Assessing the impact of Welsh solar developments on bats

Report No:1003

Author names: Maya Griffin[1,2], Jan Collins[2], Flora Tiley[1], Lisa Worledge[2], Paul Lintott[1]

Author affiliations: [1] School of Applied Sciences, University of the West of England, Bristol, UK; [2] Bat Conservation Trust, London, UK

About Natural Resources Wales

Natural Resources Wales' purpose is to pursue sustainable management of natural resources. This means looking after air, land, water, wildlife, plants and soil to improve Wales' well-being, and provide a better future for everyone.

Evidence at Natural Resources Wales

Natural Resources Wales (NRW) is an evidence-based organisation. We seek to ensure that our strategy, decisions, operations and advice to the Welsh Government and others are underpinned by sound and quality-assured evidence. We recognise that it is critically important to have a good understanding of our changing environment.

We will realise this vision by:

- Maintaining and developing the technical specialist skills of our staff;
- Securing our data and information;
- Having a well-resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
- Communicating our evidence in an open and transparent way.

This Evidence Report series serves as a record of work carried out or commissioned by NRW. It also helps us to share and promote the use of our evidence by others and develop future collaborations. However, the views and recommendations presented in this report are not necessarily those of NRW and should, therefore, not be attributed to NRW.

Report series: Evidence Report

Report number: 1003

Publication date: 1st September 2026

Contract number: AISFBW 2025

Contractor:	Bat Conservation Trust
Contract manager:	Jan Collins
Title:	**Assessing the impact of Welsh solar developments on bats**
Author(s):	**Griffin MLU, Collins J, Tiley F, Worledge L, Lintott PR**
Technical editor:	Sam Dyer
Quality assurance:	Tier 2
Peer reviewer(s):	Elwyn Sharps
Approved by:	Liz Halliwell
Restrictions:	None

Distribution list

Core distribution list managed by the Library: National Library of Wales, British Library, Welsh Government, NatureScot, Natural England.

Other organisations and individuals to whom this report has been distributed by the authors or contract manager: upon completion and approval by NRW, the report will be circulated to everyone who shared knowledge and contributed evidence. We will also share more widely via the Bat Conservation Trust's (BCT) and the University of the West of England's contacts and communication channels, including but not limited to CIEEM eNews, the ALGE online forum, BCT Bat Groups and Corporate e-bulletins, the BCT website and social media channels.

Acknowledgements

Many thanks to Sam Dyer of NRW for his contribution to the development of this report. We would also like to thank everyone who assisted with this project, shared knowledge or contributed evidence. Some contributors requested that they remain anonymous.

- AECOM
- BSG Ecology Ltd
- Buglife
- Clarkson & Woods Ltd
- CPRW: The Welsh Countryside Charity
- Deeproot Software
- Forestry Commission

- Greena Ecological Consultancy
- Government of Jersey – Natural Environment
- Keele University
- Natural Power
- RSK Biocensus Ltd
- SSE
- The Chartered Institute of Ecology and Environmental Management (CIEEM)
- UK Bat Steering Group (including representatives from Natural England, Natural Resources Wales, NatureScot, Department for Agriculture, Environment and Rural Affairs (Northern Ireland), Joint Nature Conservation Committee, Environment Agency, Forestry Commission, Forest Research, National Trust, Vincent Wildlife Trust, Bat Conservation Ireland and Bat Conservation Trust).
- University of Exeter
- Vattenfall
- WPO
- Wychwood Biodiversity

Recommended citation for this volume:

Griffin MLU, Collins J, Tiley F, Worledge L, Lintott PR. 2026. Assessing the impact of Welsh solar developments on bats. NRW Evidence Report No: 1003, 103pp, Bangor.

Contents

Crynodeb gweithredol

Mae gosodiadau solar yn ehangu'n gyflym ledled y DU fel rhan o'r broses bontio i ynni carbon isel. Mae datblygiadau ffotofoltäig (PV) wedi'u gosod ar y ddaear yn cael eu lleoli fwyfwy o fewn tirweddau sydd hefyd yn bwysig i ystlumod a bywyd gwyllt arall. Fodd bynnag, nid yw dealltwriaeth ecolegol wedi cadw i fyny â thwf y diwydiant. Mae tystiolaeth ynghylch sut mae datblygiadau solar yn effeithio ar boblogaethau ystlumod yn parhau i fod yn gyfyngedig, ac mae'n cynnwys astudiaethau tymor byr yn bennaf.

Felly mae penderfyniadau cynllunio a mesurau lliniaru yn dibynnu ar sylfaen dystiolaeth gymharol fach ac ansicr. Fodd bynnag, mae rheoleiddiwyd ac ymgynghorwyr ecolegol yn ceisio canllawiau cliriach ar sut i asesu effeithiau posibl, dylunio rhaglenni monitro, a rheoli safleoedd mewn ffyrdd sy'n lleihau risgiau i ystlumod. Comisiynwyd y prosiect hwn i asesu tirwedd bresennol a dyfodol datblygiad solar yng Nghymru, syntheseiddio gwybodaeth gyfredol, adolygu data cyn-adeiladu a monitro sydd ar gael, nodi bylchau mewn tystiolaeth, a datblygu argymhellion ymarferol i lywio datblygiad a pholisi solar yn y dyfodol yng Nghymru.

Cyfunodd y prosiect sawl llinyn gwaith cyflenwol. Gwnaethom ymgymryd â dadansoddiad tirwedd gan ddefnyddio ArcGIS (system gwybodaeth ddaearyddol), i fapio dwysedd, dosbarthiad a chapasiti cymharol datblygiadau solar yng Nghymru sy'n weithredol ar hyn o bryd (yn cynhyrchu trydan), cais cynllunio wedi'i ganiatáu (yn aros neu'n cael ei adeiladu) ac yn y broses gynllunio (cais wedi'i gyflwyno, apêl wedi'i chyflwyno neu gais wedi'i ddiwygio). Fe wnaethon ni hefyd fapio'r gorchudd tir o amgylch datblygiadau solar yng Nghymru i archwilio cyd-destun cynefinoedd ac i ddeall agosrwydd ffermydd solar i ardaloedd gwarchodedig ar gyfer natur. Cynhaliwyd adolygiad llenyddiaeth o astudiaethau a adolygwyd gan gymheiriaid, adroddiadau technegol, ac ymchwil sy'n dod i'r amlwg ar effeithiau ecolegol datblygiad solar ar ystlumod. Fe wnaethom gynnal dadansoddiad o'r dulliau arolygu cyfredol a'r strategaethau lliniaru a ddefnyddir ar hyn o bryd ar gyfer datblygiadau solar yng Nghymru. Yn ogystal, fe wnaethom archwilio adroddiadau monitro ôl-adeiladu i ddeall ymatebion ystlumod a arsylwyd a chyfyngiadau methodolegol. Fe wnaethon ni ymgorffori trafodaethau gydag ymgynghorwyr ecolegol a chynrychiolwyr y diwydiant solar ledled y DU i gofnodi arfer cyfredol, heriau monitro, a thueddiadau sy'n dod i'r amlwg. Canolbwyntiodd y gwaith hwn yn ar gyd-destun Cymru a'r DU yn ehangach yn bennaf, gan ddefnyddio ymchwil ryngwladol lle bo'n berthnasol i ddeall mecanweithiau posibl a bylchau gwybodaeth.

Ar hyn o bryd mae datblygiadau ffotofoltäig solar gweithredol yng Nghymru wedi'u crynhoi yn Ne Cymru, yn enwedig y de-ddwyrain, er bod cynigion mwy newydd yn dangos lledaeniad graddol yn fewndirol i Ganolbarth Cymru a thuedd tuag at gynlluniau mwy. Mae'r rhan fwyaf o ddatblygiadau wedi'u lleoli o fewn tirweddau bugeiliol sy'n cael eu dominyddu gan laswelltir wedi'i wella yn hytrach na thir âr. Mae llawer o safleoedd yn agos at gynefinoedd ystlumod sydd wedi'u dynodi'n genedlaethol ac yn rhyngwladol, gyda chyfagosrwydd eang at Goetir Hynafol a gorgyffwrdd nodedig ag Ardaloedd Cadwraeth Arbennig (ACA), Safleoedd o Ddiddordeb Gwyddonol Arbennig (SoDdGA) a gwlyptiroedd Ramsar, yn enwedig yn rhanbarthau yn y de ac aberoedd. Gyda'i gilydd, mae hyn yn dwyn sylw at y potensial cryf ar gyfer rhyngweithio rhwng datblygiadau solar a chynefinoedd pwysig i ystlumod chwilio am fwyd a chymudo ledled Cymru.

Mae'r dystiolaeth sydd ar gael yn dangos bod ymatebion ystlumod i ddatblygiadau solar yn amrywiol iawn a bod cyd-destun tirwedd, rheoli cynefinoedd, dyluniad safle ac ecoleg rhywogaethau ystlumod yn dylanwadu’r gryf arnynt. Mewn llawer o achosion, mae gweithgarwch ystlumod o fewn ardaloedd araeau solar yn is nag mewn cynefinoedd naturiol cyfagos, er y gall lefelau gweithgarwch fod yn gymharol â thir âr sy'n cael ei ffermio'n ddwys, gan ddibynnu ar y math o osodiad a chyd-destun y dirwedd. Ymddengys bod cysylltedd cynefinoedd a phresenoldeb nodweddion cyfagos fel coed neu gyrff dŵr yn chwarae rhan bwysig yn y ffordd y mae ystlumod yn defnyddio tirweddau gyda datblygiadau solar. Awgrymwyd bod gwahaniaethau mewn rheoli cynefinoedd a mathau o dda byw â'r potensial i ddylanwadu ar ysglyfaeth sy’n infertebratau, a thrwy hynny effeithio ar ystlumod. Gall cydrannau strwythurol datblygiadau solar, gan gynnwys araeau paneli/modiwlau, ffensys, a seilwaith cysylltiedig, ddylanwadu ar lwybrau hedfan, ymddygiad cymudo, neu effeithlonrwydd wrth chwilota am fwyd. Hefyd mae arwynebau llyfn artiffisial, a newidiadau i amgylcheddau acwstig neu synhwyraidd, wedi'u cynnig fel ysgogwyr ymddygiad posibl, er bod tystiolaeth yn parhau i fod yn gyfyngedig ac yn arbrofol i raddau helaeth.

Ceir ansicrwydd sylweddol yn gysylltiedig â'r sylfaen dystiolaeth gyfredol. Mae cwmpas a thrylwyredd arolygon ystlumod cyn-adeiladu yn amrywio'n sylweddol rhwng safleoedd, ac nid yw mesurau lliniaru bob amser yn cael eu llywio gan ddosbarthiad, patrymau gweithgaredd, na gofynion ecolegol ystlumod a nodwyd yn ystod asesiadau sylfaenol. Mae rhaglenni monitro yn fyrdymor ac yn digwydd cyn i welliannau i gynefinoedd aeddfedu, gan gyfyngu ar y gallu i asesu canlyniadau ecolegol cronnus a hirdymor. Yn aml mae data llinell sylfaen yn anghyson neu'n absennol, a lle maent yn bresennol, nid oes dulliau monitro cyfatebol, gan wneud cymariaethau cyn ac ar ôl yn annibynadwy. Yn ogystal, mae'r potensial ar gyfer effeithiau ar raddfa tirwedd, yn enwedig lle mae datblygiadau lluosog yn digwydd o fewn cwmpasau cartrefi ystlumod, angen mwy o ystyriaeth mewn prosesau cynllunio ac asesu.

Mae'r darganfyddiadau'n pwysleisio'r angen i gryfhau ein dealltwriaeth o sut mae ystlumod yn rhyngweithio â datblygiadau solar. Ceir bylchau allweddol yn y dystiolaeth yn cynnwys deall pa mor effeithiol yw mesurau lliniaru a gynigir yn gyffredin (e.e. cadw gwrychoedd, lleiniau byffer, llai o olau) wrth osgoi neu leihau effeithiau negyddol ar ystlumod ac asesu a yw presenoldeb gosodiad solar yn arwain at ddadleoli ystlumod o ardaloedd chwilota am fwyd, cymudo neu fudo a ddefnyddiwyd gynt. Bydd datblygu canllawiau cenedlaethol i safoni dyluniad arolygon, asesu effaith, cynllunio mesurau lliniaru, dylunio monitro ac adrodd data yn hanfodol er mwyn sicrhau bod tystiolaeth yn cael ei chasglu'n gyson a bod datblygiadau solar yn cael eu hasesu a'u rheoli gan ddefnyddio dulliau cadarn a chymaradwy. Byddai cryfhau casglu data sylfaenol drwy fabwysiadu protocolau arolygu mwy cyson yn gwella dibynadwyedd asesiadau effaith ac yn darparu sylfaen ar gyfer monitro cymharol er mwyn canfod canlyniadau'n well. Mae monitro hirdymor yn hanfodol i ddeall sut mae poblogaethau ystlumod yn addasu wrth i gynefinoedd aeddfedu a datblygiadau solar heneiddio. Po gyntaf y bydd y canllawiau hyn ar gael, cynharaf y gellir llenwi'r bylchau yn y dystiolaeth, a nodwyd drwy'r prosiect hwn. Byddai hygyrchedd gwell a chasglu data monitro yn ganolog hefyd yn cyflymu dysgu ac, yn y tymor hwy, yn gwella canllawiau ar sail tystiolaeth.

Mae dulliau cynllunio ar raddfa tirwedd sy'n ystyried cysylltedd cynefinoedd ac effeithiau cronnus yn debygol o fod yn fwy effeithiol nag asesiadau safle wrth safle ynysig. Bydd integreiddio ystyriaethau ecolegol yn nyluniad ffermydd solar, fel ffurfweddiad araeau, rheoli cynefinoedd a strategaethau goleuo, yn bwysig wrth i'r sylfaen dystiolaeth gynyddu.

Executive summary

Solar installations are expanding rapidly across the UK as part of the transition to low-carbon energy. Ground-mounted photovoltaic (PV) developments are increasingly located within landscapes that are also important for bats and other wildlife. However, ecological understanding has not kept pace with the growth of the industry. Evidence on how solar developments affect bat populations remains limited and is predominantly comprised of short-term studies.

Planning decisions and mitigation measures therefore rely on a relatively small and uncertain evidence base. However, ecological consultants and regulators are seeking clearer guidance on how to assess potential impacts, design monitoring programmes, and manage sites in ways that reduce risks to bats. This project was commissioned to assess the current and future landscape of solar development in Wales, synthesise current knowledge, review available pre-construction and monitoring data, identify evidence gaps, and develop practical recommendations to inform future solar development and policy in Wales.

The project combined several complementary strands of work. Landscape analysis was carried out using ArcGIS (a geographic information system) to map the relative density, distribution and capacity of solar developments in Wales that are currently operational (generating electricity), consented (awaiting or under construction) and in planning (application submitted, appeal lodged or application revised). Land cover around solar developments in Wales was mapped to explore habitat context and understand the proximity of solar farms to protected areas for nature. A literature review of peer-reviewed studies, technical reports, and emerging research was conducted on the impacts of solar developments on bats. The current survey methods and mitigation strategies used for solar developments in Wales were analysed. Additionally, post-construction monitoring reports were examined to understand observed bat responses and methodological limitations. Discussions with ecological consultants and solar industry representatives across the UK were incorporated to capture current practice, monitoring challenges, and emerging trends. This work focused primarily on Wales and the wider UK context, while drawing on international research where relevant to understand potential mechanisms and knowledge gaps.

Operational solar PV developments in Wales are currently concentrated in South Wales, particularly the south-east, although newer proposals indicate a gradual spread inland into Mid Wales and a trend towards larger schemes. Most developments are located within pastoral landscapes dominated by improved grassland rather than arable land. Many sites

occur close to nationally and internationally designated bat habitats, with widespread proximity to Ancient Woodland and notable overlaps with Special Areas of Conservation (SACs), Sites of Special Scientific Interest (SSSIs) and Ramsar wetlands, particularly in southern and estuarine regions. Together, this highlights the strong potential for interaction between solar developments and important bat foraging and commuting habitats across Wales.

The available evidence indicates that bat responses to solar developments are highly variable and strongly influenced by landscape context, habitat management, site design, and bat species ecology. In many cases, bat activity within solar array areas is lower than in nearby natural habitats, although activity levels may be comparable to intensively farmed arable land, depending on installation type and landscape context. Habitat connectivity and the presence of surrounding features such as trees or water bodies appear to play an important role in how bats use landscapes with solar developments. Differences in habitat management and livestock grazing have the potential to affect invertebrate prey availability, with consequent effects on bats. Structural components of solar developments, including panel/module arrays, fencing, and associated infrastructure, may influence flight paths, commuting behaviour, or foraging efficiency. Artificial smooth surfaces and changes to sensory environments have also been proposed as potential behavioural drivers, although evidence remains limited and is largely experimental.

There are substantial uncertainties associated with the current evidence base. The scope and rigour of pre-construction bat surveys vary considerably between sites, and mitigation measures are not always informed by the distribution, activity patterns, or ecological requirements of bats identified during baseline assessments. Monitoring programmes are short-term and occur before habitat enhancements have matured, limiting the ability to assess cumulative and long-term ecological outcomes. Baseline data are frequently inconsistent or absent, and where they are present, they are not matched by equivalent monitoring methods, resulting in unreliable before-and-after comparisons. In addition, the potential for landscape-scale effects, particularly where multiple developments occur within bat home ranges, requires greater consideration in planning and assessment processes.

The findings emphasise the need to strengthen our understanding of how bats interact with solar developments. Key evidence gaps include the effectiveness of commonly proposed mitigation measures (e.g. hedgerow retention, buffer zones and reduced lighting) in avoiding or reducing negative impacts on bats; whether the presence of a solar installation displaces bats from previously used foraging, commuting or migratory areas; and the spatial and temporal extent of any such impacts. The development of national guidance to provide standardisation of survey design, impact assessment, mitigation planning, monitoring design and data reporting will be essential to ensure evidence is collected consistently and solar developments are assessed and managed using robust, comparable approaches. Strengthening baseline data collection by adopting more consistent survey protocols would improve the reliability of impact assessments and provide a basis for comparable monitoring to better detect outcomes. Long-term monitoring is essential to understand how bat populations adapt as habitats mature and solar developments age. The sooner this guidance is made available, the sooner the evidence gaps, identified through this project, can be filled. Greater accessibility and central collation of monitoring data would also accelerate learning and, in the longer-term, improve evidence-based guidance.

Landscape-scale planning approaches that consider habitat connectivity and cumulative impacts are likely to be more effective than isolated site-by-site assessments. Integrating ecological considerations into solar farm design, such as array configuration, habitat management and lighting strategies, will be important as the evidence base increases.

1. Introduction

Aims and objectives

This review aims to provide an evidence-based overview to inform Natural Resources Wales' approach to solar development and bat conservation. It examines the ecological setting of solar developments in Wales to understand the landscape and habitat context in which developments occur. It also reviews the scientific literature to evaluate the current understanding of the impacts of solar developments on bat populations. In addition, the report assesses the range and effectiveness of survey, mitigation and monitoring strategies currently employed, alongside examples of emerging best practice from research and industry. It identifies key evidence gaps and areas of uncertainty, and brings the findings together to develop a series of recommendations to help inform assessment, decision-making and the consideration of bats within the planning, design and management of solar developments.

Background

Biodiversity loss has accelerated rapidly in recent centuries, primarily driven by anthropogenic activities (Ellis, 2021; Wiebe and Wilcove, 2025). Habitat destruction, climate change, and environmental pollution are major contributors to this decline; however, a coordinated global approach to addressing these issues remains lacking (Festa *et al*., 2023; Jaureguiberry *et al*., 2022; Pettorelli *et al*., 2021). Renewable energy is one of the most important strategies in meeting rising energy demands whilst combating many of the drivers of biodiversity loss, but the effects of such technologies are often overlooked (Gibson *et al*., 2017). Renewable energy sources have lower carbon emissions; however, they are usually more land-use intensive (Brook and Bradshaw, 2014), alongside several other unforeseen consequences for wildlife, leading to a 'green-green' dilemma. Over the past few decades, there has been extensive research into the ecological impacts of wind energy development on wildlife (e.g. Thaxter *et al*., 2017) and the effectiveness of mitigation strategies designed to minimise such conflicts (e.g. Estellés-Domingo and López-López, 2025). In contrast, the potential impacts associated with other forms of renewable energy infrastructure, such as solar, tidal, and wave energy, remain comparatively understudied.

Overview of solar energy development globally

Solar energy harnesses renewable energy from the sun, either as heat or electricity. Heat can be captured using solar thermal systems, which generate hot water or provide space heating for domestic, commercial, or industrial use. Electricity can be produced either through concentrated solar power (CSP), which uses mirrors or lenses to focus sunlight onto a receiver that heats up to produce steam that drives a turbine, or through PV technology, which converts sunlight directly into electricity using semiconductor materials. PV technology is now the dominant form of solar electricity worldwide (EI, 2025; IEA, 2025) due to falling installation costs, modularity (which allows for flexible scaling, expansion and easier maintenance), and suitability for domestic, community and utility-scale applications, including in regions with limited direct sunlight. The focus of this review will be on solar electricity, particularly PV technology, as CSP is not currently applicable to the UK.

The global uptake of solar energy has been driven by governmental policies aimed at accelerating the transition to low-carbon energy systems and reducing dependence on fossil fuels. The direct and indirect advantages of solar development include the absence of greenhouse gas or toxic emissions during operation, opportunities for land restoration or dual land use (e.g. solar-grazing, where livestock graze beneath panels, or pollinator-friendly management), diversification and security of national energy supplies. In some cases, improvements are made in water resource efficiency through the reduction of water use compared with conventional power plants (Solangi *et al*., 2011). As the scale and pace of deployment increase across the UK, understanding the ecological, social and environmental implications of different solar technologies is essential for sustainable planning and regulatory decision-making.

Solar development in the UK

Solar PV installations have grown from negligible commercial capacity in the early 2000s to contributing a substantial source of renewable energy by the mid-2020s. In 2010, installed solar electricity generating capacity was at 95 megawatts (MW), whereas by the end of October 2025, there was a total of 20.7 gigawatts (GW) of solar electricity capacity in the UK, across 1,877,000 installations (Department for Energy Security and Net Zero, 2025). There was a rapid increase in solar installations between 2010 and 2017, largely driven by government subsidies, notably the Renewables Obligation and Feed-in Tariff (Blaydes *et al*., 2025). However, the subsidies were reduced in 2015, and both were closed to new applicants by 2019. From 2014, the Renewables Obligation was gradually replaced by the Contracts for Difference support scheme, designed to provide greater revenue stability and incentivise investment in low-carbon power (Watson and Bolton, 2024). Although solar PV and other established technologies were initially eligible for the scheme, they were excluded between 2016 and 2020. New planning policies were also introduced around this time, including statutory biodiversity duties. These factors caused growth to plateau until 2022, when solar was reintroduced to the Contracts for Difference scheme, planning permission restrictions were reduced, costs fell, and technological advances enabled larger solar installations in a greater number of locations (Wilfred *et al*., 2026).

Solar energy in Wales has seen significant growth over recent years, with total installed solar PV capacity rising to approximately 1.3 GW by 2023 across more than 86,000 individual projects (Welsh Government, 2025). In 2023, Wales added 108 MW of new capacity, over double that of the amount installed in 2022, with growth in small-scale and rooftop systems making up 64% of that year's installations.

Part of the expansion of solar in Wales has been driven by community and public-sector projects; for example, the community group Egni Co-op has installed over 90 rooftop systems across South Wales, which in 2022 saved these sites over £119,000 in electricity costs and over 1,000 tonnes of carbon emissions (Egni Co-op, 2025). This community-scale model complements larger solar installations by bringing generation closer to demand, which can reduce transmission losses, infrastructure requirements and grid pressure, alongside increasing public support for the renewable transition. A dual approach of utility-scale and community-level solar in Wales maximises the benefits of renewables, with large farms generating the majority of energy whilst community and rooftop installations spread social, economic and sustainability gains more widely by enhancing resilience, ownership, and support for sustainable energy across different scales and communities.

The size of ground-mounted solar farms in Wales has also increased substantially in recent years. In 2015, solar farms typically occupied sites ranging from 1 to 100 acres and had an average generating capacity of approximately 8 MW (Senedd Research, 2015). However, the development of larger projects, such as Shotwick Solar Park in Flintshire (72 MW), commissioned in 2016, and Llanwern Solar Farm in Newport (75 MW), commissioned in 2021, reflects a shift away from predominantly small-scale installations. This trend has been supported by advances in PV efficiency, which have reduced the average land area required per MW of installed capacity in 2024 to almost half that required in 2011 (Wilfred *et al*., 2026).

The Clean Power Action Plan (Department for Energy Security and Net Zero, 2024) is the UK Government's attempt to deliver clean power by 2030 alongside ensuring secure and affordable energy supplies, developing jobs, industry and investment in renewables, and promoting growth, whilst protecting biodiversity and mitigating the effects of climate change. It holds the ambition that solar will produce 45–47 GW annually by 2030, reflecting the rapid growth of this industry. Delivering clean power is a cross-UK mission and complements the Welsh Government's target to meet the equivalent of 100% of Wales's annual electricity consumption from renewable sources by 2035. However, the Welsh Government has no specific targets for renewable technology types (Welsh Government, 2025).

Although solar farms typically have an operational lifespan of 25–40 years, proposals have been made to repower sites at the end of this period rather than decommission them to further support clean energy targets. This may have implications for biodiversity restoration (Tinsley *et al*., 2024).

Installation types

The rapid expansion of conventional ground-mounted solar PV developments is occurring alongside deployment across multifunctional spaces such as rooftops, car parks, industrial estates, and water bodies. In the UK, considerable protections remain in place for Best and Most Versatile (BMV) agricultural land, meaning developers must demonstrate clear justification for its use relative to alternative options such as previously developed land (brownfield) or lower-grade farmland. While land quality receives explicit attention, the Department for Energy Security and Net Zero’s (2025) *Solar Roadmap* notably omits reference to siting constraints near Protected Areas for wildlife and potential ecological or landscape-scale implications. In contrast, the Welsh Government’s (2023) *Designing for Renewable Energy in Wales* states that designated sites and those with rich biodiversity should be avoided for solar development in line with the step-wise approach of Planning Policy Wales (Welsh Government, 2024).

The growing demand for solar is likely to drive development across a wider range of locations and installation types, including:

Commercial buildings and car parks

Domestic solar installation has grown rapidly in recent years; however, uptake on commercial buildings has historically been constrained by planning requirements for systems exceeding 1 MW generation capacity. The removal of these requirements is expected to stimulate a significant increase in commercial-scale rooftop installations. Building-integrated photovoltaic (BIPV) systems are also on the rise. BIPVs form part of the construction of buildings and are therefore multifunctional, providing insulation, protection, aesthetic value, etc., in addition to generating energy. While currently a relatively niche market, these additional benefits are expected to encourage BIPV adoption and support the global transition to carbon-neutral infrastructure in the coming years (Osseweijer *et al*., 2018). In parallel, solar canopies over outdoor car parks are becoming increasingly common, reflecting the growing demand for electric vehicle charging infrastructure, the opportunity to provide weather protection for vehicles, and the ability to generate power close to areas of high daytime demand. Car-park canopies may also avoid land-use conflicts that arise from conventional ground-mounted systems.

Vertical, bifacial, dual-tilt and tracking systems

Vertical solar installations alongside bifacial PV panels and dual-tilt systems represent emerging technologies with distinctive spatial and ecological characteristics compared with conventional ground-mounted arrays. Vertical arrays are typically installed in narrow strips along field boundaries, transport corridors, or existing fencing lines, thereby reducing land take and limiting shading footprints while enabling continued agricultural or conservation land management (Masna *et al*., 2023). Bifacial panels, capable of capturing light from both their front and rear surfaces, can increase energy yield in high-albedo environments and are particularly suited to more dispersed or vertically oriented layouts (Badran and Dhimish, 2024). These approaches may decrease habitat fragmentation by retaining open ground surfaces and simplifying wildlife movement beneath the structures; however, their environmental impact has not been fully assessed.

Dual-tilt systems comprise paired (back-to-back) panels mounted in an A-frame configuration, with one surface-oriented east and the other west. This arrangement broadens the generation profile by increasing morning and late-afternoon output, reduces inter-row shading, and enables higher module density per unit area. Solar tracking systems orient modules to follow the sun's position, thereby maximising energy yield. The most common configuration is single-axis tracking, which rotates rows around one axis to follow the sun's east–west movement throughout the day, while dual-axis systems additionally adjust for seasonal changes in solar elevation (Sadeghi *et al*., 2025). Bifacial modules can be integrated with tracking systems to further increase energy generation. Trackers are usually stowed horizontally at night to minimise wind loading. In the UK, tracking systems are currently less common than fixed-tilt (south-facing) systems due to higher cost, complexity, and maintenance requirements. As the UK explores non-conventional solar installations to alleviate land-use pressures, these technologies present opportunities for higher densities of energy production with reduced spatial conflict, but require ecological assessment as deployment scales up.

Floating photovoltaics

Floating photovoltaic (FPV) systems, or 'floatovoltaics', solar arrays installed on buoyant platforms anchored within lakes, reservoirs, quarries, or sheltered bays, are expanding worldwide. FPVs typically exhibit 10–15% higher energy yields and improved module longevity due to passive cooling by the underlying water body (Elminshawy *et al*., 2024). They may also reduce evaporation from the water body through panel shading, delivering potential water-resource benefits (Rocha *et al*., 2024), and can limit algal blooms, improving water quality (Haas *et al*., 2020).

Despite the UK possessing over 500 reservoirs and many suitable artificial water bodies, current FPV uptake remains low. Key constraints include uncertainties around impacts on water-body ecology, limited long-term operational evidence in temperate climates, and the need to align developments with reservoir management, recreational use, and biodiversity objectives. Nonetheless, FPV is recognised as an emerging sector with substantial future potential.

Agrivoltaics

Agrivoltaics, co-locating solar PV installations with agricultural production, aims to reduce land-use competition by allowing dual use of farmland for energy generation and food production. Three dominant agrivoltaic configurations exist:

1. **Inter-row systems**, where panels are installed between crop rows;
2. **Greenhouse PV**, in which solar modules act as partial or full replacements for greenhouse roofing materials; and
3. **Elevated or stilt-mounted arrays**, with panels raised several metres above crops to maintain adequate light penetration and allow machinery access.

Agrivoltaics can stabilise yields between years by moderating extremes such as frost and high temperatures, while reducing irrigation demand (Widmer *et al*., 2024). In a UK context, there is growing interest in systems compatible with grazing (particularly sheep), soft fruits, horticulture, and shade-tolerant crops, though the evidence base concerning biodiversity interactions, microclimate, soil conditions, and livestock behaviour remains limited.

Ecovoltaics

Ecovoltaics, or 'conservoltaics', is an emerging concept that stems from agrivoltaics but instead co-prioritises ecosystem services with energy generation as a multifunctional land use approach to maximise the sustainability and nature-compatibility of PV systems (Knapp and Sturchio, 2024; Nordberg and Schwarzkopf, 2023). This is achieved through careful solar array design with integrated ecological enhancements and management to restore and support biodiversity, plant productivity, soil health and climate resilience (Boscarino-Gaetano *et al*., 2024; Sturchio and Knapp, 2023). This approach aims to address the 'green-green' dilemma that has arisen from conventional PV installations. Examples of ecovoltaic PV array design include (Merheb *et al*., 2025):

1. **Single-axis tracking systems** to provide a dynamic microenvironment which exposes all the plants beneath the arrays to periods of direct sunlight and rainfall;
2. **Semi-transparent solar panels** to permit the transmittance of some wavelengths of light to the vegetation beneath the panels;
3. **Larger inter-row spaces** to enable longer periods of direct sunlight to reach the dominant vegetation; and
4. **Vertical or horizontal panel alignment** during rainfall to control soil moisture.

Ecovoltaics may be favoured over agrivoltaics in some cases, as it can be deployed on a range of degraded land-cover types as a restoration tool (Sturchio and Knapp, 2023). While this concept is currently most widely explored in Australia and the USA, it can be adapted to complement a variety of climatic conditions and ecosystems. The terms 'ecovoltaics' or 'conservoltaics', and the implementation of specific ecosystem-driven array designs are not common in the UK; however, 'nature-friendly' solar developments that aim to improve on-site biodiversity, primarily through habitat enhancement and creation, are relatively well-established and supported by environmental legislation.

Battery storage integration

Battery energy storage systems (BESS) are becoming integral components of solar developments as they store excess solar energy generated during peak irradiance, which can be discharged during periods of lower production or higher demand. Although BESS compounds are relatively compact, building new infrastructure can introduce a wider range of pollutants to the landscape, including security lighting and increased noise during cooling and charging cycles.

Co-location with other forms of renewable energy

The co-location of solar installations with other renewable technologies, most commonly onshore wind turbines, has the potential to maximise land use and share grid infrastructure, alongside increasing the overall efficiency of energy generation. Hybrid systems can share access routes, substations and operational systems, which can lead to more efficient energy generation strategies (i.e. wind output being higher in winter and solar during summer), whilst potentially minimising habitat loss. Combining multiple renewable technologies can reduce the distribution of single-technology developments across the landscape, which can limit fragmentation of wildlife when viewed at a national level. However, combining technologies within one area can lead to cumulative pressure, with factors such as increased human presence, more complex lighting and noise regimes, and larger operational footprints having a greater impact on local wildlife.

