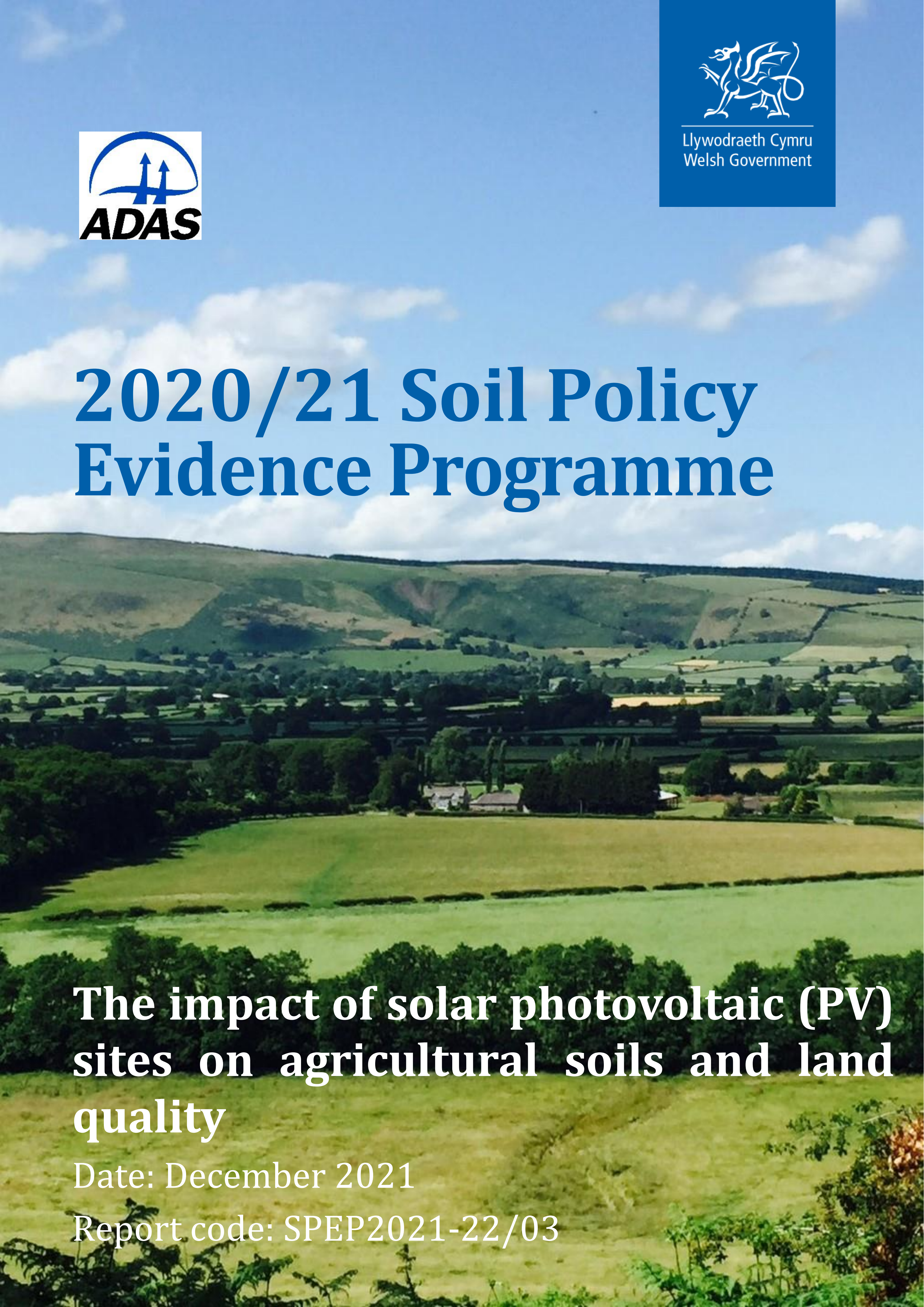

2020/21 Soil Policy Evidence Programme

The impact of solar photovoltaic (PV) sites on agricultural soils and land quality

Date: December 2021

Report code: SPEP2021-22/03

Welsh Government

The impact of solar photovoltaic (PV) sites on agricultural soils and land quality

Work Package Two A: Industry Overview

December 2021

ADAS

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1 INTRODUCTION

1.1 Introduction

This report provides an overview of the 'solar farm' (ground mounted solar photovoltaic (PV) developments) industry in the United Kingdom. It includes the development of the industry and the likely impact of installations on agricultural soils and land. The work, under the Welsh Government's Soil Policy Evidence Programme SPEP 2021-22/03, is to inform Welsh Government and Natural England specialists when dealing with solar PV planning applications.

1.2 Sources of Information

This report has been prepared by ADAS consultants with input from the wider RSK Group.

The statistical information presented throughout this report is derived from the Department for Business, Energy and Industrial Strategy (BEIS) Renewable Energy Planning Database (June 2021 update) (BEIS, 2021a) - referred to either as BEIS Renewables Database or BEIS, 2021a. The Database tracks the progress of UK renewable electricity projects over 150kW through the planning system[1]. It provides as accurate and comprehensive a snapshot as possible of the progress across of projects through the following stages:

- inception
- planning
- construction
- operation
- decommissioning

The database is updated during the month following the end of each quarter.

Specifically, our analysis of the BEIS Renewables Database refers to ground mounted solar PV schemes with >1 MW capacity.

[1] A scheme generating 150kW requires about 1200m² and would typically be a roof-mounted scheme on, for example, a large commercial building. 150kW is very much at the lower end of the scale for ground-mounted schemes, where the generating capacity is usually quoted in MW (1MW = 1000kW)

For Sections 3 – 4, on the impact on land and soil arising from ground-mounted solar PV, we have contacted solar PV developers and consultants who work with solar PV developers to ask for their perspective. This has included everyone involved in the workshop which took place on Thursday 2nd September 2021, Solar Energy UK and other ADAS clients.

2 DEVELOPMENT OF THE INDUSTRY

2.1 Government subsidy payments

Large-scale ground-mounted solar PV has been seen as a good investment opportunity since government subsidies for renewable energy generation became available in the UK in 2002. Agricultural landowners have been tempted by land rental values offered by developers which are likely to be well in excess of the income which can be generated from farming activities. Subsidy payments for new schemes have been available through:

- Renewable Obligation Certificates (2002 - 2017) – tradeable certificates issued to operators of accredited renewable generating stations for the electricity they generate.
- Feed-in Tariff (2010 – 2019) – above market payments to producers of electricity generated by multiple technologies for up to 20 years, although the tariff rate for 50kW+ solar schemes was cut in 2011 in response to European speculators lining up to establish multiple solar farms in the West Country that would have absorbed disproportionate amounts of the fund.
- Contracts for Difference (introduced in 2014) – where generators are paid the difference between the 'strike price', a price for electricity reflecting the cost of investing in a particular low carbon technology, and the 'reference price', a measure of the average market price, thus encouraging investment, although solar PV was excluded from 2015 to 2020.

Government subsidies were always intended to stimulate the market until the cost of renewable generation reached parity with fossil fuel generation and this has had a dramatic impact on the number of schemes brought forward. The closure of Renewable Obligation Certificates in particular, produced a peak in planning applications for new large-scale solar PV schemes in 2014 – 2016 and there has been a drop since then – as is shown in the tables in Table 2.5, Section 2.5.

There has been a resurgence of interest in subsidy-free solar over the past 2 years arising from a continued drop in capital installation costs, the rising price of electricity and the availability of more cost-effective battery storage to improve income potential. In England, this interest is typically at just below 50MW which is the threshold for planning applications requiring a Development Consent Order (DCO) rather than a planning application to a Local

Planning Authority. In Wales, the equivalent threshold (introduced in 2019) is 10MW and is called a Development of National Significance.

A number of large DCO schemes are now coming forward, in England and Wales.

2.2 Who are the developers?

At the peak of solar development in the UK between 2010 and 2015, multiple developers took advantage of the business opportunities created by subsidised solar PV and developed a range of services and installation offers. These included:

- Existing energy suppliers
- Landowners – who initially developed schemes on their own land and subsequently sought further development opportunities
- Solar PV developers
- Investors looking for secure income from green investment opportunities
- Consultants & contractors offering services to developers and operators of solar PV schemes.

