
☐ 2015

4. When did the Feed in Tariff close to new projects?

☐ 2005
☐ 2010
☐ 2019
☐ 2021

5. Which orientation optimises output of a PV array in the UK?

☐ North
☐ South
☐ East
☐ West

6. Which tilt angle is nearest optimum for a fixed position of a PV array?

☐ 0°
☐ 30°
☐ 90°
☐ 180°

7. What is the approximate grid electricity carbon conversion factor for China?

☐ ⅛ kgCO_2e/kWh
☐ ¼ kgCO_2e/kWh
☐ ½ kgCO_2e/kWh
☐ 1 kgCO_2e/kWh

8. What is the approximate grid electricity carbon conversion factor for the UK?

☐ 1 kgCO_2e/kWh
☐ ½ kgCO_2e/kWh
☐ ¼ kgCO_2e/kWh
☐ ⅛ kgCO_2e/kWh

9. In addition to renewable energy technologies, which of the following does the Microgeneration Certification Scheme provide quality assurance for?

☐ Batteries
☐ Coal
☐ Insulation
☐ Building energy management systems

10. What certificates are available in the UK to denote electricity generated by an appropriately licensed renewable generator?

☐ Renewable Energy Certificate
☐ Renewable Energy Guarantee of Origin Certificate
☐ Realtime Price Index
☐ Renewable Price Certificate

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