Projected solar development in Wales

Over the next decade, solar development in Wales is anticipated to increase markedly, driven by efforts to meet the Welsh Government's ambition for renewable electricity generation to match 100% of consumption by 2035, alongside the statutory net zero target for 2050. Current analyses suggest that renewable energy generation may need to more than quadruple to meet projected future demand (RenewableUK *et al*., 2025). Based on the most recent update (at the time of writing) to the Renewable Energy Planning Database (REPD, 2025), there are currently 120 operational ground-mounted PV developments, an additional 62 developments with planning granted (awaiting or under construction) and 31 in planning (application submitted, appeal lodged or application revised) across Wales (>0.15 MW). Due to a change to the installed capacity minimum threshold, developments below 1 MW in the planning system before 2021 are not included in the REPD.

ArcGIS was used to map the relative density, distribution and capacity of solar developments in Wales that are operational (generating electricity), planning granted (awaiting or under construction) and in planning (application submitted, appeal lodged or application revised). The highest density of solar developments is located in the south of Wales, particularly the south-east (Figure 1). This broadly reflects the priority areas for solar energy identified by the Welsh Government in 2019, based on criteria such as irradiance, centres of population, grid connection, vehicular access, landscape and visual impacts, ecosystem services and resilience, and historic environment (Welsh Government, 2019). Welsh planning and energy policy places emphasis on siting solar developments on lower-grade agricultural land, brownfield, and in locations capable of being sensitively integrated into existing landscapes (Welsh Government, 2023; 2024). While intended to minimise impacts, this approach is likely to drive increased development across South and Mid-Wales, particularly along established industrial and infrastructure corridors, including areas that may also support important ecological receptors. These emerging trends are already evident in the distribution of solar schemes that have secured planning permission (Figure 2). Predicted climate-driven shifts in bat distributions and solar energy expansion may further increase the total area of conflict in Wales over time, particularly in central and northern regions; however, more research is required to characterise this (Festa *et al*., 2023; Fialas *et al*., 2025).

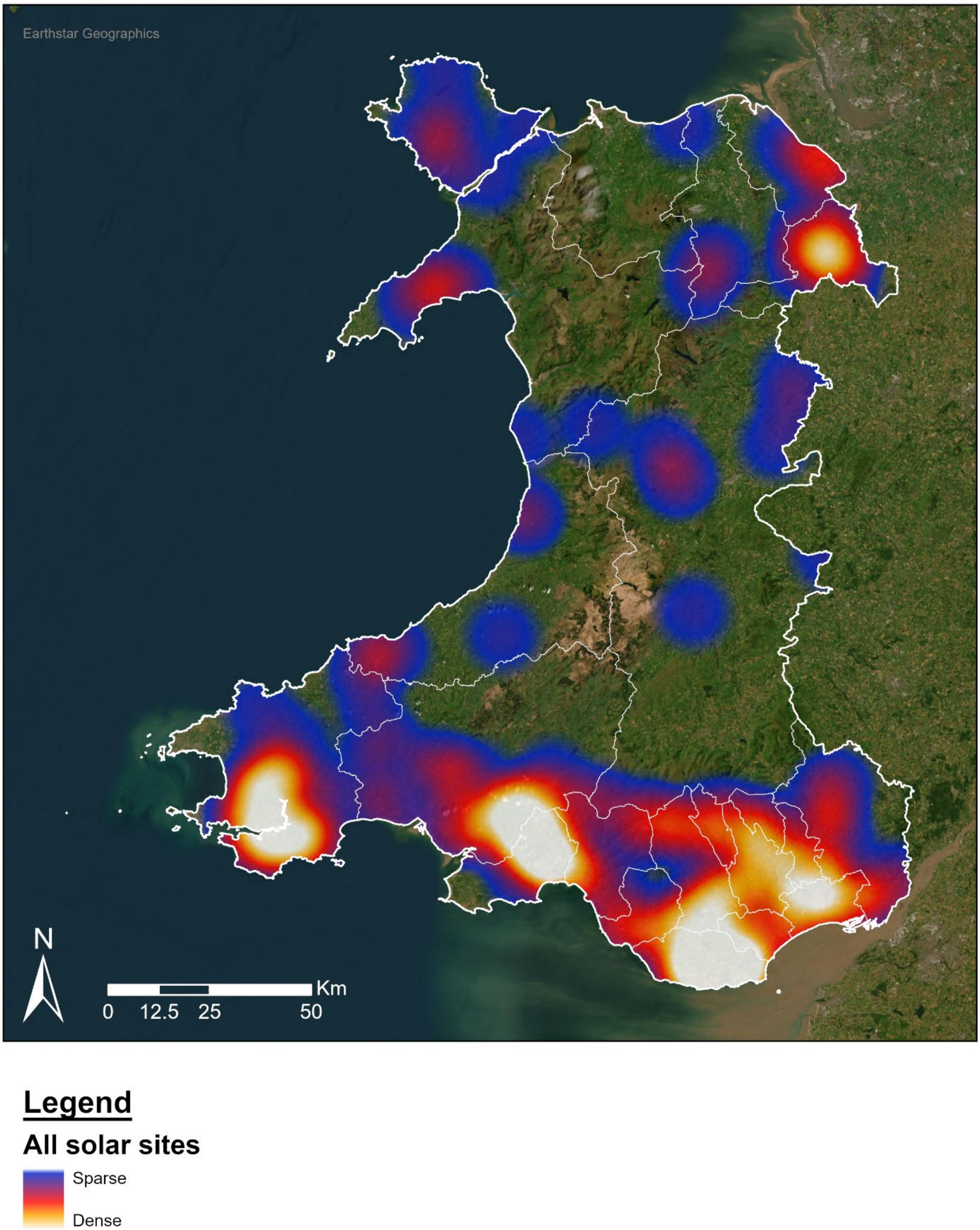


Figure 1. Relative density of ground-mounted solar developments in Wales (>0.15 MW) as of October 2025 (including operational, planning granted, and in planning). Areas of Wales where the satellite map is visible indicate the absence of solar farms. Thicker white line outlines the Welsh border; thinner white lines mark the 22 unitary authorities.

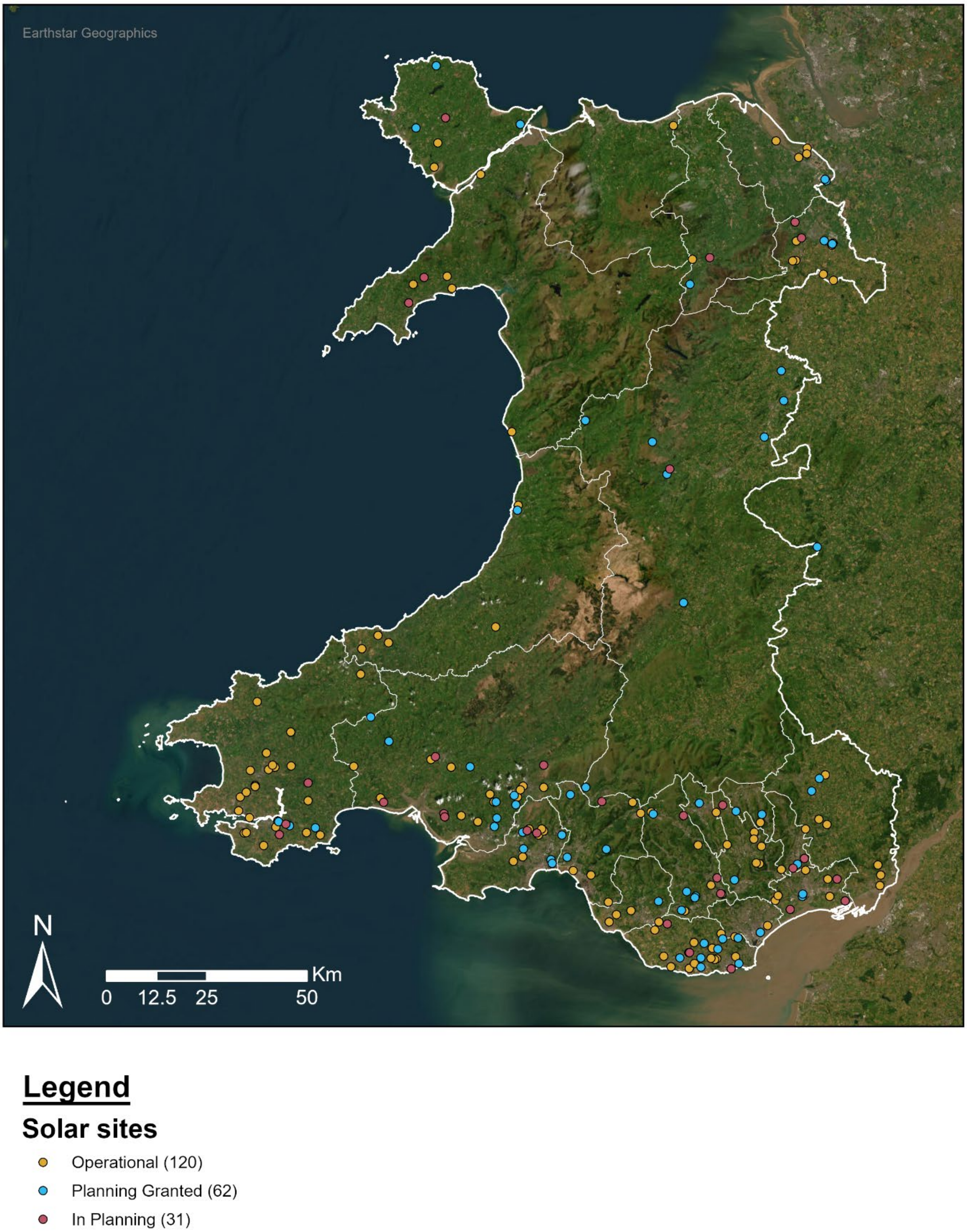


Figure 2. Distribution of ground-mounted solar developments in Wales (>0.15 MW) as of October 2025. Sites are colour-coded by development status: operational (generating electricity), planning granted (awaiting or under construction), and in planning (application submitted, appeal lodged or application revised). Locations are based on the centre point of each solar development. Thicker white line outlines the Welsh border; thinner white lines mark the 22 unitary authorities.

There is considerable variation in the size of the operational solar installations across Wales. South Wales contains a high frequency of smaller-scale developments (<9 MW), particularly along the coast, including areas of Pembrokeshire, and in South East Wales along the Severn Estuary corridor. In contrast, solar developments in North Wales are more spatially dispersed and skewed towards larger-capacity installations, likely reflecting differences in land availability, grid infrastructure, and landscape suitability. These regional patterns have implications for both cumulative effects and the spatial distribution of ecological impacts and should be considered when assessing potential risks to wildlife (Figure 3).

The average installed capacity of all the ground-mounted solar developments in Wales is 11.7 MW. This varies greatly across development statuses, with operational sites having an average capacity of 7.6 MW (ranging between 0.5–75 MW), those with planning granted averaging 16.2 MW (0.15–160 MW), and sites currently in planning averaging 19.1 MW (0.3–125 MW). It is important to note that capacity information was missing for four developments in the REPD (two with planning granted and two in planning) and therefore were not included in the above averages. The large number of smaller operational developments likely relates to the popularity of the Feed-in Tariff between 2011 and 2017, which supported sites <5 MW. Advances in technology, grid infrastructure, and the growing demand for renewable energy are driving an increase in the scale of individual solar developments. Once schemes that have already secured planning permission are constructed, the number of large-scale installations (>31 MW) is projected to increase by approximately 600%, with the majority located in South East Wales.

While solar farms with planning granted (consented) remain concentrated in the south-east, with a smaller number of larger developments along the North Wales coast, there is a notable shift compared to existing installations, with a higher frequency of smaller developments emerging inland across Mid-Wales (Figure 4A). A broadly similar spatial pattern is evident among schemes currently in the planning process, which remain concentrated in South East Wales (including some relatively large developments), alongside smaller-scale proposals in Mid and North Wales (Figure 4B). It is important to note that five solar developments could not be mapped due to missing information (capacity or coordinates) in the REPD. These include two with planning granted in Neath Port Talbot and Blaenau Gwent, and three in planning in Carmarthenshire, the Vale of Glamorgan and Caerphilly.

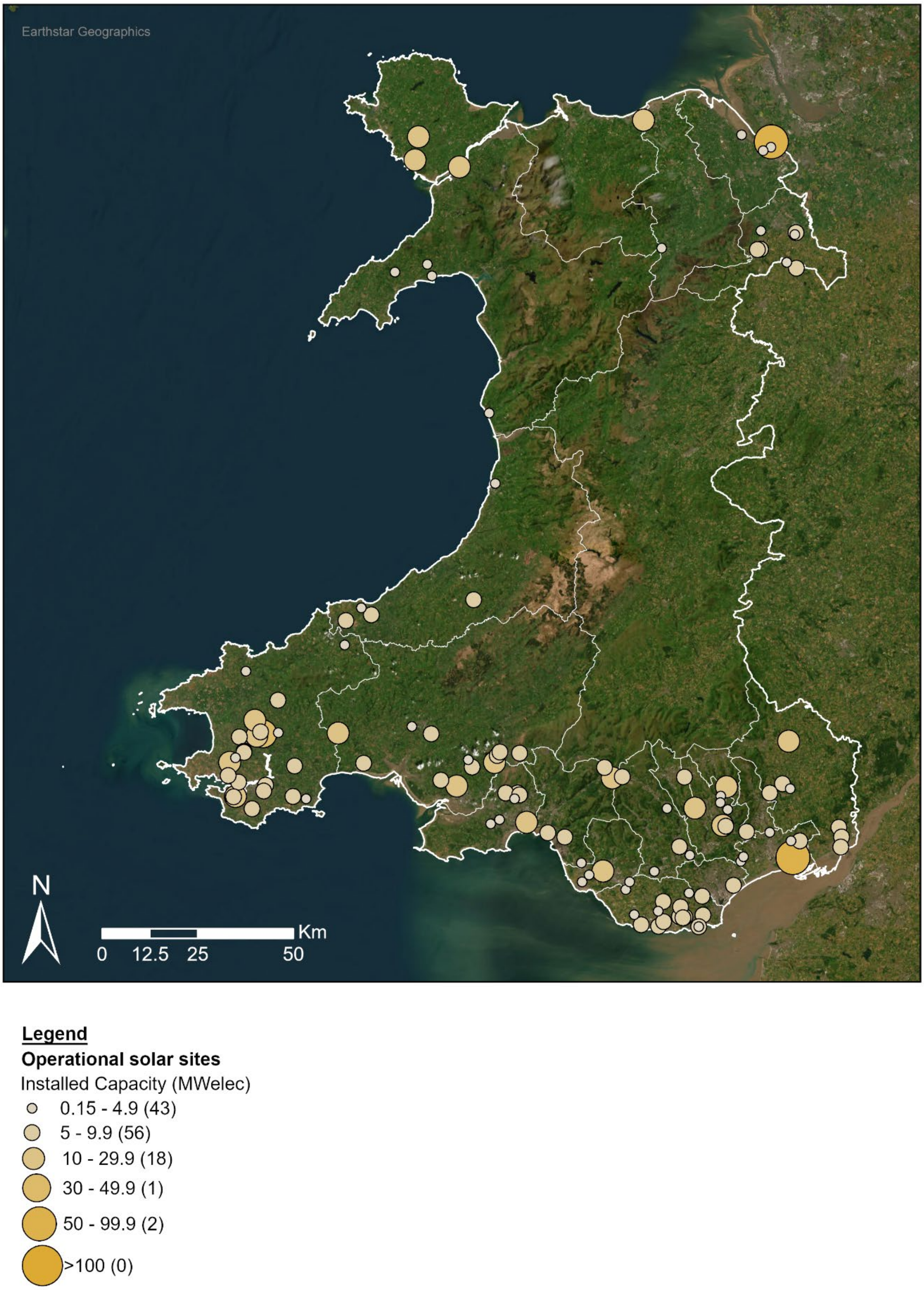


Figure 3. Capacity of operational ground-mounted solar developments in Wales as of October 2025. Sites are colour-graded and sized by relative installed capacity (megawatt electric, MWelec). Locations are based on the centre point of each solar development. Thicker white line outlines the Welsh border; thinner white lines mark the 22 unitary authorities.

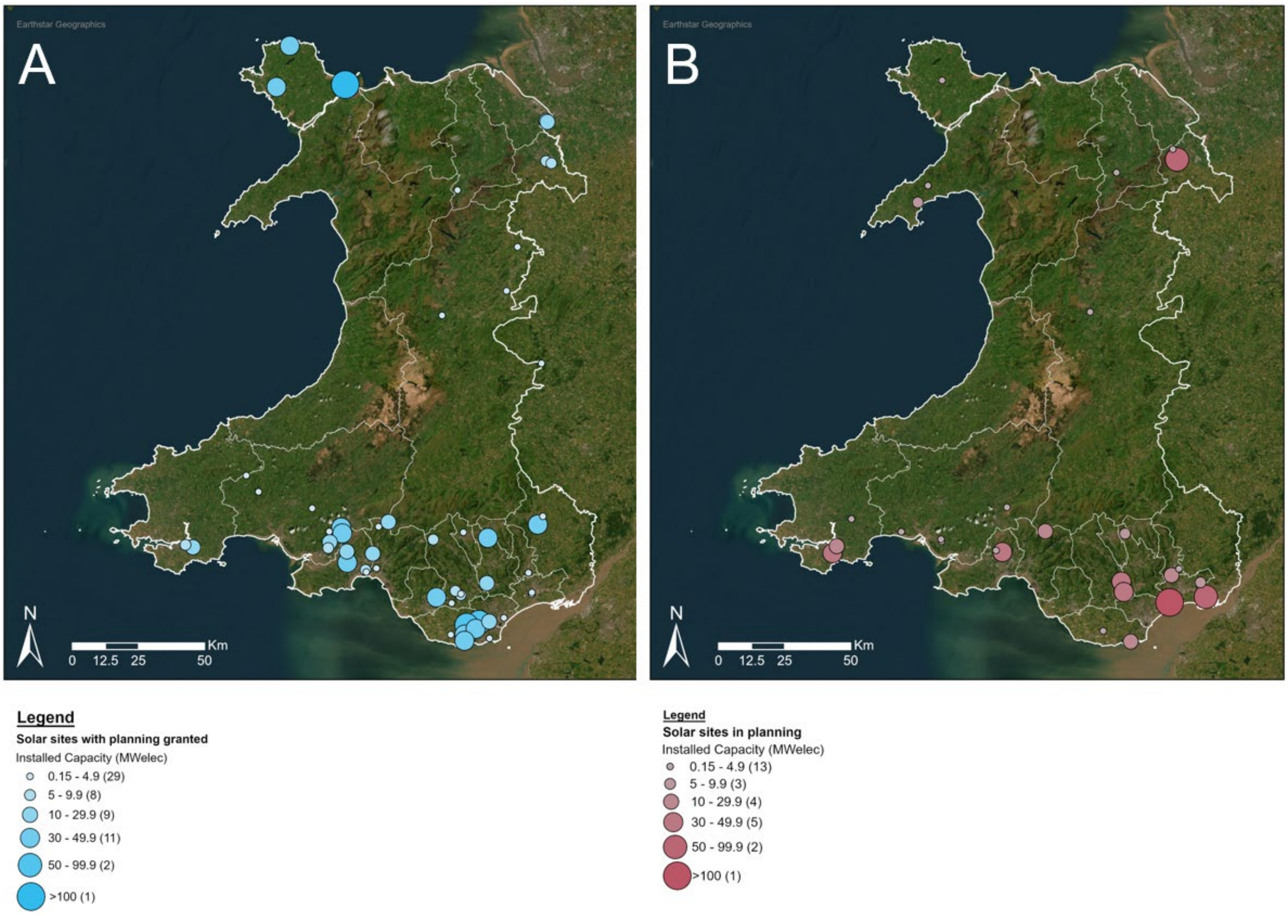


Figure 4. Capacity of ground-mounted solar developments with planning granted (A) and in planning (B) in Wales as of October 2025. Sites are colour-graded and sized by relative installed capacity (megawatt electric, MWelec). Locations are based on the centre point of each solar development. Thicker white line outlines the Welsh border; thinner white lines mark the 22 unitary authorities.

Legal context of bats in relation to solar energy

All bat species within the UK are legally protected, including their breeding sites and resting places (roosts), under domestic legislation which retains obligations from international treaties and the European Habitats Directive. In England and Wales, the principal protective instruments include the Wildlife and Countryside Act (1981) (as amended) and the Conservation of Habitats and Species Regulations (2017) (as amended). In Wales, the Environment (Wales) Act 2016 and the Environment (Principles, Governance and Biodiversity Targets) (Wales) Act 2026 further impose a statutory biodiversity duty on public authorities to maintain and enhance biodiversity.

These statutory protections make it a criminal offence, unless authorised by a valid licence, to:

- deliberately kill, injure or capture a bat,

- deliberately disturb bats (in particular if the level of disturbance can be shown to impair their ability to survive; to breed or reproduce; to rear or nurture their young; to hibernate or migrate; or significantly affect local distribution or abundance),
- intentionally or recklessly disturb a bat in a roost,
- damage or destroy a bat roost (even if bats are not present at the time), or
- intentionally or recklessly obstruct access to a roost.

For solar-power developments, whether rooftop PV installations or ground-mounted solar farms, these protections become particularly relevant. Roof works and building conversions may affect bat roosts (for example, by altering the thermal or structural characteristics of a roof space or by blocking access points), and demolition (for example, to allow for the construction of a solar installation) could result in roosts being destroyed. Developers must therefore carry out appropriate ecological surveys at an early stage. If roosts are present, mitigation and/or licensing arrangements may be required.

In the Welsh planning context, public bodies and planning authorities must also have regard to the biodiversity duty under the Environment (Wales) Act 2016, meaning that consideration should be given to how the scheme contributes to or impacts on biodiversity, including protected species such as bats. Hence, solar-power projects in Wales should not only avoid breaches of the protected-species legislation but should also integrate biodiversity considerations (such as maintaining commuting corridors, avoiding unnecessary lighting, and retaining appropriate buffer habitats) and seek to enhance biodiversity as part of the planning and environmental-assessment process (Welsh Government, 2024).

Developers, ecologists and planning authorities should refer to the most up-to-date good-practice guidance for bats (for example, Bat Surveys for Professional Ecologists Good Practice Guidelines 4th edition, 2023, and the UK Bat Mitigation Guidelines, 2023). Planning authorities should also follow the approach recommended for them by the regulator in Wales (NRW's GPG 3: approach to bats and planning). Ensuring that bat survey, mitigation and monitoring requirements are addressed at the earliest possible stage reduces the risk of delay, licence refusal or enforcement action later down the line. However, there is currently no specific guidance relating to bats and solar farms, unlike for onshore wind farms (NatureScot *et al*., 2021).

2. Ecological setting of solar developments

Relationship between solar developments and habitat types

Habitat maps of solar farm landscapes in Wales were produced in ArcGIS using the UK Centre for Ecology and Hydrology Land Cover Map 2024 dataset (Rowland *et al*., 2025). This land parcel dataset was created by classifying the land surface of Great Britain into 21 land cover categories based on Biodiversity Action Plan habitats, to a pixel resolution of 10 m.

Across the 213 ground-mounted solar developments (operational, planning granted and in planning) in Wales, the dominant local land cover type within a 1 km radius of their centre points is improved grassland (52.9%). The next most prevalent land cover types within 1 km of solar farms are broadleaved woodland (12.4%), arable and horticulture (9.4%), suburban areas (7.7%), urban areas (7.5%), acid grassland (3.3%), coniferous woodland (1.7%) and heather grassland (1.3%). All remaining habitat types each account for less than 1% of land cover within 1 km of solar developments across Wales. This is broadly consistent with Tinsley *et al*. (2024), who recorded a very low occurrence of habitats such as supralittoral rock and sediment, littoral rock, calcareous grassland, fens and swamps around solar sites in England.

When the radius is extended to 4 km, the overall landscape composition remains similar to that observed at the 1 km scale, but several broader patterns become more apparent. Improved grassland remains dominant, followed by broadleaved woodland; however, suburban land cover becomes more prominent across the wider landscape and urban land cover becomes proportionally lower, reflecting the more rural setting beyond the immediate vicinity of sites. Semi-natural habitats such as acid grassland and coniferous woodland increase in relative extent at this scale, and littoral sediment habitats appear within the wider landscape context. In contrast, arable and horticultural land represents a smaller proportion than at the local scale. All remaining habitat types account for less than 1% of land cover within 4 km of solar developments across Wales (Figures 5, 6, 7 and 8).

These patterns suggest that solar farms are generally sited near lower-quality habitats such as arable and urban land, which are both proportionally more prominent at the local scale than across the wider landscape. However, the data also highlight the high frequency with which solar developments are installed on improved grassland, typically a higher quality habitat than arable or urban land, and their regular proximity to broadleaved woodland, which is a key habitat for bats. This trend is consistent with that found in Wales by Blaydes *et al*. (2025) and Wilfred *et al*. (2026), and contrasts with the dominant land cover type in which solar farms are installed in England (arable and horticulture). However, Wilfred *et al*. (2026) reported that although improved grassland constitutes a larger proportion of the total land area in Wales than arable land and therefore, in absolute terms, hosts solar farms more frequently, its use for solar development is not proportional to its availability. In relative terms, improved grassland is used less frequently than would be expected based on its abundance. This indicates that arable land is preferentially selected for solar development in Wales despite its lower overall extent. Additionally, Wilfred *et al*. (2026) found that solar farms in Wales are predominantly sited on Grade 3 (good-moderate) agricultural land quality, followed by Grades 2 (very good), 4 (poor), and 5 (very poor). Grade 1 (excellent) land does not appear to have been used for any solar developments in Wales, although it has been utilised in some regions of England (Wilfred *et al*., 2026). These trends suggest that planning intentions to avoid the use of BMV agricultural land are not consistently adhered to in practice.

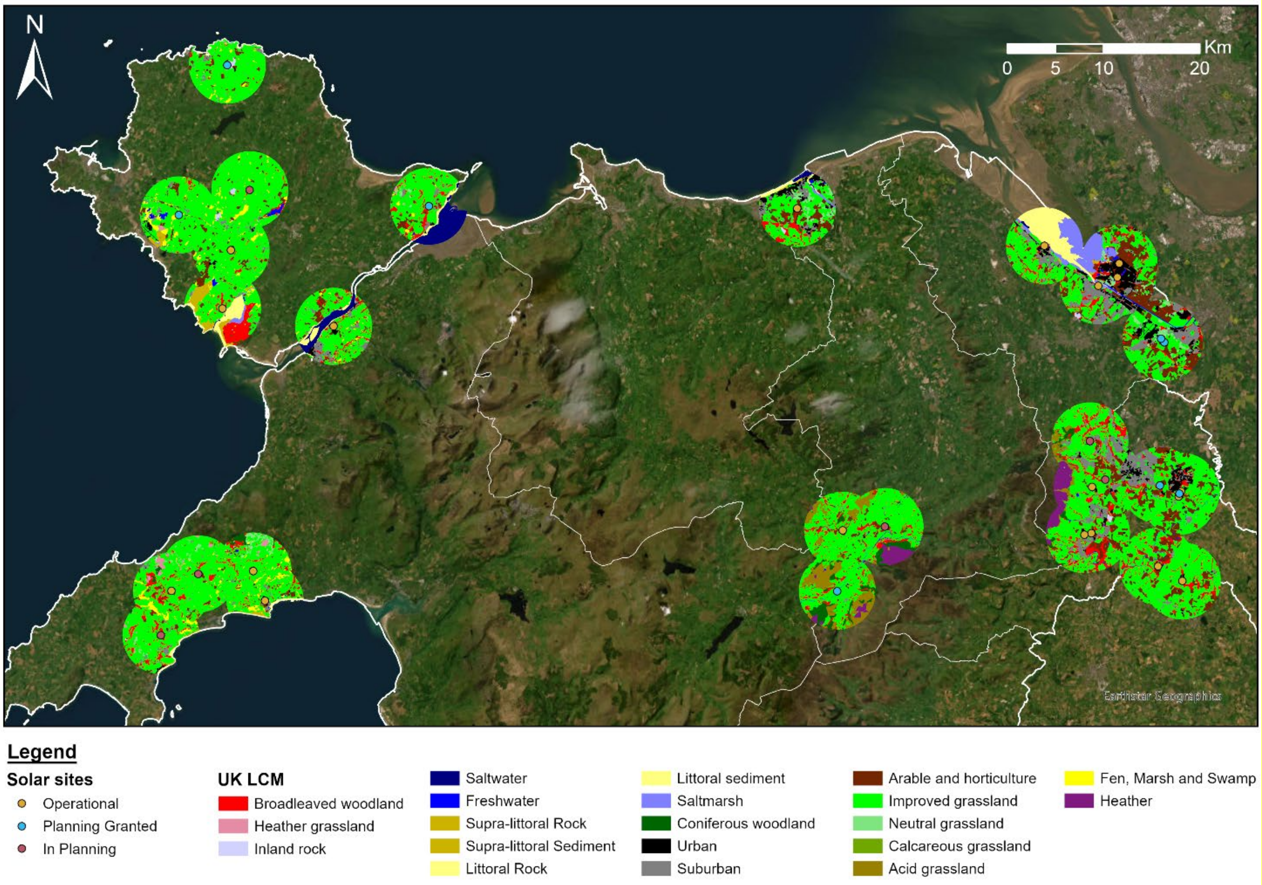


Figure 5. 4 km buffer land cover map of ground-mounted solar developments (operational, planning granted and in planning; >0.15 MW) in North Wales as of October 2025 (Rowland *et al.*, 2025). Buffers are based on the centre of each solar development rather than the site boundary. Thicker white line outlines the Welsh border; thinner white lines mark the unitary authorities.

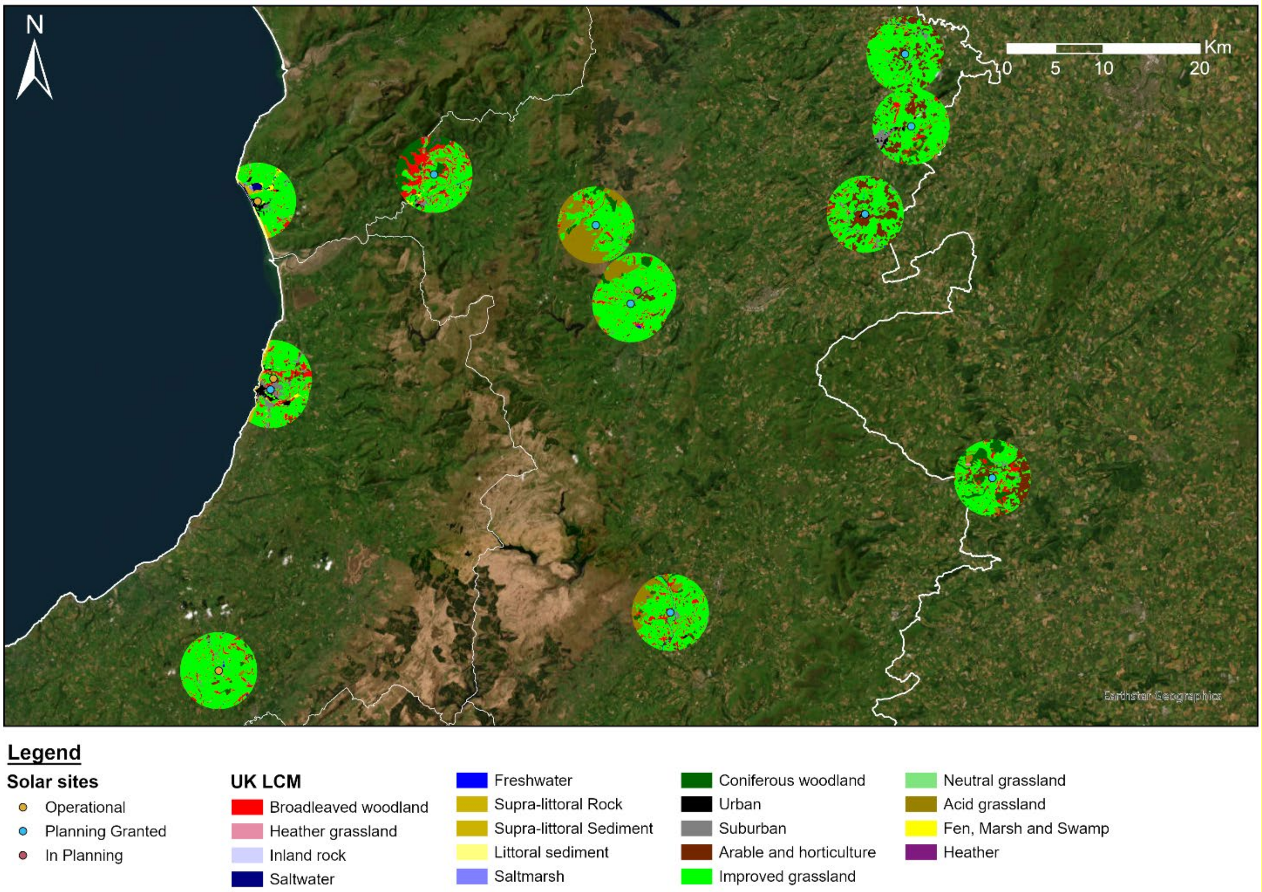


Figure 6. 4 km buffer land cover map of ground-mounted solar developments (operational, planning granted and in planning; >0.15 MW) in Mid Wales as of October 2025 (Rowland *et al.*, 2025). Buffers are based on the centre of each solar development rather than the site boundary. Thicker white line outlines the Welsh border; thinner white lines mark the unitary authorities.

