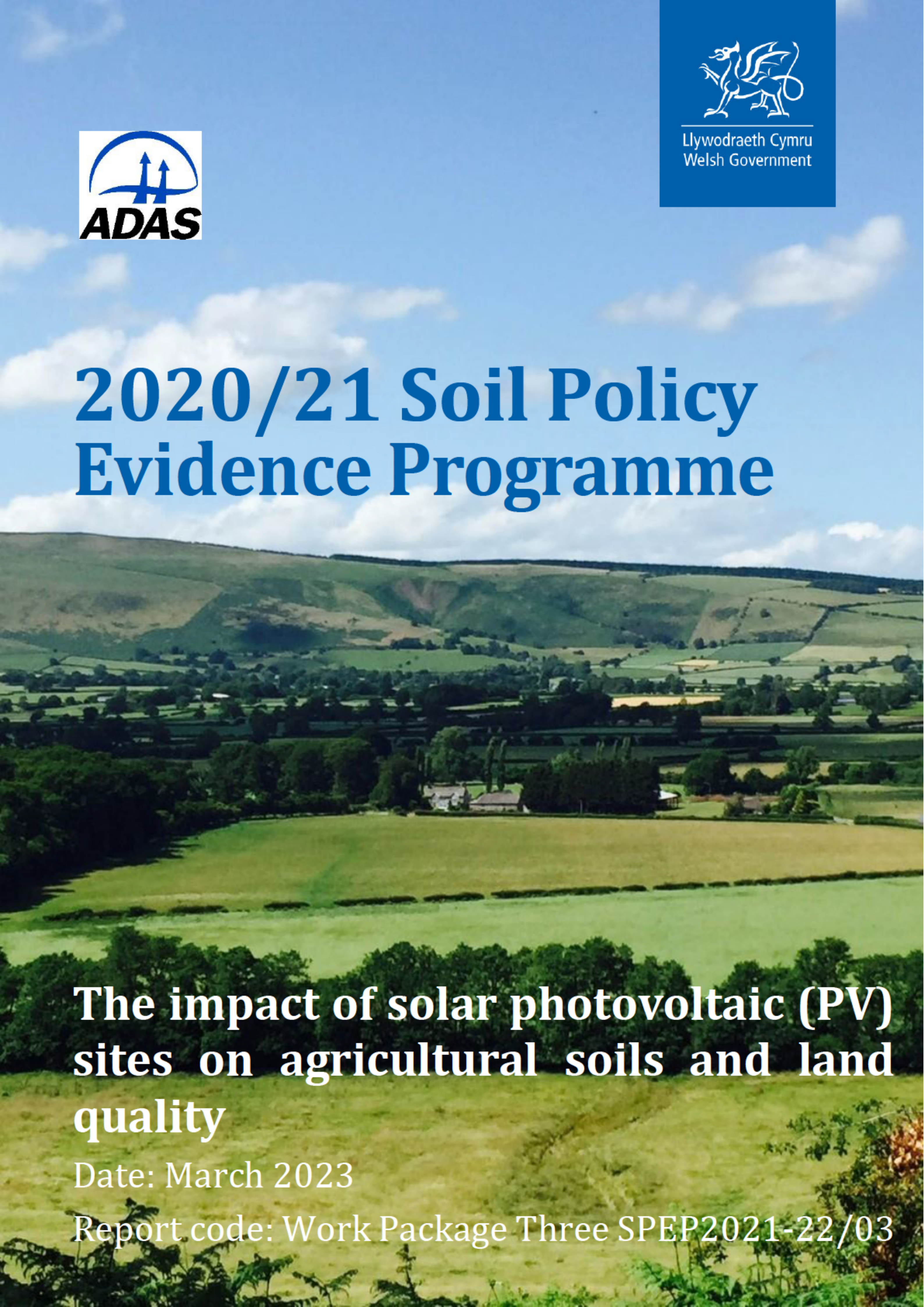

Llywodraeth Cymru
Welsh Government

2020/21 Soil Policy Evidence Programme

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

Date: March 2023

Report code: Work Package Three SPEP2021-22/03

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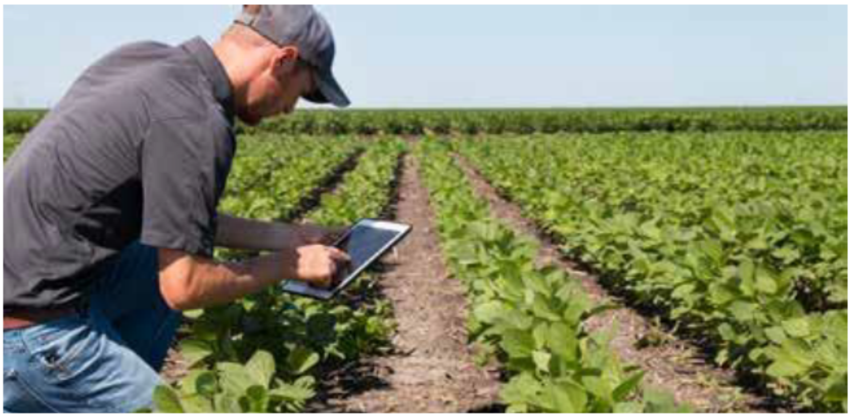

The impact of solar photovoltaic (PV) sites on agricultural soils and land

Work Package Three: Review of Impacts

March 2023

ADAS

ADAS GENERAL NOTES

Project No.: 1010857-WP3

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EXECUTIVE SUMMARY

This report is part of an evidence-based assessment of the impact of solar photovoltaic (PV) sites on agricultural land and soil. 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 photovoltaic (PV) planning applications.

The impacts on Best and Most Versatile[1&2] (BMV) agricultural land from the construction, operational and decommissioning phases are reviewed, based on the findings of the earlier literature review (WP1), best practice and extensive experience of land restoration. The main impact of the three phases of development is deep soil compaction resulting in the loss of versatility of Best and Most Versatile agricultural land and in wetter parts of England and Wales the loss of Best and Most Versatile agricultural land. An assessment is made of the reversibility of the impacts. Soil compaction results mainly from trafficking and alleviation is reported to depths of 45cm. It can take many years for soils to recover from compaction and compaction may be permanent. Runoff from panels can result in rivulets, which can lead to soil loss by erosion.

The benefits of topsoil carbon capture and soil structural improvements are reported for grassland. Research on the impact of solar PV panels on microclimate beneath panels highlights the changes in temperature on vegetation growth.

The decommissioning phase involves the removal of the solar PV site infrastructure. The issues of 'pile pull out' are considered, including corrosion and fracture of the piles.

Good soil handling conditions may mitigate the threats to soil and land. Appropriate planning with a quality soil resource and management plan is essential at the planning application stage to ensure that conditions, as part of the planning process, are relevant and focussed on the restoration of the land to agriculture.

[1] Planning Policy Wales Paragraphs 3.58-3.59 Edition 11 February 2021 and National Planning Policy Framework

[2] Land classified as Grade 1, 2 and 3a. MAFF Agricultural Land Classification Guidelines. 1988

CONTENTS

1 BACKGROUND

This report is part of an evidence-based assessment of the impact of solar photovoltaic (PV) sites on Best and Most Versatile (BMV) agricultural land and associated soils. 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 photovoltaic (PV) planning applications.

A detailed search of published research and industry experience has been undertaken to inform this report. The search concentrated on the impacts of solar PV sites on agricultural land and soils within the UK and internationally. There have been few studies of solar PV sites which have a focus on the impacts on agricultural land and soils. This is largely because solar PV sites are recent developments but also because in the early years sites were located on brownfield land or poorer quality agricultural land. The importance of achieving successful restoration of solar PV sites has increased in significance as the number, size and operational time frame of solar PV sites on BMV agricultural land has increased.

An overview study of the industry has been undertaken and informs this report. The distribution of solar irradiation (Huld et al,2019) across the UK ranges from approximately 900-1350kWh/m^2 per year, with the highest resource available in the South West. There has been a trend (BEIS, 2021) towards larger schemes (up to 50 MW and a typical land take of 50ha to 80ha), because of the ceiling for schemes dealt under the Town and Country Planning Act in England. There has also been a move to 'super large' solar PV schemes, generally over 300ha in size. Published sources of guidance for solar developers identified are limited and include several BRE publications (2013, 2014).

Solar Energy UK have prepared a 'best practice guide' (https://solarenergyuk.org/wp-content/uploads/2022/05/NCBPG-Solar-Energy-UK-Report-web.pdf), with much focus on the benefits for ecology and biodiversity and little consideration of the impact on soil. A virtual workshop was held on 2nd September 2021 with Welsh Government, Natural England and invited interested parties.

This report reviews the potential impacts to soil and land associated with solar PV site developments at the commissioning and decommissioning phases. The potential effects on soils during the operational phase of the site are considered and the physical reversion from low-maintenance grass to other agricultural uses typically associated with BMV agricultural land and non BMV agricultural land is undertaken.

This report follows the Technical Specification received from Welsh Government and the layout closely follows the points in the brief (Appendix 1).

ADAS gratefully received evidence from the trade body Solar Energy UK to inform this project and details of the evidence provided over December 2021 – January 2022 is provided in Appendix 2.

2 CONSTRUCTION, OPERATION AND DECOMISSIONING

2.1 Overview of Construction phase

At the time of the submission of the planning application, the solar PV developer will have prepared site outline plans showing details of all aspects of the proposed scheme. Each site is designed taking into account the site's technical assessment, landowner negotiation and grid connection. The solar PV site will typically include some key activities resulting in effects on soil and land, including:

1. Site levelling
2. Construction compound (either for operational life or the temporary during construction phase)
3. Site fencing and security
4. Access road/tracks
5. High voltage cabling
6. Low voltage cabling
7. String cabling
8. Earthing
9. Steel framing mounts and PV panels
10. Piles
11. Inverters and container bases
12. Substation

2.2 Overview of Operational Phase

Solar PV sites are usually unmanned once commissioned. Regular visits may be planned by operations and maintenance staff to undertake monitoring and site maintenance. Typical activities include grass cutting, if grazing does not keep the grass at the optimum height, management of landscaping works and panel washing. The visits will generally require a 4x4 vehicle. Grass on the site is often grazed by sheep, particularly in Wales.

2.3 Overview of Decommissioning Phase

Outline plans stating that decommissioning will be undertaken at the end of the operational life of the development are generally included in the planning application stage. A condition of planning permission is that a more detailed plan, usually about 6 months before the end of the operational life, is submitted to the planning authority. Decommissioning may be triggered by the end of the operational life of the development or by economic reasons or abandonment (Stantec, 2020).

Typical activities at the decommissioning phase may include:

1. Access roads may need to be reinforced to be able to carry traffic involved in the decommissioning phase
2. De-energise solar arrays
3. Dismantle panels and racking
4. Removal of piles from soil and reinstatement of soil into voids
5. Removal of frames and internal components
6. Removal of structural foundations and backfill sites
7. Removal of inverter stations and foundations
8. Removal of electrical cables and conduits
9. Removal of access and internal roads
10. Removal of substation.

2.4 Impacts on soil and land

2.4.1 Construction phase - overview

The construction of the solar PV site involves operations that necessarily impact on the soil and land. All activities at the construction phase involve trafficking by plant/machinery across the whole site, possibly following access tracks on parts of the site. Examples of the equipment used include excavators and dumper trucks for soil removal and storage, trenching machinery, piling rig and dumper trucks for the transportation of cabling, piles, mounts and panels on site.

The removal of a depth of soil is necessary to prepare the site compound, access roads and site tracks (where aggregate and geo textile membrane are used) and bases for inverters and substations. Site fencing, usually 2m high deer or security fencing, is placed around the site perimeter. Wooden supporting posts are often used, which do not require concrete foundations except at the corners and gateways. With typical spacings of 2.4m to 3m there are approximately 300-416 posts per 1000m run of fencing. The length of fencing varies according to the site layout and each post may be sunk at a depth of up to 1m below ground level. Metal fencing may be used where there is a risk of theft and will require concreting at every footing, which will be spaced at approximately 2m giving 500 posts per 1000m run.

2.4.2 Construction phase - piling

The PV panels are placed on frames which are attached to supporting piles. Most sites use H or I beams, driven into the ground by a piling rig (with a vibrating plate) to a depth of approximately 1.4m to 2m. The beams displace a volume of soil about equal to the volume of the pile. H beam piles are described as 'non-displacement', but soil is displaced as a soil plug forms between the flanges and moves down the pile as it is driven (Ahlvin et al, 1988).