Since then, there has been a significant reduction in the number of companies active in the sector, with a handful emerging as market leaders, such as Lightsource BP, BSR (British Solar Renewables), JBM and several others. These have tended to take on a wider range of in-house services like operation and maintenance, landscape design and management, to reduce their reliance on external partners.

The early-stage development process is high risk because many sites will not progress to a planning application. Developers need a healthy pipeline of potential schemes to ensure that there remains a sufficient number of sites which can progress. This initial development is sometimes carried out by specialists who sell the rights to a project once it is shovel ready and sometimes by developers/investors who subsequently build and own the scheme. In some cases, a project can change ownership more than once during the development and build phases. Once the scheme is operational, it offers an attractive investment opportunity with a predictable and secure income base and many have been purchased by large investment companies which have developed a portfolio of solar PV assets.

2.3 The development process

Developers identify geographical areas of interest - which may be because they have identified sub-stations or lines which are not fully utilised, therefore having adequate capacity for a solar PV scheme, or because they are targeting areas of highest solar irradiation – see Figure 2.4a (Huld & Pinedo-Pascua, 2019). A combination of desk-top and on-site searches will enable developers to find land which is relatively free of significant development constraints and which takes account of local and national planning policy and guidance. Development constraints potentially include:

- Environmental constraints – e.g. National Parks, Sites of Special Scientific Interest, Local Landscape Designations, etc
- Planning constraints – e.g. Built Heritage, Scheduled Ancient Monuments and Areas of Outstanding Natural Beauty (AONBs)
- Topography – avoiding ground too steep for development (typically 5° but may vary for individual developers) and north-facing slopes
- Agricultural land quality – minimising the inclusion of Best and Most Versatile (BMV)
- Public Rights of Way.

Having identified constraint free land and approached landowners who might be willing to lease their land for the scheme (initially in writing but subsequently in person) developers need to carry out a number of further steps to take a project forward:

- Site technical assessment - shading, site access, ground conditions, the presence of nearby high energy consumers who may take some of the generated electricity via an electrical connection which is independent of the grid (known as private wire).
- Landowner negotiation – developers and owners of the land required for the scheme (including additional land for access, grid connection, etc) will enter into agreements which cover the lifetime of the project. This will include time for gaining planning consents and a decommissioning period. Project lifetimes were originally based on the duration of government subsidy payments (20 or 25 years) but since the emergence of subsidy-free schemes, with an improvement in technology and increased length of infrastructure warranties, this has increased to 40 years. The agreement usually includes measures to protect the landowner should the asset owner cease trading and most commonly this is in the form of an independently held fund to pay for de-

commissioning costs. The agreement will also set out land rental payments. Over the last 10 years this has varied between approximately £1,500 and £3,000 per hectare per year index-linked, depending on location, variable project costs and level of government subsidy available at the time. This is well above the income generated from farming activities. Typical net profit per hectare per year per farm enterprise type can be derived from the Farm Business Survey, the most recent figures are as such:

- Medium (c. 74 ha) dairy: £244 / ha / yr
- Large (c. 190 ha) dairy: £520 / ha / yr
- Small (c. 80 ha) lowland grazing: £154 / ha / yr
- Medium (c. 108 ha) lowland grazing: £178 / ha / yr
- Large (c. 245 ha) lowland grazing: £175 / ha / yr
- Small (c. 101 ha) mixed farm: £101 / ha / yr
- Medium (c. 134 ha) mixed farm: £267 / ha / yr
- Large (c. 325 ha) mixed farm: £177 / ha / yr
- Small (c. 170 ha) cereals: £454 / ha / yr
- Medium (c. 266 ha) cereals: £395 / ha /yr
- Large (c. 579 ha) cereals: £579 / ha / yr

- Grid connection - application to the appropriate Distribution Network Operator (DNO) for a grid connection offer. Most DNOs offer a two-stage application process (fees applicable): a budget quote which usually takes about 4 weeks and provides a non-binding connection offer, and full application which can take up to 13 weeks and provides a fully-costed quotation for both the non-contestable works (which can only be done by the DNO themselves) and the contestable works (which can be market tested). A connection quote is usually valid for a 6 month period and most DNOs ask for a deposit to secure the capacity. In order to avoid capacity being held by developers for projects which were unlikely to progress, DNOs introduced milestones (eg. planning application submitted) and failure to meet milestones would result in withdrawal of the offer and the capacity becoming available for other schemes. To date, nearly all solar PV schemes in the UK are connected to the DNO networks – which means connection to an 11kv, 33kv or possibly a 132kv line or substation (via their own substation which has a client side and a DNO controlled side). It is understood that some 50MW+ schemes are currently under consideration which could connect direct to the National Grid.

- Financial modelling – all developers have their own financial model. Many of the installation costs are formula-based but the cost of grid connection varies considerably and it is only possible to put together an economically viable scheme when all the variable costs are known.
- Planning application – this is likely to be the most expensive element of the process and as the costs cannot be recovered should the planning application be refused at Council and at Planning Appeal stage, developers will only move to this stage if every aspect of the scheme looks positive. Some developers have in-house planning teams who prepare and submit applications whilst others use specialist planning consultants. The determination of Planning Applications in England for schemes below 50MW are dealt with by local planning authorities under the Town and Country Planning Act (1990 as amended), whilst projects over 50MW must secure approval via the more complex (and expensive) Development Consent Order process. In Wales, schemes above 10MW are classed as Developments of National Significance (DNS) and determined by Welsh Government.

2.4 Geographical spread

The map below (Figure 2.4a. Huld & Pinedo-Pascua, 2019) shows the distribution of solar irradiation across the UK ranging from approximately 900 – 1350 kWh/m ^{2} per year, with the highest resource available in the South West. Indeed, much of the initial development was focused there. However, unlike wind turbine projects, where the underpinning economics are highly dependent on wind speed, solar PV schemes have been developed right across the UK, in locations which meet all other criteria. The spread northwards to sites with lower solar irradiation has been assisted in recent years by increased panel efficiencies.