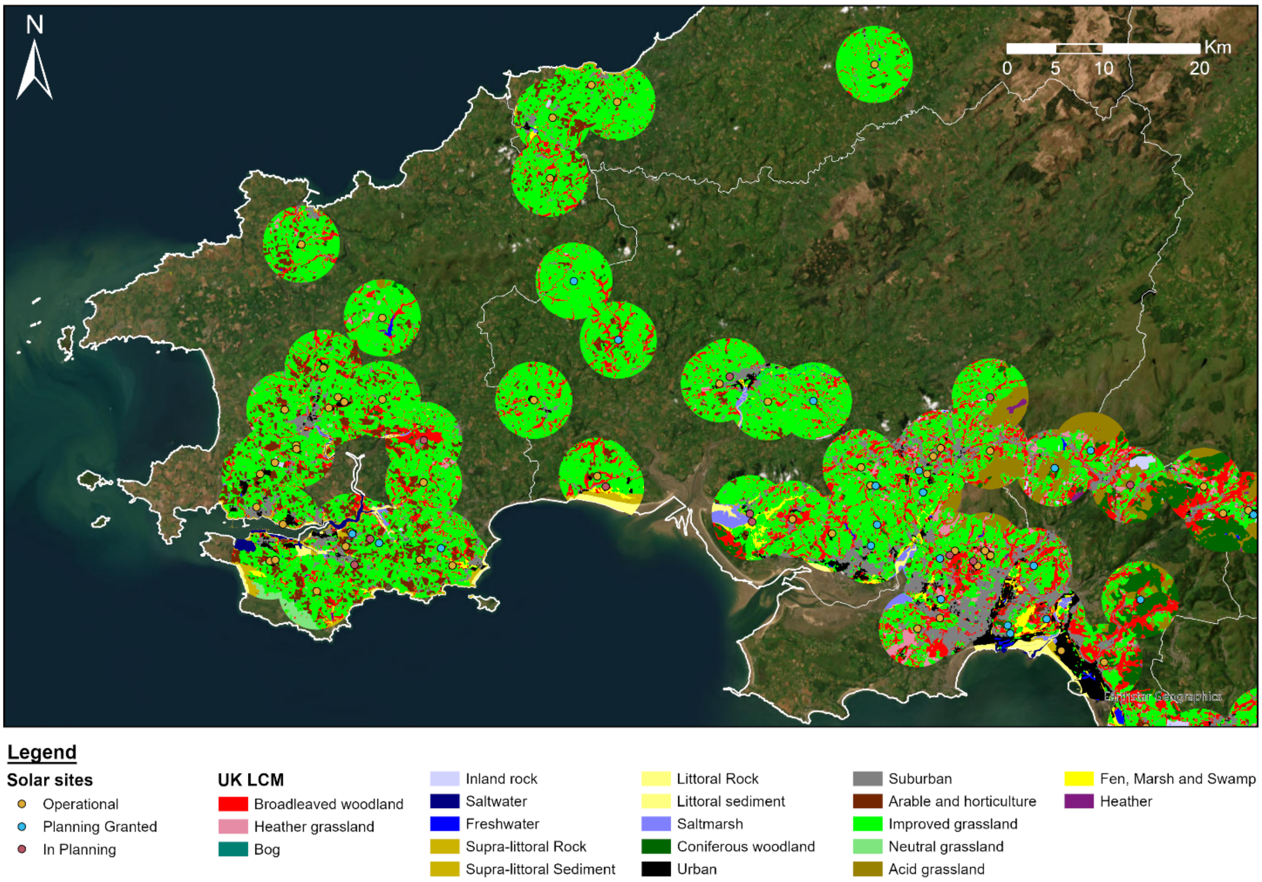


Figure 7. 4 km buffer land cover map of ground-mounted solar developments (operational, planning granted and in planning; >0.15 MW) in South West Wales as of October 2025 (Rowland *et al*., 2025). Buffers are based on the centre of each solar development rather than the site boundary. Thicker white line outlines the Welsh border; thinner white lines mark the unitary authorities.

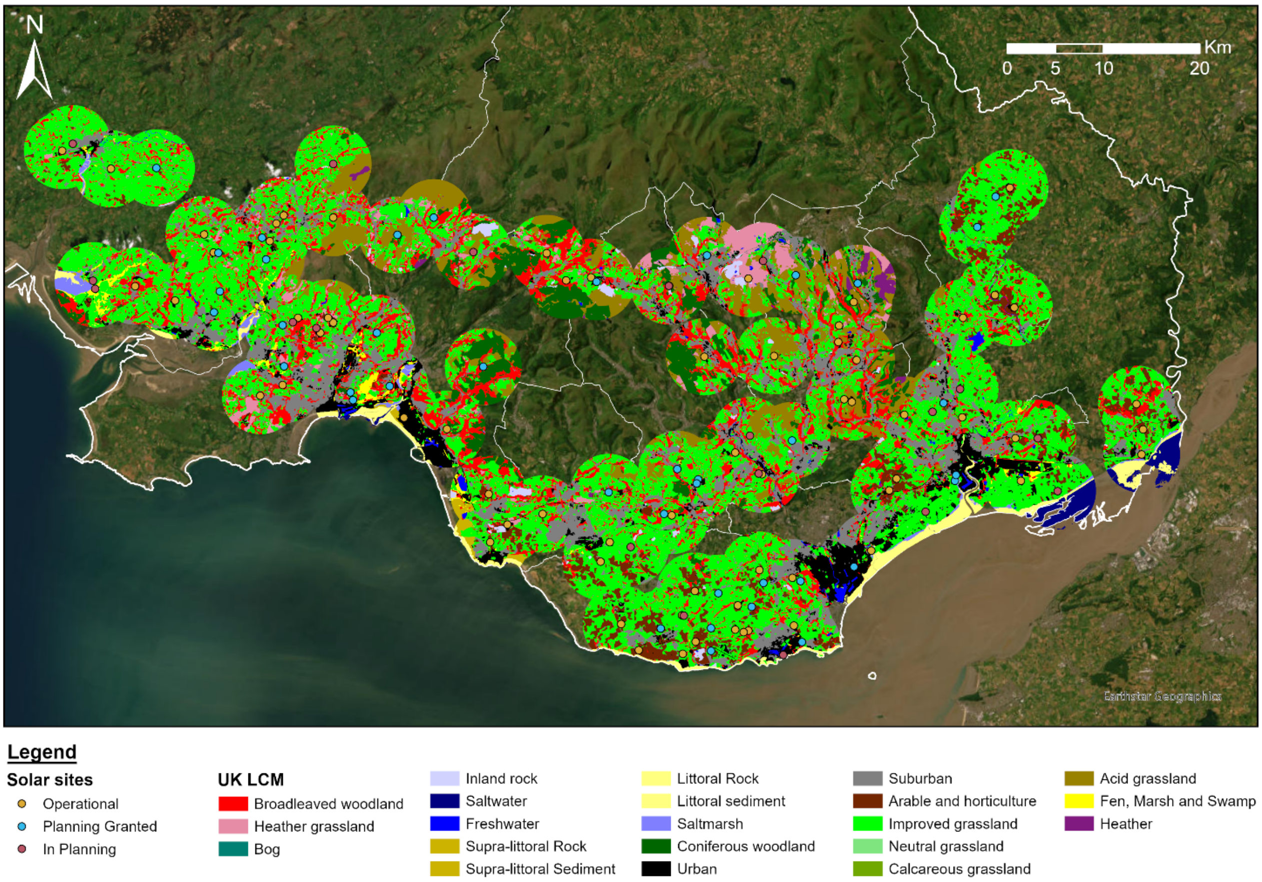


Figure 8. 4 km buffer land cover map of ground-mounted solar developments (operational, planning granted and in planning; >0.15 MW) in South East Wales as of October 2025 (Rowland *et al*., 2025). Buffers are based on the centre of each solar development rather than the site boundary. Thicker white line outlines the Welsh border; thinner white lines mark the unitary authorities.

Understanding links between protected areas for bats and solar developments

Bats have substantial core sustenance zones (CSZ), which are areas surrounding a communal bat roost within which habitat availability and quality will have a significant influence on the resilience and conservation status of the colony using the roost, with an average CSZ of 3 km for UK bat species (BCT, 2016). NRW utilises extended CSZ distances that have the potential to impact Annex II bat roosts (termed 'roost impact zones' in this report) for use in Habitats Regulations Assessments of European protected sites, such as SACs (NRW, *in prep*). Annex II species are animal and plant species of community interest whose conservation requires the designation of SACs. The SACs in which Annex II bat species are a primary reason for the selection of the site and/or qualifying feature were identified. The presence of solar farms around each SAC was assessed using NRW's roost impact zones specific to their designated Annex II bat species (8 km for *Rhinolophus hipposideros*, 12 km for *Rhinolophus ferrumequinum* and 20 km for *Barbastella barbastellus*), to understand potential disturbance (Table 1). Additionally, the presence of solar farms around SSSIs designated for bats, Ancient

Woodlands, and Ramsar sites was assessed, given the strong association between woodland and wetlands and bat activity. For all protected sites, buffers of 4 km were mapped in ArcGIS to understand potential impacts between solar developments and the average CSZ of UK bat species (3 km; BCT, 2016), with an extra 1 km added to capture the site boundaries of larger solar farms, since only the coordinates for their centre points were available in the REPD.

Overlap between bat SACs and solar developments

There are ten SACs within Wales where bat species are a primary or qualifying reason for their designation (total area 71.6 km^2). There is a total of ten solar developments (7 operational, 2 planning granted and 1 in planning) within 4 km of these sites (Figure 9) and 72 solar farms within the roost impact zones of the three relevant Annex II bat species (Table 1). This highlights a strong potential for interaction between solar developments and priority bat species in Wales. A higher proportion (5.8%) of operational solar farms are within 4 km of a SAC designated for bats than those with planning granted (3.2%) and in planning (3.2%), potentially reflecting an increased awareness of the impacts of solar farms on bats.

Almost all the overlap between the SAC buffers and solar farms occurs in Pembrokeshire, with a few operational sites particularly close to SAC boundaries. The only other unitary authority with overlap is Monmouthshire, which has one operational site within 4 km of a SAC designated for bats (Figure 9). The average capacity of the solar farms within the 4 km and roost impact zone buffers is 7.4 MW. The SAC with the largest number of solar developments (n = 25) within its roost impact zone is ‘Pembrokeshire Bat Sites and Bosherston Lakes’. Meanwhile, ‘Usk Bat Sites’ SAC has solar farms with the largest mean capacity (33.5 MW) within its roost impact zone (Table 1).

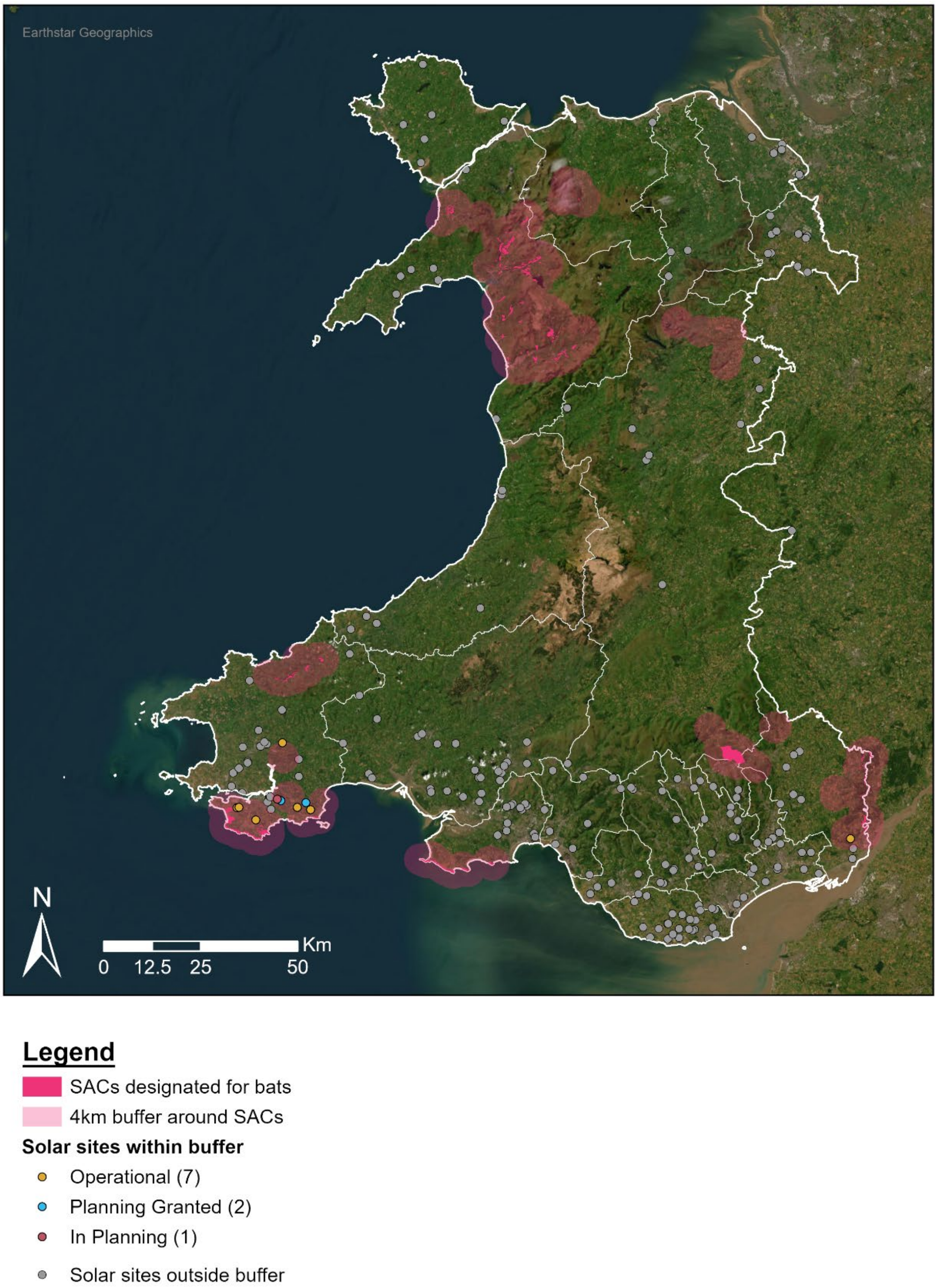


Figure 9. Special Areas of Conservation (SACs) designated for bats in Wales in relation to ground-mounted solar developments (>0.15 MW). Solar sites within 4 km of a SAC boundary are colour-coded by development status: operational (generating electricity), planning granted (awaiting or under construction), and in planning (application submitted, appeal lodged or application revised). Solar developments outside the 4 km buffers are shown in grey. Proximity is calculated from the centre point of each solar development rather than the site boundary. Thicker white line outlines the Welsh border; thinner white lines mark the 22 unitary authorities.

Table 1. Number and mean capacity of the ground-mounted solar developments (operational, planning granted, and in planning) within NRW's roost impact zones, specific to the Annex II bat species for which each Special Area of Conservation (SAC) is designated. Where a SAC is designated for two bat species, the roost impact zone used corresponds to the species that is the primary reason for site selection and has the largest impact zone. Some SACs list a bat species only as a qualifying feature.

SAC	Annex II bat species	Roost impact zone (km)	Number of solar farms within zone	Mean size of solar farms within zone (MW)
Glynllifon	*Rhinolophus hipposideros*	8	0	0
Gwydyr Forest Mines	*R. hipposideros*	8	0	0
Limestone Coast of South West Wales	*Rhinolophus ferrumequinum*	12	20	10.4
Meirionnydd Oakwoods and Bat Sites	*R. hipposideros*	8	0	0
North Pembrokeshire Woodlands	*Barbastella barbastellus*	20	13	7.6
Pembrokeshire Bat Sites and Bosherston Lakes	*R. ferrumequinum*	12	25	8.9
Tanat and Vyrnwy Bat Sites	*R. hipposideros*	8	1	1.2
Usk Bat Sites	*R. hipposideros*	8	3	33.5
Wye Valley and Forest of Dean Bat Sites	*R. ferrumequinum*	12	7	6.5
Wye Valley Woodlands	*R. hipposideros*	8	3	5.6

Overlap between bat SSSIs and solar developments

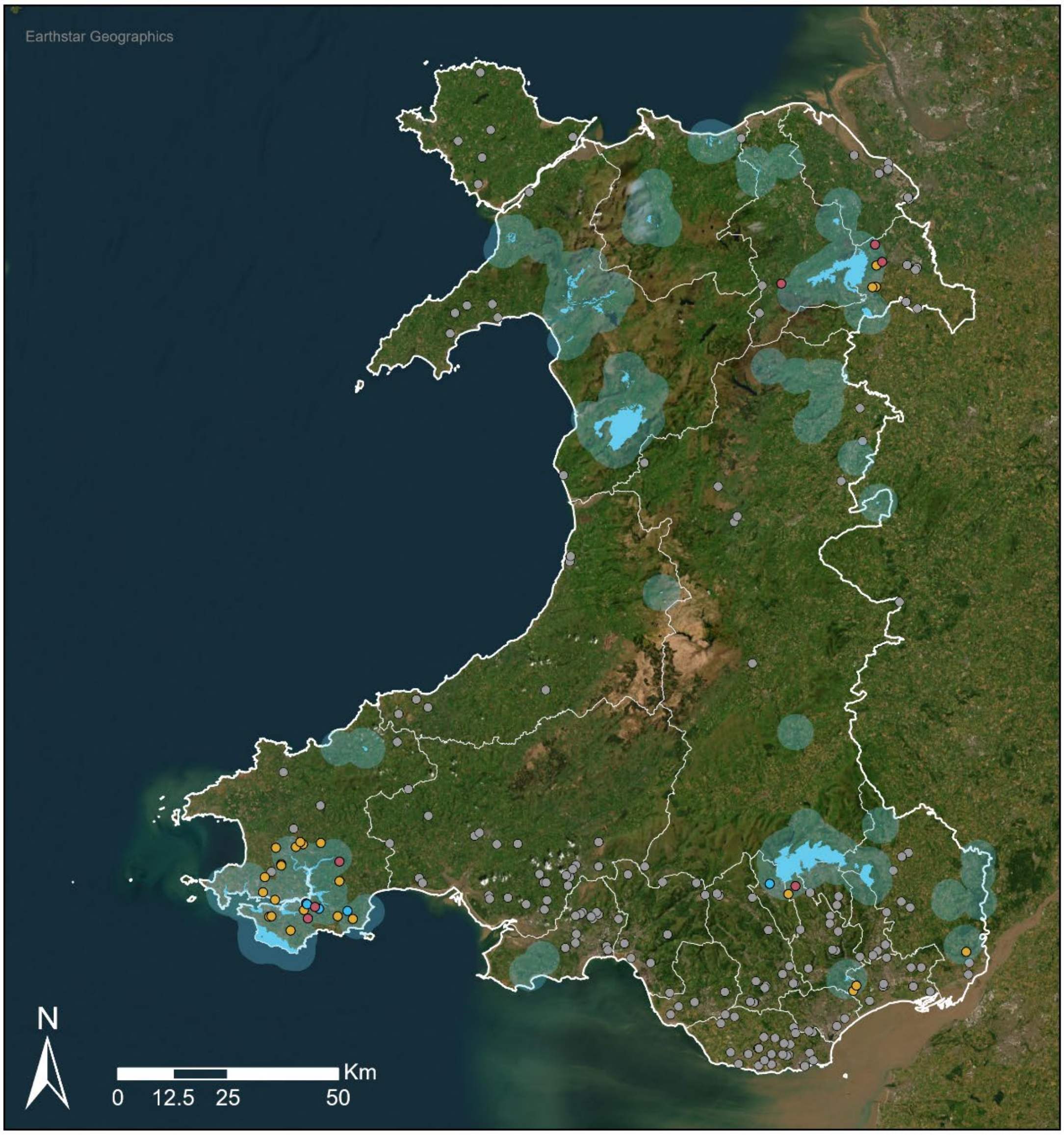
Of the 64 SSSIs in Wales where bats are a feature of the designated site (total area 261.4 km^2), there are a total of 36 solar developments (25 operational, 4 planning granted and 7 in planning) within 4 km of these sites (Figure 10). This indicates a relatively high likelihood of interactions between solar farms and habitats of importance for bat conservation. The average capacity of the solar farms within these buffer zones is 9.2 MW. As with the SACs, a higher proportion (20.8%) of operational solar farms are within 4 km of an SSSI designated for bats than those with planning granted (6.5%). Conversely, those currently in planning have the greatest proportion (22.6%) within the SSSI buffers, possibly due to the increasingly limited availability of suitable sites for solar developments; however, some may not receive planning permission. Reflecting the spatial overlap between SACs and their underlying SSSIs, solar farms intersecting SSSI buffers are also concentrated primarily in Pembrokeshire; however, additional instances occur in the south-east and north-east (Figure 10).

Overlap between Ancient Woodlands and solar developments

There are 950 km^2 of Ancient Woodlands across Wales, and all 213 solar developments (average capacity 11.7 MW) are within 4 km of Ancient Woodland (Figure 11). Overall, 27% (253 km^2) of Ancient Woodland in Wales is within 4 km of a solar farm. This pattern is broadly consistent with that observed in England, where Tinsley *et al*. (2024) found priority woodland habitat to occupy similar land areas within a 6 km buffer around solar sites and randomly selected locations, suggesting that solar development does not systematically avoid such habitats at this spatial scale. Ancient woodlands provide ample roosting and foraging opportunities for numerous bat species; therefore, such extensive overlap with solar developments at a landscape scale could affect woodland connectivity and bat use of these valuable habitats.

Overlap between Ramsar sites and solar developments

Of the 12 Ramsar sites in Wales (total area 510.1 km^2), there are a total of 29 solar developments (17 operational, 8 planning granted and 4 in planning) within 4 km of these sites (Figure 12). The average capacity of the solar farms within these buffer zones is relatively high (17.3 MW), likely due to a few particularly substantial developments near the Severn and Dee Estuaries (Figures 3 and 4). A slightly higher proportion (14.2%) of operational solar farms are within 4 km of a Ramsar site than those with planning granted (12.9%) and in planning (12.9%), potentially reflecting an increased awareness of the impacts of solar farms on biodiversity, especially waterfowl (Anderson *et al*., 2025). Most of the overlap occurs near marine or estuarine Ramsar sites; however, some solar farms also intersect freshwater site buffers such as bogs and fens in Swansea and the Llyn Peninsula, respectively. These areas likely support rich foraging resources for bats, including aquatic insects that could be negatively impacted by solar panels within range (Horváth *et al*., 2010).



Legend

SSSIs designated for bats

4km buffer around SSSIs

Solar sites within buffer

- Operational (25)
- Planning Granted (4)
- In Planning (7)
- Solar sites outside buffer

Figure 10. Sites of Special Scientific Interest (SSSIs) with bat features in Wales in relation to ground-mounted solar developments (>0.15 MW). Solar sites within 4 km of an SSSI boundary are colour-coded by development status: operational (generating electricity), planning granted (awaiting or under construction), and in planning (application submitted, appeal lodged or application revised). Solar developments outside the 4 km buffers are shown in grey. Proximity is calculated from the centre point of each solar development rather than the site boundary. Thicker white line outlines the Welsh border; thinner white lines mark the 22 unitary authorities.

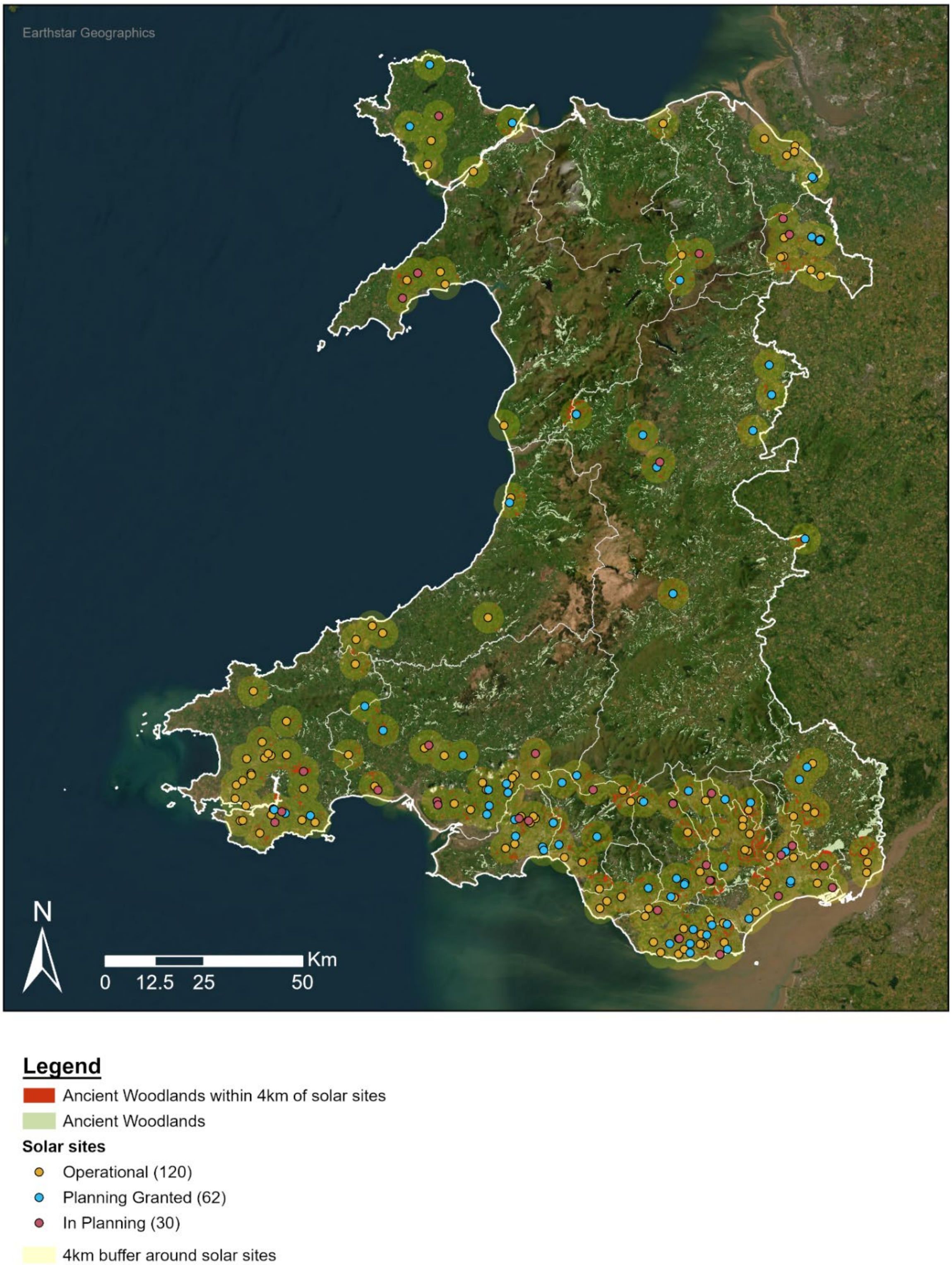


Figure 11. Ancient Woodlands in Wales within 4 km of a ground-mounted solar development (red) and those outside the 4 km buffers (green). All Welsh solar farms fall within 4 km of Ancient Woodland. Solar sites are colour-coded by development status: operational (generating electricity), planning granted (awaiting or under construction), and in planning (application submitted, appeal lodged or application revised). Buffers are based on the centre point of each solar development rather than the site boundary. Thicker white line outlines the Welsh border; thinner white lines mark the 22 unitary authorities.

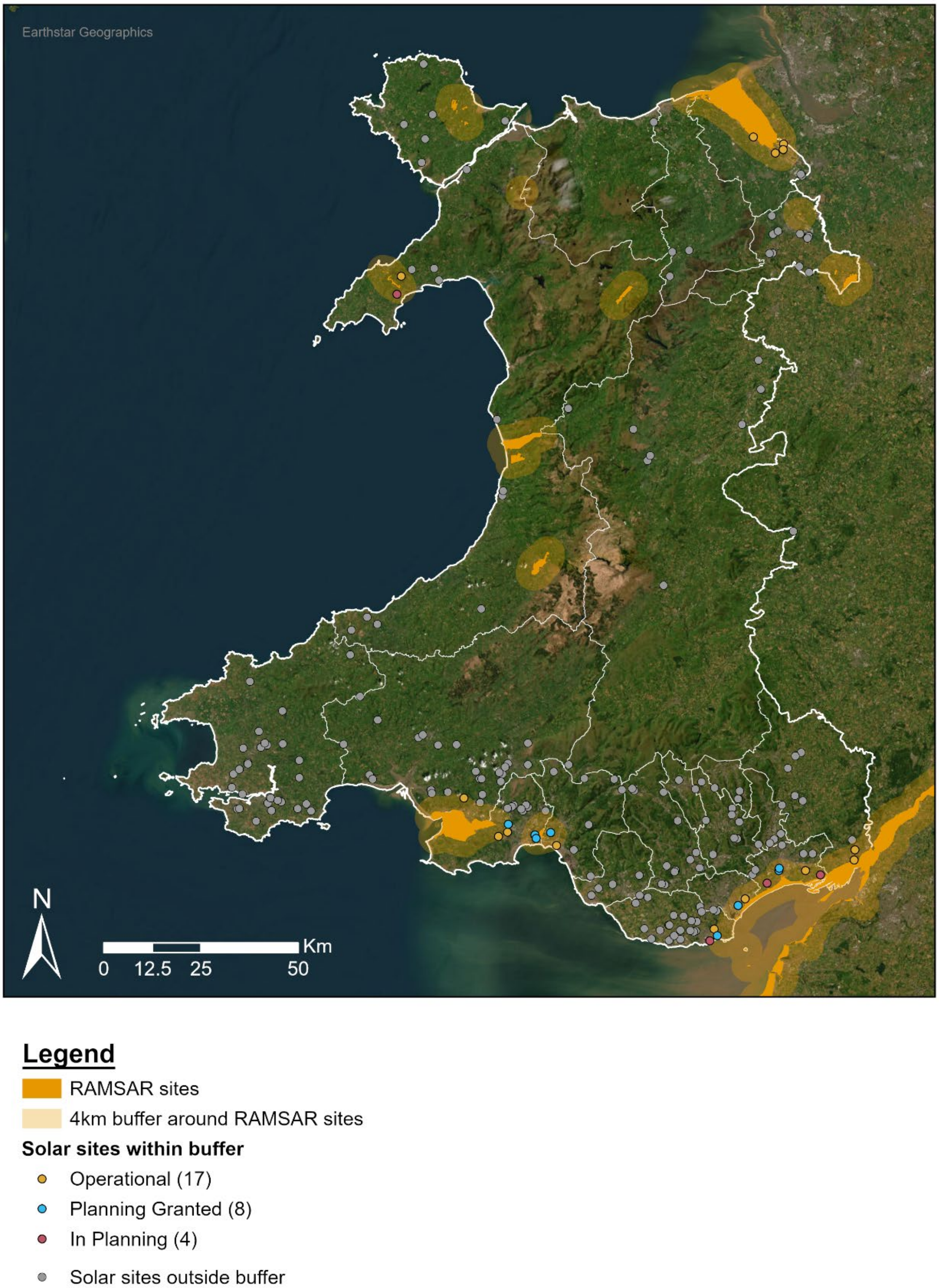


Figure 12. Ramsar sites in Wales in relation to ground-mounted solar developments (>0.15 MW). Solar sites within 4 km of a Ramsar site boundary are colour-coded by development status: operational (generating electricity), planning granted (awaiting or under construction), and in planning (application submitted, appeal lodged or application revised). Solar developments outside the 4 km buffers are shown in grey. Proximity is calculated from the centre point of each solar development rather than the site boundary. Thicker white line outlines the Welsh border; thinner white lines mark the 22 unitary authorities.

3. Evidence of bat interactions with solar

Methodology

We searched Google Scholar and Scopus for English language peer-reviewed publications highlighting the interaction between bats and solar developments. The search fields differed according to the options available within each database. For Google Scholar, we performed a full-text search using the default keyword settings, whereas for Scopus, searches were restricted to titles, abstracts, and keywords. For any relevant paper, we included a search of citation records to include publications in our review that may not appear in the respective databases. The following search terms were used to find studies on the interactions between bats or their prey and solar developments: ('bat*' OR 'Chiroptera' OR 'insect*' OR 'invertebrate*') AND ('solar' OR 'photovoltaic*' OR 'voltaic*' OR 'PV' OR 'renewable*') AND (farm* OR energ* OR park* OR industr* OR development* OR installation* OR power OR panel* OR array* OR field* OR facilit* OR technolog*). The asterisks are wildcards to search for all words that begin with that stem, e.g. a search including facilit* returns both facility and facilities. Given the substantial body of work on this topic within the ecological sector, we also searched for relevant grey literature, conference proceedings, technical reports, and unpublished data. The search for literature was conducted between November 2025 and January 2026. No publication date limits were applied to the search.

To gather further information relating to bats and solar farms, a call for evidence was published on the BCT news webpage, social media accounts and in the Chartered Institute of Ecology and Environmental Management (CIEEM) newsletter. This call invited formal documents and anecdotal evidence from bat groups, ecologists, practitioners, local authorities, developers, regulators, landowners, statutory agencies, non-governmental organisations and volunteers. Meetings were held with several interested stakeholders to gain deeper insights into their experiences with bats and solar farms. The topic was also raised at the UK Bat Steering Group meeting in January 2026 to obtain feedback on the areas covered. Some contributors requested that their submissions remain anonymous.

Article screening and classification

For the review process, all scientific articles that appeared in each search string were exported to the Rayyan intelligent systematic review tool (Ouzzani *et al*., 2016). At least two reviewers screened the studies at the title, abstract, and full-text stages, including only those in the final review that explicitly examined interactions between bats or their prey and solar technologies. We defined interaction as any measured effect, whether positive, negative or neutral.