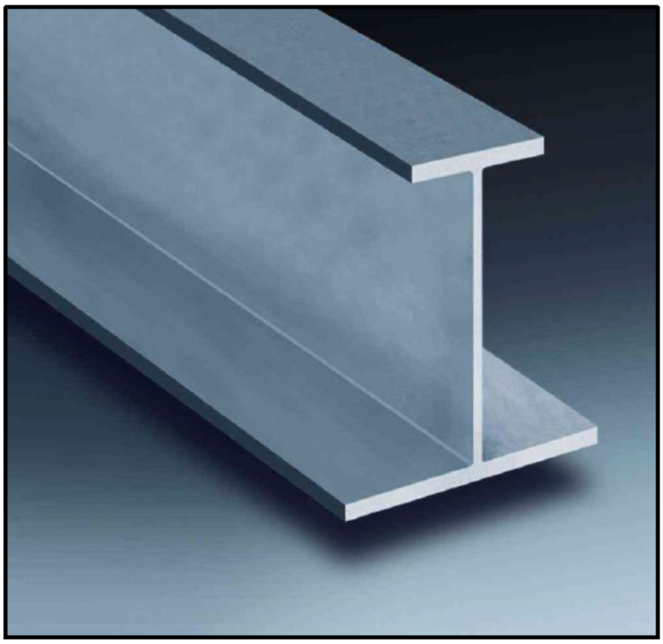

Figure 1: H beam (Sinosources)

H beams have wider flanges than I beams, which have tapered edges. In sandy soils the displaced volume results in compaction of the soil surrounding the pile. In clay soils displacement piles create high stresses in the soil. There is no spoil on the surface.

Helical piles or screws are cylindrical posts with a helix near the bottom of the post and the helix part resists being pulled out by creating a cone of soil above it. Helical piles are installed by digging an initial guiding hole and using a skid steer vehicle with a rotating attachment to spin the pile into place. Helical piles have a smaller surface and will embed with minimal soil disturbance.

Figure 2: Helical beams

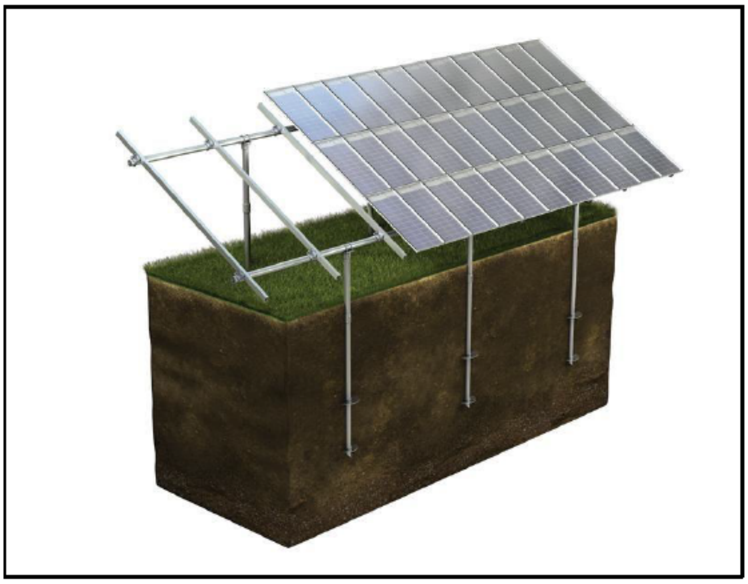

Figure 3 Helical piles at depth (Goliathtechpro.com)

H beams are used on larger scale developments as they have a stronger load bearing and require fewer penetrations per rack compared to helical anchors or ground screws.

The number of piles required is determined by the site layout. One case study in WP2 gave the number of piles as 492 piles per ha. Many planning applications for solar PV sites usually include an elevation plan of the solar panel and give the number of PV panels as an illustration, but not the number of piles required.

Ballasted systems provide a non-penetrating foundation to support solar PV frames. The concrete bases can be used on land fill sites or where deep penetration from H beams may damage archaeological features.

2.4.3 Construction phase – soil movement

The development of solar PV sites requires the excavation of soils associated with construction compounds, access roads and trenching for cables. Soil removal is usually undertaken for construction of the site compound and access roads/tracks, where a geo-textile membrane may be placed over the subsoil and covered with a surface layer of aggregate. The depth of soil stripped for the compound and for the foundation of bases for inverters and substations should be determined by an assessment of soil resources on site. A review of the case studies (WP 2a) showed removal of soil to depths of up to 30cm i.e. typically topsoil, but excavation to this depth could mix in some subsoil if it is not stripped separately. Trenches created by a trenching machinery will require the removal of soil to a depth of typically up to 1.2m (i.e. a layer of topsoil and subsoil and on some sites overburden) and a width of up to 0.75m. The cables are placed in sand with a suitable backfill placed over. The amount of trenching and cabling is site specific, and one case (Estuary Farm WP2) reported a cabling requirement of approximately 2km on the site.

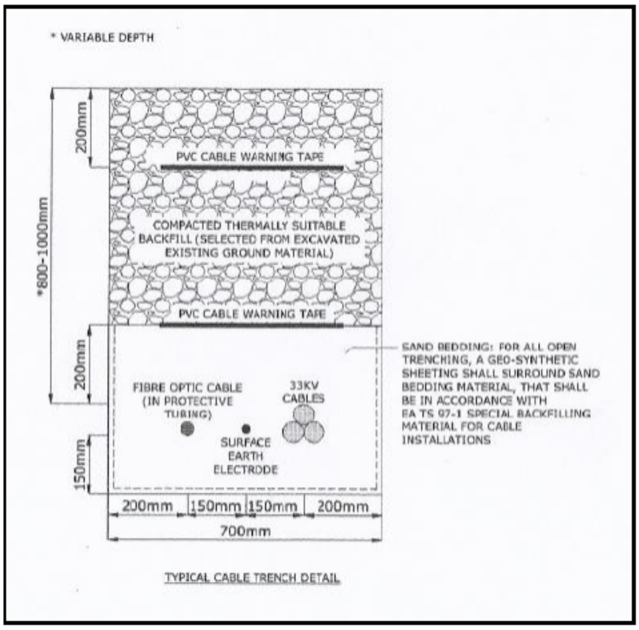

Figure 5: Typical cabling trench details

Site levelling works may be required depending on the site contours and on sites where tilting PV panels are used. Such an engineering operation will disturb the topsoil and it may be that some fill is required on site.

Damage to field drainage systems can occur as piles are driven into the ground, resulting in localised or widespread wet areas within the site.

2.4.4 Operational Phase

During the operational life of a solar PV site there is likely to be minimal disturbance of the site. The wooden posts of deer/security fencing will require replacing through the lifetime of the development due to rot. Frequency of replacement will be greatest in wet or exposed sites. Excavation of the post hole will be required and then re-compaction of the soil leading to localised compaction around the hole and along the access track.

Land between and underneath the PV panels is often grazed by sheep and where there are high numbers of sheep a solid compaction layer 2 cm to 6 cm over a wide area may result (Defra, 2021). There is likely to be some instances of run-off from the solar panels, which could result in the compaction of soils at the base of the panels (Choi et al,2020). Over time rivulets can form along the trailing edge of the panel with potential risk of soil erosion creating rills and gullies across the site. The sand bed could act as a drain, especially on heavy textured soils, leading to drainage discharges or wet patches at the down slope end of each trench.

Figure 6: Channels created by panel runoff within 12 months of site operation commencing

2.4.5 Decommissioning Phase

When the decommissioning phase is triggered at the end of the operational life of the solar PV site, operations to remove the physical infrastructure commence. Access roads and tracks may require reinforcing to be of a standard suitable for heavy machinery. Trafficking will again occur across the site on and off the site tracks as panels, frames and inverter cabins and substations are removed. Cabling may be removed from trenches and string cabling will be dismantled. Access roads, and construction compounds will have aggregate and the geo-textile membranes removed. Where the inverter cabins have been placed on an aggregate base or concrete plinth then this should be removed.

The extraction of the piles is likely to be more problematical than the initial installation (per. comm. P. Woodfield, Technik GS). Pile extraction is undertaken typically with a 13-ton excavator and vibrating pile driver attachment, which removes one beam and then tracks to the next one (per. comm. I. Woolley, Twig Group). A vibrating plate shakes the soil at removal stage, to ensure that the soil stays in place with little disturbance as the H beam is lifted out of the ground, this reduces the risk of soil attaching to the H beam and resulting in a larger area lifting. The volume occupied by the steel beam is the theoretical void. Where there are granular soils e.g. sands and gravel, the soil will fall into the void to occupy the space. The soils do this through a combination of gravity, flow if below the water table and the likely vibration effects while withdrawing the piles (per. comm. M. Wheeler, Binnies).

In clay soils there will be softening and swelling to close the void over time partially or wholly. Plugging can occur in clay soils where the soil may stick to the pile and be withdrawn with the pile, in effect pulling out a solid unit defined by the flanges and width of the pile. The volume of the soil pulled out is greater than in sandy soils and can produce a local ground settlement as soil swells or collapses to fill the void unless measures are taken to fill the void at the time of withdrawal. The clay or soil adhering to the pile can be cleaned off and returned to the hole and then the void is minimal as bulking takes up part of the volume, but this may mix topsoil and subsoil unless carefully managed. Widespread ground settlement is unlikely to occur, although there may be localised ground surface settlement at the point of the pile extraction. It is expected that any localised ground surface settlement would be removed at the time of cultivations on the site. There is no known reported experience of pile pull out within the solar industry in the UK. A study of civil structures in Japan, where the ground is 'soft' and many structures use pile foundations, reported that 'filling' the void was effective in reducing ground subsidence and that the 'filler' must suit the ground conditions (Inazumi et al, 2017). At this stage in the life of the ground-mounted solar PV industry, the impact of pile pull-out on agricultural land and soil is a 'grey' area with few conclusions having been drawn to date.

2.5 Risks to agricultural land quality

During the construction and decommissioning phases there will be soil movement and soil handling on site. During the commissioning, operational and decommissioning phases there will be trafficking by a range of machinery, including dozer, tracked excavator, wheeled backhoe loader, hydraulic hammer rig and rotary bored piling rig, vibrating plates, which can result in soil compaction. The main cause of compaction is the compressive forces applied to the soil from the wheels or tracks of machinery. Hakansson (1985) found that an axle load of 10 tonnes increased soil bulk density to a depth of 50 cm. Compaction may be very persistent in the subsoil and possibly permanent (Hakansson et al 1988). Where there is '*industrial compaction'* the depth of compaction can extend to depths of 1m (Spoor, 2006) and may persist for up to 30 years (Batey, 2009).

Low ground pressure tyres and tracked machinery may reduce the impact of compaction. Tracked vehicles can reduce rut depth by up to 40%, compared to extra wide or soft tyre options (Bygden etc al, 2003). The weight on tracked machinery is concentrated beneath the idlers and the bogies (the wheels within the tracks).

Field identification of soil compaction includes evidence of waterlogging on the surface or in subsurface horizons, an increase in soil strength or bulk density, low visible porosity, poor structural conditions, soil colour and rooting pattern (Batey, 2009).

Techniques for loosening compacted soils to depths of about 45cm are established, but at lower depths correcting problems may not be effective and economic and engineering equipment is required.

As well as the forces applied to the soil, the soil water content and bearing capacity are critical at the time the pressure is applied – this is true for both the instance of compaction and the alleviation of compaction.

Soil compaction can occur and be unrelated to mechanical forces, for example finely aggregated soil 'tumbling' down from the surface when cracks are open and wide (Batey,2009). There is potential for soil falling into the voids created when piles (e.g. H-beams) are removed.

The impact of soil compaction is well documented (Batey, 2009) and crop growth, yield and quality may be adversely affected. There are also wider environmental implications relating to water and air quality.

The extent of trafficking and soil disturbance can cover a substantial proportion of a solar PV site. Satellite imagery of three solar schemes is included in Appendix 3 to this report. This imagery shows:

- 1) Hunstpill Level Solar Farm, Sedgemoor District – pre-construction
- 2) Hunstpill Level Solar Farm, Sedgemoor District – during-construction
- 3) Lamby Way Solar Farm, Cardiff – pre-construction
- 4) Lamby Way Solar Farm, Cardiff – early-construction
- 5) Lamby Way Solar Farm, Cardiff – mid-construction
- 6) Lamby Way Solar Farm, Cardiff – post-construction
- 7) Afon Llan Solar Farm, Swansea – pre-construction
- 8) Afon Llan Solar Farm, Swansea – during construction

The imagery is taken from Google Earth Pro (historical imagery), Google Earth and Bing Aerial.

A number of developers have published videos on the YouTube.com showing phases of solar farm construction in the UK. Some videos appear to show construction during good ground conditions, with suitable access tracks constructed to support the field work. Other videos, however, appear to show no consideration for topsoil preservation and work proceeding during very wet conditions, resulting in wheel ruts, surface water ponding and slurrified soil in places. Extracts from two of these videos are provided in Appendix 4. Whilst care must be taken when drawing conclusions from such limited evidence from any given site, the videos give an idea of the soil disturbance that can occur during a solar PV site construction.