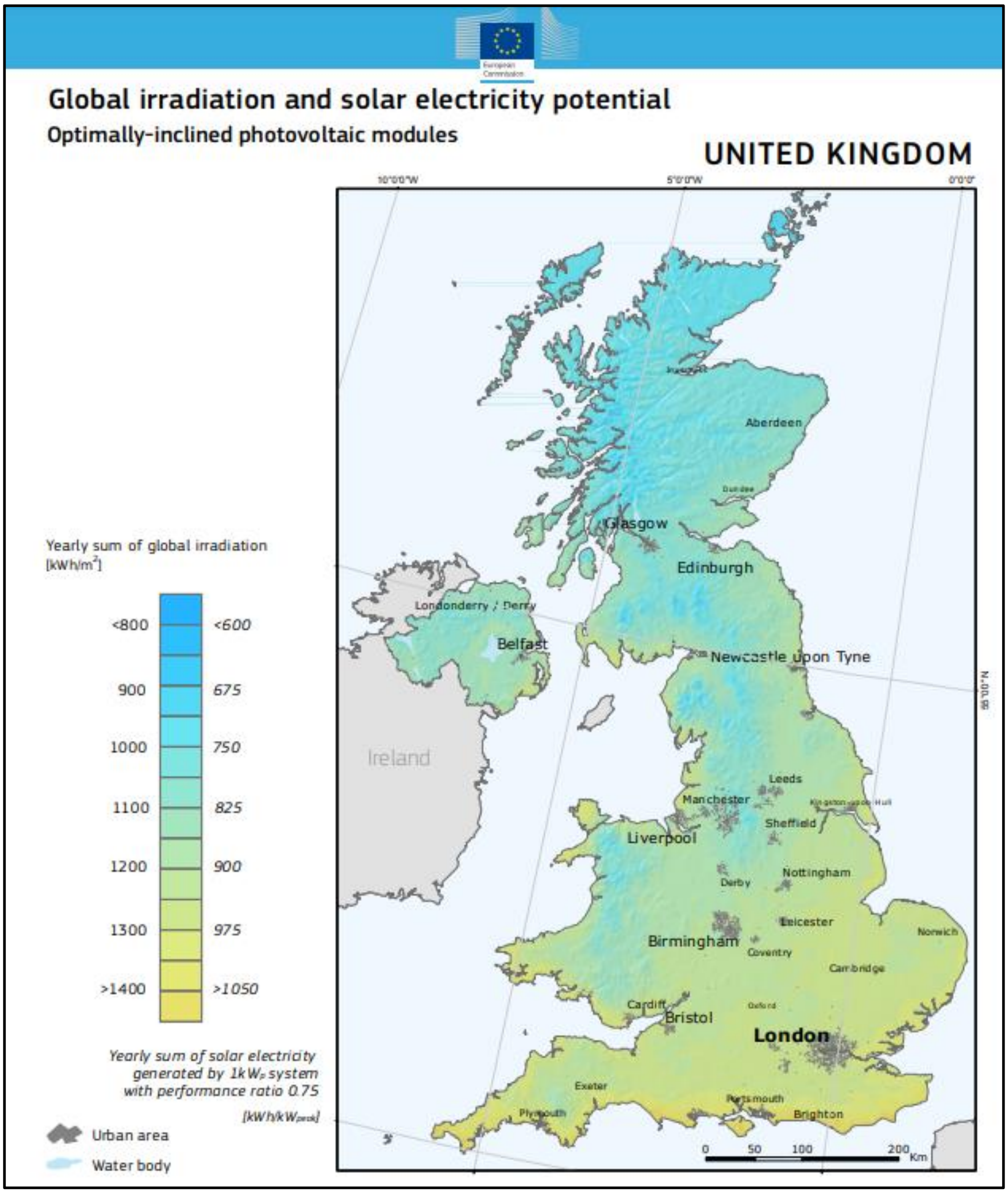


Figure 2.4a: United Kingdom – global irradiation and solar electricity potential

The four following maps (Figure 2.4b) show the distribution of built (operational or under construction) ground mounted solar PV sites in the United Kingdom. This data is derived from the BEIS Renewables Database (2021a). The maps are as such: Map 1: Number of solar farms per Local Authority District; Map 2: Density of solar farms per Local Authority District; Map 3: Solar farm capacity (MW) per Local Authority District; Map 4: Density of solar farm capacity (MW) per Local Authority District.

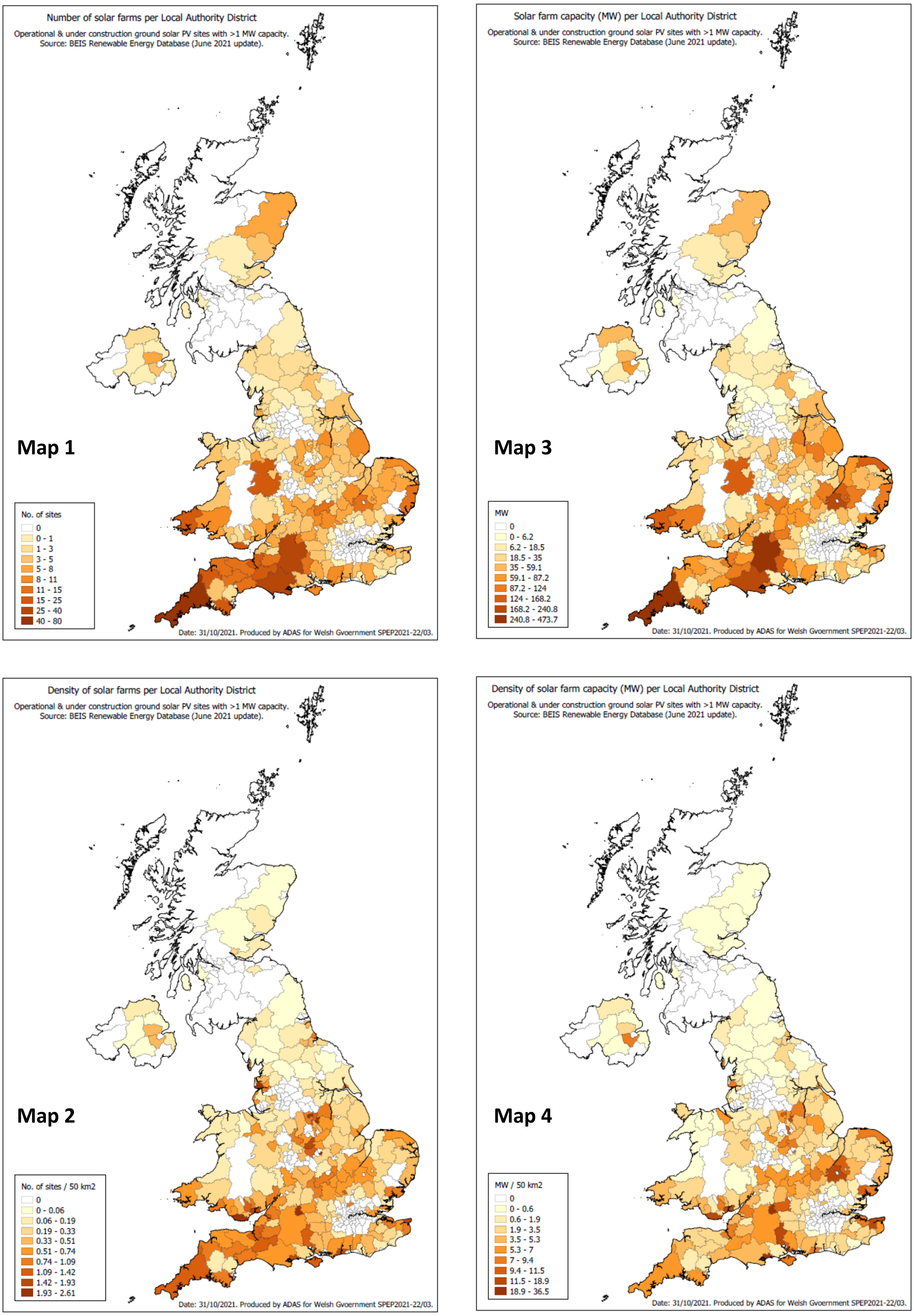


Figure 2.4b: Distribution of built ground mounted solar PV sites in the United Kingdom

These maps are included in full size as Appendices 1-4 of this report.

2.5 Growth in ground-mounted solar PV

The growth in solar PV since 2010 is shown in Figure 2.5 below (BEIS, 2021b). Earlier figures are not readily available and as can be seen from the graph, pre 2010 activity was negligible. The graph covers all generating capacities from small, roof-mounted schemes upwards.