Results

Overview

As with many rapidly expanding infrastructure sectors, scientific understanding of wildlife impacts has not kept pace with the growth of utility-scale PV energy developments (Gómez-Catasús *et al*., 2024; Lafitte *et al*., 2023; Smallwood, 2022).

A recent global review (Gómez-Catasús *et al*., 2024) demonstrates that current knowledge of PV-related biodiversity impacts is geographically and ecologically biased, with evidence predominantly derived from European and US field studies. Notably, 41% of the global research effort originates from North American desert environments, despite Asia leading in installed PV capacity. This environmental skew substantially limits the extrapolation of findings to temperate, agricultural and semi-natural landscapes, where the majority of new PV capacity is now being deployed.

Methodological limitations further constrain the broader applicability of research published to date. Over half of studies (53%) have focused on single PV facilities, and only 8% included pre-construction baseline data, severely limiting the ability to detect cumulative impacts, long-term ecological change, or population-level effects (Gómez-Catasús *et al*., 2024). In terms of taxonomic focus, research has been disproportionately directed towards plants, arthropods, birds and microorganisms, with reptiles and mammals receiving the least attention. Most critically for this review, only ~1% of published studies have examined the impacts of solar developments on bats (of any species), highlighting a profound evidence gap in relation to one of the most sensitive and legally protected mammal groups in European landscapes (Gómez-Catasús *et al*., 2024; Lafitte *et al*., 2023). Within this context of limited, geographically biased and taxonomically uneven evidence, the following section synthesises the available literature specifically examining the impacts of solar developments on bat populations, focusing on behavioural responses, activity patterns, habitat use and potential population-level implications.

Impacts of solar developments on bats

Several studies have used paired-site designs to assess the impacts of ground-mounted PV systems on bat activity (Barré *et al*., 2023; Baudouin *et al*., 2026; Montag *et al*., 2016; Szabadi *et al*., 2023; Szoldatits *et al*., 2025; Tavernier *et al*., 2026; Tinsley *et al*., 2023). The majority (6/7) of these studies reported significantly lower bat activity on solar farms for at least two species or species groups compared to the reference sites. Tavernier *et al*. (2026) found all seven species studied (100%) to be less active in solar fields than in intensive and extensive grassland habitats. Similarly, Tinsley *et al*. (2023) reported negative effects for six of eight (75%) species/species groups, Barré *et al*. (2023) recorded reduced foraging activity for five of seven (71%) taxa, Baudouin *et al*. (2026) found significantly lower activity for eight of fourteen (57%) species/groups, and Szabadi *et al*. (2023) detected reduced activity for three of six (50%) taxa within solar farms. Montag *et al*. (2016) assessed total bat activity and species richness, rather than species-level responses, and therefore could not evaluate species-specific sensitivities.

A range of studies have highlighted clear species- and guild-specific vulnerabilities. Species adapted to anthropogenic or open habitats appeared able to exploit solar farms to a similar extent as other open land uses (e.g. arable fields and grassland), whereas habitat specialists associated with woodland, riparian corridors and structurally complex environments exhibited stronger negative responses (Szabadi *et al*., 2023). Differences were also evident between echolocation guilds, with mid- and short-range echolocators showing greater behavioural modification than long-range echolocators, suggesting that open-habitat specialists may be more tolerant of solar farm environments (Barré *et al*., 2023). Tinsley *et al*. (2023) partially supported this pattern, reporting reduced activity of edge and clutter habitat feeders in both the centre and boundaries of solar farms relative to matched control sites; however, they also recorded lower activity of *Nyctalus* spp. (open-habitat foragers) across solar farm habitats, indicating that tolerance is not consistent across open-space species. Only one study reported higher bat activity at solar farms, where ecovoltaic sites in the USA were compared with arable fields, suggesting that habitat enhancement within PV developments may partially offset the ecological impacts of solar infrastructure (Szoldatits *et al*., 2025). However, this has not yet been demonstrated within a European context.

The mechanisms underlying these observed changes in bat activity were not directly tested in these studies; however, several explanatory hypotheses were proposed, including habitat loss — particularly of foraging areas (Barré *et al*., 2023; Tinsley *et al*., 2023), habitat alteration through increased structural clutter (Barré *et al*., 2023; Smallwood *et al*., 2022; Szoldatits *et al*., 2025), and habitat degradation via sensory pollution (Barré *et al*., 2023; Baudouin *et al*., 2026; Montag *et al*., 2016; Szabadi *et al*., 2023; Szoldatits *et al*., 2025; Tavernier *et al*., 2026; Tinsley *et al*., 2023). These mechanisms are explored further below in relation to landscape context, solar technology and installation type.

Habitat loss

During the early development of PV infrastructure, land management frequently involved extensive clearance, soil grading and compaction, and turfing to minimise maintenance requirements (Hernandez *et al*., 2014; Tyson, 2025). Although standard practices have since evolved to reduce ecological impacts and support dual-use systems such as agrivoltaics, most solar farms still require some degree of vegetation clearance and ongoing management. This is necessary to prevent shading of PV surfaces, maintain vehicle access, and enable the construction and operation of supporting infrastructure, particularly transformers, substations, site offices, inverter stations, and BESS, which are typically built on concrete foundations and often surrounded by cleared perimeters functioning as firebreaks. However, the proportion of sealed land at a typical solar farm has been estimated to lie between 0.8 and 1% of the total area (Peschel and Peschel, 2025).

Although the solar panel arrays themselves generally have a relatively small physical footprint, being mounted on steel piles driven into the ground, concrete pedestals are required in certain substrate conditions. Similarly, cabling infrastructure typically has low long-term vegetation impacts, as most cables are installed in trenches that are subsequently revegetated. Nevertheless, despite efforts by developers to minimise habitat loss, the construction phase can involve the permanent removal of scrub, shrubs, sections of hedgerow and/or trees, all of which may constitute important bat foraging and roosting habitats (WEST, Inc., 2017). While compensatory planting schemes are commonly implemented elsewhere on site, the effectiveness of such mitigation in maintaining local bat populations remains unverified, largely due to the absence of robust pre- and post-construction monitoring data.

Solar developments are frequently situated near trees, including ancient woodland, with often just the minimum 15 m buffer implemented (designed for tree root protection only). The current and future tree heights and conditions at each site are rarely considered during buffer design. This can result in direct degradation of irreplaceable bat habitat due to the requirement to manage or remove trees that begin to pose a risk to solar infrastructure or energy generation throughout the development's lifespan (Forestry Commission, 2025a). In a woodland context, felling or thinning of edge trees can have knock-on effects on the wider woodland habitat quality due to increased vulnerability to wind damage, deer browsing, soil loss, microclimatic alterations and wildfire spread (Forestry Commission, 2025b).

There are also indications of functional habitat degradation that extend beyond direct vegetation removal. Studies examining bat activity along field boundaries have reported lower activity levels for multiple species along solar field boundaries compared with reference site boundaries, even when compared to intensively farmed landscapes (Baudouin *et al*., 2026; Tavernier *et al*., 2026; Tinsley *et al*., 2023). Although this pattern may partially reflect the influence of adjacent solar infrastructure, it also indicates potential degradation of linear foraging habitat quality and connectivity, both of which are important components of bat commuting networks and foraging efficiency.

A potentially more significant source of foraging habitat loss arises from solar arrays altering the growing conditions beneath them through changes in sunlight exposure (full or partial shading throughout the day), local temperature regimes (cooler during the day and warmer at night), and rainfall distribution (sheltering beneath panels and concentrated runoff at lower panel edges) (Armstrong *et al*., 2016; Elamri *et al*., 2018; Gómez-Catasús *et al*., 2024; Vervloesem *et al*., 2022). These microclimatic changes may indirectly reduce bat activity via trophic cascades, through alterations to soil properties and reductions in plant biomass that support lower invertebrate abundance (Barré *et al*., 2023; Kocsis *et al*., 2025; Zitzmann *et al*., 2024); however, available evidence suggests that these relationships are more complex, context-dependent, and highly site-specific (Szoldatits *et al*., 2025; Tavernier *et al*., 2026; Tsafack *et al*., 2022).

Furthermore, 'heat island' effects are a microclimatic change associated with solar arrays that could directly affect bat insect prey (Fthenakis and Yu, 2013). The dark-coloured, low-reflectance PV panels readily absorb solar radiation during sunny days and then re-radiate heat, causing localised increases in air temperature (up to 18 m above and 300 m away from a solar farm perimeter), particularly during spring and summer evenings and nights with low wind speeds at large solar farms (Barron-Gafford *et al*., 2016; Fthenakis and Yu, 2013). These heat islands may attract some aerial insect species, increasing insect activity on and above the solar arrays (Horváth *et al*., 2019), particularly on cooler evenings when surrounding areas are less thermally favourable, as ectotherms rely on the external environment to regulate body temperature and thus metabolic activity (González-Tokman *et al*., 2020). Such effects may improve localised foraging opportunities for bats, but could also increase the risk of bat-panel collisions if close to the smooth surfaces (Greif *et al*., 2017). In addition, excessively high sustained temperatures and associated reduced humidity levels could potentially harm or deter insects (González-Tokman *et al*., 2020; Horváth *et al*., 2020); however, PV heat island effects are likely to be short-lived (Fthenakis and Yu, 2013). It has also been proposed that heat island effects associated with solar farms could increase the temperatures and evaporation rates of nearby wetlands and shallow water bodies if prolonged (Fthenakis *et al*., 2011), potentially lowering dissolved oxygen and water levels, and altering aquatic plant and insect communities (favouring stress-tolerant species), and the timing of their seasonal life-cycle events (González-Tokman *et al*., 2020). This could have secondary effects on bat species whose diets comprise a large proportion of aquatic insects, and raises concerns around pond creation as a biodiversity enhancement at solar farms. However, further research is required to characterise such risks, as a recent study discovered 'cool island' effects at large solar farms in arid regions during the daytime (Guoqing *et al*., 2021).

It is often assumed that where pre-construction field management supported higher-quality bat foraging habitat than post-construction management, reductions in open-habitat foraging activity are likely, and vice versa. For example, solar developments established on intensively farmed arable or brownfield sites are commonly expected to improve foraging habitat quality over time due to the cessation of chemical inputs and increased plant diversity (Foxley *et al*., 2023; Tinsley, 2024). These positive effects are predicted to be even more pronounced at ecovoltaic sites or developments incorporating extensive biodiversity enhancements into long-term management plans, where compliance is sustained (Szoldatits *et al*., 2025). This assumption is supported by a case study in South West England, where ditches bordering arable land supported very little wildlife. In contrast, those adjacent to solar fields were rich in biodiversity, including numerous invertebrate species and evidence of water vole, thought to result from reduced exposure to agricultural chemical runoff, particularly pesticides (Anonymous Submission; SEUK, 2025). Moreover, a monitoring project in Germany reported an overall positive effect of solar farms on bat activity, which was largely attributed to the absence of pesticides increasing the foraging resources at PV facilities; however, statistical analyses were not performed (Peschel and Peschel, 2025).

Pesticides not only deplete insect populations, but some can also directly harm bats via inhalation during night spraying, drinking water contamination, skin contact in roosts or biomagnification through their diet, potentially resulting in metabolic changes, endocrine disruption, genotoxicity, immunosuppression and organ failure at bioaccumulation sites (Oliveira *et al*., 2021; Russo *et al*., 2024; Sandoval-Herrera *et al*., 2021). While the cessation of pesticide use at solar sites is obviously beneficial to bats, this land management change does not eliminate the persistent organic pollutants already present in the environment (Schanzer *et al*., 2022). Additionally, PV panels can contain various hazardous chemicals, depending on the generation, such as lead, ethylene vinyl acetate, chlorofluorocarbons and flame retardants (first generation), and cadmium telluride and copper indium gallium diselenide (second generation). There is the potential for these components to leach into the surrounding environment if the modules become damaged (e.g. by acid rain or natural disasters) or are approaching their end-of-life (Anderson *et al*., 2025; Panthi *et al*., 2021; Zimmermann *et al*., 2013), which could have ecotoxic effects on bats and their prey. However, operational solar farms are associated with significantly lower levels of environmental pollution than fossil fuel power stations (Fthenakis *et al*., 2011).

Empirical evidence does not consistently support the assumption that habitat enhancement alone offsets the effects of solar infrastructure. There are currently no studies directly comparing bat activity at ecovoltaic sites and conventional PV developments, limiting the ability to evaluate the mitigation potential of biodiversity-focused design. A graduate research project at William & Mary University (Virginia) is currently addressing this gap by comparing bat activity at solar sites with and without pollinator habitat enhancements (Tyson, 2025). The species of wildflowers, location, season, size, structure and age of these enhancements should be considered in monitoring studies, as these are likely to influence the number of crepuscular and nocturnal insects they support. Additionally, wildflower fields bordering hedgerows have been found to attract more bats than those without hedgerows, irrespective of insect abundance (Peter *et al*., 2025). Such synergistic habitat enhancements should therefore be incorporated into solar farm design. Interestingly, Szabadi *et al*. (2023) recorded similar bat activity levels at conventional solar farms and arable fields across species, suggesting that either foraging habitat quality is not substantially improved at many solar sites or that other factors counteract any habitat gains. Similarly, Tavernier *et al*. (2026) reported higher bat activity in intensively managed grasslands than within solar fields, further indicating that drivers beyond habitat quality alone may be influential.

This interpretation is supported by Griffin *et al*. (*in prep*.), who measured bat activity at the same sites before and after the installation of a model solar farm and recorded significant species-specific increases and decreases in activity both within fields and along boundaries, despite identical foraging habitat conditions. As all other variables were controlled or accounted for, this indicates that the solar arrays themselves were driving behavioural changes. However, this study captured only immediate responses (0–4 days post-installation), and some degree of habituation is likely to occur at operational sites over longer timescales.

There is also limited research examining changes in prey availability and bat activity associated with transitions in grazing regimes, particularly the shift from cattle to sheep grazing that occurs at many solar developments (Tinsley, 2024). Cattle-grazed pasture is known to be a valuable bat foraging habitat, particularly for *Eptesicus serotinus*, *Pipistrellus spp.* and *Myotis spp.* (Ancillotto *et al*., 2017; Downs and Sanderson, 2010). Furthermore, Szabadi *et al*. (2025) reported *Pipistrellus kuhlii/nathusii* activity to be significantly higher on cattle farms than on horse farms in Hungary, potentially due to differences in insect densities associated with their manure and housing. Sheep have been found to attract fewer biting midges than cattle (Ayllón *et al*., 2014); in contrast, sheep dung can attract a greater number of beetles than cattle dung and tends to decompose more slowly (Dormont *et al*., 2007; Finn and Giller, 2002; Wiesinger and Suarez-Rubio, 2026). Additionally, grazing behaviour and diet composition differ between cattle and sheep, producing contrasting vegetation structures, which could subsequently shift the insect assemblages available (Fraser *et al*., 2022). For example, greater floral resources and pollinators are associated with cattle grazing (Cutter *et al*., 2022). A recent study on sheep grazing in Austria found the activity of small bat species (*Pipistrellus* spp. and

Hypsugo savii) to be higher in grazed pastures compared to pre-grazed pastures, which was attributed to specific changes in habitat structure and prey species. Interestingly, they recorded *Nyctalus noctula* activity to be significantly higher in post-grazed pastures than pre-grazed pastures, possibly due to peaks in coprophilous Diptera species associated with older dung (Wiesinger and Suarez-Rubio, 2026). From these studies, it is plausible that a transition from cattle to sheep grazing could lead to a shift in bat community composition, but there is no research that tests this directly.

Changes to grazing regimes can also have implications for parasitic infections, and thus parasite treatment and ecotoxic residues. For example, isolated sheep grazing is associated with higher endoparasite loads compared to mixed or alternate grazing with cattle and cattle alone (Brito *et al*., 2013; Mahieu and Aumont, 2009; Wiesinger and Suarez-Rubio, 2026). Parasiticide-treated sheep's dung can have lethal and sub-lethal effects on a range of invertebrate species, therefore either depleting food resources or presenting possible bio-magnification risks to bats (Beynon, 2012; McCracken, 1993). While the lower sheep grazing intensities often adopted at solar farms might help control the spread of parasites, they could also reduce the abundance of parasitic insects available to bats (Ayllón *et al*., 2014). However, heavy sheep grazing can negatively impact numerous insect species due to habitat degradation (Fraser *et al*., 2022; Ma *et al*., 2017; Tsafack *et al*., 2022); therefore, a shift towards less-intensive grassland management is likely to benefit insects and bats overall.

Bat responses to solar farmland management appear to be species-specific and mediated by foraging strategy. Baudouin *et al*. (2026) found that sheep grazing benefited *Plecotus austriacus*, whereas *P. kuhlii* activity was higher at mechanically mown solar sites, likely reflecting differences in prey selection and hunting behaviour. They also reported a negative relationship between mid-range echolocator activity and vegetation height, suggesting that some grassland 'enhancement' measures currently implemented at solar farms may not benefit all bat guilds. In contrast, a study on a UK university campus recorded significantly higher total bat activity and species richness over a meadow compared to a lawn until the meadow was mown. Species-specific differences in grassland preference were also apparent, with *E. serotinus*, *Pipistrellus pipistrellus* and *Plecotus auritus* more abundant over the meadow, and *Nyctalus leisleri*, *N. noctula* and *P. nathusii* more strongly associated with the lawn, highlighting further land management sensitivities (Marshall *et al*., 2023). Collectively, these findings suggest that uniform management prescriptions are unlikely to support bat diversity effectively. Instead, solar farm designs that support structurally diverse habitats, incorporating varied vegetation structure, management regimes, and microhabitat features, are more likely to support multi-species assemblages and diverse foraging strategies.

Barré *et al*. (2023) specifically examined bat foraging behaviour at solar farms and found that several taxa flew faster and straighter and emitted fewer feeding buzzes at solar fields than at control sites, indicating lower foraging habitat quality, potentially linked to reduced prey biomass. In contrast, Tinsley (2024) reported that, except for Coleoptera (likely dominated by diurnal taxa), there was no overall difference between solar farms and paired control fields in the abundance of invertebrate species that are likely to be of value to bats. Similarly, Tsafack *et al*. (2022) found that solar farms did not affect the average abundance of tenebrionid beetles collected in pitfall traps compared to control fields in

China. Interestingly, the solar sites reduced the dominance of the most abundant species, leading to higher beetle diversity and a more balanced community structure. This effect was attributed to higher plant biomass and cooler temperatures at the solar farms compared to the exposed control sites. However, the experiment took place within a desert steppe ecoregion; therefore, such findings may not apply across species and climate zones. These studies suggest that prey availability may not be a primary driver of reduced bat activity, although the insect sampling methodologies, research locations and survey protocols likely influenced the outcomes.

Conversely, a recent study in the Netherlands used emergence traps to survey soil-emergent arthropods at solar farms and found that solar fields supported lower abundance and richness of Diptera than both intensive and extensive grasslands (Kocsis *et al*., 2025). Given that Diptera form a substantial component of the diet of many bat taxa (Tinsley, 2024), this reduction could influence bat foraging activity at solar sites. However, while overall arthropod biomass was significantly lower at solar fields than at extensive grasslands, it was similar to that recorded at intensive grasslands (Kocsis *et al*., 2025), mirroring the comparable bat activity levels observed by Szabadi *et al*. (2023) at solar and arable sites. Furthermore, Zitzmann *et al*. (2024) almost exclusively recorded common generalist carabid beetle species at solar farms in Germany and rarely sampled species of conservation concern. They also recorded spatial differences in carabid species richness and activity density across solar farms, with pitfall traps under solar panels collecting significantly fewer species and individuals than traps installed within inter-row spaces and at the edges of solar farms. This may have implications for bat foraging opportunities (particularly gleaning species) and solar farm design, with densely packed arrays spanning entire fields likely less favourable.

Methodological constraints complicate interpretation of these findings. Insect monitoring studies often group taxa at the order or family level, making it difficult to determine whether statistically significant differences between sites reflect changes in prey species important to bats. This limitation is particularly relevant where traps operate across both diurnal and nocturnal periods, as in the studies by Kocsis *et al*. (2025), Tinsley (2024), Tsafack *et al*. (2022) and Zitzmann *et al*. (2024). Additionally, the majority of invertebrate studies at solar farms have focused solely on diurnal species (Blaydes *et al*., 2024; Lec'Hvien *et al*., 2025; Parker and McQueen, 2013; Peschel and Peschel, 2025; SEUK, 2025; Walston *et al*., 2023); for example, although Montag *et al*. (2016) recorded a significantly higher abundance of diurnal invertebrate pollinators at solar plots compared to control plots, it is not known whether this trend translates to nocturnal species.

A project involving nocturnal insect monitoring at a solar farm is currently in development, which should provide improved resolution on bat-relevant prey availability. This research, conducted by the University of Exeter in collaboration with RSK Biocensus and funded by EDF Power Solutions, aims to assess the broader impacts of solar developments on a range of biodiversity receptors. As part of the project, an experimental study is planned to evaluate diurnal and nocturnal pollinator behavioural responses to various planting approaches within a simulated ground-mounted solar farm, equipped with low-light cameras. This experiment will specifically examine whether panel-driven shading, temperature and moisture gradients create a microclimate with distinct vegetation and pollinator communities, with potential knock-on effects for predators such as bats.

Overall, the current evidence suggests that even where total prey abundance is similar between solar farms and control sites, PV infrastructure may alter the spatial arrangement and accessibility of nocturnal insects, potentially reducing the functional quality of foraging habitat for bat species (Barré *et al.*, 2023; Tinsley, 2024). Interestingly, WEST, Inc. (2017) proposed that aerial insects may accumulate on the leeward sides of PV arrays on windy nights, as panels could provide shelter analogous to hedgerows and trees, potentially creating exploitable foraging opportunities for bats, particularly clutter-adapted species (H.T. Harvey and Associates, 2013); however, this effect has not yet been empirically tested. Artificial light at night (ALAN) at solar facilities may also attract insects that could be exploited by light-tolerant bat species, but light-averse species are negatively affected by illumination. As a result, ALAN is typically minimised at most solar developments, limiting its potential role as a consistent foraging resource.

Szoldatits *et al*. (2025) highlighted the importance of temporal dynamics in relation to foraging habitat, showing that ecovoltaic sites in the USA supported the highest bat activity earlier in the season (May–June) compared to paired arable fields. This pattern was attributed to limited prey availability in the surrounding landscape and the elevated energetic demands of pregnant and lactating bats during this period. This is supported by Heim *et al*. (2016), who recorded lower bat activity over arable fields in Germany during the lactation period. In contrast, Tavernier *et al*. (2026) recorded consistently lower bat activity and occurrence in solar fields than in intensive and extensive grasslands across all temporal scales measured, including seasonal comparisons. However, most studies have been unable to robustly assess seasonal variation due to limited survey duration and temporal coverage. For example, Barré *et al*. (2023) were constrained to nine nights of monitoring in late September, substantially limiting the generalisability of their findings across seasons. In addition, within-night temporal patterns have rarely been examined, and some studies only recorded bats for a short period each night. For example, Szoldatits *et al*. (2025), Barré *et al*. (2023), and Szabadi *et al*. (2023) recorded bat activity during a two-, three- and four-hour window each night, respectively, which may have influenced species detection and activity estimates. These limitations highlight the importance of extended surveys that span entire seasons and nighttime periods to capture temporal variation in bat responses to solar developments.

Habitat alteration: increased clutter

Ground-mounted PV developments introduce substantial structural clutter into previously open environments. This includes the entire physical footprint of a solar facility, such as security fencing, transmission lines and buildings (substations, transformers, site offices and BESS), alongside extensive arrays of PV panels mounted on frames and their associated inverters (Smallwood, 2022). These elements can modify bat foraging and commuting habitats by obstructing vegetation, creating physical barriers to movement, disrupting established flight paths, and posing a collision risk (Barré *et al*., 2023).

There is evidence that such infrastructure can result in direct injury and mortality. For example, *Miniopterus orianae bassanii* juveniles have been recorded with broken bones following collisions with metal fencing near roost exits (Ingeme *et al*., 2018), and a subsequent study identified trauma from roost-associated fencing and infrastructure strikes as the most common cause of death in this species (Holz *et al*., 2020). Collision risks also appear to extend beyond roost-adjacent infrastructure and across species. Smallwood (2022) estimated that perimeter fencing accounted for approximately 20% of bat fatalities at solar projects in California, equating to 2.56 bats per kilometre of fencing per year, or an estimated total of 2,304 bat fatalities annually. *Parastrellus hesperus* was noted as being particularly vulnerable to fencing fatalities. Similarly, monitoring at a newly constructed utility-scale PV development recorded bat carcasses of four different species associated with perimeter fencing, a transmission tower, and buildings, which were attributed to collision events (WEST, Inc., 2017), although no further carcasses were detected during subsequent surveys at that site or two additional solar developments.

Perimeter fencing at PV facilities is typically at least two metres high to exclude large mammals such as deer, placing it within the flight height of many bat species. Where developments span multiple fields, fencing may intersect hedgerows perpendicularly, creating barriers across established foraging and commuting routes and increasing collision risk. Although most fences are likely detectable by bats and may be learned and avoided over time, enforced alterations to flight paths impose energetic costs and may reduce route efficiency or deter use of traditional corridors due to increased navigational complexity.

While bat carcasses are rarely associated with large static structures such as pylons and radio masts, and insectivorous bats are not considered at risk of electrocution from power lines (Smallwood, 2022), transmission infrastructure and associated guy wires nonetheless represent potential collision hazards for bats moving through landscapes surrounding solar farms (WEST, Inc., 2017).

Within the interior of PV facilities, solar array structures may also disrupt bat movement, potentially deterring bats from foraging within fields, commuting across sites, or using boundary features (Tinsley *et al*., 2023). However, the influence of arrays is highly configuration-dependent, with substantial variation across developments in height, tilt angle, inter-row spacing, spatial arrangement and proximity to boundary features, each of which may differentially affect bat movement through solar farms (Barré *et al*., 2023).

Greater distances between panel rows are expected to facilitate bat movement by reducing structural clutter and increasing available foraging space, thereby encouraging bats to fly between rows (Benbouzid and Simon, 2025; Zitzmann *et al*., 2024); however, this assumption remains untested, and the inter-row spacing of study sites is rarely reported in the literature (Baudouin *et al*., 2026; Montag *et al*., 2016; Szabadi *et al*., 2023; Szoldatits *et al*., 2025; Tavernier *et al*., 2026; Tinsley *et al*., 2023). Similarly, plans for occasional wider gaps between arrays, intended to function as biodiversity corridors through solar farms (Anonymous Submission), are yet to be examined. In addition, increasing the distance between arrays and field boundaries is frequently recommended as a mitigation measure to maintain bat activity along linear landscape features (Forestry Commission, 2025a; Montag *et al*., 2016; Taylor *et al*., 2019), yet there is currently little evidence to define optimal buffer distances or to demonstrate their effectiveness. Unlike small-scale (<9 m^2) permitted solar installations, there is no minimum boundary setback distance imposed for solar farms (DCLG, 2012), despite at least 70% of solar sites in Great Britain containing hedgerows (Wilfred *et al*., 2026). Boundary buffer and inter-row distances are highly variable across solar farms, but are generally dominated by designs that maximise energy generation while accommodating maintenance vehicle access and cable trenches, rather than those that prioritise ecological receptors.

One study that measured bat activity along solar farm boundaries reported significantly lower activity in four taxa compared with matched control boundaries, but did not assess the influence of different field-margin widths. This suggests either an effect of the nearby arrays on bat behaviour or a reduction in the functional quality of boundary habitats at solar sites, despite their structural similarity to control features (Tinsley *et al*., 2023). In contrast, an experimental study comparing two buffer distances (10 m and 20 m) between a model solar installation (24 panels arranged in a 6 × 4 grid) and a field boundary found that most bat species' activity along the boundary did not differ significantly from baseline levels under either distance treatment. However, two taxa (*P. pipistrellus* and *Plecotus* spp.) showed increased activity at the boundary and concurrent decreases above the solar panels, irrespective of buffer distance, indicating a potential displacement effect caused by the presence of the panels rather than buffer width (Griffin *et al*., *in prep*.). At operational solar farms, this displacement may be amplified due to the absence of surrounding open-field habitat into which bats can redistribute.

This is supported by a Welsh monitoring case study that recorded lower bat activity within a solar farm and higher activity in adjacent fields after construction relative to pre-construction levels, suggesting possible displacement effects, although no statistical analyses were conducted. Similarly, Baudouin *et al*. (2026) found that the activity of 9 of 14 species negatively correlated with distance from the solar farm fence (i.e. activity declined towards the centre of solar farms), potentially reflecting increasing array density and greater distance from high-quality surrounding habitats. However, this pattern was not assessed relative to boundary proximity in paired control fields, meaning it may also reflect natural differences in bat activity between edge and open habitats rather than a solar-specific effect.

The effects of artificial structural clutter introduced by PV infrastructure are likely to be strongly species-specific. For passive listening or gleaning species, it is possible that solar arrays could block vegetation beneath panels, potentially reducing prey signal reception, accessibility and foraging efficiency, and deterring use of solar farms where accessible vegetation is of low foraging quality (Zitzmann *et al*., 2024). For example, PV panels negatively impacted *Plecotus* spp. activity in open fields but not at boundaries in Tinsley *et al.*'s (2023) study. Similarly, for low-flying aerial hawking species, the physical clutter created by panel arrays may impede manoeuvrability and prey capture in flight (Barré *et al*., 2023; Tinsley, 2024). In contrast, high-flying species are less likely to be directly impacted by solar infrastructure. This is supported by Baudouin *et al*. (2026) and Szabadi *et al*. (2023), who found no differences in *Nyctalus* spp. activity between solar farms and surrounding open habitats; however, Tinsley *et al*. (2023) recorded significantly lower *Nyctalus* spp. activity at solar farms compared to control sites.

Experimental evidence supports the importance of panel surface properties as well as structure and deployment. Griffin *et al*. (*in prep*.) recorded a gleaning species group (*Plecotus* spp.) exhibiting similar activity levels under control conditions and when exposed to solar panels with textured surfaces, whereas activity declined significantly following the introduction of smooth-surfaced panels. This indicates that the panel structures themselves did not act as a strong physical barrier; rather, the behavioural response was specifically associated with surface smoothness. This is likely because *Plecotus* spp. have relatively good vision and can fly low and slowly, enhancing navigation around the panel structures, whereas their sensitive hearing may have increased their vulnerability to acoustic interference from the smooth surfaces (Coles *et al*., 1989; Eklöf *et al*., 2014).

In contrast, Griffin *et al*. (*in prep.*) found two edge-habitat hawking species to show increased activity under solar panel treatments relative to baseline, with panel texture influencing only one of them. As these responses occurred immediately after panel installation, they may reflect short-term responses to novel stimuli; however, they also suggest that solar arrays may function as a form of artificial edge habitat that is tolerated, or even exploited, by some taxa. This is partially supported by Baudouin *et al*. (2026), who reported a positive correlation between mid-range echolocator activity and solar panel coverage (i.e. solar farm size); however, this relationship may have been influenced by the surrounding landscape composition associated with larger developments. They also found no difference in short-range echolocator activity between solar farm cores and surrounding habitats, possibly reflecting their adaptation to navigating complex environments. Meanwhile, Szoldatits *et al*. (2025) recorded comparable or elevated activity across a range of bat guilds at solar farms compared to reference sites; however, their study was restricted to solar farms with habitat enhancements.

Field observations further indicate that structural clutter may not universally deter bat use of solar farms. For example, using thermal imaging, Griffin (*in prep*.) recorded *Pipistrellus* bats frequently flying between rows of solar panels assembled in fields. Additionally, GPS tracking of *R. ferrumequinum* in Devon showed that more than 30% of the recorded locations of two individuals occurred within an operational solar farm (Billington, 2020). Similarly, a tracking study in Wiltshire found that two *R. ferrumequinum* repeatedly visited a solar farm over several nights, with multiple GPS locations recorded within the solar arrays; however, both individuals spent more time overall in an adjacent grassland field (Foxley *et al*., 2025). As *R. ferrumequinum* is a low-flying species that employs both aerial hawking and gleaning foraging strategies, these observations suggest that the structural complexity associated with solar arrays does not necessarily act as a barrier to movement or foraging. Instead, in some contexts, it may increase habitat use through the provision of shelter in previously open fields.

However, the majority of broader comparative studies consistently report reduced activity of lower-flying, edge-associated or clutter-adapted species within the centres of conventional solar farms relative to control sites (Baudouin *et al*., 2026; Szabadi *et al*., 2023; Tavernier *et al*., 2026; Tinsley *et al*., 2023), with some taxa also shifting towards faster, straighter commuting flight patterns, potentially reflecting obstacle avoidance behaviour (Barré *et al*., 2023). Comparative measurements of flight height distributions at solar farms and in open fields would therefore provide valuable insight into whether bats are vertically redistributing their flight paths to avoid solar infrastructure, helping to distinguish between behavioural adaptation, spatial displacement, and reduced functional availability of foraging and commuting habitat. Such studies should control for species and habitat characteristics, as these strongly influence bat flight behaviour (O'Malley *et al*., 2025). For example, solar farms with lower boundary heights may encourage lower flight trajectories, increasing interactions with solar arrays (particularly where field margins are narrow); however, this hypothesis remains untested.