On all sites there is the potential impact on soils from the spillage or leakage of fuel and oil. Contaminants only affect agricultural land classification grading where they have or are likely to have a detrimental long-term effect on the physical condition of the soil (MAFF,1988), the yield, cropping and the stocking rates. It is likely that the impact on solar PV sites will be minimal, as bio-oils are widely used and incidents managed through control of contaminants and action.

The supporting information for solar PV sites indicates that galvanised aluminium or steel posts are used to support the frame. Galvanising involves a coating of zinc with thickness ranging from 0.3mm to 3.5mm. The impact on soil and land from the zinc coating is unknown. Defra's code for using sewage sludge (Defra,2018) gives thresholds for zinc in soils of 200 – 300mg/kg; these levels are very unlikely to be achieved from the presence of piles in the soil, although the base level of zinc could influence the threshold. Research on agricultural land has shown that zinc in soils diminishes biological activity (Moffett et al, 2003).

The maintenance of on-site ditches will be key to ensuring that surface water is managed on site. Should maintenance not be undertaken, there is a potential impact of flooding on land. Many solar PV site planning applications consider surface run-off within a management strategy.

3 AGRICULTURAL LAND QUALITY

This section of the report looks specifically at agricultural land, and the risk of residual impacts of solar PV sites on agricultural land quality and Best and Most Versatile (BMV) agricultural land.

The Agricultural Land Classification (ALC) system is used in England and Wales to determine agricultural land quality. The ALC system provides '*a framework for classifying land according to the extent to which its physical or chemical characteristics impose long-term limitations on agricultural use*'. The main factors influencing agricultural production and therefore agricultural land quality are climate, site and soil. These three factors and the interactions between them form the basis of classifying agricultural land into one of five grades, as described in Table 1 below.

Table 1: Agricultural Land Classification Grades

Agricultural Land Classification Grades
Grade 1 – excellent quality agricultural land Land with no or very minor limitations to agricultural use. A very wide range of agricultural and horticultural crops can be grown and commonly include top fruit, soft fruit, salad crops and winter harvested vegetable. Yields are high and less variable than on land of lower quality.
Grade 2 – very good quality agricultural land Land with minor limitations which affect crop yield, cultivations or harvesting. A wide range of agricultural and horticultural crops can usually be grown but on some land in the grade there may be reduced flexibility due to difficulties with the production of the more demanding crops such as winter harvested vegetables and arable root crops. The level of yield is generally high but may be lower or more variable than Grade 1.
Subgrade 3a – good quality agricultural land Land capable of consistently producing moderate to high yields of a narrow range of arable crops, especially cereals, or moderate yields of a wide range of crops including cereals, grass, oilseed rape, potatoes, sugar beet and the less demanding horticultural crops.

Agricultural Land Classification Grades (continued)
Subgrade 3b – moderate quality agricultural land Land capable of producing moderate yields of a narrow range of crops, principally cereals and grass or lower yields of a wider range of crops or high yields of grass which can be grazed or harvested over most of the year.
Grade 4 – poor quality agricultural land Land with severe limitations which significantly restrict the range of crops and/or level of yields. It is mainly suited to grass with occasional arable crops (e.g. cereals and forage crops) the yields of which are variable. In moist climates, yields of grass may be moderate to high but there may be difficulties in utilisation. The grade also includes very droughty arable land.
Grade 5 – very poor quality agricultural land Land with very severe limitations which restrict use to permanent pasture or rough grazing, except for occasional pioneer forage crops.

Agricultural land of Grade 1, 2 and Subgrade 3a is considered to be the best and most versatile (BMV) agricultural land in England and Wales.

Two of the principal limitations to agriculture, considered by the ALC system, are soil wetness and soil droughtiness. Soil wetness limits the flexibility of agricultural land by reducing the number of days available for safe cultivations and harvesting. The greater the soil wetness limitation the fewer days available. Soil wetness is influenced by climate (i.e. rainfall v evapotranspiration) and soils (primarily the soil water / drainage regime and topsoil clay content). Soil droughtiness limits the capacity of agricultural land to economically support certain crops. The greater the soil droughtiness limitation the less crop available water there is during the growing season and the less economically viable certain, or in the worst cases all, crops become. Soil droughtiness is influenced by climate (e.g. rainfall v evapotranspiration) and soils (primarily soil structure, soil depth, soil stone content and soil texture).

An assessment of soil wetness and droughtiness can demonstrate the residual impact of solar PV sites on agricultural land quality.

3.1 'Disturbed' and 'Undisturbed' Agricultural Soils / Land

In areas of a solar PV site, including the compound, access tracks, bases for inverters/substations, the soil will be stripped during the construction phase, stored and then replaced at the time of decommissioning. In areas of cable trenching the soil will be stripped, placed close to the trench and then reinstated once the cable is in place. In this report these areas are considered to be *'disturbed'*.

For this report areas in which soils are not stripped or reinstated and remain in situ are considered to be *'undisturbed'* land. These areas of 'undisturbed', soils may still be impacted during the various construction phases, via trafficking.

The ALC system recognises the classification of 'disturbed' land, which has different criteria for classifying land from 'undisturbed land'. Therefore the two are assessed differently:

- the agricultural quality of *'disturbed'* land is assessed with reference only to the soil textural, structural and porosity characteristics.
- the agricultural quality of '*undisturbed'* land is assessed with reference to soil colour (gleying[3]), textural, structural and porosity characteristics for determining the soil wetness limitation.
- the assessment of soil droughtiness for both 'disturbed' and 'undisturbed' land considers the soil texture, structure, organic matter and stone content.

3.2 Agricultural Land Classification Grade Scenarios

In the following sections several scenarios are outlined to indicate the potential residual impacts of solar PV sites on agricultural land quality. The scenarios concentrate on the residual impact of unremediated soil compaction on agricultural land, specifically relating to ALC grade according to soil wetness and soil droughtiness.

The assessment of ALC grade according to soil wetness (MAFF ALC Guidelines Section 3.4 and Appendix 3) considers climate, soil water regime and soil texture. Soil water regime is influenced by climate plus subsoil structure, consistency and porosity – each of which will be impinged by unremediated compaction.

The scenarios assume that unremediated (sub)soil compaction has resulted in a slowly permeable layer (SPL) at a shallower depth in the soil profile than was previously the case. The depth to a SPL is key to assessing soil water regime and ultimately ALC grade according to soil wetness. A SPL prevents the downwards movement of water in the soil profile and can lead to surface water perched at shallow depth for periods of the year, particularly autumn through to spring, and particularly problematic in wetter soil types or wetter areas

[3] A greyish, pale and ochreous colouring indicative of waterlogging.

of England and Wales. This can negatively impact the flexibility of agricultural land, potentially lowering quality and ALC grade.

A similar set of scenarios could be made of the potential residual impact of unremediated (sub) soil compaction on ALC grade according to soil droughtiness. The assessment of soil droughtiness considers climate, soil texture and, again, soil structure, consistency and porosity.

Several scenarios have been prepared to demonstrate the impact on soils using Field Capacity Days covering a range of hypothetical climates across England and Wales. Field Capacity Days (FCD) is a theoretical climatic model of the number of days in a typical year that accumulated precipitation exceeds accumulated evapotranspiration. It is based on historical climatic data in England and Wales, and wetter, cooler areas have higher FCD (e.g. >300 FCD in Welsh hills) than warmer, drier areas (e.g. 100 FCD in SE Cambridgeshire). It corresponds with the soil concept of Field Capacity, is the water content of a soil after gravitational drainage over approximately a day.

As is standard with the ALC system, the scenarios assume that soils have or could have an appropriate underdrainage system and the assumption is made that such a system will be in place at the end of the solar PV site decommissioning phase.

Several examples are presented to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) and the interaction with the climate variable Field Capacity Day (FCD) on BMV agricultural land. A summary of the scenarios is given below and detailed tables are in Appendix 5.

3.2.1 Scenario 1: Wetness Class I Medium-Textured Soils (Disturbed Land)

Several scenarios for 'disturbed' soils are presented in Appendix 5 (Table A) to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land.

The following summary demonstrates the potential impact on land during the lifetime of a solar PV site. The pre-construction soil profile belongs to Wetness Class I[4] and has a medium-textured topsoil. During the construction phase the soil is stripped and stored in soil bunds.

[4] Wetness Class (WC) I = freely-draining soil. WC II = moderately freely-draining. WC III = imperfectly-draining. WC IV = poorly-draining. WC V = very poorly-draining. WC VI = permanently waterlogged.

- in an area with a FCD of 230 the impact of an introduced slowly permeable layer at a depth of between 25cm and 60cm would place the reinstated soil profile in Wetness Class IV and the agricultural land classification grade of Subgrade 3b. The agricultural land classification grade before commissioning would be Subgrade 3a, hence there is an impact at decommissioning on BMV land.
- in a drier part of England, with a FCD of 125, with an introduced SPL at a depth of between 35cm and 60cm, the reinstated profile is placed in Wetness Class III and the resultant ALC grade is Subgrade 3a. Prior to commissioning the ALC grade is given as Grade 1, hence there is an impact on the versatility of the BMV land at decommissioning.

3.2.2 Scenario 2: Wetness Class I Medium-Textured Soils ('Undisturbed' Land)

Several scenarios for 'undisturbed' soils are presented in Appendix 5 (Table B) to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land. For 'undisturbed' soils reference is made to soil colour (gleying[5]), textural, structural and porosity characteristics for determining the soil wetness limitation.

The scenario is a pre-construction soil profile placed in Wetness Class I, which has a medium-textured topsoil:

- in an area with a FCD of 230, where there is an introduced slowly permeable layer at a depth of between the surface and a depth 80cm with gleying present below a depth of 40cm, the soil at decommissioning is placed in Wetness Class III and an ALC grade of Subgrade 3b. Prior to commissioning the ALC grade is given as Grade 3a, hence there is an impact at decommissioning on the BMV land.
- in an area with a FCD of 230, where an introduced slowly permeable layer is present at a depth of 25cm and gleying is present in the soil profile above 40cm the soil is placed in Wetness Class V and Grade 4. There is an impact at decommissioning on the BMV land.
- in a drier part of England, with an FCD of 125, where there is gleying present below a depth of 40cm and a slowly permeable layer starting between a depth of 35cm to 42cm the soil at decommissioning is placed in Wetness Class III and Subgrade 3a.

[5] A greyish, pale and ochreous colouring indicative of waterlogging.

Prior to commissioning the ALC grade is given as Grade 1, hence there is an impact on the versatility of the BMV land at decommissioning.

3.2.3 Scenario 3: Wetness Class II Light-Textured Soils (Disturbed Land)

Several scenarios for 'disturbed' soils are presented in Appendix 5 (Table C) to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land. The pre-construction soil profile belongs to Wetness Class II[6] and has a light-textured topsoil. During the construction phase the soil is stripped and stored in soil bunds.

The following summary demonstrates the potential impact on land during the lifetime of a solar PV site:

- in an area with a FCD of 225 the impact of an introduced slowly permeable layer at a depth of between 25cm and 60cm would place the reinstated soil profile in Wetness Class IV and the agricultural land classification grade of Subgrade 3b. The agricultural land classification grade before commissioning would be Grade 2, hence there is an impact at decommissioning on BMV land.
- in a drier part of England, with a FCD of 125, with an introduced SPL at a depth of between 35cm and 60cm, the reinstated profile is placed in Wetness Class III and the resultant ALC grade is Grade 2. Prior to commissioning the ALC grade is given as Grade 1, hence there is an impact on the versatility of the BMV land at decommissioning.

3.2.4 Wetness Class II Light-Textured Soils ('Undisturbed' Land)

Several scenarios for 'undisturbed' soils are presented in Appendix 5 (Table D) to demonstrate the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land. The pre-construction soil profile belongs to Wetness Class II and has a light-textured topsoil.

- in an area with a FCD of 225 the impact of an introduced slowly permeable layer at a depth of between 35cm and 61cm and gleying present above 40cm would place the profile in Wetness Class IV and the agricultural land classification grade of

[6] Wetness Class (WC) I = freely-draining soil. WC II = moderately freely-draining. WC III = imperfectly-draining. WC IV = poorly-draining. WC V = very poorly-draining. WC VI = permanently waterlogged.

Subgrade 3b. The agricultural land classification grade before commissioning would be Grade 2, hence there is an impact at decommissioning on BMV land.