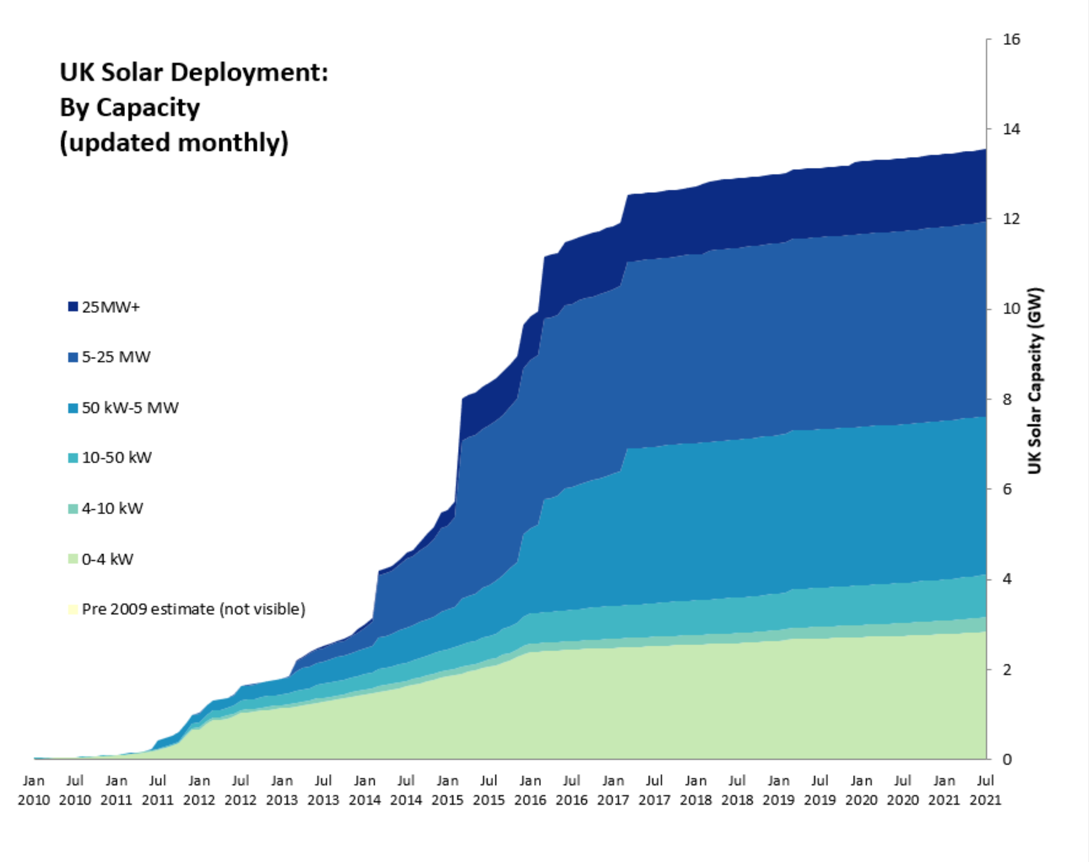


Figure 2.5: UK Solar Deployment: By Capacity

Growth in the ground mounted only sector is shown in the Table 2.5 (Data source: BEIS, 2021a). This table presents the schemes, >1 MW, which have become operational since 2010.

Table 2.5. United Kingdom: Schemes Operational 2010-2021

Year commissioned	Number per year	Mean size (MW)	Total capacity (MW)	Cumulative capacity (MW)	Total area[2] (~Ha)	Cumulative area (~Ha)
2010	0	-	0	0	0	0
2011	37	3.6	133	133	242	242
2012	26	3.1	92	210	139	382
2013	107	5.5	586	796	1,068	1,449
2014	177	9.8	1,743	2,538	3,173	4,623
2015	305	9.5	2,897	5,436	5,276	9,899
2016	256	7.1	1,817	7,252	3,308	13,207
2017	135	5.8	774	8,025	1,408	14,615
2018	14	6.9	97	8,122	176	14,790
2019	6	9.0	54	8,176	98	14,889
2020	5	5.6	28	8,204	51	14,940
2021[3]	0	-	0	8,204	0	14,940
Total	1,066		8,204	8,204	14,940	14,940

2.6 Planning applications – showing generating capacity and land area

Tables 2.6a-d, below, show solar PV planning decisions in England, Northern Ireland, Scotland and Wales (Data source: BEIS, 2021a). Ground-mounted schemes below 1 MW have not been included in the statistical analysis, or further analysis throughout this report, because they are most likely to have been put in place by landowners rather than developers, using unproductive or waste land, at a time when significant subsidy payments were available in order that they could achieve a reasonable financial return. This type of scheme does not constitute a significant market opportunity going forward and is therefore considered not relevant to this study.

Historically, a commonly recognised metric to estimate the land area taken for solar PV sites was 4.5 acres / 1.82 hectares per 1 MW. This metric has been used for the statistical analysis in this report, including in Table 2.5, Table 2.6 and Appendices 5-9. It should be noted that this is a rough estimate only. With the improvement in solar panel efficiency in the last couple of years a metric of 1.4 ha per 1 MW would be a basis for estimate going forwards.

[2] Rough estimate using 4.5 acres / 1.82 ha to 1 MW metric, see Section 2.6.

[3] To June 2021 only.

Table 2.6a. England: Planning Decisions

England	Number	Capacity (MW)	Area (~Ha)
Submitted	1,652	17,433	31,746
Approved	1,203	11,111	20,234
operational / under construction	***950***	***7,511***	***13,678***
awaiting construction	*132*	*2,598*	*4,732*
expired or abandoned	*121*	*1,001*	*1,823*
Refused	259	2,547	4,639
Withdrawn	95	893	1,626
Pending	95	2,882	5,248
Approval rate[4]	82.3 %		

Table 2.6b. Northern Ireland: Planning Decisions

Northern Ireland	Number	Capacity (MW)	Area (~Ha)
Submitted	38	431	785
Approved	30	345	629
operational / under construction	***19***	***204***	***372***
awaiting construction	*7*	*103*	*187*
expired or abandoned	*4*	*39*	*70*
Refused	3	15	28
Withdrawn	2	16	29
Pending	3	55	100
Approval rate	90.9 %		

Table 2.6c. Scotland: Planning Decisions

Scotland	Number	Capacity (MW)	Area (~Ha)
Submitted	66	592	1,079
Approved	56	513	933
operational / under construction	***18***	***114***	***208***
awaiting construction	*20*	*261*	*476*
expired or abandoned	*18*	*137*	*249*
Refused	5	40	72
Withdrawn	2	10	18
Pending	3	30	55
Approval rate	91.8 %		

[4] Excluding withdrawn and pending submissions, i.e. approved / (submitted - withdrawn - pending) x 100

Table 2.6d. Wales: Planning Decisions

Wales	Number	Capacity (MW)	Area (~Ha)
Submitted	175	1,491	2,716
Approved	146	1,156	2,105
operational / under construction	***111***	***801***	***1,458***
awaiting construction	*21*	*250*	*455*
expired or abandoned	*14*	*106*	*192*
Refused	15	59	108
Withdrawn	6	34	62
Pending	8	242	441
Approval rate	90.7 %		

2.7 Range of sizes and changes over time

The analysis of commissioned projects reported in Table 2.5 shows that the average generating capacity peaked at 9.8 MW in 2014 and has dropped since then. This resulted from the closure of the Renewable Obligation Certificate scheme and the exclusion of solar PV from the replacement Contracts for Difference scheme. However, this finding does not take account of a trend towards bigger schemes which has emerged since about 2018 because very few of these have been commissioned yet. As shown in the Table 2.7a-d, below, there is significant increase in projects in England with a generating capacity close to 50 MW (Data source: BEIS, 2021a) - but usually no higher because of the ceiling for schemes dealt with under the Town and Country Planning Act in England. This development arises from (a) tighter project margins forcing developers to seek economies of scale, and (b) saturation of Distribution Network Operators' (DNOs) 11 kv and 33 kv networks resulting in applications to connect to higher voltage lines, which is only economically viable for bigger schemes. In Wales, a similar clustering of schemes just below 10 Mw is not seen – either in the planning stage or operational.

There is also a move in recent years towards 'super large' solar PV schemes. The Cleve Hill application on the north Kent coastal marshes is perhaps the first example of this kind and is the first to be picked up in the BEIS Renewables Database. This is a site of over 300 hectares which is proposed to generate in excess of 150 MW. In addition, there is the Alaw Mon Solar 300+ ha scheme in Anglesey, the Sunnica 800 - 1,000 ha, 500+ MW solar PV scheme proposed near Newmarket and a 500 ha, 200+ MW scheme proposed on the coastal plains of North West England. These latter projects, and any similar, are not yet picked up in the BEIS Renewables Database.

It is time consuming to assess the cumulative use of land for solar PV schemes – because of the number of schemes and the variability of schemes.

For 'built' (operational and under construction) solar PV sites it is possible to use satellite imagery to map individual sites, essentially drawing a 'redline boundary' around the visible scheme fence line, from which it is possible to assess cumulative land use and estimate cumulative use of BMV.

This work will be undertaken for Wales as Work Package 2b of this project. Wales has 117 operational sites and a reliable predictive ALC model, which is sufficiently detailed to draw site-level estimates. For England, where there are considerably more solar PV sites to be considered and there is not a reliable predictive ALC model, another methodology may need to be considered.

Table 2.7a. England: Applications Submitted 2010-2021

Year	Number	Mean MW	Median MW	No. 45 - 49.99 MW
2010	23	4.1	5.0	0
2011	89	4.4	5.0	0
2012	189	7.9	5.3	2
2013	246	10.7	8.6	5
2014	420	10.9	8.2	4
2015	471	6.3	5.0	4
2016	18	4.8	4.5	0
2017	7	10.8	7.2	0
2018	14	33.4*	4.7	0
2019	37	24.7	20.0	10
2020	66	27.1	24.0	22
2021	66	28.9	30.0	25

* Includes Cleve Hill in Kent.