Interestingly, Montag *et al*. (2016) proposed that solar arrays could function as navigational features for bats in a manner similar to linear landscape elements such as hedgerows, but noted that it may take several years for the effects of such habituation to become apparent due to the relatively long lifespans of bats. Evidence for this hypothesis is currently limited. Baudouin *et al*. (2026) reported indications of habituation in some edge-habitat specialists (mid-range echolocators) inferred from comparatively higher activity levels at older solar farms; however, flight paths were not tracked, the observed relationships were correlational, and all sites were less than eight years old, constraining inference about long-term behavioural adaptation. In contrast, a German monitoring study concluded that the age of the 14 solar facilities surveyed did not influence the attractiveness to bats; however, statistical analyses were not performed (Peschel and Peschel, 2025).

There is also potential for elements of solar infrastructure (e.g. substations) to provide roosting opportunities, which could locally elevate activity levels of certain species; however, this remains largely untested. Given that utility-scale PV developments are relatively recent, particularly in the UK, where most sites are <15 years old and systematic bat monitoring at solar farms has only become more common since the early 2020s, it is currently too premature to draw any conclusions regarding habituation processes or long-term ecological effects.

Habitat restoration and creation measures implemented at solar sites require substantial time to establish and mature into complex functional ecosystems capable of delivering biodiversity benefits. Long-term, standardised monitoring is therefore essential to evaluate species-specific changes in bat activity, behaviour, and distribution across the operational lifespan of PV developments (25–40 years) and post-decommissioning (where applicable), as well as to detect any population-level trends associated with cumulative bat-solar interactions and collision risk (Karban *et al*., 2024; Tinsley *et al*., 2024).

Habitat degradation: sensory pollution - smooth surfaces

Smooth surfaces are rare in natural environments; consequently, the introduction of artificial smooth materials such as glass, cladding, sheet metal and PV panels represents a novel sensory challenge for wildlife. One of the few naturally occurring smooth surfaces is still water. Bats have evolved to locate drinking sites using the acoustic signature of calm water surfaces, which generate distinctive echo patterns. Experimental and field studies have demonstrated that bats can misidentify artificial smooth horizontal surfaces (e.g. plastic, metal and polished wood) as water due to the similarity in reflected echoes (Greif *et al*., 2017; Greif and Siemers, 2010; Rahman *et al*., 2024; Russo *et al*., 2012). For example, Russo *et al*. (2012) observed bats repeatedly attempting to drink from a Perspex sheet placed over part of a natural water source before eventually accessing the uncovered area or abandoning the site. This behaviour has been shown to be driven by acoustic cues rather than learned association, as adding surface texture eliminates the response (Rahman *et al*., 2024), and bats have attempted to drink from smooth horizontal plates in dark laboratory conditions (Greif *et al*., 2017; Greif and Siemers, 2010).

Ensonification experiments (artificially generating ultrasound and analysing the returning echoes) further demonstrate that the acoustic reflections from smooth artificial surfaces are virtually indistinguishable from those of still water (Greif and Siemers, 2010). Such surfaces can therefore function as sensory traps, potentially increasing energetic costs, disrupting normal foraging and drinking behaviour, and elevating collision risk (Greif *et al*., 2017).

Whether solar panels elicit similar responses in bats remains poorly understood. Because most PV panels are installed at a fixed, inclined and south-facing angle to maximise solar gain, it has been argued that the risk of misidentification as water is low, as the surfaces tested in the above studies were all horizontal and still water surfaces are typically the same (Peschel and Peschel, 2025; Taylor *et al*., 2019). However, Griffin *et al*. (*in prep*.) recorded a significant increase in activity of species associated with aquatic habitats, *P. pygmaeus*, above smooth-surfaced solar panels tilted at 35°, compared to textured panels and control treatments. While this response may indicate acoustic misclassification of the panels as water surfaces, potentially triggering approach behaviour in search of aquatic prey, indirect effects via insect attraction to the panels cannot be excluded (Horváth *et al*., 2010). Importantly, solar tracking systems are usually positioned horizontally at night (Baudouin *et al*., 2026), theoretically increasing the likelihood of water-mimicry effects and drinking attempts. Griffin *et al*. (*in prep*.) also filmed bats interacting with both tilted (35°) and horizontal panels in a field experiment, although no drinking attempts were recorded; interpretation is limited by small sample sizes and ongoing footage analysis. FPV systems may present a higher theoretical risk, as panels are typically installed horizontally or at shallow inclines and directly overlay water bodies, potentially both mimicking water surfaces and obscuring genuine drinking resources. However, at present, there is no evidence demonstrating such effects.

Static artificial smooth surfaces can also increase collision risk for bats because they act as acoustic mirrors through specular reflection, whereby most of the returning sound energy is reflected away in a single, concentrated direction. This contrasts with diffuse reflection from textured surfaces, where sound scatters in multiple directions and a portion of the echo returns to the emitter. Because the angle of reflection equals the angle of incidence, a bat approaching a smooth surface at an acute angle may receive little or no echo from its own call, as the reflected sound is directed away. This loss of acoustic feedback can cause smooth surfaces to be perceived as open, unobstructed airspace, increasing the likelihood of collision. Laboratory experiments using a smooth vertical metal plate recorded 78 collision or near-collision events, particularly when bats emitted fewer calls on approach (Greif *et al*., 2017). Field experiments produced similar results, with 23 collisions recorded with a smooth vertical plastic plate and none with a textured control surface (Greif *et al*., 2017). PV panels are typically installed at inclined rather than vertical angles, which may reduce this collision risk. However, Ingeme *et al*. (2018) documented juvenile *Miniopterus orianae bassanii* colliding with a smooth metal surface positioned at a 45° angle, indicating that inclined smooth surfaces can still present a collision hazard, particularly for inexperienced individuals. It is important to note that both these field trials were conducted in close proximity to roost exits, where bat densities and flight speeds are usually high and pre-established emergence paths may be followed with less vigilance of novel objects, meaning sonar jamming and collision risk could have been elevated relative to typical foraging or commuting environments, and therefore may not be directly representative of wider landscape-scale risk (Bollinger, 2021; Grodzinski *et al*., 2009). Solar arrays are unlikely to be located in proximity to bat roosts; consequently, bats may have a greater ability to detect the panels and adjust their flight paths before collision.

Szabadi *et al*. (2023) suggested that the less reflective rear surfaces of conventional PV panels may provide sufficient acoustic cues for orientation, although this mitigation mechanism does not apply to bifacial panels or dual-tilt arrangements. This interpretation is partially supported by Griffin *et al*. (*in prep*.), who filmed bats interacting with solar panels tilted at 35° in a field experiment and, to date, have not detected any direct collisions, though the footage is still being analysed. However, when panels were positioned adjacent to a linear feature, several 'near-collision' events were observed, in which a low-flying species with a highly directional call approached within centimetres of the panel surface before abruptly manoeuvring away. This behaviour was attributed to impaired acoustic detection during oblique approach, with reliable echo information only becoming available once the bat was perpendicular to the panel surface.

Importantly, Griffin *et al*. (*in prep.*) cleaned their solar panels (with unscented washing-up liquid) before every treatment to ensure surface texture consistency, whereas operational solar developments in the UK typically clean their PV arrays infrequently, usually no more than one to two times per year. This practice reflects the expectation that rainfall, and, in rare cases, self-cleaning surface coatings, will remove most loose debris (Anonymous solar developers, *pers. comm.*, 2025–26; Mozumder *et al*., 2019). Nevertheless, soiling can accumulate over time, particularly in the form of bird droppings and biofilms, which may increase surface roughness and thus the detectability of solar panels during the pre-cleaning period. This implies that acoustic interference associated with solar farms may remain relatively low in dusty or high-soiling environments until cleaning occurs; however, this has not been empirically tested. In practice, developers typically remove any accumulated debris that measurably reduces energy yield. Additionally, it has been argued that solar panel surfaces are not as smooth as often assumed, owing to the micro-scale irregularities of tempered glass and the presence of surface coatings, which could modify their acoustic properties (Peschel and Peschel, 2025; Rahman *et al*., 2024). However, these surface features are typically engineered at sub-wavelength scales to enhance optical transmission and are therefore orders of magnitude smaller than the wavelengths of sound used in bat echolocation (Mozumder *et al*., 2019). As a result, they are unlikely to produce meaningful acoustic scattering within the biologically relevant frequency range (Smotherman *et al*., 2022).

Beyond these studies, there is limited empirical research assessing bat collision risk with solar panels at operational pitch angles and heights, and systematic bat carcass monitoring at PV facilities remains uncommon, particularly in the UK (Conkling *et al*., 2023; Smallwood, 2022). This is largely because PV-related bat mortality has not been established as a significant risk pathway, especially when compared to mortality associated with CSP facilities and wind farms (Smallwood, 2022; Thaxter *et al*., 2017). One project that conducted systematic carcass searches at a PV development in the USA found no carcasses within the solar arrays themselves, although four were recorded in association with surrounding infrastructure, potentially reflecting proximity to key bat habitats (WEST, Inc., 2017). However, carcass-based evidence must be interpreted cautiously, as scavenging, carcass relocation and post-injury movement can substantially bias mortality estimates and spatial attribution (Conkling *et al*., 2023; Manville, 2016). Another multi-site study in California estimated a mean mortality rate of only 0.06 bats/MW/year attributable to PV arrays across 11 installations (Smallwood, 2022); however, the increasing deployment of bifacial, dual-tilt and vertical PV systems may plausibly elevate future collision risk, indicating a need for proactive assessment and monitoring (Badran and Dhimish, 2024).

Even if the risks of bats mistaking solar panels for water or colliding with them are low at conventional PV developments, the installation of extensive areas of artificial smooth surfaces in rural landscapes introduces large-scale novel acoustic clutter that may generate orientation and foraging challenges for bats (Barré *et al*., 2023; Montag *et al*., 2016). When bats approach smooth surfaces perpendicularly, their echolocation calls are reflected directly back with high intensity. These strong returning echoes can mask or interfere with biologically relevant acoustic cues, including object and prey echoes, prey- or predator-generated sounds and conspecific social calls. This effect is likely to be amplified in multi-individual flight contexts, where numerous high-intensity reflections from different bats may overlap, increasing acoustic 'noise' and reducing signal discrimination. Such clutter echoes could also exacerbate collision risks; however, bats have evolved several strategies to reduce acoustic masking and operate in noisy environments (Corcoran and Moss, 2017).

Solar arrays installed at shallower tilt angles (e.g. at lower latitudes or where space constraints favour reduced inter-row shading) or horizontally present a larger area of exposed smooth surface to bats flying above them, potentially intensifying acoustic interference effects. This provides a plausible mechanism for the lower bat activity recorded at solar farms using single-axis tracker systems compared to fixed-tilt systems, as trackers are typically stowed horizontally at night (Baudouin *et al*., 2026). Meanwhile, panels installed at steeper tilt angles and oriented towards linear features may increase the potential for acoustic disturbance to bats using these habitats, depending on buffer distances and species-specific call propagation and hearing ranges. Further research is required to characterise the spatial extent of these effects.

Species with highly sensitive auditory systems, particularly those that employ passive listening or low-intensity echolocation strategies, may be especially vulnerable to acoustic masking effects. This may explain why Griffin *et al*. (*in prep*.) recorded significantly fewer *Plecotus* spp. calls in the presence of smooth-surfaced solar panels compared to textured panels and baseline conditions, suggesting either behavioural avoidance or a switch to passive listening to reduce disruptive echo interference. Similarly, Barré *et al*. (2023) documented reduced foraging behaviour at solar farms across multiple species, characterised by faster, straighter flight paths and fewer feeding buzzes. These behavioural changes may reflect impaired prey detection and reduced foraging efficiency caused by acoustic interference from solar infrastructure, rather than reduced prey availability (Tinsley, 2024). Consequently, solar fields may predominantly function as commuting corridors rather than functional foraging habitats, representing a form of behaviourally mediated functional habitat loss rather than direct habitat removal.

Collectively, these characteristics suggest that solar farms may constitute acoustically complex and potentially confusing environments for many bat species, encouraging avoidance of array areas in favour of more acoustically familiar habitats in the surrounding landscape (Montag *et al*., 2016). Whether the effects of this form of habitat alteration persist even where high-quality foraging habitat is introduced or retained within solar fields remains uncertain and requires further investigation. Although ecovoltaic sites have been shown to support higher bat activity than row-crop agricultural fields (Szoldatits *et al*., 2025), intensively managed grasslands have still been found to support higher activity levels than solar fields (Tavernier *et al*., 2026). This contrast suggests that habitat enhancement alone may not be sufficient to offset the ecological effects of solar infrastructure, and that structural and sensory components of PV facilities may continue to constrain bat activity even in otherwise improved foraging environments. Enhancing connectivity to more favourable alternative foraging habitats (e.g. wildflower fields without solar panels) within the site footprint and surrounding landscape may therefore help compensate for this (Peter *et al*., 2025).

Habitat degradation: sensory pollution — artificial and polarised light

Although sensitive lighting regimes are usually employed at PV developments, any external nighttime security or amenity lighting, particularly if not sensor-operated, could deter light-averse bat species (Stone *et al*., 2015). Overall illumination may increase if the lighting is directed upwards or at reflective surfaces such as solar panels. In addition, such lighting can act as a sensory trap by attracting positively phototactic flying insects, which light-tolerant bat species may exploit (Voigt *et al*., 2021). While this may create temporary foraging opportunities, it might also increase the risk of bats colliding with solar infrastructure (e.g. fencing) and contribute to long-term population-level impacts on phototactic insect communities (WEST, Inc., 2017).

Light interactions with solar panels may also pose additional challenges for bats. Most solar panels reflect horizontally polarised light to an equal or greater extent than water surfaces, particularly at dusk and dawn, when both insects and bats are most active (Horváth *et al*., 2010; Takács *et al*., 2024). This phenomenon, termed ‘polarised light pollution’ (PLP) or the ‘lake effect’, can cause positively polarotactic aquatic/aquatic-associated insects to mistake solar panels for water surfaces, encouraging landing and oviposition, even when panels are angled (Horváth *et al*., 2009; Horváth *et al*., 2020; Kriska *et al*., 2008). Preferential attraction to artificial surfaces that polarise light within the ultraviolet range has also been documented for certain insect species (Fraleigh *et al*., 2021). PLP vulnerable taxa, including Diptera, Ephemeroptera, Trichoptera, Odonata and Coleoptera (Farkas *et al*., 2016; Fraleigh *et al*., 2021; Horváth *et al*., 2010; Horváth *et al*., 2014) form a substantial component of the diets of many UK bat species (Vaughan, 1997; Tinsley, 2024).

Potential consequences of this sensory trap include adult insect mortality, inviable eggs, and longer-term population declines, with indirect knock-on effects for bats (Takács *et al*., 2024). However, evidence supporting these outcomes remains limited (Gómez-Catasús *et al*., 2024). For example, Tinsley (2024) found no significant differences in aquatic insect abundance or richness between solar farms and reference sites; however, insects were surveyed using ground-based Malaise traps rather than from above or directly on panel surfaces, meaning PLP attraction was not directly measured (Tinsley, 2024). Although the sites in Tinsley's (2024) study were not located near major freshwater habitats, it should be noted that the attraction radius to PLP sources can be relatively large for strong-flying species (Buglife, *pers. comm.*, 2025). Therefore, proximity to freshwater is not necessarily a prerequisite for aquatic insects to be relevant disturbance receptors at PV developments.

Tinsley (2024) argued that the consistently low bat activity recorded at many solar farms implies that associated polarised light pollution (PLP) is not creating a significant feeding resource for bats, potentially because other factors (e.g. electromagnetic fields (EMFs), microclimatic change and habitat alteration) are reducing insect populations and overriding any attraction effects. However, most studies to date have focused on solar sites that have been operational for several years, meaning that any PLP-induced insect population declines may already have occurred, thereby masking earlier attraction effects and contributing to reduced bat activity.

This interpretation is supported by Griffin *et al*. (*in prep*.), who recorded significantly higher *P. pygmaeus* feeding buzz activity above smooth solar panels compared to textured panels and baseline (no panel) conditions. This response may reflect attraction to aquatic insects drawn to smooth panel surfaces, which form a substantial component of *P. pygmaeus'* diet. In contrast, the textured and baseline conditions did not generate PLP. Although insect activity was not measured directly in this experiment, it is unlikely that bats would exhibit increased feeding buzzes in the absence of increased prey availability. Importantly, the solar panels were assembled immediately after the baseline condition at the same location and were not connected to any electrical components, meaning there were no EMFs, noise, significant microclimatic changes or habitat alterations that could have influenced insect activity; thus, the smooth surfaces were driving the response in isolation. This supports the interpretation that additional operational variables at active solar farms may subsequently modify bat-prey dynamics and potentially suppress these initial attraction effects. It would be helpful to measure the polarised light levels and air temperatures in conjunction with bat and insect activity, or only record bat activity during complete darkness, to confirm whether PLP was driving the observed response.

If solar panel surfaces are attracting large aggregations of aquatic insects, real-time impacts to aerial hawking bats may also arise through the redistribution of insects within the airspace, for example, via reduced availability of flying insects or increased bat-panel collision risk (Barré *et al*., 2023). Similar concerns have been raised for birds foraging around solar panels, and many waterfowl species can themselves be misled by the lake effect (Anderson *et al*., 2025; Diehl *et al*., 2024; Fleming, 2025). The sensitivity of bats to polarised light remains poorly understood and therefore requires further targeted research (Horváth, 2024).

Applying the reverse of Tinsley's logic, it is also possible that at some ground-mounted solar farms, the cessation of pesticide use and the enhancement of insect habitats may offset negative impacts on insect populations; however, these effects are likely to be highly species- and site-specific. Additionally, some reports suggest that solar panel surfaces rarely reach temperatures high enough to cause thermal injury to insects (Horváth *et al*., 2020), with one German study reporting that they only occasionally exceeded 50°C (Peschel and Peschel, 2025). Instead, observational accounts suggest that a range of insect taxa, including non-aquatic species, may preferentially land on PV panels to rest and thermoregulate, i.e. 'warm up' (Feltwell, 2014; Peschel and Peschel, 2025). If substantiated, this behaviour could represent an unintentional enhancement of insect habitat availability, especially in cooler climates, that may further offset the negative effects associated with solar farms. However, this interpretation is based on anecdotal evidence and has not yet been investigated experimentally using PV panels (Horváth *et al*., 2019). Furthermore, if a solar panel is too hot (>58°C), this may reduce the negative effects of PLP, as insects are likely to leave the surface promptly before laying eggs or dehydrating (Horváth *et al*., 2020).

It is important to note that FPV systems may amplify PLP-related risks because panels are installed directly over aquatic habitats, increasing the likelihood that polarotactic aquatic insects will be misled by the lake effect. Further research into the interactions between aquatic insects and PV installations is therefore required to clarify these relationships.

A key feature of solar panels that increases the risk of PLP is their smooth, dark surface. Consequently, proposed mitigation strategies have focused on modifying panel surface properties, including the introduction of surface texture and the use of white gridding. Several types of anti-reflective coatings, primarily developed to improve energy efficiency by increasing light transmission to photoactive components, have been shown to simultaneously reduce the reflection of polarised light. However, these coatings are not effective at eliminating PLP attractiveness for all species (Horváth *et al*., 2020; Száz *et al*., 2016). As a result, panel surface texturisation specifically designed to disrupt polarised light cues is now being explored. One promising approach mimics the microtexture of rose petals, which has been shown to substantially reduce PLP (Fritz *et al*., 2020), although further work is required to assess its scalability and feasibility for large-scale PV manufacture. The incorporation of white gridding around solar cells has also been demonstrated to reduce the attractiveness of solar panels to aquatic insects by disrupting PLP signals; however, its effectiveness appears to be species-specific (Black and Robertson, 2020; Horváth *et al*., 2010). All-black PV modules are increasingly installed owing to their aesthetic appeal and modest gains in efficiency (Iandolo *et al*., 2018); however, their greater surface uniformity is likely to exacerbate PLP in most cases.

At present, no solar panel surface modification simultaneously addresses both polarised light pollution and the acoustic challenges posed to bats. To maintain or enhance energy efficiency, surface texturing typically needs to occur at a sub-wavelength scale, which is too fine to scatter sound within the frequency range relevant to bat echolocation. Bat species with high-frequency calls at close distances have been found to detect wires and particles with diameters as small as ~0.05 mm (Gustafson and Schnitzler, 1979; Smotherman *et al.,* 2022); however, most bats' lower detection threshold appears to be closer to 0.2 mm (Møhl, 1988; Rahman *et al.,* 2024; Sümer *et al.,* 2009). In principle, a carefully designed macrotexture could increase light trapping while also reducing PLP and enhancing acoustic feedback, but this concept has yet to be investigated.

An alternative approach is the addition of 0.5–2 mm diameter strings or ridges along the borders of solar cells, which may preserve energy efficiency while reducing both PLP and acoustic reflectivity (Rahman *et al*., 2024). However, at an industrial scale, cost-benefit considerations, along with potential interference with panel cleaning and water or dirt runoff, are likely to constrain uptake.

More speculative solutions include robotic, textured panel covers deployed at night to improve acoustic feedback for bats, although deployment would need to overlap with dusk and dawn periods when bat activity is highest, potentially resulting in a small reduction in energy production. Another option would be the development of solar tracking systems capable of rotating panels by 180 degrees at night to expose textured rear surfaces; however, this approach would not be compatible with bifacial panels.

Habitat degradation: sensory pollution — noise and electromagnetic fields

The construction of PV developments typically occurs during daylight hours and, therefore, is unlikely to disturb active bats (WEST, Inc., 2017). In addition, solar sites are usually surveyed for roosting bats prior to development as part of the ecological assessments, meaning that roosts should not occur in close enough proximity to construction activities for noise disturbance to be ecologically significant, particularly given the rapid attenuation of high-frequency sound in air. However, there are no set roost buffer zones for solar farm construction works, so disturbance from the associated noise remains a possibility. Furthermore, although the risks are substantially lower than those associated with other renewable technologies such as wind power (e.g. Teff-Seker *et al*., 2022), operational solar developments may still generate forms of sensory pollution through high-frequency acoustic emissions and/or EMFs from live infrastructure, which could affect bats and/or their insect prey (Classen-Rodríguez *et al*., 2021; Lovich and Ennen, 2011; Nicholls and Racey, 2007; Thill *et al*., 2024).

For example, substantial high-frequency noise (>10 kilohertz) has been recorded near PV inverters, transformers and cooling fans during peak daytime operation (Griffin, *in prep*.; Zikri *et al*., 2025), and BESS may emit high-frequency noise during nocturnal operation (Storm *et al*., 2011). High-frequency acoustic noise has been associated with reduced bat and insect activity, potentially through masking, distraction, or deterrence effects (e.g. Classen-Rodríguez *et al*., 2021; Finch *et al*., 2020; Gilmour *et al*., 2021; Schaub *et al*., 2008). Consequently, localised reductions in bat and insect prey activity may occur in the immediate vicinity of BESS; however, noise emissions are unlikely to act as a primary driver of bat activity patterns at the site scale (Peschel and Peschel, 2025). Nevertheless, bats roosting near inverters or transformers may be chronically exposed to noise within their auditory sensitivity range, particularly during periods of peak solar generation. The potential impacts of such exposure on roosting bats remain poorly understood and need additional investigation.

While the EMF strengths adjacent to inverters at solar farms are potentially sufficiently high to be relevant to bats (Tell *et al*., 2015), the frequencies are much lower than those known to affect bat activity (Nicholls and Racey, 2007). Insects, on the other hand, may be disturbed by the low-frequency EMFs at solar energy sites (Tinsley, 2024). Tell *et al*. (2015) measured 60 hertz (Hz) EMFs with magnetic field strengths between 15 and 177 microtesla (μT) adjacent to transformers and inverters at solar facilities in the USA under cloudy and clear conditions. The equivalent frequency in Europe would be 50 Hz, reflecting differences in AC generation standards; these are categorised as extremely low frequency (ELF) EMFs. Exposure to short-term 50 Hz EMFs with magnetic field strengths as low as 20 μT has been shown to impair the cognitive abilities of honeybees, while exposure to 100 μT affected locomotory behaviour and feeding capabilities (Shepherd, 2018).

Furthermore, stress biomarkers are significantly higher in honeybees located close to (10–25 m) active transmission towers (50/60 Hz) with mean EMF intensities of 9.47 μT, which was associated with disrupted pollination behaviour (Molina-Montenegro *et al*., 2023). This raises concerns about pollinator habitat creation in proximity to solar infrastructure emitting such frequencies (Tinsley, 2024). Negative impacts of ELF EMFs on numerous other insect species have also been recorded (Balmori, 2021; Shepherd, 2018; Stanojević *et al*., 2005; Thill *et al*., 2024), suggesting that some bat prey species may also be vulnerable if such EMFs are present when they are active. Most components of a solar development will not emit strong EMFs when electricity is not being generated (i.e. at night); however, facilities with battery storage systems that discharge at night, or electricity lines shared with other sources (e.g. wind turbines, substations), may continue to produce EMFs under low-light conditions. Whether this is sufficient to indirectly affect bats via disruption to their nocturnal and crepuscular insect prey around such EMF sources requires further research.

Landscape context

As highly mobile animals, bats are strongly influenced by surrounding land use and habitat quality, meaning that landscape context plays a key role in shaping activity levels within solar farms. It has been suggested that solar developments embedded within mosaic landscapes may maintain higher bat activity through enhanced habitat connectivity (Szabadi *et al*., 2023). Supporting this, Tinsley *et al*. (2023) found greater bat species richness at solar farms located near freshwater habitats, alongside species-specific positive responses to the proximity of other land cover types. Similarly, at ecovoltaic developments, the proportion of tree cover within 500 m of sites has been shown to have a significant positive effect on overall bat activity (Szoldatits *et al*., 2025). Tavernier *et al*. (2026) also reported species-specific responses to the spatial configuration of forest and freshwater patches in the surrounding landscape, with freshwater emerging as a stronger cross-species determinant of bat activity than forest cover.

Protected sites designated for bats within the wider landscape are therefore likely to influence bat activity at solar farms, but may themselves be affected by solar developments, even where there is no direct spatial proximity, given that bat home ranges in the UK can extend up to 30 km (Robinson and Stebbings, 1997). Evidence for such landscape-scale connectivity effects can be drawn from a novel study using stable isotope analysis, which demonstrated that many birds killed at solar energy facilities in California originated from outside the state (Conkling *et al*., 2020). The study also found that species local to solar developments had lower population growth rates than species originating from further afield, potentially indicating population-level impacts of solar energy infrastructure. However, the dataset included CSP facilities, which have higher fatality rates than PV farms and are not currently applicable to the UK. Insufficient bat carcasses were recovered to conduct equivalent analyses for them (Conkling *et al*., 2020).

It may be the case that where higher-quality habitats surround a solar farm, bats preferentially use those areas, particularly where limited habitat enhancements have been implemented within the solar site itself (Peschel and Peschel, 2025). This is supported by multiple studies comparing bat activity at solar developments with nearby forest, freshwater, grassland, arable and settlement habitats, which generally found lower activity at solar sites relative to most other habitat types, with species-specific patterns reflecting habitat preferences (Baudouin *et al*., 2026; Szabadi *et al*., 2023; Tavernier *et al*., 2026). However, Szabadi *et al*. (2023) recorded similar activity levels at solar and arable sites across bat species, suggesting comparable habitat quality. Interestingly, Peter *et al*. (2025) found hedgerow-bordered wildflower meadows in agricultural landscapes supported greater bat activity than the same meadows with open boundaries, especially where forest habitat was more distant, suggesting that such enhancements are particularly valuable in landscapes lacking alternative foraging habitat. However, these effects varied with season, indicating that landscape use by bats may also be season-dependent, potentially in response to the timing of agricultural practices and associated shifts in relative habitat quality (Heim *et al*., 2016). In this context, solar farms with habitat enhancements may provide important foraging opportunities during specific periods of the year, particularly when bats' energetic and resource requirements are elevated, as demonstrated by Szoldatits *et al*. (2025).

Habitat enhancements, such as bat boxes, may increase bat activity at solar farms by attracting individuals from the surrounding landscape and, when appropriately designed, positioned, and maintained, can increase local carrying capacity (Russo *et al*., 2024). However, their effectiveness is highly selective, with most bat boxes being used by common, generalist species and therefore providing limited conservation benefit for priority or specialist taxa (Boscarino-Gaetano *et al*., 2024). Consequently, where the objective is to support a broader assemblage of bat species, greater emphasis should be placed on the protection and enhancement of natural roost features within solar developments. Conversely, Russo *et al*. (2024) suggest that habitat enhancements such as bat boxes, wildlife ponds and wildflower meadows at solar farms may function as ecological traps, attracting bats and insects into environments where PV panels and associated infrastructure pose potential collision, oviposition or EMF-related risks. However, empirical evidence currently remains insufficient to resolve the balance between potential benefits and risks, highlighting the need for further research at operational solar farms.

Currently, there is considerable uncertainty regarding the spillover effects of solar farms on adjacent habitats and the species they support. Ongoing research aims to address this evidence gap. At the University of Exeter, Postgraduate Researcher Will Rees is deploying acoustic recorders across established solar farm landscapes in South West England to investigate attraction, repulsion, or neutral responses of bat species to PV infrastructure. The study involves one sampling session at each solar farm between 2025 and 2026, conducted between mid-April and early July. A large array of acoustic recorders will be deployed simultaneously along matched hedgerows for seven days per site in three spatial configurations: bisecting the solar farm, along the solar farm perimeter, and at increasing (~100 m) distances from the site boundary. The findings are intended for publication in an open-access journal in 2027.

In parallel, Ivin Wilfred Raj, a Postgraduate Researcher at Keele University, is also investigating the impacts of solar farms on bats. His study integrates landscape-scale characteristics with habitat and site-specific parameters, including solar farm size and design. Bat activity at solar farms will be compared with that at adjacent agricultural sites to identify potential differences in habitat use. This research aims to produce evidence-based recommendations to inform solar farm design, siting, and management practices that minimise adverse impacts on bat populations.

In Europe, solar farms are commonly situated within homogeneous agricultural landscapes (Tavernier *et al*., 2026; Tinsley *et al*., 2024). If solar infrastructure is deterring some bat species, the quality of surrounding habitats and their connectivity will need to be improved to accommodate displaced taxa and reduce competition for already limited resources within agricultural systems. The installation of additional solar developments within the same landscape (e.g. within <20 km bat ranging distances) has the potential to further compound these pressures. While large (≥10 MW) projects are typically subject to more stringent environmental impact assessments, a dispersed distribution of small and medium-sized facilities within a similar spatial footprint can bypass comprehensive scrutiny due to more limited environmental assessment requirements. This can result in greater cumulative loss of semi-natural habitats and increased landscape fragmentation than would be the case with a single large development, particularly when considered alongside co-located wind and hybrid renewable energy infrastructure.

For these reasons, multiple studies have highlighted the need for synergistic environmental assessments for solar developments of all scales, emphasising that landscape-scale energy planning approaches prioritising habitat connectivity should replace isolated, site-by-site assessments to prevent cumulative ecological impacts (Baudouin *et al*., 2026; Gómez-Catasús *et al*., 2024; Szabadi *et al*., 2023; Tavernier *et al*., 2026).

Solar technology and installation type

PV installations that involve solar tracking systems, floatovoltaics, bifacial panels, dual-tilt or vertical arrangements are all present in the UK and may pose greater risks to bats than conventional fixed-tilt PV farms. This is primarily due to the increased extent and complexity of smooth, reflective surfaces which could interfere with echolocation-mediated perception. Outside the UK, CSP developments, such as solar power towers and parabolic trough systems, pose a substantially greater risk to bat survival because they generate extreme temperatures by concentrating solar radiation using mirrors.

Smallwood (2022) estimated an average bat fatality rate of 5.49 bats/MW/year at CSP facilities, compared with just 0.06 bats/MW/year at PV installations. Manville (2016) similarly concluded, based on preliminary evidence, that solar power towers are the most lethal solar technology for bats. This is attributed to the intense solar flux field of superheated air that forms around the tower receiver, which can cause singed wings, thermal shock or death to bats passing through the zone, even during periods of relatively low ambient sunlight. Bats (and insectivorous birds) are drawn into this hazardous area by insects attracted to the concentrated light, which are themselves vulnerable to injury and mortality; as a result, these facilities are often described as 'mega-traps' for wildlife (Jeal *et al*., 2019). While parabolic trough systems also concentrate sunlight, this occurs along a focal line rather than a single point, resulting in lower peak temperatures and reduced, though still significant, risk (Manville, 2016). This pattern is supported by Conkling *et al*. (2023), who reported substantially higher numbers of bat carcasses at solar power towers (n = 104) compared with parabolic troughs (14) and PV facilities (3); however, these figures represent raw, uncorrected counts. In addition, the extensive mirror arrays at CSP developments may increase collision risk for volant wildlife (Conkling *et al*., 2023). It is important to note that fatality rates at solar facilities are often derived from opportunistic carcass searches and are therefore likely to be underestimated (Manville, 2016). While CSP developments clearly present a high risk to bats, they are currently not relevant within a UK context and are therefore not considered further in this review.

Rooftop solar installations, by contrast, are widespread in the UK, but their impacts on bats remain poorly understood. Concerns have been raised regarding the lack of consideration of bat roosts in roof-mounted solar panel planning conditions (DCLG, 2012). Such installations could alter the thermal or structural characteristics of roost spaces within buildings or even block access points. Solar panels installed on older buildings or structures near mature trees may be more likely to impact bat roosts than ground-mounted solar farms. Collision risk may also be greater due to higher local bat activity and panel height, although empirical evidence supporting this remains limited. The risk may be broadly comparable to that posed by large windows, glass façades or smooth external cladding, depending on panel orientation and angle (Stilz, 2017). BIPVs may present a higher collision risk than rooftop panels because they are more frequently installed in a vertical orientation. Nevertheless, BIPVs are currently most prevalent in urban environments, where bat activity is generally lower, and the species present may already be habituated to navigating landscapes dominated by smooth, artificial surfaces.