- in a drier part of England, with a FCD of 125, with an introduced SPL at a depth of between 35cm and 61cm and gleying above 40cm, the profile is placed in Wetness Class III and the resultant ALC grade is Grade 2. Prior to commissioning the ALC grade is given as Grade 1, hence there is an impact on the versatility of the BMV land at decommissioning.
- in areas with a FCD of 170 or lower with a light-textured soil changes in the Wetness Class and resultant grade may have minimal impact on BMV land (Appendix 5 Table D). However the introduction of a slowly permeable layer may influence the available water holding capacity of the soil profile and soil droughtiness may have an impact on the BMV land.

3.2.5 Summary

To summarise on both disturbed and undisturbed land, the soil wetness assessment shows the impact of unremediated soil compaction leading to gleying in the soil and the introduction of a slowly permeable layer. The potential loss of BMV agricultural land or its versatility increases in wetter parts of England and Wales.

In slightly drier parts of England and Wales there is loss of BMV agricultural land depending on the starting depth of the slowly permeable layer. Loss of versatility of BMV agricultural land, for the soil textures considered, occurs in slightly drier parts depending on the interaction of the Wetness Class and the FCD of the location.

3.3 Soil Compaction and Soil Droughtiness

Section 3.4 and Appendix 4 of the MAFF ALC Guidelines (1988) outline the methodology for assessing the soil droughtiness. Soil droughtiness indicates the degree to which a shortage of soil water may influence the range of crops grown and the yields achieved. Droughtiness is more likely to be a limitation to crop growth in areas of relatively low rainfall or high evapotranspiration. The interaction of the climate, soil texture, soil stoniness, subsoil structure, subsoil porosity and subsoil consistency influences the degree of the severity.

On solar PV sites both disturbed and undisturbed land at decommissioning may be affected by the introduction of unremediated soil compaction. This could reduce the crop available water of the soil profile, changing the ALC grade in the soil droughtiness assessment and may result in downgrading and /or loss of BMV.

The change in the grade may arise from a change in the soil profile characteristics, particularly soil consistence (the resistance to crushing) leading to changes in the available water holding capacity in the subsoil. The following scenario shows the impact of a change in the available water capacity of a subsoil on BMV land:

- Location – south east England
- Climatic moisture deficit for wheat is 122mm and potatoes 118mm
- ***Prior to commissioning***: the profile subsoil has a good structural condition with the resultant crop adjusted water capacity for wheat of 110mm and for potatoes of 89mm.

  The moisture balance limits place the profile in Subgrade 3a

- ***At decommissioning***: the profile subsoil has a moderate structural condition with the resultant crop adjusted water capacity for wheat of 106mm and for potatoes of 85mm.

  The moisture balance limits place the profile in Subgrade 3b.

In more severe cases unremediated soil compaction may prevent root penetration. Occurring at shallow depth this may have a significant impact on crop available water which may result in downgrading by more than one ALC grade. The depth of root penetration can only be assessed by the examination of soil pits.

3.4 Soil Mixing

Soil mixing may occur in the construction and decommissioning phases and is identified in Section 3.3 of the ALC Guidelines (MAFF,1988) as a potential limitation to grade. A study of the effects of golf course development on high quality agricultural land (MAFF,1995) considered the impact of soil mixing on the reversibility of high quality agricultural land. Where mixing of very different soils e.g. sands with clays occurred subsequent agricultural management was potentially difficult. The severity of the impact will depend on the amount of mixing- the ratio of different soil textures and other soil properties such as soil structure, stone content and organic matter content. It is difficult to assess the impact on BMV agricultural land from soil mixing but where it causes significant management problems, post-decommissioning, an independent assessment would be required – both to quantify and to remediate.

3.5 Reversibility or otherwise of the impacts on BMV agricultural land

One of the key impacts on BMV agricultural land is soil compaction, which can vary considerably from very minimal and short term to severe, which possibly cannot be rectified. Compaction in the subsoil below about 45cm is unlikely to be practicable and economic to alleviate (Batey, 2009) and is unlikely to respond quickly to natural recovery through the freeze-thaw cycle. Where compaction is present at depth it is a long-term limitation and it is taken into account in the ALC Guidelines (MAFF, 1988) through reduced permeability in the wetness assessment and crop available water in soil droughtiness assessment. There will be compaction at the time of construction, which may remain for the lifespan of the development. Further compaction may result at the decommissioning phase.

The timescale for reversibility is undefined but is taken in this report as the point at which decommissioning is completed. The time taken for a soil with compaction to recover depends on the severity of the compaction and the soil type. Business Wales (2018) and Froehlich et al (1985) reported that natural recovery of a compacted soil is complex and a slow process. Batey (2009) refers to 30 years for a compacted soil to recover, where 'industrial' compaction extends to depths of 1m or more (Spoor, 2006). Hakansson (1988) reported that compaction may be very persistent in the subsoil and permanent. Nawaz et al (2012) presented a review of research and concluded that soil compaction is rapid and easy to create with agricultural machinery but it can be years before the soil is recovered. Keller at al (2017) noted that knowledge regarding soil compaction rates is 'sketchy' with experimental evidence of recovery periods from a few months to years and decades. Differences in laboratory and field experiments highlight the 'partial and incomplete' knowledge of the key processes involved in soil structure recovery.

Keller et al (2021) undertook research at the Swiss Soil Observatory to quantify and monitor short-term recovery after prescribed compaction. After 2 years it was noted that different soil physical properties follow different recovery paths and rate. Bulk density and air permeability had not fully recovered to pre-compaction values in the topsoil and subsoil. Post compaction recovery rates decreased with soil depth and differed between soil properties.

A study of soil compaction on golf courses (MAFF, 1995) reported that the inappropriate handling of soils resulted in severe compaction and a deterioration of soil structure. In the period 1988 to 1993 construction work, such as soil stripping and trafficking, was undertaken on a number of golf courses during the winter months. A finding of the report was that if soil stripping had been carried out in a more controlled way parts of golf courses might have been practically reversible to an agricultural land quality closer to the pre-construction quality.

A study undertaken by Defra (2016) considered compaction in grassland on 300 grassland fields. The study considered how grassland management may be used to influence soil compaction and how management can be targeted to alleviate or avoid compaction. The careful management of machinery use in terms of when and how many times soils are trafficked was a key influence on the level of soil compaction.

Current techniques for alleviating compaction above depths of 45cm, particularly in drier parts of England and Wales, indicate that some reversibility of the impact on BMV agricultural land is possible. However not all soils respond and silty soils, where there is structural instability, may be problematic.

Where deep compaction occurs in soil the reversibility of the impacts on BMV agricultural land are given in scenarios (sections 3.2.1 to 3.2.4 and Appendix 5). The impact of compaction on disturbed soils and undisturbed soils are assessed separately. In the case of disturbed soils there may not be any compaction if the soils associated with cable trenching are replaced in an unconsolidated condition. There are many unpredictable factors, such as soil strength and prevailing moisture content, that will affect the level of compaction and the potential to successfully alleviate damage.

In the case of compacted soils and the pre-construction Wetness Class I soil, reversibility involves the removal of the slowly permeable layer within 80 cm at decommissioning. The ALC Guidelines (MAFF,1988) consider that '*where significant compaction occurs below 35cm… it may be difficult or impossible to ameliorate practically or economically. Such compaction is therefore a long-term limitation which is taken into account through reduced permeability and water capacity in the wetness and droughtiness assessments*'.

Batey (2009) reports that techniques for loosening compact soils operating to depths of about 45cm are established. In the case of a soil profile in Wetness Class II it may be that the impact on BMV agricultural land is reversible and some loss of versatility is reversed. For example, in the drier parts of England with a FCD of 125 where there is compaction close to a depth of about 45cm and gleying present below a depth of 40cm, then the impact of compaction on BMV agricultural land is normally reversible, with the Wetness Class moving from Wetness Class III to Wetness Class II.

Any soil mixing may impact on BMV agricultural land but each site will have individual characteristics and it is difficult to prescribe for a potential impact. Small amounts of soil mixing should be reversible as the subsoil and topsoil are mixed by cultivation and soil biota but where significant soil mixing does occur the reversibility of the impact on BMV agricultural land becomes increasingly challenging.

4 POTENTIAL IMPACTS (POSITIVE AND NEGATIVE) ON SOILS DURING THE OPERATIONAL PHASE

4.1 Introduction

During the operational phase of the solar PV site there are minimal activities on site and the site is usually unmanned. Routine maintenance at the site may include grass cutting, if grazing does not keep the grass at the optimum height, landscape management (e.g. hedge trimming) and an annual PV panel wash. The electrical systems may be monitored monthly and a grazier to manage stock grazing may access the site. Access is typically by 4x4 vehicles and it is unlikely that any heavy machinery will be required.

Grazing of grassland by sheep required careful management. Excessive stocking rates and / or grazing on soils susceptible to damage during wet weather, may negatively impact the soil during the operation phase and may pose environmental issues such as increased surface water runoff.

4.2 Claimed benefits of topsoil carbon capture and soil structural improvements

Much guidance (BRE, 2013 and 2014a) and many planning applications promote the benefits to biodiversity of solar PV sites.

Agricultural land use change, often from arable 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). SOM is the cornerstone of soil health; it is beneficial to soil structure, the resistance of the soil to erosion, plant / crop available water, plant / crop available nutrients, earthworm numbers, soil microbiology and biodiversity etc. Furthermore, as a carbon store it is of particular importance today and in the future.

Reports of changes in soil carbon resulting from land reversion are reported by Conant et al (2001). More recently Connant 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).

Defra (2009) reported that the quantity of C that can be stored in any soil is finite. Following a change in management practice levels C 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 arable use to a grassland use does not continue and the rate of accumulation will decline until a new equilibrium is reached. Where the land use change is from long term grasslands it is expected that the initial properties at commissioning of the solar PV site would be different from short term grassland and arable land.

Maintaining 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. Soil organic matter is more rapidly lost than it is accumulated (Freibauer et al, 2004).

A study by Gosling et al (2017) considered the potential for the conversion of arable cropland to grassland to sequester carbon in the short to medium term. The study reported no difference in soil organic carbon stocks in the top 30cm of the soil profile in grassland up to 17 years old and arable cropland at sites across the UK.

The conversion of tillage to grassland resulted in an increased carbon storage in the range 1.1 to 7.0 CO_2e/ha/year (Dawson and Smith, 2006). Conversion of grassland to tillage cropping was estimated to result in carbon losses in the range 2.2 to 6.0 CO_2e/ha/year. It was also reported that converting areas of farmland to grass buffer strips and hedges/shelter belts would enhance soil organic matter and increase C storage on a smaller scale. The baseline soil reference values prior to commissioning are key to understanding any change in SOM over the lifetime of the solar PV site. The land use and factors, such as the changes in management practices e.g. reduced tillage operations, at each site prior to commissioning impact on the baseline soil reference values and potential level of change in SOM.

The relationship between increased SOM and improved soil structure is documented (Cranfield, 2001) and recognised in land management practices with minimum tillage or no tillage operations (Game and Wildlife Conservation Trust, 2020). It is also recognised that reverting arable agricultural land to low-maintenance grassland will improve soil structure. The term soil structure refers to the shape, size, orientation, degree of development, porosity and consistency of aggregates of soil particles. Structure influences the movement of air, water, carbon, nutrients, roots and microorganisms within soil. An improved soil structure is beneficial to many of the key ecosystem services performed by soils, including regulation of air and water, carbon capture and support of plants.

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 during the array's 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.

Key points from studies on land use changes and soil carbon include:

- The initial increases in the early years do not continue
- To maintain an increase in the level of soil carbon the land has to be taken permanently out of arable cultivation or rotation
- Soil organic matter is more rapidly lost than it is accumulated.

There is limited evidence specifically relating to solar PV sites to confirm the benefits to soil health. Baseline site specific soil reference values are required with long-term monitoring to provide evidence of the changes and legacy in the soil health at a solar PV site over a typical lifetime of 40 years.

Factors such as the disturbance of the soil at the construction phase may impinge the development of benefits through the operation phase. Even in the most successful cases (of soil carbon capture, health and structure improvement), improvements are likely to be only temporary and decrease with disruption at decommissioning and again at the return to arable cropping.

The physical presence of solar PV arrays on land is known to cause seasonal and diurnal variations in air and soil microclimate (Armstrong et al, 2016). The work by Alona Armstrong and her team at Lancaster University, particularly the work of Carvalho et al (2021), is looking at the effect of solar PV sites on soil specific factors, including soil organic carbon, nutrients and pH, bulk density, above ground biomass, soil microbial community etc. The work is in its early stages but managed to survey 35 solar PV sites in England and Wales in 2021 and will survey more sites in 2022. This and further such work could be very instructive.

In summary, further evidence is required to substantiate the benefits of SOM at solar PV sites and the claims cited by developers in planning applications.