Table 2.7b. Northern Ireland: Applications Submitted 2010-2021

Year	Number	Mean MW	Median MW	No. 45 - 49.99 MW
2010	0	0	0	0
2011	0	0	0	0
2012	0	0	0	0
2013	2	5.0	5.0	0
2014	8	8.4	6.4	0
2015	21	14.8	8.5	0
2016	3	10.3	4.9	0
2017	2	3.6	3.6	0
2018	0	0	0	0
2019	0	0	0	0
2020	1	1.0	1.0	0
2021	1	3.8	3.8	0

Table 2.7c. Scotland: Applications Submitted 2010-2021

Year	Number	Mean MW	Median MW	No. 45 - 49.99 MW
2010	0	0	0	0
2011	1	2.0	2.0	0
2012	0	0	0	0
2013	1	2.4	2.4	0
2014	9	11.4	10.0	0
2015	37	5.9	5.0	0
2016	3	5.0	5.0	0
2017	3	26.7	20.0	0
2018	1	1.0	1.0	0
2019	7	15.1	19.9	0
2020	2	27.5	27.5	0
2021	2	5.0	5.0	0

Table 2.7d. Wales: Applications Submitted 2010-2021

Year	Number	Mean MW	Median MW	No. 8-10 MW
2010	2	1.3	1.3	0
2011	5	3.6	3.9	0
2012	13	8.0	7.4	1
2013	28	9.9	8.0	4
2014	38	7.2	5.5	3
2015	67	5.1	5.0	5
2016	2	29.0	29.0	0
2017	1	1.0	1.0	0
2018	4	22.5	19.5	1
2019	5	3.4	2.0	1
2020	4	33.5	35.0	0
2021	6	29.1	21.5	0

2.8 Technology developments

A recent development is that schemes are now being put forward where different technologies are co-located on the same site and dealt with through a single planning application. This applies to co-location of solar with (a) other energy technologies (eg. energy storage), or (b) with other enterprises which will consume some of the electricity generated (eg. vertical farming).

A further development is the consideration of more efficient (but more expensive) panels which enable greater generation from smaller sites. This includes double-sided panels which generate from both irradiated and reflected sunlight, and panels which tilt on a north-south axis to boost generation early and late in the day at times of peak demand.

3 INTERVENTIONS DURING INSTALLATION PHASE

3.1 Guidelines for building solar farms

Currently, the only relevant source of guidance for solar developers that we have identified is the BRE (2014) Agricultural Good Practice Guidance for Solar Farms. Ed J Scurlock. Solar Energy UK are preparing a Natural Capital Best Practise Guide and have produced a scoping report but it was clear from discussion at the workshop held on 2nd September 2021 that existing thinking about the environmental impact of solar PV on agriculture is focused on ecology and biodiversity and not soil. Feedback from those participants with direct responsibility for building solar farms suggested that they would be open to guidance but that it is currently lacking.

3.2 Site layout

At the time that a planning application is submitted, the developer will have drawn outline site plans showing details of all aspects of the scheme, in order that the planning authority can assess its impact on the environment, local residents, etc. Construction details will be included although it is possible that the installation company may subsequently submit a non-material amendment request for alternative designs (eg. to the proposed mounting system).

The example outline plan below is based on a planning application for a 15MW scheme in Norfolk with a central inverter design. The application was successful and the scheme was commissioned in 2016. It shows the panels in East-West orientated rows, roads, security fence, inverter stations, control and storage rooms. The design specified 2500 array structures each with 8 piles – giving a total of 20,000 piles which is an average of 662 piles per hectare across the site. The fenced area is 30.19 hectares and the panel footprint (the area directly underneath the panels) is 93,779m² or 31% of the fenced area. The remaining land is made up of internal access tracks, gaps between rows of panels, retained shrubs and trees with associated shading clearances and the clearance around the outside of the solar array structures to the site fence.

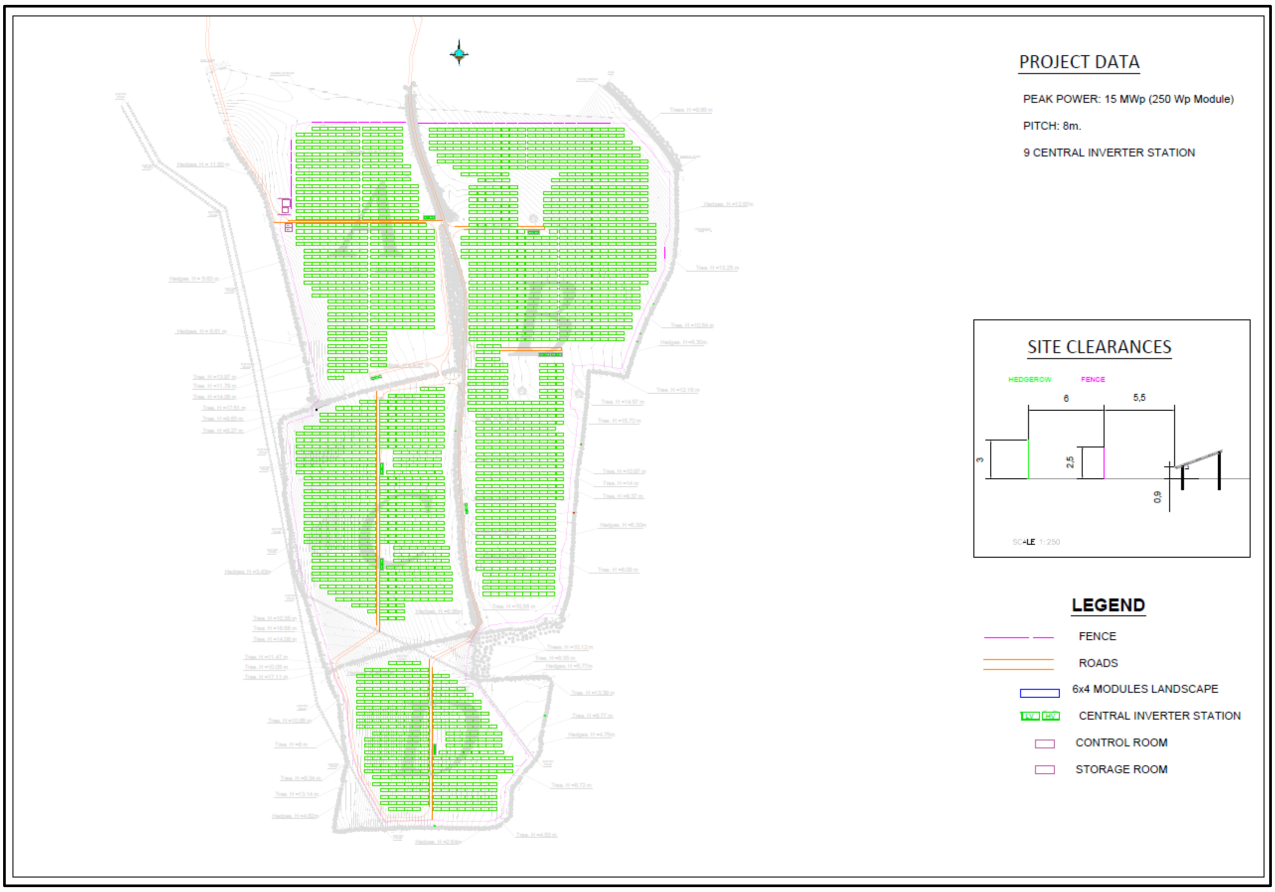


Figure 3.2: Example site layout

3.3 The basic operation of a solar farm

Solar irradiation hits the photovoltaic cells in the solar panels and generates direct current (DC) electricity which is converted to alternating current (AC) by an inverter for export to the grid. Irradiation can be in the form of direct sunlight or diffuse irradiation, as on cloudy days. Panel performance will vary throughout the day with the greatest generation when the sun is at its zenith on summer days. The quoted generating capacity of the panels is at peak performance. Panels (modules) are arranged in tables. A table of modules is called a string. Each string is connected to an inverter – either centrally located in invertor containers (typically shipping containers or equivalent) or to a string inverter mounted at the rear of each string. The latter design does not require centrally located inverters, just a connection to the switch room. As string inverter technology has improved, this design has become more common, reducing the impact on the land because housing for central inverters is not required, thus slightly reducing land take or increasing the area available for panels.