Limitations

A key methodological limitation common to many studies of bat activity at solar developments is the reliance on static acoustic detectors to compare bat activity within solar arrays with that recorded at control sites, typically open fields. Acoustic monitoring has several inherent constraints related to species-specific differences in call intensity, frequency, and detection range, which can bias detection probabilities and lead to inaccurate representations of relative abundance and habitat use. These limitations may be further compounded by the use of control sites where structural characteristics differ substantially from those within solar fields. Variations in physical clutter can influence sound propagation, potentially resulting in inconsistent detection rates between sites and confounding the interpretation of activity data.

Specifically, solar panels can act as acoustic barriers, creating “blind spots” in which bat calls, particularly higher-frequency calls, may not reach detector microphones when panels obstruct the line-of-sight between bats and the detector. As a result, detectors located within solar arrays may fail to record bat passes, leading to false-negative detections and potential underestimation of bat activity at solar sites (Barré *et al*., 2023). In addition, the reflective properties of solar panels may generate call echoes that complicate acoustic signal interpretation, particularly where automated classifiers are used. These effects are likely to be most pronounced where detector height is lower than array height, or where detectors are positioned close to reflective surfaces. For example, in Tinsley *et al*. (2023), detectors were installed at a height of 1.27 m, which is below the typical height of solar arrays in the UK (approximately 2–4 m). The use of equipment that doesn’t meet industry standards may also exacerbate detectability issues; for example, Szabadi *et al*. (2023) deployed AudioMoth detectors, which have limited high-frequency sensitivity.

There may also be species-specific detectability differences in solar fields, arising from variation in call frequency, intensity and flight height. For example, lower-flying species may be more affected by acoustic interference within arrays than higher-flying species, further biasing activity estimates. Nevertheless, as bats are moving acoustic targets, it is likely their presence will eventually be detected within solar sites; however, the total number of recorded passes may be artificially reduced. Consequently, measures of presence or absence and species richness are likely to be more reliable than relative activity levels, which should be interpreted with caution.

Conversely, Griffin *et al*. (*in prep*.) recorded significant species-specific differences in bat activity between their textured and smooth-surfaced solar panel treatments (i.e. same fundamental structure), which suggests that any acoustic barrier effects were not significant. In further support of this, they also recorded higher bat activity during both the panel treatments compared to baseline (no panels) for some species; the opposite would occur if bat calls were being blocked by the solar panels. However, they did ensure that their detector microphones were installed above the solar panels, which may have reduced acoustic blind spots.

The degree to which detectability is reduced within solar arrays has not yet been quantified, although ongoing work using artificial bat calls aims to address this limitation (Clarkson & Woods, *in prep*.). Importantly, some studies have attempted to account for detectability constraints, either through statistical adjustment (Baudouin *et al*., 2026) or by excluding detections within modelled three-dimensional acoustic blind spots at control sites to match conditions within paired solar sites (Barré *et al*., 2023). Additional approaches that could improve bat detection include the use of manned detectors, imaging technologies or radio-tracking alongside static detectors, and deploying multiple detectors at different heights above and below the arrays to reduce blind spots (Montag *et al*., 2016).

Most studies assessing bat activity reviewed here employed a paired-site design. Although solar and reference sites were typically matched on broad habitat characteristics, it is not possible to fully control for environmental heterogeneity without a Before-After-Control-Impact design implemented at the same site. For instance, in Tinsley *et al*. (2023), the surrounding landscapes of PV facilities and their corresponding control sites differed in the proportion of arable land and levels of habitat connectivity (factors known to strongly influence bat activity). Moreover, bat roost proximity and fine-scale grassland habitat quality were rarely reported or explicitly matched between paired sites, and boundary features often differed; such inconsistencies may confound observed effects (Foxley *et al*., 2023). Comparability among studies was further limited by the frequent omission of information regarding solar site age, layout, and land management practices. Nevertheless, paired-site designs offer the advantage of controlling for weather conditions and nightly variation in bat activity, as surveys can be conducted concurrently at solar and reference sites (Barré *et al*., 2023; Baudouin *et al*., 2026; Szabadi *et al*., 2023).

Studies assessing bat mortality at solar developments using carcass searches are also subject to substantial and often unavoidable limitations. Observer bias may arise from variation in searcher experience, eyesight, motivation, and search methodology. Foot-based searches can yield up to three times as many fatalities as vehicle-based searches

(Smallwood, 2022), while the use of detection dogs is substantially more effective, particularly for small-bodied carcasses such as bats (Conkling *et al*., 2023).

Although detection trials are commonly used to estimate searcher efficiency, these often rely on inappropriate surrogate species (e.g. small birds), which do not accurately reflect bat carcass size or composition and can lead to biased correction factors (Smallwood, 2022). Surrogates may also influence estimates of scavenger removal rates, resulting in further inaccuracies in carcass persistence modelling. In addition, many recovered carcasses cannot be identified to species level, preventing species-specific impact assessments (Smallwood, 2022). Detecting the cause of death is also challenging, as carcasses found at solar sites may have died from natural causes or been relocated from elsewhere.

Sample sizes from solar sites are frequently small, often due to data access restrictions, limiting the generalisability of mortality estimates (Conkling *et al*., 2023). There are also documented instances of data obfuscation or falsification within fatality reporting (Manville, 2016), underlining the need for transparent, independently verifiable and peer-reviewed approaches. While some sources of bias can be partially corrected, it is not possible to quantify or compensate for all sources of error (Smallwood, 2022). As a result, there is a recognised need for standardised monitoring protocols, although consensus on the most appropriate approach has yet to be reached (Manville, 2016).

Lastly, the geographical applicability of the existing evidence base is limited. Only three of the bat-solar farm studies reviewed were conducted in the UK (Griffin *et al*., *in prep*.; Montag *et al*., 2016; Tinsley *et al*., 2023), with most sites (35/40) located in South West England. Other studies originate from France (Barré *et al*., 2023; Baudouin *et al*., 2026), Hungary (Szabadi *et al*., 2023), the Netherlands (Tavernier *et al*., 2026), and the USA (Conkling *et al*., 2023; Manville, 2016; Smallwood, 2022; Szoldatits *et al*., 2025). Differences in species assemblages, climate, habitat context, and solar PV characteristics (including technology, layout, management, and site age) must therefore be carefully considered when extrapolating findings to a Welsh context.

Summary

Table 2. Summary of potential drivers of bat activity at solar developments, including the strength of evidence for each.

Driver	Strength of evidence	Notes	Key references
Habitat loss Habitat loss can arise through several mechanisms associated with solar development, including: • direct clearance of vegetation, • reductions in vegetation height, • the creation of barrier effects from solar infrastructure, • microclimatic alterations such as changes in shading, moisture and temperature, and • shifts in grassland management regimes. These changes can collectively reduce habitat quality and availability for bats and their insect prey.	Emerging	• Extensive vegetation clearance rare. • Habitat loss severity depends on previous habitat quality and land management relative to that throughout the operational phase of the solar development. • Cessation of pesticide use is beneficial, but parasiticides from livestock remain a threat. • Transition from cattle to sheep grazing could alter insect community. • Mixed findings from insect studies at solar farms, including higher, lower and similar abundance, differences in community composition, and lower richness relative to control sites; spatial variation in abundance and richness within solar farms also observed. • Bats decrease their feeding behaviour over solar farms compared to paired control sites. • Ecovoltaic sites can support higher bat activity than arable fields. • Solar farm layout is important; however, evidence on optimum design is limited. • Enhancements such as the creation of mosaic habitats and improved connectivity may help mitigate effects across species. • Limited long-term data available to capture habitat maturation and bat habituation.	Ayllón *et al*., 2014; Barré *et al*., 2023; Brito *et al*., 2013; Fraser *et al*., 2022; Kocsis *et al*., 2025; Montag *et al*., 2016; Szabadi *et al*., 2023; Szoldatits *et al*., 2025; Tavernier *et al*., 2026; Tinsley, 2024; Tsafack *et al*., 2022; Vervloesem *et al*., 2022; Wiesinger and Suarez-Rubio, 2026; Zitzmann *et al*., 2024

Driver	Strength of evidence	Notes	Key references
Increased structural clutter Conversion of open habitat to artificial cluttered habitat could: • deter/displace bats, • alter bat community composition, • disrupt flight paths, and • introduce collision risk with infrastructure across a facility's physical footprint (e.g. fencing).	Emerging	• A range of bat guilds in Europe/USA appear to avoid solar farms entirely or are displaced to boundaries. • Solar panels can create acoustic blind spots that confound bat activity monitoring. • Limited evidence of bats directly interacting with panels for foraging or other purposes. • Arrays could provide shelter or navigational benefit. • Collision risk higher near roost exits or for inexperienced bats. • UK species collision rates and habituation understudied. • Limited evidence on whether solar farm configuration and habitat enhancements could help mitigate.	Barré *et al*., 2023; Baudouin *et al*., 2026; Griffin *et al*., *in prep*.; Holz *et al*., 2020; Ingeme *et al*., 2018; Montag *et al*., 2016; Smallwood, 2022; Szabadi *et al*., 2023; Tavernier *et al*., 2026; Tinsley *et al*., 2023; WEST, Inc., 2017
Sensory pollution: smooth surfaces **Confusion** with water due to the reflection of analogous echoes may lead to attraction and drinking attempts.	Limited	• Tilted panels less likely to trigger water-mimicry. • Panels stowed horizontally at night and Floating Photovoltaics (PV) pose higher theoretical risk. • Limited evidence from operational PV farms. • Associated energetic costs and collision risk unquantified. • Introducing texture (strings) to panels can prevent drinking attempts.	Greif *et al*., 2017; Greif and Siemers, 2010; Griffin *et al*., *in prep*.; Rahman *et al*., 2024; Russo *et al*., 2012
Sensory pollution: smooth surfaces **Collision** with solar panel surfaces due to impaired detectability when approached from an angle.	Limited	• Theoretical risk based on studies involving other smooth surfaces (e.g. plastic, metal) positioned vertically or at 45° in lab or near roost exits. • Empirical evidence of collision with conventional PV panels is limited, but a small number of carcasses have been found near arrays in the USA. • Risk may increase for vertical bifacial systems and decrease if debris has accumulated on panels. • Likelihood of fatal collisions not yet understood.	Greif *et al*., 2017; Griffin *et al*., *in prep*.; Ingeme *et al*., 2018; Smallwood, 2022

Driver	Strength of evidence	Notes	Key references
Sensory pollution: smooth surfaces **Acoustic clutter** from strong returning echoes when panel surfaces are approached perpendicularly could mask or distract from important acoustic signals and deter bats from array areas. Effects increased during multi-bat flight.	Emerging	• Effects appear amplified for species with low-intensity calls and passive listeners with sensitive hearing. • May reduce foraging efficiency and encourage avoidance of array interiors. • Panels stowed horizontally at night may intensify acoustic interference due to greater smooth surface area exposed. • Unclear whether habitat enhancements compensate. • Panel macrotexture mitigation yet to be explored.	Barré *et al*., 2023; Baudouin *et al*., 2026; Griffin *et al*., *in prep*.; Montag *et al*., 2016; Szoldatits *et al*., 2025; Tavernier *et al*., 2026
Sensory pollution: polarised light Smooth, dark panels can reflect horizontally polarised light, attracting aquatic insects to oviposit. This could indirectly affect bats through: • altered prey distribution, • increased collision risk, and • insect population declines.	Emerging	• Panel angle, coatings and design, insect taxa, time of day and proximity to aquatic habitat can influence severity. • Limited long-term data. • Floating PV systems likely increase risk. • High panel temperatures may pose a risk of thermal injury to insects, but could also offer beneficial warm microhabitats in cooler conditions. • May enhance bat foraging opportunities. • Bat visual sensitivity to polarised light likely limited. • Mitigation for polarised light pollution is available.	Black and Robertson, 2020; Fraleigh *et al*., 2021; Griffin *et al*., *in prep*.; Horváth *et al*., 2009; Horváth *et al*., 2010; Horváth *et al*., 2014; Horváth *et al*., 2020; Horváth, 2024; Kriska *et al*., 2008; Száz *et al*., 2016; Takács *et al*., 2024; Tinsley, 2024
Sensory pollution: artificial light Nighttime security lighting or reflected light could deter light-averse bats and attract insects, which light-tolerant bats may exploit.	Reasonable	• Typically mitigated via sensitive lighting regimes. • Effects are species-specific. • May contribute to long-term insect population impacts.	Stone *et al*., 2015; Voigt *et al*., 2021
Sensory pollution: acoustic noise High-frequency noise from inverters, transformers, or battery systems may disturb bats or their prey. Construction phase noise has potential to disturb roosting bats.	Emerging	• Most operational noise emissions are light-dependent; therefore, active bats unlikely to be affected. • High-frequency noise is directional and attenuates rapidly; therefore, limited site-scale impacts. • Bats roosting close to equipment may face chronic noise exposure, but the impacts on roosting bats are not well understood. • Few empirical studies on operational PV sites.	Classen-Rodríguez *et al*., 2021; Finch *et al*., 2020; Gilmour *et al*., 2021; Schaub *et al*., 2008; Storm *et al*., 2011; Zikri *et al*., 2025

Driver	Strength of evidence	Notes	Key references
Sensory pollution: electromagnetic fields Extremely low frequency electromagnetic fields (e.g. 50 Hz) may disrupt insect prey or indirectly affect bats through prey behaviour.	Limited	• No evidence that the strengths and frequencies of electromagnetic fields at solar farms could disturb bats. • Effects on insects are possible near electrical equipment. • Indirect effects on bats via prey are untested.	Balmori, 2021; Molina-Montenegro *et al*., 2023; Nicholls and Racey, 2007; Shepherd, 2018; Tell *et al*., 2015; Thill *et al*., 2024
Landscape context • Surrounding land strongly influences bat activity; proximity to freshwater and tree cover associated with higher activity and species richness at solar sites. However, solar farms may act as less preferred habitat unless enhancements and connectivity are present. • Possibility for protected bat sites to be negatively impacted by nearby solar developments. • Likely cumulative impacts of multiple solar farms in the same landscape.	Emerging	• Seasonal and species-specific variation; solar farms may provide foraging opportunities in agricultural landscapes at specific times of year. • Spillover effects are understudied. • Habitat enhancements at solar farms may function as ecological traps by attracting bats and insects into a potentially dangerous environment. • If solar farms are displacing bats, surrounding habitat quality and connectivity need to be improved.	Baudouin *et al*., 2026; Conkling *et al*., 2020; Russo *et al*., 2024; Szabadi *et al*., 2023; Szoldatits *et al*., 2025; Tavernier *et al*., 2026; Tinsley *et al*., 2023
Installation/technology type Vertical, bifacial, dual-tilt, tracking, rooftop, building-integrated PV and floating PV panels could increase acoustic interference risks. Concentrated Solar Power (CSP) developments can attract insects and bats into lethal solar flux fields.	Limited	• Newer PV technology risks are largely unquantified. • The angle and smooth surface area influence sensory pollution risks. • Lower bat activity associated with solar tracking systems. • Limited studies on rooftop solar, which could be in proximity to roosts. • Vertical panels, building-integrated PV and floating PV panels are not yet common in UK. • Building-integrated PVs are usually in urban environments. • CSP not currently relevant to UK.	Baudouin *et al*., 2026; Conkling *et al*., 2023; Manville, 2016; Smallwood, 2022; Stilz, 2017

4. Assessment of current bat survey, mitigation and monitoring practice

Methodology

The Renewable Energy Planning Database (REPD, 2025) was used to identify a subset of 90 (42% of the total dataset) ground-mounted solar farm developments dating from 2010 to 2025 across Wales. The subset was obtained through stratifying the REPD by application date, county, capacity (MW) and development status. Applications that had been withdrawn, abandoned or expired were excluded from review. We included sites that were within the planning system to ensure we captured recent submissions that were acting on the latest guidance and legislation. Each corresponding planning authority and application reference number was retrieved from the REPD and used to locate the planning application from the respective planning portal. All available ecology reports and other documents featuring bats or matters related to bats were downloaded from each planning portal. Only 63 applications were both locatable in planning portals and accompanied by ecology documentation, representing 70% of those searched and 30% of the total dataset.

Following the manual review of 10 reports to identify appropriate content categories for the summary spreadsheet, Google NotebookLM was used to assist with information extraction from every subsequent source by submitting the spreadsheet column headings as prompts. Each answer was verified using the source-linked reference feature. Reports formatted unconventionally or with additional information were manually reviewed in greater detail. The documents were compared to identify differences in practice, changes in practice over time, adherence to standards and guidance, inconsistencies and missing information, with a focus on bat surveys, bat mitigation strategies, bat habitat enhancements and post-construction bat monitoring.

Additional targeted evidence sourcing was achieved through contacting ecological consultants, local authority ecologists, statutory agency advisors, renewables environmental specialists and solar developers directly. The targeted emails emphasised the requirement for post-construction bat monitoring evidence, due to the low number of Welsh bat monitoring reports found through the REPD.

Results

We extracted data from operational sites (n = 36, 57%), sites under construction (n = 2, 3%), sites awaiting construction (n = 20, 32%), sites where applications were submitted (n = 4, 6%), plus a site where the application was rejected. The minimum lifespan of a solar farm was 25 years (50% of sites), whereas the maximum projected lifespan of a site was 40 years (35% of sites). The mean installed capacity of the 63 sites was 16.2 MW (95% confidence interval (CI): 9–23 MW), whereas the median was 5 MW, highlighting that most solar installations across Wales are relatively small, with the occasional large-scale development. Similarly, this is reflected in the area of the solar sites, with the mean site area being 28 hectares (ha) (95% CI: 14–42 ha), whilst the median was 11 ha.

Background data search

Most sites (94%) undertook desk-based assessments to identify any statutory or non-statutory designated sites and to collate existing information and historical records relevant to the potential presence of bats on or adjacent to the development footprint. Installation capacity did not differ between sites that completed desk-based studies and those that did not; in both cases, the median capacity was 15 MW. Three of the developments that had no desk-based assessments or surveys relating to bats were installed prior to 2015, which likely reflects the more limited recognition at the time of the potential ecological impacts of solar infrastructure on bats.

There was considerable variation in the radius used for desk-based searches, which ranged from 0.5 km to 5 km (median: 2 km). A significant positive relationship was identified between search radius and installation capacity ($t = 3.8$, $df = 57$, $p < 0.001$), indicating that larger sites generally employed wider search areas. However, this relationship was not uniform: the site with the largest installation capacity (160 MW) applied only a 2 km search radius, demonstrating that search effort was not consistently scaled with development size. There was relatively little justification in most reports for the radius used, although one report outlined that, due to the nature of the development proposals, impacts of the array are likely to be very localised rather than having a much wider zone of influence; therefore, protected species records from within only 500 m of the site were requested.

There was little consistency in how the results from desk-based data searches were reported. These searches compile existing bat records derived largely from ad hoc observations rather than systematic survey efforts; therefore, absence of records cannot be interpreted as species absence, and the data do not provide a robust baseline for comparing activity between sites. Reporting formats also varied: some site reports presented numerical summaries where available, whereas others used qualitative descriptors such as “several”, “many”, or “numerous”, and many records lacked explicit counts. Record totals alone offer limited ecological insight unless linked to confirmed roosts or survey context. Among reports that included quantified records, 16% documented no existing records, and two sites reported more than 250 bat passes; however, this variation is more likely to reflect differences in recording effort and data availability than true differences in baseline bat presence.

A total of 71% of sites had Section 7 species of principal importance (Environment (Wales) Act 2016) recorded within the desk-based assessment. *P. pipistrellus* were recorded at 68% of all sites (n = 43), whilst *P. pygmaeus* were found at 51% (n = 32), *N. noctula* at 43% (n = 27), *P. auritus* at 41% (n = 26), *R. hipposideros* at 33% (n = 21), and *R. ferrumequinum* at 14% (n = 9) of all sites. The desk-based assessments revealed that roosts were in the proximity of 30% (n = 19) of sites. The level of detail on roost proximity varied between sites; for example, one report stated that there was a mixed roost of pipistrelles and *R. hipposideros* 1.1 km away, whereas another report stated that there was an important *R. hipposideros* roost “*very nearby*” but did not quantify this remark. The closest recorded roost to a site was a *P. pipistrellus* site 90 m away, whilst at a different site, a *Myotis daubentonii* roost was 400 m away, within a bridge.

The desk-based surveys also flagged that 24% of sites were close to areas noted for their wildlife (not all specifically bats), including three sites wholly or partially within SSSIs (one of which was rejected), two sites located entirely within Sites of Importance for Nature Conservation, one within a Special Landscape Area, one within a B-line (a non-statutory protected site aimed at creating a network of habitats) and several sites close to SACs designated for horseshoe bats. However, there were no significant differences in surveying effort or mitigation strategies between sites on or near designated sites and those which were not.

Preliminary ecological assessment

The majority of sites (69%) undertook a Preliminary Ecological Appraisal to assess the site's ecological value before development; these were generally the smaller sites with a mean installed capacity of 5 MW (95% CI: 3–7 MW). Whereas the 25% of sites which submitted an Environmental Impact Assessment had a mean installed capacity of 48 MW (95% CI: 24–72 MW). A sizeable proportion of the 90 planning applications originally searched for were either unlocatable in the planning portals (33%) or were missing all or some of the associated ecology reports (37%). Three sites (5%) that only had a brief letter or comment from an ecologist uploaded to the planning portal were included in the review; these were relatively small sites ranging between 0.6 and 7.7 MW. One site (2%) that only had a brief ecological mitigation document available in the planning portal was also included in the review; this was a relatively large site (18 MW).

Potential roost features

The potential for tree roosts within the solar sites was identified in 75% (n = 47) of cases. Locations with no potential roost features (PRFs) were either sites with no trees within the developable area, trees that were too young, or sites containing Scots pine and Leyland cypress trees with no decay, crevices or holes. Of the sites with potential, they ranged from those with a few trees to sites with mature trees, including Pedunculate Oak and Ash with cracks and holes, with medium to high bat potential.

Buildings with potential to support bat roosts were identified at 33% of sites (n = 21), the vast majority of which were located outside the site boundary. Most buildings were assessed as being of low value for roosting or hibernating bats, reflecting their construction type or condition. In many cases, buildings were agricultural (e.g. metal-clad barns) or were in a state of disrepair, limiting their suitability for bats. A small number of structures were identified as having some roosting potential. These included an electrical substation located outside the site boundary, where fascia boards could provide roosting opportunities, as well as adjacent farm buildings and associated outbuildings. No further measures for bats were suggested as the potential roost buildings were to be retained.

Bat activity surveys

Across the 63 solar farm developments reviewed, pre-construction bat surveys were undertaken at 9 sites (14%). Of these, 89% had planning applications submitted after 2018. In contrast, only 42% of projects that did not include bat survey work were submitted after 2018, suggesting that such surveys have become more common with time. Sites where bat surveys were conducted had 11–250 (mean = 86) bat records (some from within the site area) of 2–12 (mean = 6) bat species (including 1–6 Section 7 species) returned by the desk-based assessments. In comparison, the desk-based surveys returned fewer (0–131, mean = 20) bat records (nearest 100 m away) of 0–10 (mean = 4) bat species (0–6 Section 7) for sites that excluded bat surveys. The sites with bat surveys were also generally larger, with a median installed capacity of 8.9 MW, compared to 5 MW at sites where no bat surveys were reported.

Of the ecology reports for the sites that conducted pre-construction bat surveys, three (33%) considered direct impacts of solar arrays on bats, including collision risks and the potential to mistake solar panels for water surfaces. Meanwhile, nine (17%) of those that excluded bat surveys considered such impacts. The reports that considered direct impacts often cited Natural England's Technical Information Note (Natural England, 2011) or their most recent evidence review (Taylor *et al*., 2019). Most of these reports concluded that the risks are similar to those of other smooth, static manmade structures or negligible due to the panel tilt angles and inter-row spaces. Relatively few reports (n = 3) included specific details of why bat surveys were not required. One report stated that bat habitat would not be impacted, one highlighted that there was no proposal to fell a mature tree or demolish a building of potential roosting value, and one highlighted that there was no need, as suitable habitats for bat populations were limited to boundary features and these were retained.

Of the nine sites where bat surveys were undertaken, three were limited to preliminary roost assessments, focusing on specific features within trees, buildings, or an underpass. The remaining six sites implemented a more comprehensive survey approach, including bat activity transects and static detector monitoring. However, only one site provided methodological details to enable the survey to be partially replicated post-construction. While this site included maps of transect routes and a clear surveying protocol, the precise locations of static detector placements were not reported. Reasons provided for pre-construction bat activity surveys included "*to assess the species present and commuting/foraging routes*" and "*due to the scale of the development and resultant change to the natural landscape*".

Suitable bat foraging habitat was identified at 92% of solar development locations (n = 58). Sites assessed as unsuitable for bats were typically characterised by open landscapes dominated by species-poor, agriculturally improved grassland, offering limited structural or botanical complexity. One site was classified as supporting sub-optimal foraging habitat due to an anticipated low abundance of insect prey; however, this assessment acknowledged that adjacent woodland margins and hedgerows may provide foraging opportunities for bats. Hedgerows were the most frequently identified habitat feature at sites where suitable foraging habitat was recorded. Other linear features, including treelines and watercourses, were also commonly present in the vicinity of installations and were considered likely to contribute to local bat activity. In contrast, grassland within most sites was generally regarded as of low value for bat foraging, owing to a lack of habitat structure and limited botanical diversity typically associated with higher quality foraging habitats. One report noted that, although the site was largely composed of improved grassland and arable land, *R. ferrumequinum* is known to forage over grazed agricultural landscapes. At a separate site, the presence of purple moor-grass and rush pasture was highlighted within one field, a habitat type that was considered to be of relatively higher quality for foraging bats.

Mitigation strategies

Roost mitigation measures

Roost mitigation measures were proposed for all sites where trees with the potential to support bat roosts were identified. Most mitigation strategies prioritised the retention of mature trees within the site. Where tree removal was proposed, this was typically justified on the basis that the trees formed part of conifer plantations considered to be of low ecological value, or that felling was required due to the presence of fungal disease. Four reports specified that root protection zones should be established around retained trees to prevent soil compaction and damage from construction machinery. However, there was variation in the recommended extent of tree protection, with one report specifying a setback distance of 15 m, while another recommended a reduced buffer of 10 m.

Several studies noted that, where trees with bat roost potential could not be retained and required felling or disturbance, mitigation should be implemented in accordance with either CIEEM's Bat Mitigation Guidelines or "*Bat Conservation Trust guidance*". In contrast, roost mitigation measures for buildings were largely absent, given the lack of active roost sites found in proximity to solar installations and the lack of need to remove buildings to facilitate construction. Only one report proposed enhancements for buildings, suggesting that existing roosting features could be enhanced by boarding up the structure to create a more secure and stable roosting environment for bats.

Bat boxes

The installation of bat boxes was recommended in 49% of reports, assumed to primarily be an enhancement measure, as no bat roosts were destroyed, and any trees/structures with PRFs were retained at all sites. No clear pattern was evident in relation to the scale of development. Sites where bat boxes were not recommended had a slightly higher median installation capacity (7 MW) compared to sites where bat boxes were recommended (5 MW). Differences in bat box recommendations were similar regardless of bat presence: 53% of sites without bat box recommendations had at least one priority bat species recorded during desk-based assessment, compared with 68% of sites where bat boxes were recommended.

Of the 29 sites where bat box installation was proposed, only 10 reports specified the number of boxes to be installed. Recommended numbers varied considerably, ranging from 4 to 32 boxes per site, with a mean recommendation of 12 boxes. Of the 29 sites, just 34% provided guidance on the type of bat box to be installed, with recommendations largely limited to Schwegler models (including a range of designs such as 1FF, 1FW, 2F and 2FN) and Kent bat boxes. Information on the intended target species for the bat boxes was largely absent, and limited consideration was given to the selectivity of bat boxes by bats.

Bat box installation guidance was generally limited. Only one report provided detailed advice on placement, recommending installation at a range of heights and aspects to create complementary roosting conditions, with southerly and westerly aspects favoured to maximise the likelihood of uptake. Two reports specified distances from the application site at which bat boxes should be installed; one recommended installation on mature trees at least 30 m from construction working areas, while another proposed installation within suitable woodland located approximately 600 m from the site, as the "*habitat offers excellent opportunities to increase the site's suitability for bats*".

Artificial lighting

Measures to minimise the potential impacts of artificial lighting on bats were included in 86% of sites (n = 54). The anticipated level of lighting varied between developments; however, most reports stated that no permanent external lighting would be installed within the site. One site proposed the use of emergency lighting and motion-activated security lighting, but noted that lighting would be directional and used only when required, with the site remaining largely unlit. On this basis, the report concluded that light spill onto surrounding bat habitats would be negligible. Several reports also highlighted an increased risk of lighting impacts during the construction and decommissioning phases. To mitigate this risk, restrictions on night-time working were recommended during these periods to reduce potential disturbance, including night-time lighting, to bats.

Retention of bat habitats

Measures to retain bat foraging and commuting habitat were included at most sites. In many cases, this centred on the retention of existing linear features, particularly hedgerows, which were consistently identified as key landscape elements supporting bat activity. Many reports specified that all existing hedgerows within and adjacent to the site would be retained, with several also extending this to the protection of associated trees, woodland edges, ditches and watercourses. In a small number of reports, it was acknowledged that the permanent removal of some hedgerows would be required to facilitate the solar installation. This typically involved the loss of relatively short sections of hedgerow (generally <20 m in length). However, two sites identified more substantial losses: one reported the removal of approximately 280 m of internal hedgerow, while another indicated that around 10% of the site's hedgerow network (approximately 300 m) would be lost. This site proposed that 400 m of native hedgerow would be planted as compensation; however, it was unclear where on the site this would be or how landscape connectivity would be influenced. Boundary enhancement measures commonly included hedgerow reinstatement, gapping-up, replanting with native species, and long-term management prescriptions, such as maintaining hedgerows at heights of 2–3 m to improve structural complexity. In several cases, boundary enhancement proposals involved the creation or restoration of substantial lengths of hedgerow, including the reinstatement of previously defunct boundaries, thereby aiming to increase habitat connectivity and potential foraging opportunities for bats.

While much of the retained foraging habitat was located along site boundaries, some reports also identified foraging and commuting features within the site footprint that were not solely boundary related. These included the retention of internal hedgerows, mature trees, woodland blocks, and drainage features, which were recognised as contributing to habitat heterogeneity and providing additional foraging and navigation opportunities across the site. In a smaller number of cases, woodland edges and adjacent off-site habitats were mentioned as forming part of the retained foraging resource.

Buffer zones

A strategy to manage buffer zones was present in 57% of reports; however, there was considerable variation in their purpose. Commonly cited measures included buffers along field drains, ditches, hedgerows, and treelines, with several reports recommending a minimum 2 m buffer from drainage features and wider buffers (10 m) adjacent to trees or woodland edges to reduce disturbance and maintain habitat connectivity. There were two studies that focused on buffers during construction, with recommendations that a 1 m buffer should be maintained between machinery, digging and storage and the sensitive hedge line, and that 10 m should be left between construction and watercourses and trees. There were a small number of cases which proposed substantially larger buffer zones, such as a 100 m wide retained wildlife area that should be enhanced through the sowing of wildflowers for nature conservation and wildlife.

Land management

Across the 63 sites assessed, the transition from pre-construction to post-construction land management indicates a shift away from intensive agricultural practices. Prior to development, 46 sites (73%) were under intensive agricultural management, including intensively managed or improved grassland, heavily grazed pasture and arable farming. Post-construction, 38 of these sites (60% of all sites, 83% of those previously intensively managed) moved to less intensive management regimes. These typically involved low stocking density grazing or management regimes focused on extensive or non-intensive practices with a focus on the grassland retained beneath and between solar panels. A further seven sites (11%) had post-construction non-intensive management plans, although it was not clear from reports what the management regime had been pre-construction.

Where sites were subject to non-intensive management post-construction, this was typically delivered through changes to grazing and vegetation management regimes beneath and between panel arrays. The most proposed approach involved the use of low-intensity livestock grazing, most frequently with sheep, to maintain a short but structurally varied sward. This approach was often presented as a replacement for pre-construction regimes characterised by higher stocking densities (of mostly sheep and/or cattle), frequent silage cutting or arable cultivation. Low-intensity sheep grazing was generally described as serving multiple functions, including vegetation control, soil protection and biodiversity enhancement. Several reports highlighted that reduced grazing pressure would allow greater persistence of flowering plants within the sward, supporting increased invertebrate abundance while avoiding excessive scrub encroachment. In contrast to intensive pasture management, these regimes were structured to allow a more heterogeneous grassland structure to develop over time.

In some cases, non-intensive management was proposed through reduced or modified cutting regimes rather than grazing. These approaches involved infrequent mowing, delayed cutting, or rotational management, with the intention of minimising disturbance during key periods for invertebrates and other wildlife. Several solar developments highlighted that following construction, there would be a substantial reduction in fertiliser, herbicide and pesticide application. For example, one report highlighted that stock should not be grazed following treatment with Ivermectin due to its detrimental impact on dung and soil invertebrates.

Invasive species

Management measures for the control or removal of invasive non-native species, most commonly Himalayan balsam and Japanese knotweed, were included in 44% of reports (n = 28). Approaches to invasive species management varied between sites and, in some cases, reflected differing management objectives. Several reports advocated non-chemical control methods, noting that the use of herbicides should be avoided to support sympathetic habitat management and minimise potential impacts on non-target species. In contrast, other reports identified repeated treatment with glyphosate as best practice for effective control, particularly where Japanese knotweed was present, and emphasised the need for multi-year treatment programmes to achieve successful eradication.