4.3 The influence of shading and microclimates beneath panels on soil microbial activity

While the increased levels of SOM are recognised in grassland 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 solar PV arrays on microclimate and the consequences for carbon (C) cycling at Westmill Solar Park. The research found that 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 sites on plant–soil processes, which underpin key ecosystem services, is poorly understood.

The microclimatic variability within a solar PV site arises from a lower temperature under the PV arrays. The above ground plant biomass was four times higher in the gap between arrays and the control areas compared to the biomass under the PV arrays. The soil temperature is cooler under the PV arrays and between the PV arrays during the winter due to the interception of shortwave radiation by the solar PV arrays.

The shadow cast by the PV arrays varied from under 2 m in the month of June to just under 11 m in the month of December. The cooling is likely to be significant in terms of ecosystem function with the temperature differences affecting key plant-soil processes from productivity to decomposition (Marrou et al 2013). Thomas et al (2020) expected rising soil temperatures on site would increase soil organic carbon losses due to the increased rates of microbial decomposition.

Recent work in the Netherlands has considered the design of the site layout and the impact on soil (van Aken et al 2021). A comparison of the amount of ground irradiance in terms of intensity and distribution between two south-facing solar park configurations and east-west orientated panels was made. Two variants were made- one with standard solar panels and another with semi-transparent solar panels and bifacial panels. A 77% coverage with semi-transparent and bifacial panels 'performed better on soil quality' with a more even distribution of light on the soil than standard panels with a 53% coverage. The study recommended the establishment of criteria for ground radiation under and between panels.

4.4 The influence of solar developments on soil loss and erosion

Soil loss can occur during the construction phase as soil is stripped for the construction of a compound, bases for inverters and substation, and access tracks. Many solar PV site layouts do not plan space for soil storage bunds and propose to spread the soil in thin layers alongside the access track. This leaves the stripped soil barely visible in the landscape and difficult to reclaim at the restoration phase. This approach is likely to contribute to soil loss, as the soil will not be recovered to its original volume at the decommissioning phase.

Across a solar PV site disturbance can cause the loss of the surface vegetation (see Appendices 3 and 4) and this will leave a site far more vulnerable to soil loss from erosion.

Runoff from solar panels has an influence on soil erosion. Water is known to run along the edge of the panels then fall to the ground at localised points and form rivulets. This has the potential to cause soil erosion, the risk of which is strongly influenced by slope and soil type. Choi (2020) reported erosion and one of the case studies in WP2a (Estuary Farm[7]) considered the possibility of runoff from solar panels causing compaction of soils at the base of the panels and resulting in rivulets forming along the edge of the rows of panels. While there may not be a significant increase in runoff, small channels will have formed with potential of soil loss. This problem is likely to be more severe in erodible soils such as sandy soils on slopes before a vegetation cover establishes. However, the steepness of the slope would be an even stronger influence. The risks are repeated at the construction and decommissioning phases.

4.5 A summary of claimed benefits to soil from previous cases (WP 2a case studies)

The case studies referred to in WP 2a have been reviewed for any claimed benefits to soil within the supporting documentation.

- **Tyddyn Cae Solar Farm Gwynedd**[8] – there is reference to a reduction in nutrient input to the land as a result of changing from an arable use to grassland. The statement is made that ‘soil health is essential for long term sustainability of farming, and solar farms could play an important role by resting soils through the life of the solar farm, allowing soil nutrients to restore naturally, without the need for regular use of fertilizers.’ and reference is made to BRE (2014a).

[7] https://www.west-norfolk.gov.uk/planning_and_development Ref: 21/01432/FM

[8] https://amg.gwynedd.llyw.cymru/planning/index.html?fa=getApplication&id=24205 Ref: C14/0885/33/LL

- **New Works Solar Farm Telford**[9] – the site falls outside BMV agricultural land. There is no reference to claimed benefits to soil. Reference is made to the Solar Energy UK's publication 'The Natural Capital Value of Solar'.
- **Estuary Solar Farm, King's Lynn**[10] – there is no reference to claimed benefits to soil. The proposal is to use an 'under-utilised area of agricultural land' and enhance the 'once arable habitat' with wildflowers and species diverse grassland.

The case studies do not give any site-specific detail on benefits to soil in the supporting documents for the planning application.

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[9] https://secure.telford.gov.uk/planning/pa-applicationsummary.aspx?applicationnumber=TWC/2021/0737 Ref: TWC/2021/0737

[10] https://www.west-norfolk.gov.uk/planning_and_development Ref: 21/01432/FM

5 ARE SOLAR PV SITES REVERSIBLE TO AGRICULTURE WITHOUT RESIDUAL (NEGATIVE) IMPACT?

5.1 Introduction

A brief review and summary of the hypothesis: '*that solar PV sites are physically reversible to agriculture without residual (negative impact) in the BMV and Non-BMV context*' is presented. The evidence base to support this hypothesis and the main issues influencing reversion to agriculture are identified.

5.2 Evidence Base

The key residual impact on the land is soil compaction. Defra (2016) reported that careful management of machinery use in terms of when and how many times soils are trafficked was a key influence on the level of soil compaction on grassland.

Current techniques on alleviating soil compaction are effective in the topsoil and upper subsoil, generally above a depth of 45cm (Batey, 2009). The depth of the uppermost compacted layer (e.g. after remediation) may be the determining factor in the realisation of potential agricultural use. Keller et al (2021) provide evidence that the recovery of soil from compaction was longer than 2 years. Compaction may be very persistent in the subsoil and possibly permanent (Hakansson et al 1988). Where there is 'industrial' compaction the depth of compaction can extend to depths of 1 m (Spoor, 2006) and may persist for up to 30 years (Batey, 2009). A review by Nawaz et al. (2021) refers to time scales of 5 to 18 years for soils to recover from compaction with the aid of agricultural machinery and for soil to recover from compaction naturally (without aid) 100 to 150 years.

At the point of decommissioning there is likely to be a residual impact of soil compaction across solar PV sites. The impact may affect the agricultural use of the land and decisions about cropping and yields.

Soil mixing has been reported by Choi (2020) where there was a greater fraction of coarse particles in the study solar PV site soil than the reference soil. It was considered that the difference arose during the construction phase, when the topsoil was disturbed and fine soil particles were lost by water erosion. Soil mixing has potential to occur at other stages in the life of a solar PV site, such as pile extraction.

5.3 The main issues influencing reversion to agriculture

At decommissioning all materials are expected to be removed including the removal of piles from the soil. Most standard steel products corrode, particularly in the upper part of the pile and this may adversely affect the ability to extract the piles after 40 years. (Non-corrosive materials could be used but have cost implications). It may be that piles fracture and are difficult to extract without additional digging. An engineering solution, where extraction is adversely impacted, would be to partially cut down the piles and provide a capping layer of soil (per comm. P Woodfield, Technik GS). Any residual piles are likely to have a negative impact on whether the land is physically reversible to agriculture unless buried sufficiently deep to enable cultivations and drainage. Where residual piles could not be buried to a depth to allow cultivations the grading of the land would take into account the severity of the limitation. Land with severe or very severe limitations, which restrict the range of crops, is placed into either Grade 4 or Grade 5 in the MAFF Agricultural Land Classification system. To bury the piles to a sufficient depth would mean excavating to a depth of at least 1.0-1.2 metres. This would result in significant soil disturbance if many of the piles were affected in this way.

Where galvanised beams are used zinc is present in the galvanised coating. There are two methods of galvanising used- 'continuous galvanising' and 'batch hot dip galvanising' (per. comm. A Whalley, Milestone Communications). Continuous galvanising (DIN EN 10327) gives a thinner coating, so the expected life is lower. If the beams are batch hot dip galvanised then standard ISO14713-1 applies, which includes reference to exposure to soil. Corrosion in soil is dependent on the soil's mineral content, the nature of the minerals and organic components and the water and oxygen contents. The impact of any interaction between the piles and the soils and potential loss of zinc coating over 40 years and whether there is any residual impact may need to be considered (per. comm J Williams, ADAS). Guidance from Defra (2018) on the use of sewage sludge on land states that the maximum quantity of zinc that can be applied per ha is 150kg over 10 years. Potentially any loss of zinc from piles could be well within this limit, but there is no supporting evidence. There is also evidence that high zinc levels in soils affects the soil biological activity (Moffett et al, 2003).

Handling soil in suitable conditions has an influence on the reversion of land to agriculture. Different soil textural classes have more resilience to structural damage and are more responsive to remediation during soil handling. Light textured soils e.g. sand, loamy sand, sandy loam and sandy silt loam have a higher resilience to structural damage than medium texture soils e.g. soil with 18-27% clay content. Silt loam soils and heavy soils with >27% clay content have a low resilience to damage. Soil should only be handled or trafficked when as dry and as friable as is practicable. If handled or trafficked in adverse conditions damage to the soil structure can easily occur.

The period available for soil handling and trafficking on a solar PV site can influence the impact on the soil, the resultant structural damage and reversion to agriculture. The Institute of Quarrying (2021) has prepared a map of England and Wales showing climatic zones when vegetated mineral soils may be in a sufficiently dry condition according to their geographic location, depth of soil and clay content. When the clay content is between 10% and 27% in the topsoil in Wales, the South West and North of England the indicative on-average period when soils may be in a sufficiently dry condition for handling is generally late May to early October. For similar soils in central parts of England it is generally late April/early May to early November, while in the East of England it is generally late April to early December. The location of the proposed solar PV site and susceptibility of a soil type to structural damage should be considered at the design stage to ensure timeliness of soil handling and trafficking. A soil in West Wales with a medium clay loam texture and clay content of 24% will have a shorter window for soil handling and trafficking than the same soil in East Anglia. The impact of climate and climatic zones should be built into the design statement at the pre-planning stage of a site.

A research study into end of life decision making for solar farms (Windemer,2021) reported that there may be changes in ownership of the solar PV site with a change in the priorities for the site. The study considered finance for decommissioning, reporting that bonds are not always used in the solar sector as it is 'felt that decommissioning will not present a challenge'. The study found that some developers considered that decommissioning may be self- funding through the resale value of equipment and materials from the site. A sample decommissioning plan (Solar Energy UK, 2022) refers to the provision of a decommissioning fund either through a surety bond, an irrevocable standby letter of credit or other financial security.

Developers may consider that the scrap value of the panels etc on site will cover the costs of decommissioning. There are few contingency plans in place and should operators encounter financial instability and the economics of solar PV change during the project life and trigger early decommissioning then this may influence the reversion of the site to agriculture and other changes of land use may be sought.

Finances available for decommissioning are part of the responsibility of the operator or landowner or both and can influence the reversion to agriculture. It is the responsibility of the planning authority to ensure that the developer or landowner has secure finances or a bond in place to fund decommissioning.

5.4 Summary

There is evidence that soil compaction from machinery can have a residual impact on soil and land. Soil mixing may occur during construction and in the voids left after piles are extracted. Soil compaction and mixing may result in issues for land management. Removal of physical infrastructure on site and re-instatement of soil/land is necessary if the land is to be capable of reversion to a BMV agricultural land quality as well as a non BMV agricultural land quality.

The finance available for the required decommissioning and the timings of these operations may be an influencing factor on the reversion to agriculture. There may be financial constraints, time penalties and contractual performance issues that affect the decommissioning programme and the quality of remediation works.

6 THE PARALLELS BETWEEN MINERAL SITE RESTORATION AND SOLAR PV SITE RESTORATION

There are a few parallels between mineral site restoration and solar PV site restoration. In both situations soil will have been subject to stripping, some form of storage and then spreading over a subsoil. Subsoil compaction is likely to be found in both situations.

There are significant differences in the approach to restoration undertaken.

- Mineral site restoration is detailed as part of the planning application stage, supported by a soil resource management plan and restoration is subject to a statutory aftercare period of 5 years. There is published guidance for solar PV sites (BRE, 2013) recommending that a soil resource management plan be prepared as part of the planning application. Where soil resource plans have been prepared they have usually been undertaken as a condition of planning approval.
- While mineral sites require planned soil storage in the form of bunds many solar PV site layouts do not typically accommodate soil storage in bunds within the site and soil may be spread thinly alongside access tracks on undisturbed land.
- Solar PV site restoration involves the pull out of piles with soil disturbance at the decommissioning phase.
- Only part of a solar PV site generally requires restoration with soil spreading. Most of the area is not disturbed by soil stripping but is subject to trafficking and therefore may be compacted. Mineral site restoration good working practices involve spreading the soil in such a way that trafficking is minimised but all the soil is disturbed leading to a greater disturbance of soil structure and soil biota.

In summary, there are significant differences between mineral site restoration and solar PV site restoration. The main parallel is the need for a soil management plan to protect the soil resource.