The total electricity generated is exported via a metered sub-station. The substation has a client-side and a Distribution Network Operator (DNO) side. The DNO is responsible for the connection from the substation back to the point of connection on their network.

3.4 Construction programme

Below is a typical list of activities for the construction phase. Not all activities will result in an intervention to land and soil, but the key ones are discussed in more detail in the subsequent sections.

- Set up construction compound
- Site security
- Install fence
- Install CCTV
- Commission CCTV & security system
- Install piles
- Install steel framing
- Install PV panels
- Install string cabling
- Connection of string cabling
- Install access road
- Install ducts
- Install inverter container bases
- Install substation base
- Install inverters
- Install substation
- HV (high voltage) cabling
- Earthing
- DC (direct current) cabling
- LV (low voltage) cabling
- Substation completion

3.5 Construction compound

A portion of the site, usually immediately inside the main point of access, is designated for temporary storage of the scheme components before they are distributed around the site for installation. Once this process has been completed, the area used can become part of the main solar installation site, although for bigger schemes, a small portion may be retained as a car park. There will have been a greater compaction of this area than across the site in general. We have not seen construction guidance or best practice applicable to temporary compounds.

3.6 Access roads

Once operational, access for maintenance vehicles is required to central inverter containers and substation. This is usually installed as a stone track of 3-4m width. Further access within the site is principally for grounds maintenance and repairs to the security fence and this does not require a stone surface as in most cases this would be carried out using a farm vehicle.

3.7 Mounting systems

Mounting systems are steel frames supported by posts. Panels (modules) are arranged in tables. The number of modules in a table will depend on the dimensions of the modules. A typical configuration is shown below. In this case, each table is comprised of 4 rows of 6 panels in landscape orientation, at 20° inclination, with double support.

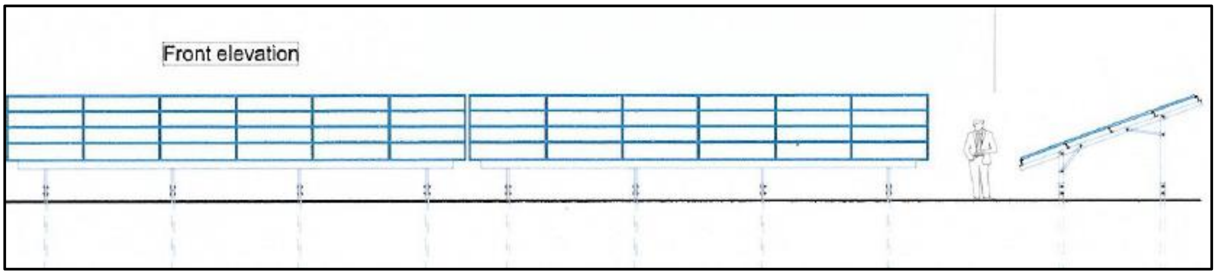


Figure 3.7a: Example mounting system

The number of posts per table and the type selected will depend on:

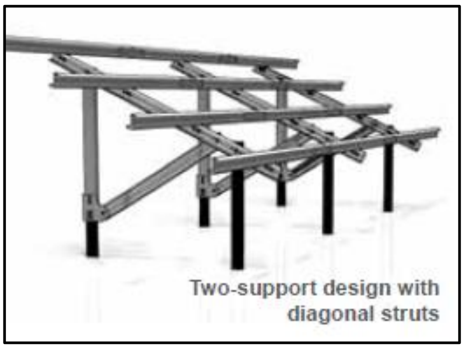
- topography – slope and aspect
- wind loading – exposed locations and tables at the edge of the array may require additional support
- ground conditions – a geotechnical survey will be carried out to assess the ability of the ground to support the structure, which may vary across the site.

Most schemes do not require the posts to be concreted into the ground – they can be pile-driven (usually to a depth of 1.4 – 1.8m) or screwed. Screw posts are more expensive and are typically used on shallow sites such as ex-landfill. Pile driven post systems are available with a single central support only or with 2 posts. Thus approximately double the number of piles will be needed for a 2 post mounting system. However, there is a trade-off between the number of piles and the cross-sectional area of the posts as shown below:

Table 3.7

Support system	Typical post cross section (mm)	Cross sectional area (mm^2)	Example
Single (central) post mounting system	250 x 100	25,000	Schletter FS Uno
Double post mounting system	100 x 50	5,000	Schletter FS Duo

The images below are of Schletter mounting systems including central support (FS Uno), two support design (FS Duo), and screw type (TerraGrid). Schletter mounting systems have been used in many solar installations in the UK.



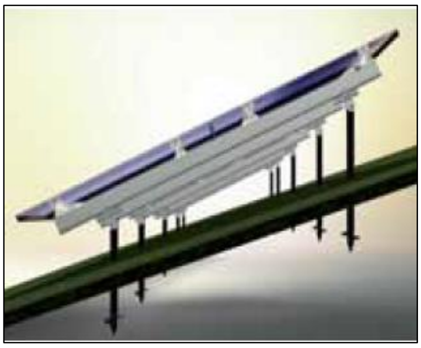


Figure 3.7b: Schletter FS Uno (left) Schletter FS Duo (centre) Schletter Terragrid (right)

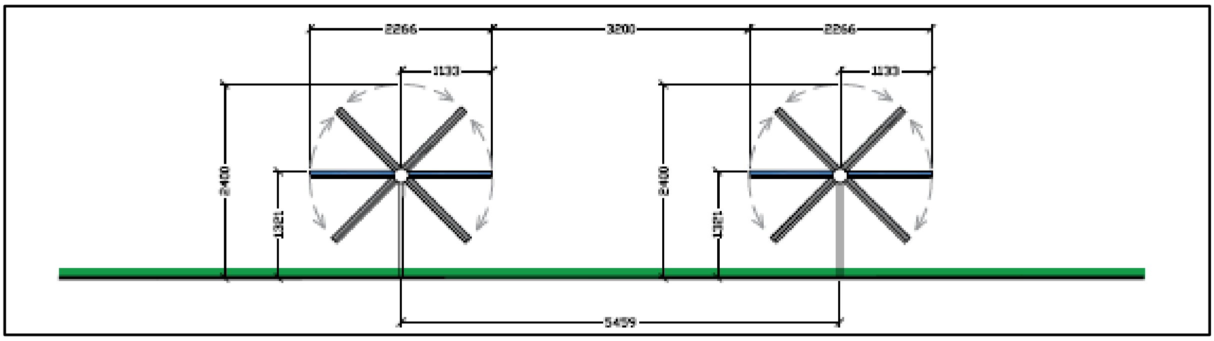
A piling rig is required for pile-driven legs (as shown in the picture below) and special drilling units are needed for installing screwed legs.

Figure 3.7c: Piling rig (from Solar Park Developments)

A ground survey is required to investigate the pile foundation at the site. Load tests on the post are undertaken and then a post is pulled out, bringing up the geological layers and to allow sampling to determine the probability of corrosion in the soil. Piling has an associated risk of damage to existing field drainage systems, buried archaeology or the cap of a landfill site. Floating foundations are available and in use in the United Kingdom but they are more expensive and therefore atypical.

3.8 Panels

The most common type of panel used for large-scale solar PV schemes in the UK is fixed mono-facial. However, as the cost of panels has reduced sharply over the last 10 years, it has become more worthwhile for developers to consider alternative, more expensive, panel technologies as the balance between panel density and land take has shifted. We have identified schemes in the planning system which specify bifacial panels – which have photovoltaic cells on both top and underside surfaces, collecting reflected and refracted light underneath. These are rare in the UK but can be used where land area is limited. Tracking panels (either on a single east-west axis or dual east-west / north-south axes) are also rare as the additional capital and running costs are unlikely to be outweighed by increased generation because of the high number of cloudy days in the UK. A tracker mounting system can be subject to additional preparation such as ground levelling and assessment of wind loads.