Monitoring strategies

Across the 63 sites reviewed, very few reports set out a clear post-construction monitoring strategy to assess bat responses to solar developments. Only three sites outlined bat-specific monitoring proposals, while a further three reports referred more generally to the need for post-development biodiversity monitoring without clearly stating whether bats would be included.

Of the sites that did propose bat monitoring, the scope and level of detail varied considerably. One site included the proposal within its Landscape and Ecology Management Plan to undertake bat box inspections five years post-development. A second site recommended bat activity monitoring using automated detectors during each of the first three years following construction. This report also stated that potential collision impacts on bats should be monitored, although no methodology was provided to explain how such impacts would be assessed.

The most detailed monitoring strategy was provided by a single site, which recommended post-development bat surveys in years 1 and 3. This approach specified that surveys should be undertaken along the same transects and at the same locations as those used during the baseline assessment, thereby enabling direct comparison of pre- and post-development activity levels. The proposed methodology included a combination of walked transects, automated detector surveys and bat box checks in the third year.

Common themes

There were common themes across the majority of the 63 solar farms that were assessed during this review. There was an emphasis on habitat retention, low-intensity land management and a transition to supporting grassland compatible with both operational requirements and a more biodiverse environment. Mitigation and enhancement measures were mostly focused on the retention and management of existing linear features, particularly hedgerows, treelines and woodland edges, which reflect the agricultural landscape in which most of these projects were based. However, the level of detail, justification and consistency in approach varied considerably between sites, particularly in pre- and post-construction bat surveying and monitoring.

Monitoring data

Academic research projects are rarely able to collect robust pre-construction baseline and post-construction monitoring data at solar developments due to the time and funding requirements; therefore, the systematic collection, collation, and synthesis of monitoring data generated through the planning and consenting process is important.

Despite multiple calls for evidence, no post-construction monitoring reports from Welsh solar developments were submitted directly to inform this review. The single Welsh example considered in this report was obtained independently via a local authority planning portal. In addition, one post-construction monitoring report was submitted from an English solar development to inform the review. This absence of submissions is likely to reflect a combination of limited post-construction bat monitoring currently being undertaken and a lack of clear expectations or incentives for developers and consultants to share monitoring outputs for wider scrutiny, alongside concerns about how findings may be interpreted and the potential implications this could have for perceptions of the industry.

Although over 120 UK operational solar farms undergo annual biodiversity monitoring using a standardised methodology as part of the ‘Solar Habitat’ report (SEUK, 2025), targeted bat or nocturnal insect surveys are not typically included. The preceding ‘Solarview’ report did, however, note that 14% (15/106) of the bat boxes inspected at 30 solar farms in 2018 contained evidence of roosting bats. The success rate of bat boxes varied across sites and monitoring years and didn’t seem to correlate with installation date (Clarkson & Woods, 2018). In 2019, only 10% (6/60) of the bat boxes inspected were used by bats, with 44% (26/60) inhabited by nesting birds (Clarkson & Woods, 2019). They highlighted that Schwegler 1FF and 1FD boxes were particularly attractive to bats, even when installed on fence posts (Clarkson & Woods, 2018; 2019). In 2020, *P. pygmaeus* and

P. auritus bats were found in bat boxes at the solar farms monitored, though no further details were provided (Clarkson & Woods, 2020).

During post-construction monitoring, it is important to verify and report the implementation, status and efficacy of any mitigation or enhancement measures proposed in the original management plans. This helps inform the interpretation of bat monitoring data and the requirement of adaptive management. For example, Montag *et al*.'s 2016 study, which assessed biodiversity at 11 operational solar farms in southern UK, highlighted that the Biodiversity Management Plan at over half of the sites had not been fully adhered to. This included failing to install bat boxes, planting the wrong species (e.g. coniferous instead of deciduous trees) and not sowing the grassland seed mixes specified. They also noted that some planting had failed to establish. Similarly, 20% of the solar farms monitored by Clarkson & Woods in 2018 had not installed bat boxes, despite these being recommended in the site management plans (Clarkson & Woods, 2018). Such shortcomings could influence bat utilisation of the sites, and thus the evaluation of the developments' overall impact on bats.

Welsh monitoring report

The single Welsh monitoring report assessed comprised a large (>70 MW) solar farm built in the early 2020's in South Wales. Monitoring was required to satisfy a condition of the planning consent. Baseline bat activity data using static detectors in six locations (four inside the Red Line Boundary (RLB) and two outside) was collected six years prior to its installation, with monitoring occurring one and three years after in the same locations. The detectors were installed for a minimum of five nights during each survey.

Although both sets of post-construction monitoring were conducted in spring, summer and autumn, only summer and autumn data were compared due to incomplete baseline data. Bat box checks were also carried out during the third year of monitoring.

Monitoring outcomes

Year 1

Bat species richness declined at all six monitoring locations during both seasons (summer and autumn) relative to baseline conditions. No *P. nathusii* or *Plecotus* spp. calls were identified at any of the monitoring locations, despite their presence at several locations during the baseline surveys. Bat activity within the RLB decreased dramatically at all four monitoring locations across all recorded species, and one location recorded no bat passes at all (where an average of 170 passes had been recorded pre-construction). Outside the RLB, activity declined at one of the two monitoring locations. At the remaining location, activity increased; however, this increase was limited to *P. pipistrellus*, *P. pygmaeus*, and *N. noctula*, with activity of all other species declining. It is important to note that, although new native hedgerows had been planted as per the Landscape and Ecological Management Plan (LEMP), none of the planned grassland habitat creation or enhancements had been carried out in time for the first year of monitoring due to the landowner's activities in the fields, and the hedgerow would not have matured. This is likely to have impacted insect and bat activity within the RLB.

Year 3

By the third year, bat species richness showed no consistent pattern across monitoring locations, increasing at some locations relative to baseline and remaining the same or decreasing at others. However, all the locations recorded an increase in species richness compared to the year 1 findings, including the return of small numbers of *P. nathusii* and *Plecotus* spp. Additionally, two new species were detected that had not been recorded during baseline or year 1 surveys: *E. serotinus* and *R. hipposideros*. A consistent trend was evident in activity levels compared to baseline, with bat passes associated with the solar array areas substantially lower in year 3. However, at three of the four monitoring locations within the RLB, bat activity had increased relative to the year 1 results, suggesting potential signs of recovery or habituation. Monitoring locations outside the solar farm recorded similar or higher activity compared to baseline and year 1, which may indicate displacement of bat activity towards habitats where solar panels are absent.

It was noted that, although grassland enhancements had been implemented prior to the third year of monitoring, habitats within the solar array fields had not yet reached optimal condition. The establishment of certain plant species may have been constrained by overgrazing and the use of herbicides in some areas; consequently, adjustments to grassland management were recommended. On this basis, invertebrate diversity within the array fields was expected to increase in subsequent years. In addition, monitoring recorded an overall increase from baseline in the number of aquatic invertebrate species within the site's ditch system two years after the solar farm construction, likely reflecting improved management practices. However, whether increases in invertebrate diversity will be sufficient to mitigate the effects of the arrays themselves on bats remains uncertain, particularly given that the panels at this site are fixed at a relatively shallow tilt angle, which could amplify acoustic interference (Baudouin *et al*., 2026; Greif *et al*., 2017).

Bat activity monitoring beyond year 3 post-construction was not included in the original Monitoring and Contingency Plan. Nevertheless, the year 3 monitoring report recommends further bat activity surveys in year 10 to assess whether bat activity levels have recovered following habitat maturation and the implementation of improved management measures.

Bat box monitoring

Of the 15 (out of 32) bat boxes checked in the third year after installation, only one box was found to be occupied. This box supported a single *P. pipistrellus* and was located on the edge of an array area. Access constraints meant that not all boxes could be inspected, due to their placement over reens (drainage ditches) or on dead trees. Many boxes were assessed as being in sub-optimal locations, including placements on the north-facing sides of trees or within dense vegetation, therefore not following the requirements outlined in the LEMP. In response, scrub and ivy were trimmed at several locations to clear box entrances and improve suitability for future occupation. The repositioning of some and the introduction of four additional bat boxes were planned as remedial actions.

Monitoring constraints

Baseline data coverage was less comprehensive than post-construction monitoring, as static detectors were deployed at only a subset of locations in each season (two locations in summer and the remaining four locations in autumn). To ensure comparability, analyses were restricted to datasets from equivalent seasons only. The lack of baseline data constrains the ability of the monitoring data to evaluate seasonal variations in bat activity. Additionally, the static detectors were installed solely on boundary habitat features due to the presence of livestock within the fields during the baseline surveys; therefore, the effects of the solar development on open grassland habitat use by bats (i.e. within the solar arrays) could not be assessed. Furthermore, the monitoring reports were relatively qualitative, with exact activity level changes across locations and species not specified. As the site boundary changed between the baseline and post-construction surveys, this meant that two of the bat monitoring locations were outside of the solar farm. Although not intentional, this provided useful insights into potential displacement effects at a landscape scale.

English monitoring report

One bat monitoring report from a newly constructed solar farm in England was submitted in response to the call for evidence. Bat activity monitoring at this site was recommended due to its proximity to a SAC designated for bats. Baseline monitoring comprised two walked transects and 5-day static detector surveys at seven locations, conducted once per month between May and October, five years prior to construction.

Post-construction monitoring consisted of 10-day static detector surveys at four locations, repeated three times between May and October. None of the post-construction monitoring locations coincided with the baseline locations. As a result, data from each of the three corresponding months were averaged across site locations to enable comparison of overall pre- and post-construction bat activity.

Monitoring outcomes

Year 1

Overall, species richness across locations and seasons remained unchanged from baseline. However, clear species-specific shifts in bat activity were evident. Responses were almost evenly split, with five species/species groups increasing in relative proportion and six decreasing. Species/species groups that increased in proportion post-construction included *P. pygmaeus*, *P. nathusii, N. noctula, N. leisleri*, and *R. ferrumequinum*. In contrast, the relative proportions of *P. pipistrellus*, *Myotis* spp., *P. auritus*, *E. serotinus*, R. *hipposideros*, and *B. barbastellus* all declined compared to baseline. This pattern is consistent with findings reported by Griffin *et al*. (*in prep*.), who observed increased *P. pygmaeus* activity and decreased *P. auritus* activity following the introduction of solar panels into a field, potentially reflecting differences in species-specific sensitivities.

Although the average number of passes per night across locations and species increased in May relative to baseline levels, it decreased in July and September/October. The reduction in July was substantial, while the autumn decrease was comparatively small. This seasonal pattern may reflect the findings of Szoldatits *et al*. (2025), who reported that solar farms with grassland enhancements may provide relatively better early-season (May) foraging opportunities compared to the surrounding agricultural landscape.

Monitoring constraints

Due to inconsistent survey effort and differences in sampling locations between the pre- and post-construction monitoring, any direct comparisons at this site are unreliable, as multiple confounding variables are introduced. These inconsistencies also prevent meaningful assessment of spatial patterns, which is a significant limitation given the importance of relative proximity to key bat habitats, mitigation measures, and spatial context within the site (e.g. core versus edge effects and inside versus outside the solar farm, including potential displacement effects).

In addition, analysis based solely on the relative activity levels of species provides only community-level insights. Comparing mean passes per night for each species would have allowed a more robust assessment of species-level responses.

Further bat activity monitoring is planned for years 3, 5 and 10 of operation. The year 1 monitoring report recommends that baseline survey methods be replicated as far as practicable in future surveys to enable direct comparison and meaningful interpretation of results. The owners are also pursuing year 2 bat monitoring using the correct protocol to compensate for the comparability issues identified in year 1.

Discussions on monitoring constraints

Discussions with ecological consultants and solar industry representatives across the UK indicate that:

- Due to the length of the planning process, especially for larger solar developments, the period between baseline surveys and construction is often >5 years. During this time, numerous extraneous factors could alter the site's bat activity (abundance, richness and spatial distribution), potentially resulting in unrepresentative baseline data that could invalidate the post-construction monitoring conclusions.
- Post-construction monitoring of solar developments remains at an early stage, with most monitored sites representing the immediate or short-term period following construction.
- Current monitoring largely reflects conditions before habitat enhancements and landscape planting have matured, limiting the ability to assess longer-term responses of bats to solar developments.
- There is insufficient evidence to determine whether bat activity changes over time due to habitat improvement, landscape maturation, or behavioural habituation, as these processes may take many years to become apparent.
- Many existing solar sites are not yet old enough for robust conclusions to be drawn regarding long-term ecological effects, reinforcing the need for extended monitoring periods.
- The introduction of the Net Benefit for Biodiversity approach in Wales and Biodiversity Net Gain requirements in England has increased monitoring at newer

developments, with greater emphasis on pre- and post-construction data collection. However, the evidence base for older sites remains limited, with baseline data often absent.
- Where baseline data are missing or incomplete, post-construction results should be interpreted with caution, as alternative drivers (e.g. wider population changes or climatic influences) cannot be accounted for.
- Statistical tests are not usually performed on monitoring data. Therefore, reported trends should be treated with caution, as observed patterns may not be statistically meaningful, particularly where environmental variables and sample sizes are not controlled.
- A growing volume of monitoring data is now in the pipeline, and it is anticipated that a clearer understanding of bat-solar interactions will emerge as datasets from newer developments mature.
- Data generated through planning conditions are often retained in site-specific reports, with no requirement for central collation or long-term accessibility for large-scale analysis.

5. Research priorities for bats and solar

Evidence gaps

Evidence gaps identified from the literature review, assessment of pre- and post-construction monitoring reports and a meeting with the UK Bat Steering Group in January 2026 have been collated and separated into key themes below.

Direct interactions between bats and solar farms

- Does bat behaviour (e.g. foraging, drinking, commuting, social) change in response to the presence of solar panels?
- Do bats fly higher over solar arrays than comparable open fields?
- Are bats attracted to solar panels, and if so, what are the underlying mechanisms driving this attraction?
- Do the echolocation call characteristics of bats change when flying over or between solar panels, and does this differ from adjacent habitats?
- What proportion of bats pass directly over panel arrays compared to those that show avoidance of installations?
- Are solar panels used by bats for foraging, and are there species-specific, temporal or spatial differences in this?
- Do bats use panels as navigational features within otherwise open landscapes?
- How does bat activity differ above panels compared to array edges or linear features? Is this influenced by roost proximity and location?
- Does panel configuration influence bat activity? How important are factors including panel size, height, tilt angle and spacing?
- How important is the size of a solar installation in determining bat behaviour?

Collision risk and mortality

- Do bats collide with solar infrastructure? If so, what is the magnitude of this risk?
- Which bat species, or age classes (e.g. juveniles), are more susceptible to collisions or strikes?
- Does panel configuration influence collision risk? How important are factors including panel size, height, tilt angle and spacing?
- What design and layout of security fencing minimises collision risk?
- Does proximity to linear features influence collision risk?
- Is collision risk influenced by lighting, weather conditions, habitat quality and height, roost proximity, or differences in seasonal bat activity patterns?

Prey availability

- How do solar installations alter invertebrate (including aquatic, nocturnal and crepuscular species) abundance, composition and distribution relative to pre-construction conditions? What is driving these effects?
- Do changes in land management beneath and around panels influence insect communities over time?
- Does polarised light pollution influence aquatic insect abundance, composition and distribution at solar farms, and is this related to proximity to freshwater habitats?
- Are there any noise or EMF emissions at solar developments that are impacting bat prey?
- How important is prey availability in impacting bat activity at solar farms?
- How does prey availability vary across solar sites?

Displacement and landscape-scale effects

- Does the presence of a solar installation result in the displacement of bats from formerly used roosting, foraging, commuting or migrating areas/networks?
- Do solar farms create barriers or fragment the landscape?
- How does landscape composition and configuration alter bat activity at solar farms?
- How do multiple renewable developments within the same landscape cumulatively impact bat movement and habitat connectivity?
- Do displacement effects differ between species with different foraging strategies, call characteristics or commuting behaviours?
- At what spatial scale do potential displacement effects operate?
- What are the effects of solar arrays on both sides of a boundary feature on bat activity compared to one side?
- How important is previous land management, habitat maturity and historic landscape character in determining how bats respond to solar farms? E.g. how does bat activity compare at solar sites that were previously pasture to those that were arable?

Longitudinal effects

- What are the long-term effects of solar farms on local bats and their prey at a population- and community-level?
- How does bat activity change across the lifespan of a solar farm?
- Which bat species can habituate to solar farms and to what extent?
- How long does it take for bats to habituate to a solar development?
- Does bat activity improve after solar farms are decommissioned?

Effectiveness of mitigation and enhancement measures

- How effective are commonly proposed mitigation measures (e.g. hedgerow retention, buffer zones, reduced lighting) at avoiding or reducing any negative impacts on bats and their prey?
- What minimum buffer zone is required around ancient woodland to avoid impacting this habitat and the species it supports?
- Does habitat enhancement deliver a measurable improvement in bat activity or foraging success at solar farms? If so, which types of habitat enhancement are the most beneficial?
- Are bat boxes a useful mitigation tool at solar sites? If so, what designs, placements and how many make them an effective tool?
- What are effective mitigation strategies to use during the construction of solar farms to minimise impact on bats, invertebrates and the surrounding habitat?

Methods for surveying and post-construction monitoring

- Which surveying methods (e.g. transect, automated detectors, thermal imaging, radio-tracking) are most effective at understanding the response of bats to solar installations?
- How should monitoring be designed to allow for robust pre- and post-development comparisons?
- What are appropriate timescales for monitoring to detect both short-term disturbance and longer-term ecological change?
- How can monitoring data be used to build an evidence base to understand bat responses to solar installations?

The future of solar installations

- How will FPV installations impact bat activity and behaviour, particularly for species that use water bodies as key foraging habitats?
- Will FPV alter insect emergence, distribution or availability of water surfaces, and the impact that this may have on bat foraging efficiency?
- Does collision risk change in relation to FPV infrastructure?

- Does the spatial configuration and coverage of FPV installations on waterbodies influence bat behaviour?
- Do bats respond differently to agrivoltaic and ecovoltaic systems, especially when panel spacing, height and orientation differ from conventional ground-mounted solar?
- Do agrivoltaics and ecovoltaics support greater habitat complexity and invertebrate abundance, richness and diversity compared to standard solar installations, and how does this influence bat foraging behaviour?
- What is the optimal management strategy to balance both agricultural productivity and biodiversity outcomes when using agrivoltaic systems?
- How will emerging panel technologies (e.g. bifacial panels, vertical or fence-mounted panels) influence bat behaviour and collision risk?
- Does the increasing installation of rooftop solar and BIPVs pose a risk to bats?
- How to ensure that existing survey, mitigation, and monitoring approaches are able to adapt to these emerging technologies?

Welsh-specific context

The evidence gaps outlined above are broadly applicable at both UK-wide and international scales. However, the distinctive habitats and ecological characteristics of Wales necessitate a national-level understanding of bat responses.

- Whilst most of the research conducted on bats and solar is very generalised and could apply to the UK and beyond, it is also worth noting that regional variations in habitat use and landscape may impact how bats respond to solar.
- Since there is a higher prevalence of permanent and semi-improved grassland in Wales compared to the greater percentage of arable land in much of England, the land-use transition associated with solar development may have different implications for bat activity and prey availability between the two countries. There is a risk that, in Wales, solar development more frequently represents a transition from relatively higher-value grassland habitats, with potentially greater impacts for bat populations.
- Given the geography of Wales, many solar developments are located within upland fringe and valley landscapes, where altitude, topography, and the distribution of suitable habitats may constrain the spatial options available to bats for commuting and foraging. The extent to which these landscapes are particularly sensitive to additional fragmentation or functional disruption associated with solar development is not currently well understood.
- Compared to much of England, where solar developments are often located within large, contiguous areas of intensively managed agricultural land, the Welsh landscape is characterised by a more heterogeneous mosaic of land uses, with ancient woodland and other semi-natural habitats widely distributed across the countryside. As a result, solar developments in Wales will likely occur within landscapes that include nearby high-quality bat habitat, rather than being isolated in agricultural landscapes.

6. Discussion and recommendations

It is evident that awareness of the potential impacts of solar developments on bats is increasing, but that the current evidence base remains limited. While further experimental and theoretical research is required, the speed at which such studies can be designed, delivered and published is unlikely to keep pace with the rapid expansion of solar developments currently planned. It is therefore imperative that the substantial volume of ecological data being collected through pre-construction Environmental Impact Assessments and related processes is better utilised, alongside a coordinated expansion of post-construction monitoring schemes that are robust, standardised and capable of assessing the long-term responses of bat populations to solar installations.

The recommendations below are drawn from the literature review, discussions arising from the call for evidence, the review of pre-construction survey and monitoring reports and discussions during the UK Bat Steering Group meeting in early 2026.

Development of guidance

- There is currently no Welsh or UK-wide standardised best practice guidance which specifically addresses interactions between bats and solar across the full lifecycle of a solar project. This can result in inconsistent approaches between planning authorities, developers and consultants.
- Preliminary guidance for bats and solar farms should be developed at a national UK level, including links to planning and licensing frameworks, to ensure consistent interpretation and application across devolved administrations.
- Any UK guidance should be aligned with emerging EUROBATS recommendations, including terminology, levels of risk, and mitigation hierarchy.
- Guidance will provide clarity for when desk-based assessments alone are appropriate or when site surveys (e.g. roost, transect and/or static acoustic) are also needed.
- Well-designed pre-construction surveys will also provide a robust baseline against which post-construction monitoring data can be compared. Pre-construction surveys should be repeated in instances where a long period (>3 years) has passed between baseline and construction to ensure a representative benchmark.
- Best practice guidance should include the development of a mitigation hierarchy for solar developments, like that developed for UK wind farms. This should prioritise impact avoidance (e.g. exclusion of locations where high impacts are predicted), followed by impact reduction (e.g. optimising layout and design), with biodiversity offsetting or compensation only considered as a last resort.
- Best practice guidance is also needed to support post-construction monitoring at solar installations. Guidance should establish thresholds for when monitoring is required, and include details on duration, frequency, and trigger thresholds for adaptive management. Monitoring programmes should be designed to detect changes in bat activity following installation, and where appropriate, to assess interactions between bats and solar panels. Monitoring design should recognise

natural temporal and spatial variability in bat activity, and that understanding of bat responses is likely to require a long-term monitoring strategy.
- Best practice should include the submission of all pre-and post-construction survey data to a centralised database, to support cumulative analysis and improve understanding of bat responses to solar developments. Efforts should be made to establish a formal statutory obligation for relevant ecological data to be collected, collated and shared.
- There is a strong need to standardise methodologies and reporting formats to improve comparability between sites and to allow for meta-analysis. Guidance should clearly state how data should be collected and reported to allow for this.
- The guidance should provide a clear framework for assessing the cumulative effects of renewable energy across a landscape.

Understanding cumulative effects

- There is a need for a clearer framework to assess the cumulative effects of multiple solar or renewable infrastructures within the same landscape, particularly in areas experiencing rapid expansion. This is especially important where multiple developments occur within bat foraging ranges or in proximity to roosts, where combined effects may influence habitat use and connectivity.
- Assessments of impact should be focused on the landscape scale rather than relying on site-level evaluations, to better understand impacts on bat populations and functional connectivity.
- Ensuring alignment and consistency between guidance for different renewable technologies, including solar and wind, is essential when considering cumulative effects at a landscape scale. Consistent advice across technologies will support coherent assessment of combined impacts on bats, reduce conflicting mitigation requirements, and enable more effective, landscape-level planning and decision-making.

Collaboration with experts and industry

- Although post-construction monitoring is not yet common practice for solar developments, the review identified difficulties in accessing existing monitoring reports. During the call for evidence, several ecological consultants reported that monitoring data held by developers could not be shared. Wider communication with developers is therefore required to frame the collection and sharing of ecological data as a mechanism to improve the effectiveness and cost-efficiency of mitigation measures, reduce uncertainty in future assessments, and support the sustainable expansion of renewable energy.
- Stakeholder collaboration should be maintained through regular workshops and online forums that bring together industry representatives, ecological consultants, statutory nature conservation bodies and academic researchers.

Evidence gaps

- Funding should be sought to progress knowledge in areas identified as evidence gaps.
- The UK Bat Steering Group identified the most significant and pressing evidence gaps as follows.
- How effective are commonly proposed mitigation measures (e.g. hedgerow retention, buffer zones, reduced lighting) at avoiding or reducing any negative impacts on bats? (Identified as a top five priority by 76% of attendees at the UK Bat Steering Group meeting in early 2026, when provided with a list of all the evidence gaps identified in this report.)
    - Does the presence of a solar installation result in the displacement of bats from formerly used foraging, commuting or migrating areas? (65% of attendees)
    - Does bat behaviour change in response to the presence of solar panels? (41% of attendees)
    - Do solar farms create barriers or fragment the landscape? (35% of attendees)
    - Do bats collide with solar panels? If so, what is the magnitude of this risk? (29% of attendees)
    - How do solar installations alter invertebrate abundance and composition relative to pre-construction conditions? (29% of attendees)
- There is a pressing need for targeted experimental studies to determine specific bat responses to solar installations, to complement longer-term pre- and post-construction monitoring, which alone is insufficient to identify the specifics of how bats interact.
- Experimental work should focus on behavioural responses of individual bats to solar infrastructure, including flight paths, foraging behaviour, avoidance, attraction, and collision risk, to improve understanding of how solar installations influence bat activity and habitat use. The use of technologies such as thermal imaging, infrared video and radio-telemetry is recommended, given that these responses cannot be reliably detected using static acoustic monitoring alone.
- There is a need to experimentally test the effectiveness of individual mitigation measures under controlled conditions. Current mitigation approaches are often implemented as combined packages, making it difficult to determine which elements are effective and which provide limited or no benefit.
- Experimental studies should seek to isolate and evaluate specific design or operational interventions, such as panel inclination or stow positions at night, array spacing, panel height, lighting regimes, and vegetation management, to establish evidence-based mitigation options.
- Research should assess whether behavioural responses change over time, including potential habituation or cumulative effects.
- Where feasible, studies should be designed to allow replication across sites and landscape contexts, enabling results to be generalised and informing future national best practice guidance.

- Experimental outputs should be directly linked to management recommendations, with clear thresholds or decision rules that can be applied within planning and licensing frameworks.

List of bat species

Common name	Scientific name	UK resident species
Barbastelle	*Barbastella barbastellus*	Yes
Serotine	*Eptesicus serotinus*	Yes
Savi’s pipistrelle	*Hypsugo savii*	No
Daubenton's bat	*Myotis daubentonii*	Yes
Southern bent-wing bat	*Miniopterus orianae bassanii*	No
Leisler’s bat	*Nyctalus leisleri*	Yes
Noctule	*Nyctalus noctula*	Yes
Canyon bat	*Parastrellus hesperus*	No
Kuhl's pipistrelle	*Pipistrellus kuhlii*	No - vagrant
Nathusius' pipistrelle	*Pipistrellus nathusii*	Yes
Common pipistrelle	*Pipistrellus pipistrellus*	Yes
Soprano pipistrelle	*Pipistrellus pygmaeus*	Yes
Brown long-eared bat	*Plecotus auritus*	Yes
Grey long-eared bat	*Plecotus austriacus*	Yes
Greater horseshoe bat	*Rhinolophus ferrumequinum*	Yes
Lesser horseshoe bat	*Rhinolophus hipposideros*	Yes

List of abbreviations

Abbreviation	Description
BESS	Battery Energy Storage System
BIPV	Building-integrated Photovoltaic
BMV	Best and Most Versatile
CSP	Concentrated Solar Power
ELF EMF	Extremely Low Frequency Electromagnetic Field
FPV	Floating Photovoltaic
GW	Gigawatt
Hz	Hertz
kHz	Kilohertz
LEMP	Landscape and Ecological Management Plan
MW	Megawatt
μT	Microtesla
PLP	Polarised Light Pollution
PRF	Potential Roost Feature
PV	Photovoltaic
REPD	Renewable Energy Planning Database
RLB	Red Line Boundary
SAC	Special Area of Conservation
SSSI	Site of Special Scientific Interest

13 References

Ancillotto L, Ariano A, Nardone V, Budinski I, Rydell J, Russo D. 2017. Effects of free-ranging cattle and landscape complexity on bat foraging: Implications for bat conservation and livestock management. Agriculture, Ecosystems & Environment 241, 54–61.

Anderson CM, Hopkins AP, Anderson JT. 2025. Assessing the Impact of Solar Farms on Waterbirds: A Literature Review of Ecological Interactions and Habitat Alterations. Conservation 5 (1), 4.

Armstrong A, Ostle NJ, Whitaker J. 2016. Solar park microclimate and vegetation management effects on grassland carbon cycling. Environmental Research Letters 11 (7), 074016.

Ayllón T, Nijhof AM, Weiher W, Bauer B, Allène X, Clausen PH. 2014. Feeding behaviour of *Culicoides* spp. (Diptera: Ceratopogonidae) on cattle and sheep in northeast Germany. Parasites Vectors 7 (1), 34.

Badran G, Dhimish M. 2024. Comprehensive study on the efficiency of vertical bifacial photovoltaic systems: a UK case study. Scientific Reports 14 (1), 18380.

Balmori A. 2021. Electromagnetic radiation as an emerging driver factor for the decline of insects. Science of The Total Environment 767, 144913.

Barré K, Baudouin A, Froidevaux JSP, Chartendrault V, Kerbiriou C. 2023. Insectivorous bats alter their flight and feeding behaviour at ground-mounted solar farms. Journal of Applied Ecology 00, 1–12.

Barron-Gafford GA, Minor RL, Allen NA, Cronin AD, Brooks AE, Pavao-Zuckerman MA. 2016. The Photovoltaic Heat Island Effect: Larger solar power plants increase local temperatures. Scientific Reports 6 (1), 35070.

Bat Conservation Trust (BCT). 2016. Core Sustenance Zones: Determining zone size [online]. Available from: Core_Sustenance_Zones_Explained_04.02.16.pdf. [Accessed 4th December 2025]

Baudouin A, Hette-Tronquart N, Brun C, Gay N, Chartendrault V, Kerbiriou C. 2026. Balancing renewable energy and biodiversity: Assessing solar farm effects on bat activity. Biological Conservation 314, 111661.

Benbouzid I, Simon D. 2025. Evaluating the Potential for Improving Biodiversity in Solar Farms [online]. Based on the 2024 MSc. Sustainability and Management dissertation by Ilyes Benbouzid. Available from: https://pure.royalholloway.ac.uk/ws/portalfiles/portal/66013440/Evaluating_the_potential_for_improving_biodiversity_in_solar_farms.pdf. [Accessed 14th November 2025]

Beynon SA. 2012. Potential environmental consequences of administration of anthelmintics to sheep. Veterinary Parasitology 189 (1), 113–124.

Billington G. 2020. Greater Horseshoe bat research in North Devon in 2020. Greena Ecological Consultancy. Unpublished report.

Black TV, Robertson BA. 2020. How to disguise evolutionary traps created by solar panels. Journal of Insect Conservation 24 (2), 241–247.

Blaydes H, Potts SG, Whyatt JD, Armstrong A. 2024. On-site floral resources and surrounding landscape characteristics impact pollinator biodiversity at solar parks. Ecological Solutions and Evidence 5 (1), e12307.

Blaydes H, Whyatt JD, Carvalho F, Lee HK, McCann K, Silveira JM, Armstrong A. 2025. Shedding light on land use change for solar farms. Progress in Energy 7 (3), 033001.

Bollinger J. 2021. Acoustic and Flight Behaviour of Emerging Greater Horseshoe Bats in Paired Flight. Unpublished MSc(R) dissertation. University of Bristol, School of Biological Sciences.

Boscarino-Gaetano R, Vernes K, Nordberg EJ. 2024. Creating wildlife habitat using artificial structures: a review of their efficacy and potential use in solar farms. Biological Reviews 99 (5), 1848–1867.

Brito DL, Dallago BSL, Louvandini H, Santos VRVD, Torres SEFDA, Gomes EF, Amarante AFTD, Melo CBD, McManus CM. 2013. Effect of alternate and simultaneous grazing on endoparasite infection in sheep and cattle. Revista Brasileira de Parasitologia Veterinária 22 (4), 485–494.

Brook BW, Bradshaw CJ. 2015. Key role for nuclear energy in global biodiversity conservation. Conservation Biology 29 (3), 702–712.

Chock RY, Clucas B, Peterson EK, Blackwell BF, Blumstein DT, Church K, Fernández-Juricic E, Francescoli G, Greggor AL, Kemp P, Pinho GM. 2021. Evaluating potential effects of solar power facilities on wildlife from an animal behavior perspective. Conservation Science and Practice 3 (2), e319.

Clarkson & Woods. *In prep*. Investigating bat call detectability at solar farms.

Clarkson & Woods. 2018. Solarview: ecological monitoring of solar sites – overview of 2018 surveys [online]. Available from: https://www.clarksonwoods.co.uk/wp-content/uploads/PDF/Solarview2018.pdf. [Accessed 19th December 2025]

Clarkson & Woods. 2019. Solarview: ecological monitoring of solar sites – overview of 2019 surveys [online]. Available from: https://www.clarksonwoods.co.uk/wp-content/uploads/2020/07/CW_2019-Solarview.pdf. [Accessed 19th December 2025]

Clarkson & Woods. 2020. Solarview: ecological monitoring of solar sites – overview of 2020 surveys [online]. Available from: https://www.clarksonwoods.co.uk/wp-content/uploads/PDF/Solarview2020.pdf. [Accessed 19th December 2025]

Classen-Rodríguez L, Tinghitella R, Fowler-Finn K. 2021. Anthropogenic Noise Affects Insect and Arachnid Behavior, Thus Changing Interactions within and between Species. Current Opinion in Insect Science 47, 142–153.