7 THE PARALLELS BETWEEN GOLF COURSES OR SIMILAR SOFT USES AND SOLAR PV SITE RESTORATION

There are very limited documented experiences of the reversibility of golf courses to agriculture.

Parallels between golf courses and solar PV sites can be found where there is site levelling and movement of soil. Golf course restoration to agriculture may involve the importation of fill and some land levelling. Fill may also have been imported at the golf course construction stage. Landscaping forms part of both golf course development and solar PV site.

The presence of physical infrastructure on a solar PV site where there may be a high density of piles (e.g. 492 piles per ha) and extensive lengths of trenching for cables are significant differences. The extent of constructed infrastructure on solar PV sites may be greater than on a golf course. The impact of compaction from trafficking would be expected to be greater on a solar PV site than a golf course development, although surface sealing on golf courses can be an issue due to footfall.

A study (MAFF,1995) reviewed the effect of golf course development on Grades 1, 2 and 3a land. The potential adverse effects that impact on high quality agricultural land are from earth moving during construction, soil mixing, sterilisation of land and construction of clubhouses and car parks. The impact of a golf course on land was defined as 'high' (more than 50% of the land irreversibly lost) to 'low' (10 to 25% of the land irreversibly lost). In the study 'irreversible' was defined as the *'ability to restore a site to a similar agricultural land quality which existed prior to development. It is not just the ability to restore land back to agricultural use'*.

The greatest irreversible loss of high quality agricultural land on golf courses resulted from earth shaping and sterilisation of land. Golf courses with the lowest impact used existing landform with little disturbance to the agricultural land. Soil mixing and compaction tended to be localised and the impact on the ALC grade of the land was variable. The study found that golf course constructions on over 30% of the courses took place in the winter period when conditions for soil handling were not suitable. The impact on high quality agricultural land and the reversibility to a similar grade was influenced mainly by the disturbance of the soil through earth moving.

Both golf courses and solar PV sites are presented as being reversible to an agricultural use.

The parallels for restoration between golf courses and solar PV sites include the disturbance of soil, soil mixing, trafficking of the land and unsuitable conditions for soil handling and trafficking during the construction, operation and decommissioning phases.

8 CAN SOIL HANDLING CONDITIONS, AS PART OF THE PLANNING PROCESS, MITIGATE OR REMOVE THREATS TO SOILS AND LAND

8.1 Soil Handling Conditions

Soil is moved through stripping, storage and replacement operations at the construction and de-commissioning phases of a solar PV site. Soil handling will be part of the construction of the site compound, access roads/track, bases for inverters and substations and cabling operations.

A soil resource assessment, undertaken as part of the pre-planning stage, gives a baseline of existing soil conditions on site. The assessment will identify different soil types and soil handling units, which will be required to be stripped, stored and replaced in discrete areas. Planning guidance on large scale ground mounted solar PV sites (BRE, 2013) recommends inclusion of a methodology for stripping, storage and replacement of soil within the developer's planning application. The Institute of Quarrying guidance on soil handling (Institute of Quarrying, 2021), applicable to the civil engineering and the wider construction sectors, refers to the need for a soil resource and management plan (SRMP) at design stage through to site closure. Defra's Code of Practice for the Sustainable Use of Soils on Construction Sites (2009) recommends the inclusion of a soil resource plan as part of pre-construction planning.

From the evidence ADAS has seen, it appears that the preparation of a soil resource and management plan (SRMP) for solar PV sites has usually been a condition of the planning permission granted by the planning authority – i.e. as a condition of permission rather than being prepared to support the planning application. The responsibility for the standard and quality of the SRMP lies with the planning authority.

The SRMP considers the management of soil at the construction phase and is a separate document to a decommissioning plan, which is generally conceived at a much later stage of the project life. From the perspective of protecting the soil resource the two documents should be closely intertwined.

While the preparation of a SRMP may meet a condition of the planning authority, on its own it cannot mitigate or remove the risks of harmful impacts on soil and land or be a guarantee for a successful outcome. The key to mitigation is how the SRMP is implemented, the time of year when construction work is undertaken and the day-to-day management on site during soil handling and trafficking. ADAS experience on infrastructure projects has shown that the on-site presence of a soil scientist can ensure that soils are stripped at the appropriate depth and in suitable conditions for soil handling. A recording of soil stripping movements and storage locations should be made.

The lifespan of a solar PV site is generally around 40 years. To safeguard the soil resources for this number of years any soil stripped is best placed in planned storage bunds within the site boundary and a record of soil type and volume in each bund made. The physical and chemical conditions of the soil are likely to have changed from the pre-construction (pre-storage) baseline. Storage can cause a reduction in soil porosity and structure. The preparation of a remediation plan with an aftercare programme as a condition of planning permission will give details on soil handling, but the implementation is key to the outcomes.

8.2 Restoration of BMV agricultural land

A research project undertaken in the 1990s considered the quality of agricultural land at the post restoration stage for a number of mineral sites (Defra, 2000). The study included 34 sites with best and most versatile agricultural land quality and of these about half had maintained their pre-working grade at the start of the 5-year aftercare period and the majority had maintained or improved the grade at the end of the 5-year aftercare period. On these sites the soil was worked in phases over a much shorter period than a solar PV site lifespan and therefore was not in long-term storage.

There are many factors that can influence the outcome of restoration of Best and Most Versatile (BMV) agricultural land and these may include:

- The inherent soil properties and variability across the site
- The amount and duration of climatic wetness
- The daily weather conditions and the soil moisture assessment prior to and during soil handling with appropriate soil handling decision making
- Soil resource and management planning at an early stage in the planning process
- Trafficking the land when soils are in suitable conditions
- Recording details (soil type, volume) of stored soils
- Using appropriate machinery in suitable conditions.

Commercial pressures can influence a restoration programme, resulting in work taking place in unsuitable conditions, resulting in damage to the soil and potentially loss of BMV agricultural land.

The condition of the soil after removal from stockpiles will be a key factor in the realistic restoration of sites with BMV agricultural land. A programme of aftercare with finances provided to cover associated costs is essential if a there is to be a realistic restoration to BMV agricultural land.

At present the decommissioning of a solar PV site covers the removal of all physical infrastructure. Some developers refer to returning the site to its pre-development condition but give limited details. A detailed decommissioning plan is not required by planning conditions until near the end of the life of the site. The detail of a soil resource and management plan should inform the decommissioning plan.

Many solar PV sites change management over the period of operation and the agreements and responsibility for decommissioning at the granting of planning permission should be taken forward to the site closure.

It is important to note that soil is naturally fragile and restored soils remain particularly vulnerable for a variable period until the new soil structure has stabilised. This means that, even if all the correct plans and procedures are put in place and followed with best practice by all contractors during all phases, restoration of disturbed soil may still fail. This may occur when high rainfall causes prolonged waterlogging before the new soil structure has stabilised and causes the soils to slump.

8.3 BMV v non-BMV agricultural land

It is important to note, despite the risks of the construction, operation and decommissioning phases to BMV agricultural land, that in many instances the soils on BMV agricultural land may potentially be easier to restore after decommissioning than non-BMV. However much depends on the site location and interactions between climate and soil.

Non-BMV agricultural land, i.e. Subgrade 3b, Grade 4 and Grade 5, is described as moderate, poor and very poor quality land respectively. It has physical or chemical limitations ranging from moderate to very severe. On any land with heavier soil types in wetter, cooler climates the soil is likely to be more susceptible to damage during the construction, operation and decommissioning phases. There will be a shorter safe window for construction, decommissioning, aftercare and even sheep grazing through the operational phase. Where droughtiness is the main limitation the characteristics of a sandy soil profile with a moderately stony subsoil may be altered during soil handling and affect the water holding capacity of the soil profile at decommissioning, leading to a change in the ALC grade.

The management history of non-BMV agricultural land will influence the baseline soil reference values and the potential carbon capture benefit of solar PV sites. Land in Subgrade 3b may be used for cereals or grass, while land in Grade 4 may be used for grass with occasional arable crops. Land in Grade 5 is typically limited to permanent pasture or rough grazing.

There may also be greater environmental risks during construction, operation and decommissioning on non-BMV agricultural land. Soils may be at field capacity or have a clayey or silty soil texture with a landform resulting in surface water runoff. In such instances there may be a greater risk of soil erosion and pollution of water courses.

Key to managing the risks at any site is an adequate soil resource and management plan tailored to the individual site which is adhered to by contractors and which flows into an appropriate, and appropriately funded, decommissioning plan, including aftercare as required.

9 TYPICAL PLANNING CONDITIONS FOR RESTORATION OF AGRICULTURAL LAND

Planning conditions may be put in place by the planning authority to address matters of soil handling, storage, replacement and aftercare. An outline soil resource and management plan should be prepared taking into account an overview of the typical planning conditions, with attention to the times of soil handling. A detailed plan should be prepared as required, taking into account typical planning conditions. The potential planning conditions should be considered at the planning stage of the solar PV site and the limitations imposed on soil handling by soil and climate interactions. Welsh Government (2014) give an example of conditions applicable to solar PV development. These conditions are reproduced below and can be linked to the three phases in the life of a solar PV site.

9.1 Whole Lifetime site Condition

General Handling of Soils

All soils shall only be stripped, handled, stored and replaced in accordance with document *(insert ref.)* dated *(insert date)* except as modified by this schedule of conditions or unless otherwise agreed in writing with the Local Planning Authority. *Reason: To prevent loss or damage of soil, or mixing of topsoil with subsoil, or subsoil with aggregate or mixing of dissimilar soil types.*
Topsoil shall be stripped to a depth of *(insert ref. / mm)*, subsoil shall be stripped to a depth of not less than *(insert ref. / mm)* and they should be stored separately in mounds within the site. *Reason: To prevent loss of soil, and ensure the direct replacement of soil*
All topsoil and subsoil shall be permanently retained on site and used in restoration. *Reason: To prevent loss of soil.*
In each calendar month, the Local Planning Authority shall be notified in writing at least 7 days before each of the following stages: (a) Before each phase of soil stripping is due to commence; (b) When soil subsoil has been prepared ready for topsoil replacement to allow inspection of the area before further restoration of this part is carried out; and (c) On completion of topsoil replacement *Reason: To ensure that the Local Planning Authority is given opportunity to check that soil operations do not occur under unsuitable conditions and to provide sufficient notice for site inspection.*

Soil Stripping

In each calendar year, soil stripping shall not commence on any phase until any standing crop or vegetation has been cut and removed.

Reason: To avoid incorporation of concentrations of decaying vegetation in soil.

Topsoil and subsoil shall only be stripped when they are in a dry and friable condition. The developer shall give 48 hours notice to the Planning Authority of the intention to carry out any soil movement operation and no movement of soils shall occur:

(a) During the months May to October (inclusive), unless otherwise agreed in writing with the Local Planning Authority; and,

(b) Topsoil and subsoil handling for the restoration of land to agriculture, shall cease during rain, applying the following criteria:

(i) If there is light rain or drizzle, handling can proceed for up to four hours unless the soils are already in too moist a state (see tables below);

(ii) If there is light rain, handling will cease if the rain has not stopped in 15 minutes; (iii) If there is heavy rain (as from intense showers, slow-moving depressions) handling shall stop immediately;

(iv) If sustained heavy rainfall (e.g. ≥10mm in 24 hours) occurs during soil stripping operations, work must be suspended and not re-started until the ground has had at least a full dry day or agreed moisture criteria (see below) can be met;

(v) Soil shall not be handled or trafficked during or shortly after heavy precipitation (including rain, snow and hail) in a waterlogged condition, and when there are pools of water on the ground surface; and

(vi) After rainfall has ceased, field tests shall be applied to determine when handling may re-start

Reason: To prevent damage to soils.