Single axis tracking panels showing morning, midday and evening tilt (from Bubney Solar Farm planning application):

Figure 3.8: Example of a tracker mounting system

There have been recent increases in both panel size and efficiency and units are now available up to 660W, compared with typically 250W 6 – 7 years ago. There have also been improvements in the software which manage performance over the course of the day as the sun moves across the sky. This has allowed panel density to be increased by up to 25% introducing shading from one row to the next at certain times of day (and in direct sunlight) but increasing overall scheme performance.

3.9 Additional equipment

Depending on whether the scheme has centrally located inverters or string inverters mounted at the rear of each string, there may be inverter containers located around the site. These are usually shipping containers, or equivalent, mounted on a concrete base. The most recent schemes may also have commercial-scale batteries which can be located adjacent to each central inverter or in a single central location, usually next to the switch room.

Each scheme has a substation which has a client-side and DNO side. Access to the DNO side is only permitted for DNO personnel and they have responsibility for the connection from the substation back to the point of connection on their network.

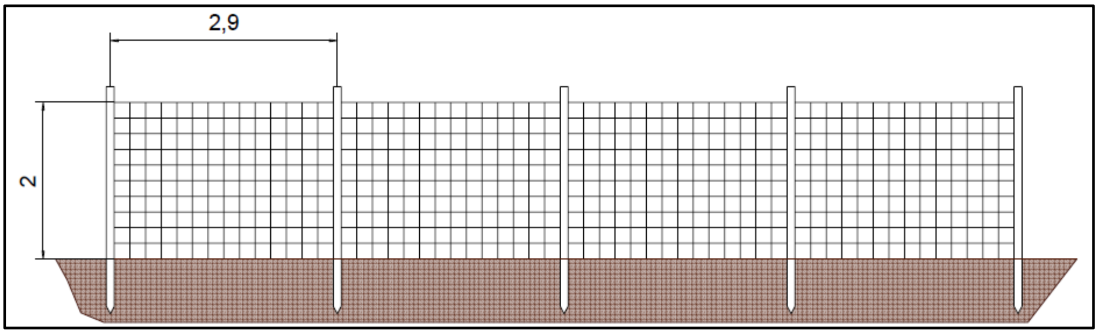
Cabling between rows of tables, inverters and substation is usually buried in trenches – typically 1m deep. Cabling from one string to the next can be above ground.

For schemes with a central inverter design, there are communication cables connecting inverter stations and string combiner boxes and there are also communications cables for the CCTV running around the perimeter of the site. These cables would normally be buried.

The HV cable connecting the scheme to the local grid is also usually buried. This may be to a point of connection within the site or external to it. If external, the cabling route may be along public highways or through adjacent privately-owned land. If the cable is installed by the DNO then it is permitted development but if it is powered up by the developer and not by the DNO then it would need planning permission. In Wales this would be either Western Power Distribution or Scottish Power.

3.10 Security fence

2m high deer fencing is usually installed for solar schemes (see example below) although design and construction may vary according to site circumstances, for example, there may be a high risk of theft requiring higher security. Typically, wooden supporting posts are used which do not require concrete foundations except at the straining posts at corners and gateways in certain circumstances. Support posts are spaced along the edge of the site at typical spacing of 2.4 to 3 m or approximately 330 - 420 posts per 1000 m run of fencing.



It is not uncommon for security fences to include small animal gates (eg. for badgers). In

nearly all cases, CCTV cameras are part of the installation.

Typical deer fence (Solar Park Developments):

Figure 3.10a

Figure 3.10b

A gap of approximately 5.5m is required between the panels and the security fence to allow tractor access. The same is required on the outside between the fence and any surrounding field boundaries, again for tractor access.

The wooden posts of deer fencing will require replacing through the lifetime of a scheme as they rot. The frequency of replacement will be greatest in particularly wet or exposed sites.

There is a risk during or at the end of life of a site that wooden posts snapped off at the base will remain in the ground. This poses a risk where land is intended to be returned to productive agriculture.

Although it appears that wooden post deer fencing is the preferred fencing material, heavier duty metal fencing such as palisade or weld mesh has been used in the past and may still be in use in certain circumstances. If metal fencing is still in use it is presumably at sites at reasonable / high risk of vandalism or theft. Metal fencing will require concrete at every footing, which will be spaced 2 m or so apart. Clearly it poses significantly greater risk to agricultural soils and land restoration.

3.11 Case studies

In order to illustrate the level of intervention to land arising from individual schemes, we have selected 3 planning applications which are currently live on the relevant planning authority portal and reviewed the documents and plans available. The 3 schemes have been selected at a range of generating capacities to assess the impact of scale. The source of information is shown but some outputs have been calculated because the information is not included (or we have not been able to find it). The outline plans for each scheme are included as appendices.

Table 3.11a. Case Study One – Tyddyn Cae Solar Farm

Tyddyn Cae Solar Farm (approved 2015)		Information Source
Local Planning Authority	Gwynedd	
Planning reference	C14/0885/33/LL	Gwynedd | Council Direct | Application | 24205 (llyw.cymru)
Generating capacity	9 MW	Planning, Design & Access Statement
Panel type	Fixed	Planning, Design & Access Statement
Land within planning application red line boundary	20 hectares	Planning, Design & Access Statement
Existing use	Agricultural	Planning, Design & Access Statement
ALC grade	3a (12 %), 3b (69 %), 4 (10 %)	ALC Report
Mounting system	Pile driven, 2 post	Planning, Design & Access Statement & Typical Panels Elevation
Pile depth	1.5 m	Planning, Design & Access Statement
Pile cross section	"H" or "Z"	Planning, Design & Access Statement
Approx. number of piles	There are approximately 36,000 modules in tables of 8 but	Estimated from Panel Elevation

	number of piles per table is not clear	
Approx. average number of piles per hectare	Unknown	
New access tracks	*1050 x 3.5 m = 3675 m^2	Measurement from Site Layout Plan (width estimated)
Access track construction	Not specified	
Total area of development. See footnote[5].	5.5 hectares	Planning, Design & Access Statement
Total area of development as a % of land within red line boundary. See footnote.	27 %	Planning, Design & Access Statement
Security fence	*1730 x 2m deer fence with approx. 500 timber posts	Measurement from Site Layout Plan

Table 3.11b. Case Study Two – New Works Solar Farm

New Works Solar Farm (awaiting decision)		Information Source
Local Planning Authority	Telford & Wrekin	
Planning reference	TWC/2021/0737	https://secure.telford.gov.uk/planning/pa-applicationsummary.aspx?applicationnumber=TWC/2021/0737
Generating capacity	30 MW	Design & Access Statement
Panel type	Fixed	Design & Access Statement
Land within planning application red line boundary	40 hectares	Design & Access Statement
Existing use	Agricultural	Planning Application Form
ALC grade & stated limitations	3b / Wetness	ALC Report
Mounting system	Pile driven, 2 post	Design & Access Statement
Pile depth	1.5m	Design & Access Statement
Pile cross section	"H" or "Z"	Design & Access Statement
Approx. number of piles	20,000	Calculated from Site Layout Plan
Approx. average number of piles per hectare	492 piles per hectare	Calculated from Site Layout Plan

[5] Here we have used text taken from the developer's own planning application documents. This is not a calculated assessment but a quote from the planning application. It is difficult to determine the entire area of soil disturbance at a site because the area of disturbance is often much wider than just the tracks, compounds, piles, trenches, fence lines etc. Site design is also subject to change.

Analysis of satellite imagery suggests that at its worst site trafficking can cover most of the land within the redline (application) boundary of a scheme. This evidence is included in WP 3 as an appendix.