Coles RB, Guppy A, Anderson ME, Schlegel P. 1989. Frequency sensitivity and directional hearing in the gleaning bat, *Plecotus auritus* (Linnaeus 1758). Journal of Comparative Physiology 165 (2), 269–280.

Conkling TJ, Fesnock AL, Katzner TE. 2023. Numbers of wildlife fatalities at renewable energy facilities in a targeted development region. PLoS ONE 18 (12), e0295552.

Conkling TJ, Vander Zanden HB, Poessel SA, Loss SR, Allison TD, Diffendorfer JE, Duerr AE, Nelson DM, Yee J, Katzner TE. 2020. Learning from Real-World Experience to Understand Renewable Energy Impacts to Wildlife. California Energy Commission. Publication Number: CEC-500-2020-012.

Corcoran AJ, Moss CF. 2017. Sensing in a noisy world: lessons from auditory specialists, echolocating bats. Journal of Experimental Biology 220 (24), 4554–4566.

Cutter J, Hovick T, McGranahan D, Harmon J, Limb R, Spiess J, Geaumont B. 2022. Cattle grazing results in greater floral resources and pollinators than sheep grazing in low-diversity grasslands. Ecology and Evolution 12 (1), e8396.

DCLG. 2012. Permitted development rights for small scale renewable and low carbon energy technologies, and electric vehicle charging infrastructure consultation: Government response [online]. Available from: https://assets.publishing.service.gov.uk/media/5a79dc2ae5274a18ba50f584/2105627.pdf. [Accessed 12th November 2025]

Department for Energy Security and Net Zero. 2024. Clean Power 2030 Action Plan: A new era of clean electricity [online]. Available from: https://www.gov.uk/government/publications/clean-power-2030-action-plan/clean-power-2030-action-plan-a-new-era-of-clean-electricity-main-report. [Accessed 6th November 2025]

Department for Energy Security and Net Zero. 2025. Solar photovoltaics deployment [online]. Available from: https://www.gov.uk/government/statistics/solar-photovoltaics-deployment. [Accessed 6th November 2025]

Diehl R, Robertson B, Kosciuch K, Stoms D. 2024. Investigating the "Lake Effect" Influence on Avian Behavior from California's Utility-Scale Photovoltaic Solar Facilities. California Energy Commission, Energy Research and Development Division. Final Project Report CEC-500-2024-055.

Dormont L, Rapior S, McKey DB, Lumaret JP. 2007. Influence of dung volatiles on the process of resource selection by coprophagous beetles. Chemoecology 17 (1), 23–30.

Downs NC, Sanderson LJ. 2010. Do bats forage over cattle dung or over cattle? Acta Chiropterologica 12 (2), 349–358.

Egni-Co-op. 2025. Egni Co-op [online]. Available from: https://aat.cymru/egni/. [Accessed 11th November 2025]

Eklöf J, Šuba J, Petersons G, Rydell J. 2014. Visual acuity and eye size in five European bat species in relation to foraging and migration strategies. Environmental and Experimental Biology 12 (1), 1–6.

Elamri Y, Cheviron B, Mange A, Dejean C, Liron F, Belaud G. 2018. Rain concentration and sheltering effect of solar panels on cultivated plots. Hydrology and Earth System Sciences 22 (2), 1285–1298.

Ellis EC. 2021. Land Use and Ecological Change: A 12,000-Year History. Annual Review of Environment and Resources 46, 1–33.

Elminshawy NAS, Osama A, Gagliano A, Oterkus E, Tina GM. 2024. A technical and economic evaluation of floating photovoltaic systems in the context of the water-energy nexus. Energy 303, 131904.

Energy Institute (EI). 2025. Statistical Review of World Energy [online]. Available from: https://www.energyinst.org/statistical-review. [Accessed 6th November 2025]

Estellés-Domingo I, López-López P. 2025. Effects of wind farms on raptors: A systematic review of the current knowledge and the potential solutions to mitigate negative impacts. Animal Conservation 28 (3), 334–352.

Farkas A, Száz D, Egri Á, Barta A, Mészáros Á, Hegedüs R, Horváth G, Kriska G. 2016. Mayflies are least attracted to vertical polarization: A polarotactic reaction helping to avoid unsuitable habitats. Physiology & Behavior 163, 219–227.

Feltwell J. 2014. Observations on the effects of photovoltaic solar panels on invertebrates at Ebbsfleet Farm, Sandwich, Kent. The Newsletter of the Kent Field Club 79, 4–17.

Festa F, Ancillotto L, Santini L, Pacifici M, Rocha R, Toshkova N, Amorim F, Benítez-López A, Domer A, Hamidović D, Kramer-Schadt S, Mathews F, Radchuk V, Rebelo H, Ruczynski I, Solem E, Tsoar A, Russo D, Razgour O. 2023. Bat responses to climate change: a systematic review. Biological Reviews 98 (1), 19–33.

Fialas PC, Santini L, Russo D, Amorim F, Rebelo H, Novella-Fernandez R, Marques F, Domer A, Vella A, Martinoli A, Figurek A, Tsoar A, Sandor A, Ibanez C, Korine C, Kerbiriou C, Voigt C, Mifsud C, Jére C, … Razgour O. 2025. Changes in community composition and functional diversity of European bats under climate change. Conservation Biology 39 (4), e70025.

Finch D, Schofield H, Mathews F. 2020. Traffic noise playback reduces the activity and feeding behaviour of free-living bats. Environmental Pollution 1 (263), 114405.

Finn JA, Giller PS. 2002. Experimental investigations of colonisation by north temperate dung beetles of different types of domestic herbivore dung. Applied Soil Ecology 20 (1), 1–13.

Fleming PA. 2025. All that glitters – Review of solar facility impacts on fauna. Renewable and Sustainable Energy Reviews 224, 115995.

Forestry Commission. 2025a. Botley West Solar Farm - Examining Authority Second Written Questions (ExQ2) [online]. Available from: [Documents | Botley West Solar Farm](). [Accessed 16th December 2025]

Forestry Commission. 2025b. GOV.UK. Edge design for woodland integration, resilience and biodiversity [online]. Available from: https://www.gov.uk/guidance/edge-design-for-woodland-integration-resilience-and-biodiversity. [Accessed 16th December 2025]

Foxley T, Lintott P, Stone E. 2023. What drives bat activity at field boundaries? Journal of Environmental Management 329, 117029.

Foxley T, Lintott P, Stonehouse S, Flannigan J, Stone EL. 2025. A high resolution spatial modelling framework for landscape-level, strategic conservation planning. Ecological Informatics 91, 103363.

Fraleigh DC, Heitmann JB, Robertson BA. 2021. Ultraviolet polarized light pollution and evolutionary traps for aquatic insects. Animal Behaviour 180, 239–247.

Fraser MD, Vallin HE, Roberts BP. 2022. Animal board invited review: Grassland-based livestock farming and biodiversity. Animal 16 (12), 100671.

Fritz B, Horváth G, Hünig R, Pereszlényi Á, Egri Á, Guttmann M, Schneider M, Lemmer U, Kriska G, Gomard G. 2020. Bioreplicated coatings for photovoltaic solar panels nearly eliminate light pollution that harms polarotactic insects. PLoS ONE 15 (12), e0243296.

Fthenakis V, Blunden J, Green T, Krueger L, Turney D. 2011. Large photovoltaic power plants: Wildlife impacts and benefits. In: Conference Record of the IEEE Photovoltaic Specialists Conference p. 002011–002016.

Fthenakis V, Yu Y. 2013. Analysis of the potential for a heat island effect in large solar farms. In: 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC) p. 3362–3366.

Gibson L, Wilman EN, Laurance WF. 2017. How green is ‘green’ energy? Trends in Ecology & Evolution 32 (12), 922–935.

Gilmour LRV, Holderied MW, Pickering SPC, Jones G. 2021. Acoustic deterrents influence foraging activity, flight and echolocation behaviour of free-flying bats. Journal of Experimental Biology 224 (20), jeb242715.

Gómez-Catasús J, Morales MB, Giralt D, del Portillo DG, Manzano-Rubio R, Solé-Bujalance L, Sardà-Palomera F, Traba J, Bota G. 2024. Solar photovoltaic energy development and biodiversity conservation: Current knowledge and research gaps. Conservation Letters 17 (4), e13025.

González-Tokman D, Córdoba-Aguilar A, Dáttilo W, Lira-Noriega A, Sánchez-Guillén RA, Villalobos F. 2020. Insect responses to heat: physiological mechanisms, evolution and ecological implications in a warming world. Biological Reviews 95 (3), 802–821.

Greif S, Siemers BM. 2010. Innate recognition of water bodies in echolocating bats. Nature Communications 1 (1), 107.

Greif S, Zsebok S, Schmieder D, Siemers BM. 2017. Acoustic mirrors as sensory traps for bats. Science 357 (6355), 1045–1047.

Griffin MLU. *In prep.* Investigating acoustic-related disturbance of bats at development sites to inform industry guidance and mitigation. Unpublished PhD thesis. University of the West of England, School of Applied Sciences.

Griffin MLU, Lintott PR, Reason P. *In prep.* Exploring bat mitigation strategies at solar farms.

Grodzinski U, Spiegel O, Korine C, Holderied MW. 2009. Context-dependent flight speed: evidence for energetically optimal flight speed in the bat *Pipistrellus kuhlii*? Journal of Animal Ecology 78 (3), 540–548.

Guoqing L, Hernandez RR, Blackburn GA, Davies G, Hunt M, Whyatt JD, Armstrong A. 2021. Ground-mounted photovoltaic solar parks promote land surface cool islands in arid ecosystems. Renewable and Sustainable Energy Transition 1, 100008.

Gustafson Y, Schnitzler HU. 1979. Echolocation and obstacle avoidance in the hipposiderid bat *Asellia tridens*. Journal of Comparative Physiology 131 (2), 161–167.

Haas J, Khalighi J, De La Fuente A, Gerbersdorf SU, Nowak W, Chen PJ. 2020. Floating photovoltaic plants: Ecological impacts versus hydropower operation flexibility. Energy Conversion and Management 206, 112414.

Heim O, Schröder A, Eccard J, Jung K, Voigt CC. 2016. Seasonal activity patterns of European bats above intensively used farmland. Agriculture, Ecosystems & Environment 233, 130–139.

Hernandez RR, Easter SB, Murphy-Mariscal ML, Maestre FT, Tavassoli M, Allen EB, Barrows CW, Belnap J, Ochoa-Hueso R, Ravi S, Allen MF. 2014. Environmental impacts of utility-scale solar energy. Renewable and Sustainable Energy Reviews 29, 766–779.

Holz PH, Stent A, Lumsden LF, Hufschmid J. 2020. Trauma found to be a significant cause of death in a pathological investigation of bent-winged bats (*Miniopterus orianae*). Journal of Zoo and Wildlife Medicine 50 (4), 966–971.

Horváth G. Polarization Sensitivity and Insensitivity in Bats. 2024. In: Horváth G, editor. Polarization Vision and Environmental Polarized Light. Cham: Springer Nature Switzerland p. 307–312.

Horváth G, Blahó M, Egri Á, Kriska G, Seres I, Robertson B. 2010. Reducing the maladaptive attractiveness of solar panels to polarotactic insects. Conservation Biology 24 (6), 1644–1653.

Horváth G, Kriska G, Malik P, Robertson B. 2009. Polarized light pollution: a new kind of ecological photopollution. Frontiers in Ecology and the Environment 7 (6), 317–325.

Horváth G, Kriska G, Robertson B. Anthropogenic Polarization and Polarized Light Pollution Inducing Polarized Ecological Traps. 2014. In: Horváth G, editor. Polarized Light and Polarization Vision in Animal Sciences. 2nd ed. Berlin, Heidelberg: Springer (Springer Series in Vision Research) p. 443–513.

Horváth G, Pereszlényi Á, Egri Á, Fritz B, Guttmann M, Lemmer U, Gomard G, Kriska G. 2020. Horsefly reactions to black surfaces: attractiveness to male and female tabanids versus surface tilt angle and temperature. Parasitology Research 119 (8), 2399–2409.

Horváth G, Pereszlényi Á, Tóth T, Polgár S, Jánosi IM. 2019. Attractiveness of thermally different, uniformly black targets to horseflies: *Tabanus tergestinus* prefers sunlit warm shiny dark targets. Royal Society Open Science 6 (10), 191119.

H.T. Harvey and Associates. 2013. Desert Sunlight Solar Farm Carcass Detectability Study. Fresno, California. Prepared for Desert Sunlight Holdings, LLC, Oakland, California. Unpublished report.

Iandolo B, Mizushima I, Davidsen RS, Tang PT, Hansen O. 2018. All-black front surfaces for building-integrated photovoltaics. Japanese Journal of Applied Physics 57 (8S3), 08RH01.

Ingeme Y, Bush A, Lumsden L, Harten EV, Bourne S, Reardon T. 2018. Hit or miss could mean life or death for juvenile Southern Bent-wing Bats. In: Proceedings of the 31st Biennial Conference of the Australian Speleological Federation 195–201.

International Energy Agency (IEA). 2025. Renewables 2025: Analysis and forecasts to 2030 [online]. Available from: https://iea.blob.core.windows.net/assets/76ad6eac-2aa6-4c55-9a55-b8dc0dba9f9e/Renewables2025.pdf. [Accessed 17th November 2025]

Jaureguiberry P, Titeux N, Wiemers M, Bowler DE, Coscieme L, Golden AS, Guerra CA, Jacob U, Takahashi Y, Settele J, Díaz S, Molnár Z, Purvis A. 2022. The direct drivers of recent global anthropogenic biodiversity loss. Science Advances 8 (45), eabm9982.

Jeal C, Perold V, Seymour CL, Ralston-Paton S, Ryan PG. 2019. Utility-scale solar energy facilities – Effects on invertebrates in an arid environment. Journal of Arid Environments 168, 1–8.

Karban CC, Lovich JE, Grodsky SM, Munson SM. 2024. Predicting the effects of solar energy development on plants and wildlife in the Desert Southwest, United States. Renewable and Sustainable Energy Reviews 205, 114823.

Knapp AK, Sturchio MA. 2024. Ecovoltaics in an increasingly water-limited world: An ecological perspective. One Earth 7 (10), 1705–1712.

Kocsis T, de Groot A, van Beersum F, Boer J, Dimmers W, Laros I, Lammertsma D, Polling M, Schnerch B, Villing N, WallisDeVries MF. 2025. Mixed plant and arthropod biodiversity responses to solar park establishment on former agricultural lands. Journal of Applied Ecology 62 (11), 3078–3091.

Kriska G, Malik P, Szivák I, Horváth G. 2008. Glass buildings on river banks as “polarized light traps” for mass-swarming polarotactic caddis flies. Naturwissenschaften 95 (5), 461–467.

Lafitte A, Sordello R, Ouédraogo DY, Thierry C, Marx G, Froidevaux J, Schatz B, Kerbiriou C, Gourdain P, Reyjol Y. 2023. Existing evidence on the effects of photovoltaic panels on biodiversity: a systematic map with critical appraisal of study validity. Environmental Evidence 12 (1), 25.

Lec'Hvien A, Bienvenu L, Isselin-Nondedeu F, Bischoff A, Gros R, Schatz B. 2025. Effects of solar panels and management on pollinators and their interactions with plants in Southern French solar parks. Biological Conservation 307, 111209.

Lovich JE, Ennen JR. 2011. Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States. BioScience 61 (12), 982–992.

Ma J, Huang X, Qin X, Ding Y, Hong J, Du G, Li X, Gao W, Zhang Z, Wang G, Wang N, Zhang Z. 2017. Large manipulative experiments revealed variations of insect abundance and trophic levels in response to the cumulative effects of sheep grazing. Scientific Reports 7 (1), 11297.

Mahieu M, Aumont G. 2009. Effects of sheep and cattle alternate grazing on sheep parasitism and production. Tropical Animal Health and Production 41 (2), 229–239.

Manville AM. 2016. Impacts to Birds and Bats Due to Collisions and Electrocutions from Some Tall Structures in the United States: Wires, Towers, Turbines, and Solar Arrays—

State of the Art in Addressing the Problems. In: Angelici FM, editor. Problematic Wildlife: A Cross-Disciplinary Approach. Cham: Springer International Publishing p. 415–442.

Marshall CAM, Wilkinson MT, Hadfield PM, Rogers SM, Shanklin JD, Eversham BC, Healey R, Kranse OP, Preston CD, Coghill SJ, McGonigle KL, Moggridge GD, Pilbeam PG, Marza AC, Szigecsan D, Mitchell J, Hicks MA, Wallis SM, Xu Z, Toccaceli F, McLennan CM, Eves-van den Akker S. 2023. Urban wildflower meadow planting for biodiversity, climate and society: An evaluation at King's College, Cambridge. Ecological Solutions and Evidence 4 (2), e12243.

Masna S, Morse SM, Hayibo KS, Pearce JM. 2023. The potential for fencing to be used as low-cost solar photovoltaic racking. Solar Energy 253, 30–46.

McCracken DI. 1993. The potential for avermectins to affect wildlife. Veterinary Parasitology 48 (1–4), 273–280.

Merheb C, Macknick J, Davatzes N, Ravi S. 2025. Synergies and trade-offs of multi-use solar landscapes. Nature Sustainability (8), 857–870.

Møhl B. 1988. Target Detection by Echolocating Bats. In: Nachtigall PE, Moore PWB, editors. Animal Sonar: Processes and Performance. Boston, MA: Springer US p. 435–450.

Molina-Montenegro MA, Acuña-Rodríguez IS, Ballesteros GI, Baldelomar M, Torres-Díaz C, Broitman BR, Vázquez DP. 2023. Electromagnetic fields disrupt the pollination service by honeybees. Science Advances 9 (19), eadh1455.

Montag H, Parker G, Clarkson T. 2016. The Effects of Solar Farms on Local Biodiversity: A Comparative Study. Clarkson & Woods and Wychwood Biodiversity.

Mozumder MS, Mourad AHI, Pervez H, Surkatti R. 2019. Recent developments in multifunctional coatings for solar panel applications: A review. Solar Energy Materials and Solar Cells 189, 75–102.

Natural England. 2011. Natural England Technical Information Note TIN101. Solar parks: maximising environmental benefits [online]. Available from: [ARCHIVED CONTENT] Solar parks: maximising environmental benefits - TIN101. [Accessed 24th November 2025]

Natural Resources Wales (NRW). *In prep.* Buffer distances that have the potential to impact Annex II bat roosts, for use in Habitats Regulations Assessments of European protected sites.

NatureScot, Natural England, Natural Resources Wales, RenewableUK, ScottishPower Renewables, Ecotricity Ltd, University of Exeter, Bat Conservation Trust. 2021. Bats and Onshore Wind Turbines: Survey, Assessment and Mitigation [online]. Available from: https://www.nature.scot/doc/bats-and-onshore-wind-turbines-survey-assessment-and-mitigation. [Accessed 14th November 2025]

Nicholls B, Racey PA. 2007. Bats Avoid Radar Installations: Could Electromagnetic Fields Deter Bats from Colliding with Wind Turbines? PLoS ONE 2 (3), e297.

Nordberg E, Schwarzkopf L. 2023. Developing conservoltaic systems to support biodiversity on solar farms. Austral Ecology 48, 643–649.

Oliveira JM, Destro ALF, Freitas MB, Oliveira LL. 2021. How do pesticides affect bats? – A brief review of recent publications. Brazilian Journal of Biology 81, 499–507.

O'Malley KD, Schofield HW, Wright PGR, Hargreaves D, Corcoran AJ, Mathews F. 2025. Increasing canopy cover elevates vehicle collision risk for barbastelle bats (*Barbastella barbastellus*) at roads. Scientific Reports 15 (1), 37011.

Osseweijer FJW, van den Hurk LBP, Teunissen EJHM, van Sark WGJHM. 2018. A comparative review of building-integrated photovoltaics ecosystems in selected European countries. Renewable and Sustainable Energy Reviews 90, 1027–1040.

Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. 2016. Rayyan - a web and mobile app for systematic reviews. Systematic Reviews 5 (1), 210.

Panthi G, Bajagain R, An YJ, Jeong SW. 2021. Leaching potential of chemical species from real perovskite and silicon solar cells. Process Safety and Environmental Protection 149, 115–122.

Parker GE, McQueen C. 2013. Can Solar Farms Deliver Significant Benefits to Biodiversity? Preliminary Study July-August 2013. Unpublished report.

Peschel R, Peschel T. 2025. Biodiversity in Solar Farms. A Nationwide Field Study. Association of Energy Market Innovators (bne), Berlin.

Peter F, Bleumer R, Christophersen CM, Matern S, Diekötter T. 2025. Sown wildflower fields and hedgerows synergistically promote insectivorous bats. Conservation Science and Practice 7 (1), e13275.

Pettorelli N, Graham NA, Seddon N, Maria da Cunha Bustamante M, Lowton MJ, Sutherland WJ, Koldewey HJ, Prentice HC, Barlow J. 2021. Time to integrate global climate change and biodiversity science-policy agendas. Journal of Applied Ecology 58 (11), 2384–2393.

Rahman NAA, Firtha G, Szabadi KL, Jones G, Zsebők S. 2024. Mitigating the deceptive effects of smooth surfaces: subtle surface modifications can eliminate maladaptive drinking attempts by bats. Animal Conservation 9, acv.12960.

Renewable Energy Planning Database (REPD). 2025. Renewable Energy Planning Database: quarterly extract – October 2025 (quarter 3) [online]. Available from: [Renewable Energy Planning Database: quarterly extract - GOV.UK]. [Accessed 19th November 2025]

RenewableUK, Marine Energy Wales, Solar Energy UK. 2025. Wind, solar and tidal stream: Unleashing the full value of Welsh renewables [online]. Available from: 2329-renewable-energy-in-wales-report.pdf. [Accessed 20th October 2025]

Robinson MF, Stebbings RE. 1997. Home range and habitat use by the serotine bat, *Eptesicus serotinus*, in England. Journal of Zoology 243 (1), 117–136.

Rocha SM, Armstrong A, Thackeray SJ, Hernandez RR, Folkard AM. 2024. Environmental impacts of floating solar panels on freshwater systems and their techno-ecological synergies. Environmental Research: Infrastructure and Sustainability 4 (4), 042002.

Rowland CS, Marston CG, O'Neil AW. 2025. Land Cover Map 2024 (land parcels, GB). NERC EDS Environmental Information Data Centre.

Russo D, Cistrone L, Jones G. 2012. Sensory Ecology of Water Detection by Bats: A Field Experiment. PLoS ONE 7 (10), e48144.

Russo D, Tanalgo K, Rebelo H, Cistrone L. 2024. To improve or not to improve? The dilemma of “bat-friendly” farmland potentially becoming an ecological trap. Agriculture, Ecosystems & Environment 375, 109215.

Sadeghi R, Parenti M, Memme S, Fossa M, Morchio S. 2025. A Review and Comparative Analysis of Solar Tracking Systems. Energies 18 (10), 2553.

Sandoval-Herrera N, Paz Castillo J, Herrera Montalvo LG, Welch KC Jr. 2021. Micronucleus Test Reveals Genotoxic Effects in Bats Associated with Agricultural Activity. Environmental Toxicology and Chemistry 40 (1), 202–207.

Schanzer S, Koch M, Kiefer A, Jentke T, Veith M, Bracher F, Bracher J, Müller C. 2022. Analysis of pesticide and persistent organic pollutant residues in German bats. Chemosphere 305, 135342.

Schaub A, Ostwald J, Siemers BM. 2008. Foraging bats avoid noise. Journal of Experimental Biology 211 (19), 3174–3180.

Senedd Research. 2015. Solar Farms in Wales. Available from: Solar Farms in Wales [Accessed 20th October 2025]

Shepherd SJ. 2018. The Effects of Extremely Low Frequency Electromagnetic Fields on Insects. Unpublished PhD thesis. University of Southampton, School of Biological Sciences.

Smallwood KS. 2022. Utility-scale solar impacts to volant wildlife. The Journal of Wildlife Management 86 (4), e22216.

Smotherman MS, Croft T, Macias S. 2022. Biosonar discrimination of fine surface textures by echolocating free-tailed bats. Frontiers in Ecology and Evolution 10, 969350.

Solangi KH, Islam MR, Saidur R, Rahim NA, Fayaz H. 2011. A review on global solar energy policy. Renewable and Sustainable Energy Reviews 15 (4), 2149–2163.

Solar Energy UK (SEUK). 2025. Solar Habitat 2025: Ecological trends on solar farms in the UK [online]. Available from: https://solarenergyuk.org/wp-content/uploads/2025/04/SEUK-Solar-Habitat-2025-3.pdf. [Accessed 18th December 2025]

Stanojević V, Prolić Z, Savić T, Todorović D, Janać B. 2005. Effects of Extremely Low Frequency (50 Hz) Magnetic Field on Development Dynamics of the Housefly (*Musca domestica* L.). Electromagnetic Biology and Medicine 24 (2), 99–107.

Stilz P. 2017. How glass fronts deceive bats. Science 357 (6355), 977–978.

Stone EL, Harris S, Jones G. 2015. Impacts of artificial lighting on bats: a review of challenges and solutions. Mammalian Biology 80 (3), 213–219.

Storm M, Khoshmashrab S, Bright E. 2011. The sounds of solar power generation. In: Noise-Con 2011.

Sturchio MA, Knapp AK. 2023. Ecovoltaic principles for a more sustainable, ecologically informed solar energy future. Nature Ecology & Evolution 7 (11), 1746–1749.

Sümer S, Denzinger A, Schnitzler HU. 2009. Spatial unmasking in the echolocating Big Brown Bat, *Eptesicus fuscus*. Journal of Comparative Physiology A 195 (5), 463–472.

Szabadi KL, Kurali A, Estók P, Görföl T, Froidevaux JSP, Zsebők S. 2025. Bats in livestock farms—effects of farm characteristics and landscape composition on bat activity. Landscape Ecology 40 (9), 179.

Szabadi KL, Kurali A, Rahman NAA, Froidevaux JSP, Tinsley E, Jones G, Görföl T, Estók P, Zsebők S. 2023. The use of solar farms by bats in mosaic landscapes: Implications for conservation. Global Ecology and Conservation 44, e02481.

Száz D, Mihályi D, Farkas A, Egri Á, Barta A, Kriska G, Robertson B, Horváth G. 2016. Polarized light pollution of matte solar panels: anti-reflective photovoltaics reduce polarized light pollution but benefit only some aquatic insects. Journal of Insect Conservation 20 (4), 663–675.

Szoldatits KE, Walston LJ, Hartmann HM, Fox L, Stanger ME, Steele SE, Hogstrom I, Macknick J. 2025. Bat activity at ecovoltaic solar energy developments in the Midwestern United States. Global Ecology and Conservation 63, e03864.

Takács P, Száz D, Bernáth B, Pomozi I, Horváth G. 2024. Polarized Light Pollution of Fixed-Tilt Photovoltaic Solar Panels Measured by Drone-Polarimetry and Its Visual-Ecological Importance. Remote Sensing 16 (7), 1177.

Tavernier C, Nuijten R, Buij R, van Langevelde F. 2026. Solar fields in farmlands, their impact on bat presence and activity. PLoS ONE 21 (6), e0335581.

Taylor R, Conway J, Gabb O, Gillespie J. 2019. Potential ecological impacts of ground-mounted photovoltaic solar panels [online]. Available from: https://www.bsg-ecology.com/wp-content/uploads/2019/04/Solar-Panels-and-Wildlife-Review-2019.pdf. [Accessed 20th October 2025]

Teff-Seker Y, Berger-Tal O, Lehnardt Y, Teschner N. 2022. Noise pollution from wind turbines and its effects on wildlife: A cross-national analysis of current policies and planning regulations. Renewable and Sustainable Energy Reviews 168, 112801.

Tell RA, Hooper HC, Sias GG, Mezei G, Hung P, Kavet R. 2015. Electromagnetic Fields Associated with Commercial Solar Photovoltaic Electric Power Generating Facilities. Journal of Occupational and Environmental Hygiene 12 (11), 795–803.

Thaxter CB, Buchanan GM, Carr J, Butchart SH, Newbold T, Green RE, Tobias JA, Foden WB, O'Brien S, Pearce-Higgins JW. 2017. Bird and bat species' global vulnerability to collision mortality at wind farms revealed through a trait-based assessment. Proceedings of the Royal Society B: Biological Sciences 284 (1862), 20170829.

Thill A, Cammaerts M-C, Balmori A. 2024. Biological effects of electromagnetic fields on insects: A systematic review and meta-analysis. Reviews on Environmental Health 39 (4), 853–869.

Tinsley EA. 2024. The impacts and implications of solar farms for bats and invertebrates in England. Unpublished PhD thesis. University of Bristol, School of Biological Sciences.

Tinsley E, Froidevaux JSP, Jones G. 2024. The location of solar farms within England's ecological landscape: Implications for biodiversity conservation. Journal of Environmental Management 372, 123372.

Tinsley E, Froidevaux JSP, Zsebők S, Szabadi KL, Jones G. 2023. Renewable energies and biodiversity: Impact of ground-mounted solar photovoltaic sites on bat activity. Journal of Applied Ecology 60 (9), 1752–1762.

Tsafack N, Fang W, Wang X, Xie Y, Wang X, Fattorini S. 2022. Influence of grazing and solar panel installation on tenebrionid beetles (*Coleoptera Tenebrionidae*) of a central Asian steppe. Journal of Environmental Management 320, 115791.

Tyson C. 2025. Harnessing the sun to help the night [online]. W&M News, 14th October. Available from: https://news.wm.edu/2025/10/14/harnessing-the-sun-to-help-the-night/. [Accessed 24th October 2025]

Vaughan N. 1997. The diets of British bats (Chiroptera). Mammal Review 27, 77–94.

Vervloesem J, Marcheggiani E, Choudhury MAM, Muys B. 2022. Effects of Photovoltaic Solar Farms on Microclimate and Vegetation Diversity. Sustainability 14 (12), 7493.

Voigt CC, Dekker J, Fritze M, Gazaryan S, Hölker F, Jones G, Lewan D, Limpens HJGA, Mathews F, Rydell J, Spoelstra K, Zagmajster M. 2021. The Impact of Light Pollution on Bats Varies According to Foraging Guild and Habitat Context. BioScience 71 (10), 1103–1109.

Walston LJ, Hartmann HM, Fox L, Macknick J, McCall J, Janski J, Jenkins L. 2023. If you build it, will they come? Insect community responses to habitat establishment at solar energy facilities in Minnesota, USA. Environmental Research Letters 19 (1), 014053.

Watson N, Bolton P. 2024. Contracts for Difference, research briefing. House of Commons Library [online]. Available from: CBP-9871.pdf. [Accessed 27th October 2025]

Welsh Government. 2019. Assessment of onshore wind and solar energy potential in Wales, Stage 2 - Refinement of Priority Areas for Wind and Solar Energy [online]. Available from: https://www.gov.wales/sites/default/files/publications/2019-08/stage-2-refinement-of-priority-areas-for-wind-and-solar-energy_0.pdf. [Accessed 24th October 2025]

Welsh Government. 2023. Designing for Renewable Energy in Wales [online]. Available from: https://www.gov.wales/sites/default/files/publications/2023-12/designing-for-renewable-energy-in-wales.pdf. [Accessed 23rd October 2025]

Welsh Government. 2024. Planning Policy Wales: Edition 12 [online]. Available from: https://www.gov.wales/sites/default/files/publications/2024-07/planning-policy-wales-edition-12.pdf. [Accessed 24th October 2025]

Welsh Government. 2025. Energy Generation in Wales 2023 [online]. Available from: https://www.gov.wales/sites/default/files/publications/2025-02/energy-generation-in-wales-2023.pdf. [Accessed 14th October 2025]

Western EcoSystems Technology (WEST), Inc. 2017. Bird and Bat Conservation Strategy, Sunshine Valley Solar Project, Nye County, Nevada. For Sunshine Valley Solar, LLC.

Widmer J, Christ B, Grenz J, Norgrove L. 2024. Agrivoltaics, a promising new tool for electricity and food production: A systematic review. Renewable and Sustainable Energy Reviews 192, 114277.

Wiebe RA, Wilcove DS. 2025. Global biodiversity loss from outsourced deforestation. Nature 639 (8054), 389–394.

Wiesinger F, Suarez-Rubio M. 2026. Do sheep-grazed pastures support insectivorous bat activity and bat species richness? PLoS ONE 21 (1), e0341356.

Wilfred I, Harrison EG, Ashby M, Devenish C. 2026. Mapping UK solar farms for biodiversity assessments: An up-to-date, open-access spatial dataset derived from satellite imagery. Ecological Solutions and Evidence 7 (1), e70221.

Zikri JM, Sani MSM, Izran MFA, Muriban J, Prayogo GS. 2025. Sound Intensity Mapping of Power Generators in Solar Energy Systems: A Case Study on Inverter Noise Emissions. Journal of Acoustics and Vibration Research 3 (1), 22–35.

Zimmermann YS, Schäffer A, Corvini PFX, Lenz M. 2013. Thin-Film Photovoltaic Cells: Long-Term Metal(loid) Leaching at Their End-of-Life. Environmental Science & Technology 47 (22), 13151–13159.

Zitzmann F, Stern M, Schmidt M, Schirmel J. 2024. Carabid beetles in solar parks: assemblages under solar panels are severely impoverished compared to gaps between panel rows and edge areas. Journal of Insect Conservation 28 (4), 763–776.

Appendices

Data archive appendix

No data outputs were produced as part of this project.

Further copies of this report are available from enquiries@cyfoethnaturiolcymru.gov.uk.