9.2 Construction Phase

Soil Storage

All topsoil and subsoil shall be stored in accordance with document *(insert ref.)* dated *(insert date)* and in separate mounds which shall:

(a) Not exceed 3 metres in height in the case of topsoil, or exceed 5 metres in height in the case of subsoil unless otherwise agreed in writing with the Local Planning Authority;

(b) Be constructed with only the minimum amount of soil compaction to ensure stability and shaped so as to avoid collection of water in surface undulations;

(c) Not be subsequently moved or added to until required for restoration unless otherwise agreed in writing by the Local Planning Authority;

(d) Have a minimum 3.0 metre standoff, undisturbed around each storage mound;

(e) Comprise topsoils on like texture topsoils and subsoils on like texture subsoils; (f) In the case of continuous mounds, ensure that dissimilar soils are separated by a third material, which shall have previously been agreed in writing by the Local Planning Authority. *Reason: To prevent the loss of soil and minimise damage to soil structure during storage.*
Prior to soil stripping and formation of storage mounds, a scheme for grass seeding and management of all storage mounds that will remain in situ for more than three months shall be submitted for the written approval of the Local Planning Authority. Seeding and management of the storage mounds shall be carried out in accordance with the approved details. *Reason: To protect mounds from soil erosion, prevent build up of weeds in the soil and remove vegetation prior to soil replacement*
Within three months of completion of soil handling operations in any calendar year, the Local Planning Authority shall be supplied with a plan showing: (a) The area stripped of topsoil, subsoil and soil making material; (b) The location of each soil storage mound; and (c) The quantity and nature of material therein. *Reason: To facilitate soil stock taking and monitoring of soil resources*

9.3 Temporary Compound Decommissioning

Soil Replacement

Soil material shall be placed in accordance with the approved scheme. Any alteration to this working method shall only be carried out with prior approval from the Planning Authority. The soil material (topsoil and subsoil) set aside for use in the agricultural restoration shall be spread uniformly and in correct sequence. The soil profile in all areas restored to agricultural after use shall be in accordance with the approved scheme. Any intention to alter this soil depth will require prior approval from the Planning Authority. All operations to move and place soil material shall be carried out only when such material is in dry and friable condition and ground conditions are dry and firm. The developer shall give 48 hours notice to the Planning Authority of the intention to carry out any soil movement operation, and no movement of soils shall occur: (a) During the months May to October (inclusive), unless otherwise agreed in writing with the Local Planning Authority; and, (b) Topsoil and subsoil handling for the restoration of land to agriculture, shall cease during rain, applying the following criteria: (i) If there is light rain or drizzle, handling can proceed for up to four hours unless the soils are already in too moist a state (see tables below);

(ii) If there is light rain, handling will cease if the rain has not stopped in 15 minutes;

(iii) If there is heavy rain (as from intense showers, slow-moving depressions) handling shall stop immediately;

(iv) If sustained heavy rainfall (e.g. ≥10mm in 24 hours) occurs during soil stripping operations, work must be suspended and not re-started until the ground has had at least a full dry day or agreed moisture criteria (see below) can be met;

(v) Soil shall not be handled or trafficked during or shortly after heavy precipitation (including rain, snow and hail) in a waterlogged condition, and when there are pools of water on the ground surface; and

(vi) After rainfall has ceased, field tests shall be applied to determine when handling may re-start

The site shall be restored only in accordance with the approved *(insert ref)* Plan and all items therein shall be maintained to the satisfaction of the Planning Authority for a period of 5 years. Maintenance shall include the re-seeding of any areas of grassland that are in unsatisfactory condition in the view of the Planning Authority.

Reason: To ensure that the site is reclaimed in an orderly manner to a condition capable of maintaining the BMVAL[11] status.

All structures, buildings, debris and mounds shall be removed from the site on completion of permission. Compounds and access tracks shall be ripped and any resulting spoil removed from the site and the access removed unless otherwise agreed in writing with the Local Planning Authority.

9.4 Decommissioning Phase End of Life

Soil Replacement

Soil material shall be placed in accordance with the approved scheme. Any alteration to this working method shall only be carried out with prior approval from the Planning Authority.

The soil material (topsoil and subsoil) set aside for use in the agricultural restoration shall be spread uniformly and in correct sequence.

The soil profile in all areas restored to agricultural after use shall be in accordance with the approved scheme. Any intention to alter this soil depth will require prior approval from the Planning Authority.

All operations to move and place soil material shall be carried out only when such material is in dry and friable condition and ground conditions are dry and firm. The developer shall give 48 hours notice to the Planning Authority of the

[11] Best and Most Versatile Agricultural Land

	intention to carry out any soil movement operation, and no movement of soils shall occur: (a) During the months May to October (inclusive), unless otherwise agreed in writing with the Local Planning Authority; and, (b) Topsoil and subsoil handling for the restoration of land to agriculture, shall cease during rain, applying the following criteria: (i) If there is light rain or drizzle, handling can proceed for up to four hours unless the soils are already in too moist a state (see tables below); (ii) If there is light rain, handling will cease if the rain has not stopped in 15 minutes; (iii) If there is heavy rain (as from intense showers, slow-moving depressions) handling shall stop immediately; (iv) If sustained heavy rainfall (e.g. ≥10mm in 24 hours) occurs during soil stripping operations, work must be suspended and not re-started until the ground has had at least a full dry day or agreed moisture criteria (see below) can be met; (v) Soil shall not be handled or trafficked during or shortly after heavy precipitation (including rain, snow and hail) in a waterlogged condition, and when there are pools of water on the ground surface; and (vi) After rainfall has ceased, field tests shall be applied to determine when handling may re-start The site shall be restored only in accordance with the approved *(insert ref)* Plan and all items therein shall be maintained to the satisfaction of the Planning Authority for a period of 5 years. Maintenance shall include the re-seeding of any areas of grassland that are in unsatisfactory condition in the view of the Planning Authority.
Reason: To ensure that the site is reclaimed in an orderly manner to a condition capable of maintaining the BMVAL status.	
	All structures, buildings, debris and mounds shall be removed from the site on completion of permission. Compounds and access tracks shall be ripped and any resulting spoil removed from the site and the access removed unless otherwise agreed in writing with the Local Planning Authority.

Aftercare

An agricultural aftercare scheme outline strategy shall be submitted for the written approval of the Local Planning Authority at least three months before spreading of subsoil commences. The strategy shall provide for:

(a) The physical characteristics of the land to be restored, as far as it is practical to do so, to what they were when the land was last used for agriculture;

(b) A five year period of aftercare, specifying the steps to be taken and the period during which they are to be taken, and who will be responsible for taking those steps. The scheme shall include provision of a field drainage system;

(c) A detailed annual programme, to be submitted to the Local Planning Authority

Reasons: To ensure the land is capable of retaining its BMVAL status.

Before the start of the calendar *year* and every subsequent year during the aftercare period, the operator shall provide the Local Planning Authority and the landowner/occupier with a detailed annual programme for the approval of the Local Planning Authority including:

(a) Proposals for managing the land in accordance with the rules of good husbandry including planting, cultivating, seeding, fertilising, draining, watering or otherwise treating the land for the forthcoming 12 months;

(b) A record of aftercare operations carried out on the land during the previous 12 months.

Reasons: To ensure the productive afteruse of the land.

Before *(insert date)* of every year during the aftercare period, unless otherwise agreed with the Local Planning Authority in writing, a site meeting shall be arranged by the operator, to which the Local Planning Authority and the landowner/occupier *(including the Welsh Government)* shall be invited to monitor previous performance and to discuss and agree future aftercare proposals. The meeting shall also be attended by the person(s) responsible for undertaking the aftercare steps.

Reasons: To ensure the productive afteruse of the land.

Aftercare operations shall be carried out in accordance with the submitted aftercare scheme unless otherwise agreed in writing with the Local Planning Authority.

Reasons: To ensure the productive afteruse of the land.

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APPENDIX 1 – Project Brief

Soil Policy Evidence Programme SPEP 2021-22/03

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

VERSION 2 (Draft)

Introduction:

Solar photovoltaic (PV) sites started commercial distribution in the UK in 2007. The number of solar photovoltaic sites in the UK has increased from c. 1700 in 2010 to just over one million in 2019 https://www.statista.com/statistics/418830/number-of-solar-photovoltaic-installations-uk/.

It appears there has not been any systematic review of the impact of these sites on agricultural land, Best and Most Versatile (BMV) land and associated soils. The SPIES project is useful background though soil does not feature heavily [redacted] Similarly, the Armstrong *et al* (2016) paper: *Solar park microclimate and vegetation management effects on grassland carbon cycling* [redacted] is useful background.

Solar PV sites can involve significant soil disturbance in installation, operational phase and decommissioning. A recent proposed 34ha site in Wales involved 70,000 solar panels with 140,000 piles driven into the soil to 1.8 metres, 1.75km of access track and 3.5km Security fencing (boundary measurement), plus associated cabling. Because solar PV energy is relatively new, there are no UK examples of decommissioned sites.

There are questions on the reversibility of these sites back to agriculture and the longer term impact on associated land and soil. There are claimed improvements to some soil properties (e.g. increased carbon storage and improved soil structure). However, are these simply just short term for the period of the scheme?

The impact of mineral sites (e.g. sand and gravel extraction / restoration) is reasonably well understood and with field experience. This is not the case for solar PV sites, partly because the decommissioning timescales are long (c40 years) and the evidence does not yet exist. Can parallels could be drawn with other developments such as golf courses, gas pipelines, and pylons. Similarly, are there parallels with horticultural activities such as grubbing out orchards and glasshouse removal? What impacts do these have on soil, how are effects mitigated and how successful are restorations?

This review is to provide an evidence based assessment of the impact of solar PV sites on agricultural land, Best and Most Versatile (BMV) land and associated soils. The scope of the study should be within the UK but look to international experience where possible. The study will inform Welsh Government and Natural England specialists when dealing with solar PV applications.

The review could be used as evidence at planning appeals. Consequently, clarity and accessible is really important, despite the likely complexity of some technical content.

It is anticipated the work will form 4 work packages (WPs):

Work Package 1: Literature review

This work package will:

1. Identify and review any relevant research or experience related to impacts of solar PV developments (published or anecdotal) on land and soil, within the UK or internationally.
2. Identify and review any relevant research or experience, related to (e.g.) golf courses, glasshouse removal, grubbing out of orchards or similar developments / activities (published or anecdotal) on land and soil, within the UK or internationally.
3. Identify and review the key research and experience relating to mineral developments on land and soil, within the UK and internationally.
4. Host a virtual workshop with key soil specialists in the area and record key findings. The key outputs from this need to be recorded as part of the contract.
5. Summarise key findings in a clear and accessible format.

Work Package 2: Description of Solar PV site history and development stages

This work package is intended as a short and simply a statement of facts, rather than in depth interpretation:

1. Provide a summary history of solar PV sites development in the UK. This should include date introduced, number of sites over time and basic explanation of how solar PV sites work. It would be useful to know approximately how many applications there have been (split by UK country), some information on range of site size, preferred types of location, and whether cumulatively large amounts of BMV are likely to be involved. Is the average size of sites increasing?
2. Identify and summarise the main interventions to land and soil with solar PV sites at installation (e.g. pile driving, panel installation, cable laying, track-laying & fencing). Averages (e.g.) of piles / ha or metres of buried cable / tracks / ha would be useful as context. Use of case studies could help. It will be important to summarise the potential levels of disturbance and any differences between different types of site.
3. Identify and summarise the potential benefits and threats to land and soil during the operational phase of the site. Claimed benefits are (for example) topsoil carbon content increases and soil structure improvements.
4. Identify and summarise the main interventions to land and soil when decommissioning sites (e.g. soil disturbance linked with equipment removal).

Work Package 3: Review of Solar PV site impacts on land and soil:

This Work Package is the main review of impacts. It will largely be based on WPs 1 & 2.

1. Review and summarise the main threats to soil and land associated with solar PV site developments. This will need to assess commissioning and decommissioning phases. Assessment of impacts on BMV land - and its reversibility - will be very important.
2. Review and summarise potential effects (positive and negative) on soils during the active phase of the site. Claimed benefits are (for example) topsoil carbon content increases and soil structure improvements. Are such claims realistic and are they only likely to be short term for the duration of the active site? What are the effects of shading and changes in soil microbial activity and microclimates under the panels? Armstrong et al (2016) is useful background: [redacted] What effect does ‘rilling’ have on soil loss / erosion, accelerated run-off and in creating differential areas of soil

wetness? A discussion of short term changes in soil properties vs long term physical limitations (as in ALC) would be useful. A summary of claimed benefits to soil from previous cases would be very helpful.

3. Review and summarise to what extent evidence supports solar PV sites are physically reversible to agriculture in the BMV and non BMV context. What are the main issues and what evidence is there to support this? What factors influence reversibility (e.g. soil handling conditions, monitoring, soil types & climate).
4. Discuss the parallels between mineral site restoration and solar PV site restoration? Are the two comparable or do significant differences exist?
5. Discuss the parallels with golf course or similar type developments or activities and their reversibility. Are these comparable or do significant differences exist? IN Wales, Technical Advice Note 6 "TAN 6" (para 6.2.2) - Planning for Sustainable Rural Communities says, *"once agricultural land is developed, even for 'soft' uses such as golf courses, its return to agriculture as best and most versatile agricultural land is seldom practicable".*
6. Discuss to what extent soil handling conditions, as part of the planning process, can mitigate or remove any threats to soil and land. Can BMV sites realistically be restored to BMV and what factors influence this? Again, differences between sites will be useful to discuss.