New access tracks	1580 x 3.5 m = 5530 m²	Design & Access Statement & measurement from Site Layout Plan
Access track construction	Surface of aggregate, sub-base of crushed stone, with geotextile membranes. Requires soil stripping.	Typical Elevations Plan 4
Total area of development. See footnote.	22.4 hectares (solar panels, access tracks, compound and other infrastructure)	Design & Access Statement
Total area of development as a % of land within red line boundary. See footnote.	56 %	Design & Access Statement
Security fence	3762 x 1.95 m deer fence with approx. 1250 timber posts	Design & Access Statement and Site Layout Plan

Table 3.11b. Case Study Three – Estuary Solar Farm

Estuary Solar Farm (awaiting decision)		Information Source
Local Planning Authority	West Norfolk	
Planning reference	21/01432/FM	https://www.west-norfolk.gov.uk/planning_and_development
Generating capacity	49.9MW	Design & Access Statement
Panel type	Fixed	Design & Access Statement
Land within planning application red line boundary	56 hectares	Design & Access Statement
Existing use	Agricultural	Planning Application Form
ALC grade & stated limitations	BMV (Grade 1,2 and 3a)	Design & Access Statement (no ALC survey)
Mounting system	Pile driven, 2 post	Design & Access Statement/GM200 A&B
Pile depth	1.5m to 2.5m	GM200 A
Pile cross section	Not specified	
Approx. number of piles	There are 92,519 modules in tables of width 26, 19 and 13. Piles per table is not specified	Site Layout Plan
Approx. average number of piles per hectare	Unknown	Calculated from Site Layout Plan
New access tracks	Internal site tracks are not surfaced. Length of other tracks is not specified	
Access track construction	Not specified	
Total area of development. See footnote.	Not specified	

Total area of development as a % of land within red line boundary. See footnote.	Not specified	
Security fence	4380m x 2.3m fence with posts at 4m spacing approx. 1100 timber posts	Design & Access Statement and Site Layout Plan (4.38km)

4 INTERVENTIONS DURING OPERATION PHASE

After solar PV developments are commissioned they are usually unmanned and there are minimal activities. Regular visits, approximately monthly, may be planned by operations and maintenance staff to undertake monitoring and maintenance activities.

Typical maintenance activities, dependent upon the site, may include grass cutting if grazing does not keep the grass at the optimum height; management of landscaping works e.g. hedge trimming; annual panel wash with water brought onto site. There will be monthly visits to monitor the electrical systems and access by a grazier to manage grazing – satellite imagery seen during WP 2b of this project indicates that a reasonable number of sites in Wales are grazed by sheep although the percentage of sites is not known. Presumably likelihood of grazing is directly related to nature of the host farm or perhaps neighbouring farms. Most access during the operation phase will require the use of a 4x4 vehicle and it is unlikely that any heavy machinery will be required.

Agricultural land use change, often from intensive agricultural use on BMV agricultural land to low-maintenance grassland, has been cited by developers in planning applications as a benefit arising from solar PV sites. Soil carbon, mainly derived from carbon fixed by plants, is stored in soils in the form of soil organic matter (SOM). Reports of changes in soil carbon resulting from land reversion are reported by Conant et al (2001). More recently Conant et al (2017) have studied data since 2001 and confirm their earlier conclusions that improved grazing management, fertilization, sowing legumes and improved grass species and conversion from cultivation all tend to lead to increased soil carbon (C). This was a global review of relevant publications, including studies across six continents.

Defra (2009) reported that the quantity of C that can be stored in any soil is finite. Following a change in management practice levels can increase (or decrease) towards an equilibrium value at about 100 years depending on the soil type, land use and climate. The relatively 'high' annual rate of C storage reported in the early years following a land use change from intensive arable use to a grassland use does not continue and the rate will decline until a new equilibrium is reached. It may be the case that soils currently beneath permanent or long-term grassland, particularly in wetter areas of the United Kingdom, are close to or at equilibrium. Maintaining a soil at an increased SOM level, due to a change in management practice, will be dependent on continuing that practice indefinitely. Only if land is taken permanently out of arable cultivation or rotation will the benefits of C storage be realised over the long-term.

The relationship between soil structure and SOM is documented (Cranfield, 2001) and recognised in land management practices with minimum tillage or no tillage operations (Game and Wildlife Conservation Trust, 2020). The term soil structure refers to the shape and size of the blocks or aggregates of the soil particles (clay, sand and silt) within the soil found in the field. The spatial distribution of the blocks is important for the movement of air and water in the soil profile. Soil organic matter is significant to how the soil is arranged into these blocks.

While the increased levels of SOM are recognised in grassland management systems the full impact of the physical presence of solar PV arrays on grassland management is open for discussion. Armstrong et al (2016) investigated the effects of soar PV arrays on microclimate and the consequences for carbon (C) cycling at Westmill Solar Park. The research project found that solar PV arrays can cause both seasonal and diurnal variation in the ground-level microclimate such that there was an effect on terrestrial C cycling. One of the conclusions of the project is that the effects of solar PV developments on plant–soil processes, which underpin key ecosystem services, is poorly understood.

Choi et al (2020) undertook a study in Colorado USA on the effects of revegetation on soil physical and chemical properties in solar PV infrastructure over a 7- year period. The study found that soils at the solar PV site contained significantly less carbon than the reference soil. This was likely to be caused by the removal of topsoil for grading / levelling during the array's construction. The reduced C level found suggested that nutrient recycling had not fully re-established 7-years after the site construction. The ability of the soil on the site to sequester carbon was diminished relative to reference soils. The study suggested mitigation in the adoption of minimum topsoil disturbance during construction.

The benefits of solar PV sites cited as changes in topsoil carbon capture and soil structural improvements are based on documented research and experience of changing from an arable agricultural land use to a grassland use. When a solar PV site is constructed there is a physical presence on the land of ground mounted frames with solar PV panels. A new microclimate condition is created, which differs from the open grassland environment. There are consequences or C cycling and over the longer term (40 years) the impact on SOM content and soil structure may differ from that found on grassland outside the solar PV site.

In summary, during the operational phase of a solar PV site there is minimal activity which causes soil and land disturbance. The claimed benefits of topsoil carbon capture and soil structural improvements are known in the grassland environment but further evidence is required to support the benefits where there is physical infrastructure on solar PV sites.

5 INTERVENTIONS DURING DECOMMISSIONING PHASE

Decommissioning is addressed in more depth in WP 3 of this project. It is clear that decommissioning of solar PV sites will require the removal of site infrastructure, including:

- Access roads and tracks around the site, where stone aggregate is likely to have been laid on a geo-textile membrane
- Inverters and bases
- Substations
- PV panels and frames
- Piles / beams
- Buried cabling
- Fencing, including any concrete supporting fencing
- Compounds

Sites may also have bunded soil, from tracks, compounds etc, which will need to be moved and replaced on the affected areas.

The decommissioning phase will require machinery such as a vibrating plate and excavator to pull out the piles / beams, plus excavators to move soil and vehicles to transport infrastructure off-site.

During the decommissioning phase there is a risk of soil damage via trafficking, soil movement, contamination (chemical and physical) and snapped-off below ground infrastructure, including piles / beams and fence posts.

Following the removal of site infrastructure and the replacement of soil it is likely that further activities will be required to enable successful land restoration. The requirements will be site specific but may include subsoiling, seeding to grass ley for several years to strengthen soil structure, reinstallation of damaged land drains and fertiliser or lime additions.

An adequate site-specific decommissioning and restoration plan will be required to minimise the risks to soil and maximise the success of restoration. The plan would need to be adhered to and the funds in place to support the required activities.

6 REFERENCES

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APPENDICES

Appendix 1: Number of solar farms per Local Authority District

Appendix 2: Density of solar farms per Local Authority District

Appendix 3: Solar farm capacity (MW) per Local Authority District

Appendix 4: Density of solar farm capacity (MW) per Local Authority District

Appendix 5: United Kingdom – Analysis of BEIS Renewables Database

Appendix 6: England – Analysis of BEIS Renewables Database

Appendix 7: Northern Ireland – Analysis of BEIS Renewables Database

Appendix 8: Scotland – Analysis of BEIS Renewables Database

Appendix 9: Wales – Analysis of BEIS Renewables Database

Appendix 10: Case Study One Layout Plan

Appendix 11: Case Study Two Layout Plan

Appendix 12: Case Study Three Layout Plan

Appendix 10: Case Study One Layout Plan

Appendix 11: Case Study Two Layout Plan

Appendix 12: Case Study Three Layout Plan