Work Package 4: Summary of key issues and recommendations for future work

Based on the above work packages:

1 Summarise the key findings from this work. A non-technical executive summary is needed.

2 Identify evidence / knowledge / experience gaps.

3 Recommend what future work is needed to better understand the impacts of solar PV sites on soil and land.

APPENDIX 2 – Evidence Provided by Solar Energy UK

Project	Details	Wales	Information on Construction Methodology, Mitigation Techniques	Visual evidence of imagery of site impacts during construction	Construction method statements	Soil Management Plans	Evidence of soil quality improving on sites	Evidence of decommissioning requirements and provisions made for existing projects	Any further comments?
Cleve Hill Solar Park	Graveney, Kent	No	**> 'Cleve Hill Solar Park - Outline Construction Environmental Management Plan'** **Access to document** https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010085/EN010085-001554-CHSP%20-%20D6%20-%206.4.5.4.pdf **Please take specific note to 3.4(64),4.3(78). 5.5(105), 6.1 (107,108,109) and Appendices, particularly appendix E which outlines LBMP construction mitigation measures. (Appendix E - LBMP)** **>'Cleeve Hill - Environment Statement'** **Access to document -** https://drive.google.com/drive/folders/1bKEBKmZv9SqFz4K8DAlElc80Bz-1gDTF **Please take specific note to 5.5.4**		**Updates to existing documents outline construction environmental management plan revision E'** **Access to document -** https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010085/EN010085-001554-CHSP%20-%20D6%20-%206.4.5.4.pdf			> '**Cleve Hill Solar Park - Environmental Statement'** 9.5.2.6 Deposition of dust 171. Fugitive dust emissions and track-out dust during construction and decommissioning have the potential to affect ecological receptors. Chapter 16: Air Quality of the ES provides an assessment of the potential effects of the impacts of dust emissions and track-out dust. The assessment concluded that in the absence of mitigation, there was a low risk of dust soiling to ecological receptors as a result of the earthworks and trackout and a negligible risk from the construction works (building of substation, control building, battery storage units, transformers and solar panel installation). Decommissioning effects were assessed to be similar in nature and no greater than those predicted for the construction phase.	**Full Preliminary Environmental Information Report can be accessed here.** https://drive.google.com/drive/folders/1lE-fACqMlJCzrf9v0dn8DYUed6WY9xU9
Botwwnog Solar Farm	Gwynedd, 5MW	Yes	**'Soils and Agricultural Land Classification'** **Access to document - as**		**Construction Method Statement - (Proposed)**	**Soils and Agricultural Land Classification'** ***Document sent**			**Landscape and Visual Impact Assessment -** **Access to document - see zip file.**

			attached. **Please pay particular reference to 7.3.1, 7.3.2,7.3.3**		**Access to document as attached.**	**as attachment*** **Please pay particular notice to 2.2.1,**			**Please pay particular notice to chapter 7 (7.1.1-7.1.5) and chapter 10.**
Bypass Solar Farm	Lincolnshire49.9MW	No	**Ecological Impact Assessment Report Access to document** http://bypassfarmsolar.com/documents/update110920/12904_r01a_eia_as_mm_210820_compressed.pdf**Please pay particular attention to:**(4.12,4.36) No solar panels are proposed adjacent to watercourse WC1, or within the RPA of hedgerows and trees, minimising the potential for impacts to this habitat. However, the ditch and hedgerows within the site could be affected during construction by soil compaction from machinery, which could impact on the root systems, and/or by accidental damage. As such, they will be fenced and protected during construction in accordance with best practise guidance detailed in BS 5837:2012 'Trees in relation to design, demolition and construction'(British Standard, 2012) to reduce potential for impacts and accidental damage., , page 21)**Flood Risk AssessmentAccess to the document** http://bypassfarmsolar.com/documents/update110920/14516_hyd_xx_xx_rp_fr_0001_p02_bypass_farm.pdf **Please refer to page 9** of the assessment which outlines mitigation techniques			**Planning Statement, Proposed Solar farm, land at Bypass Farm, South of A1 Bypass** http://bypassfarmsolar.com/documents/update110920/bypass_farm_solar_planning_statement_v3.pdfPlease take note to point **2.1.6**			**Full planning documents can be found here** http://bypassfarmsolar.com/downloads/

			regarding to construction and soil compacting/surface run off.						
Low Farm Solar Farm	West Yorkshire, 49.9MW		**Construction Traffic Management Plan'Access to the document** https://www.boom-power.co.uk/wp-content/uploads/2021/10/General_896661-17298-HYD-XX-XX-RP-TP-P004-Construction-traffic-management-plan.pdf**'Flood Risk Assessment & Drainage Strategy'You can access the document here**https://www.boom-power.co.uk/wp-content/uploads/2021/10/FloodRiskAssessment_896753.pdf**Please refer to point 5.2.2 'Planning Statement'Access Document** https://www.boom-power.co.uk/wp-content/uploads/2021/10/General_896701-Planning-Statement.pdf**Please take note to pages - 33,34,38, 46**			**Agricultural Land ClassificationAccess the document**https://www.boom-power.co.uk/wp-content/uploads/2021/10/General_896760-AGRICULTURAL-LAND-ASSESSMENT.pdf**Please pay particular attention - Page 12**		**Design and Access Statement Access Document** https://www.boom-power.co.uk/wp-content/uploads/2021/10/DesignandAccessStatement_896749.pdf Page 32Design and Access Statement https://www.boom-power.co.uk/wp-content/uploads/2021/10/DesignandAccessStatement_896749.pdf **Pay Particular attention to page 32**	
Eveley Farm	Stockbridge, Hampshire		See attachment	See attachment					
Llanwern	Newport, South East Wales	Yes	**'Land on Caldicot levels to the south of Llanwern Steelworks site'** **Full document accessed here** https://dns.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/DNS/3213968/DNS-3213968-000525-Report%203213968%20(for		**'Local Impact Report'** **Full document can be accessed here** https://dns.planninginspectorate.gov.uk/wp-content/ipc/upl				**A full suite of planning documents can be found here** https://dns.planninginspectorate.gov.uk/projects/wales/llanwern-solar/?ipcsection=docs&stage=1

			merly%203150137).pdf **Please pay attention to points 127, 139, 240**		oads/projects/DNS/3213968/DNS-3213968-000525-Report%203213968%20(formerly%203150137).pdf **Please pay particular attention to the construction method statement on Page 27**				
Outside the UK									
Neoen Solar Farm	Australia	No				**Soil and Water Management Plan** https://parkessolarfarm.com.au/wp-content/uploads/2020/08/PL-EV-04-Soil-and-Water-Management-Plan-Rev2.pdf			

APPENDIX 3 – Satellite Imagery of Three Solar PV Sites

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APPENDIX 4 – Solar Farm Construction Images

Site A

Figure 1

Figure 2

Figure 3

Site B

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

APPENDIX 5 – Impact of Soil Wetness Limitation

Table A shows the example of a **medium-textured soil** in **Wetness Class I** before commissioning, classified as BMV land and then **disturbed** during construction, the interaction of climate (FCD) and the depth to an introduced slowly permeable layer.

Where there is evidence of an SPL starting within 60 depth cm reference is made to Figure 7 of the ALC Guidelines (MAFF, 1988) and where there is an SPL starting between 60 cm and 80 cm depth reference is made to Figure 8 of the ALC Guidelines (MAFF, 1988).

Table A Residual Impact of Introduced SPL on ALC Grade- Medium -texture soil

<table>
<tr><th rowspan="2">FCD</th><th colspan="2">Pre-construction</th><th colspan="3">Post-decommissioning</th></tr>
<tr><th>Wetness Class</th><th>ALC Grade</th><th>Depth to introduced SPL</th><th>Wetness Class</th><th>ALC Grade</th></tr>
<tr><td rowspan="3">230</td><td rowspan="3">I</td><td>3a</td><td>0 to 25 cm</td><td>V</td><td>4</td></tr>
<tr><td>3a</td><td>25 to 60 cm</td><td>IV</td><td>3b</td></tr>
<tr><td>3a</td><td>60 to 80 cm</td><td>III</td><td>3b</td></tr>
<tr><td rowspan="2">225</td><td rowspan="2">I</td><td>2</td><td>30 to 60 cm</td><td>IV</td><td>3b</td></tr>
<tr><td>2</td><td>60 to 80 cm</td><td>III</td><td>3a</td></tr>
<tr><td rowspan="3">170</td><td rowspan="3">I</td><td>1</td><td>35 to 46 cm</td><td>IV</td><td>3b</td></tr>
<tr><td>1</td><td>46 to 60 cm</td><td>III</td><td>3a</td></tr>
<tr><td>1</td><td>60 to 80 cm</td><td>II</td><td>2</td></tr>
<tr><td rowspan="2">125</td><td rowspan="2">I</td><td>1</td><td>35 to 60 cm</td><td>III</td><td>3a</td></tr>
<tr><td>1</td><td>60 to 80 cm</td><td>II</td><td>2</td></tr>
</table>

Table B shows the example of a **medium-textured soil** in **Wetness Class I** before commissioning, classified as BMV land and **undisturbed** during construction, the interaction of climate (FCD) and the depth to an introduced slowly permeable layer. Where there is evidence of gleying within 40 cm depth and an SPL within 80 cm depth reference is made to Figure 7 of the ALC Guidelines (MAFF, 1988). Where there is gleying within 70 cm depth and an SPL within 80 cm depth reference is made to Figure 8 of the ALC Guidelines (MAFF, 1988).

Table B Residual Impact of Introduced SPL on ALC Grade- Medium- textured soil

FCD	Pre-construction		Post-decommissioning			
	Wetness Class	ALC Grade	Depth to introduced SPL, with gleying <40 cm	Depth to introduced SPL, with gleying >40 cm	Wetness Class	ALC Grade
230	I	3a	0 to 25 cm		V	4
			25 to 62 cm		IV	3b
			62 to 80 cm		III	3b
				0 to 80 cm	III	3b
225	I	2	25 to 61 cm		IV	3b
			61 to 80 cm		III	3a
				28 to 80 cm	III	3a
170	I	1	35 to 46 cm		IV	3b
			46 to 74 cm		III	3a
			74 to 80 cm		II	2
				35 to 60 cm	III	3a
				60 to 80 cm	II	2
125	I	1	35 to 62 cm		III	3a
			62 to 80 cm		II	2
				35 to 42 cm	III	3a
				42 to 80 cm	II	2

Table C shows the example of a **light-textured soil** in **Wetness Class II** on **disturbed land** and the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land.

Where there is evidence of an SPL starting within 60 depth cm reference is made to Figure 7 of the ALC Guidelines (MAFF, 1988) and where there is an SPL starting between 60 cm and 80 cm depth reference is made to Figure 8 of the ALC Guidelines (MAFF, 1988).

Table C Residual Impact of Introduced SPL on ALC Grade- Light- texture soil

FCD	Pre-construction		Post-decommissioning		
	Wetness Class	ALC Grade	Depth to introduced SPL	Wetness Class	ALC Grade
230	II	3a	0 to 25 cm	V	4
		3a	25 to 60 cm	IV	3b
		3a	60 to 80 cm	III	3b
225	II	2	25 to 60 cm	IV	3b
		2	60 to 80 cm	III	3a
170	II	1	35 to 46 cm	IV	3a
		1	46 to 60 cm	III	2
		1	60 to 80 cm	II	1
125	II	1	35 to 60 cm	III	2
		1	60 to 80 cm	II	1

<u>Table D</u> shows the example of a **light-textured soil** in **Wetness Class II** on **<u>undisturbed land</u>** and the residual impact of an introduced SPL (caused by unremediated subsoil compaction) on BMV agricultural land.

Where there is evidence of gleying within 40 cm depth and an SPL within 80 cm depth reference is made to Figure 7 of the ALC Guidelines (MAFF, 1988). Where there is gleying within 70 cm depth and an SPL within 80 cm depth reference is made to Figure 8 of the ALC Guidelines (MAFF, 1988).

Table D Residual Impact of Introduced SPL on ALC Grade- Light-texture soil

FCD	Pre-construction		Post-decommissioning			
	Wetness Class	ALC Grade	Depth to introduced SPL, with gleying <40 cm	Depth to introduced SPL, with gleying >40 cm	Wetness Class	ALC Grade
230	II	3a	0 to -25 cm		V	4
		3a	25 to 62 cm		IV	3b
		3a	62 to 80 cm		III	3b
		3a		0 to 80 cm	III	3b
225	II	2	35 to 61 cm		IV	3b
		2	61 to 80 cm		III	3a
		2		35 to 80 cm	III	3a
170	II	1	35 to 46 cm		IV	3a
		1	46 to 74 cm		III	2
		1	74 to 80 cm		II	1
		1		35 to 60 cm	III	2
		1		60 to 80 cm	II	1
125	II	1	35 to 61 cm		III	2
		1	61 to 80 cm		II	1
		1		35 to 42 cm	III	2
		1		42 to 80 cm	II	1