Wilder Ecology
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# Literature review

## Impacts of ground mounted solar farm/parks on biodiversity

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Every effort has been made to date to provide an accurate assessment of the current situation, but no liability can be assumed for omissions or changes after the assessment has taken place.

# 1 Introduction

## *1.1 Purpose and scope*

This report has been prepared by SWT Trading Ltd: Wilder Ecology, the ecological consultancy of the Suffolk Wildlife Trust, for The Wildlife Trusts. Here we discuss the current scientific evidence for the impact of solar farms on biodiversity, what evidence there is on positive and negative impacts, where best practice is documented and where we still have knowledge gaps.

## *1.2 Background*

Within the United Kingdom (UK) the development of ground mounted solar has rapidly expanded over the past two decades partly due to incentive schemes and to policy changes; the Climate Change Act (and net zero ambitions), and the National Planning Policy Framework. Solar farms are now projected to grow substantially across the UK to meet the commitment of net zero by 2050 and a 68% reduction in emissions by 2030.

Currently data at the end of April 2025 demonstrates there is a total of 18.1GW of solar capacity in the UK, this is an increase of 5.9% (1.0GW) since April 2024 (DESNZ, 2025). The UK government target for solar capacity by 2035 is 70GW (GOV.UK, 2022) which requires a huge increase from the current level. To meet the national solar energy targets solely with ground-mounted solar schemes could require 0.9-1.4% of land in England the area of up to 180,000 hectares (CPRE, 2023). This could have a huge impact both on natural habitat and reduction of land used for agriculture. Nature positive guidance on design of solar farms is required to enable an enhancement of biodiversity in these essential schemes.

An additional consideration when aiming to deliver this solar capacity is compliance with the Environment Act (2021), which requires a mandatory minimum of 10% biodiversity net gain from the baseline level for solar farms. Furthermore, the development of the emerging Local Nature Recovery Strategies (LNRS) could make alignment of solar projects with the proposed strategic areas complex when seeking planning approval.

Solar farms have been typically designed and managed only to produce renewable electricity (Nordberg et al, 2021; Jarčuška et al, 2024) however there is a rapidly advancing shift in focus particularly within the UK to provide ground-mounted solar farms that are multifunctional aiming to enhance biodiversity and/or provide ecosystem services whilst harnessing solar power.

### *1.3 Definitions of key terms*

For clarity within the review the following terms have been defined as below:

- Nature positive solar farm design – a design that integrates solar infrastructure with both ecological restoration and biodiversity enhancement
- Ground mounted solar – free standing solar panels at ground level, not at higher elevation
- *Solar park – large scale installation of solar panels
- *Solar farm – solar installation generally smaller than solar park

*these terms were found to be completely interchangeable within this research

### *1.4 Aims*

This report was commissioned to explore and review the relevant evidence published regarding the design of solar farms in terms of biodiversity considerations. The aims of this literature review are to identify:

a) Published evidence on the impact of ground mounted solar on biodiversity
b) Any best practices or guidance
c) Any gaps in research

Summaries of the data found and important gaps in evidence are identified and future research recommendations made.

# 2 Methodology

## *2.1 Review of published articles*

The scope of the literature review was defined as:

- Subject matter restricted to ground mounted solar panels and biodiversity
- Focusing on UK studies – or those in similar temperature geographical locations
- Articles in English
- Articles that have been published within the years 2015-2025

A literature search was undertaken in the subsequent order using Google Scholar, Science Direct and JSTOR for research papers between 2015 and 2025, published in English, sorted by relevance. Publish or Perish (Harzing, 2016) was utilised to analyse and assess publications returned.

## *2.2 Search terms*

A trial search term was conducted to narrow down results to fit to the aims of the research:

- (“ground mounted solar” OR “solar farm” OR “solar park”) AND ‘biodiversity’ AND (‘UK’ OR ‘United Kingdom’)

This term revealed in excess of 1000 results; therefore the search term was altered. The following search term became the initial search term; ‘ground mounted solar’ to narrow down the terminology for the solar infrastructure design relevant to the research aims. Boolean operator ‘AND’ was used to combine the solar infrastructure with the *feature* ‘biodiversity’, finally restricting results with ‘AND’ (‘UK’ OR ‘United Kingdom’).

**Initial search term:**

(“ground mounted solar”) AND biodiversity AND (‘UK’ OR ‘United Kingdom’)

Following this initial first search further searches were conducted using different *features* ‘habitat’, ‘wildlife’, ‘birds’, ‘bats’ (‘insects’ OR ‘invertebrates’).

### *2.3 Review of grey literature*

The searches included both primary and review articles, in addition any grey literature such as relevant government or non-governmental organisations reviews and technical reports were accessed. References within review articles were also accessed to expand the number of sources of literature assessed. This enabled a larger data set of articles to be reviewed.

### *2.4 Citation chaining*

Where a lack of primary studies was located, a process of backward citation chaining was used whereby the references cited in the primary source were reviewed to provide additional resources. In addition to this forward chaining was also conducted to locate those that have cited the relevant article.

### *2.5 Copilot, Semantic Scholar and google search*

An additional search was conducted using Copilot, Semantic Scholar and general google with the same initial search term:

("ground mounted solar") AND biodiversity AND ('UK' OR 'United Kingdom'). The first 10 pages of results by relevance were accessed.

### *2.6 Artificial Intelligence statement*

AI tools (Semantic Scholar and CoPilot) were used to assist with identifying, screening and locating literature for this review. All subsequent analysis of relevant articles were conducted by human reviewers to ensure methodological rigour. All interpretations and summary reporting were solely conducted by the researcher.

# 3 Results

## *3.1 Overall results*

A total of 226 articles were identified across the databases from the primary search (‘ground mounted solar’) AND biodiversity AND (‘UK’ OR ‘United Kingdom’). Of those 8 were duplicated in the within Google Scholar, then 18 in the second and 3 in the third database search leading to 198 unique articles. These 198 articles were assessed and 41 of those were found relevant to the search criteria. Grey literature and citation chaining added a further 15 relevant articles. Semantic Scholar, Copilot and Google searches returned a further 8 relevant documents generating a total of 64 published documents for final review.

Table 1. Initial search results

| Search Order | Database | No of results | No of duplicate records | No of new relevant articles |
|---|---|---|---|---|
| 1 | Google Scholar | 184 | 8 | 37 |
| 2 | Science Direct | 38 | 18 | 4 |
| 3 | JSTOR | 4 | 3 | 0 |

## *3.2 Publication year*

Sources of publications were focussed to the past 11 years 2015-2025, and of the 64 articles in the final selection over two thirds, 66% were generated within the past 4 years, this year being only 6 months through.

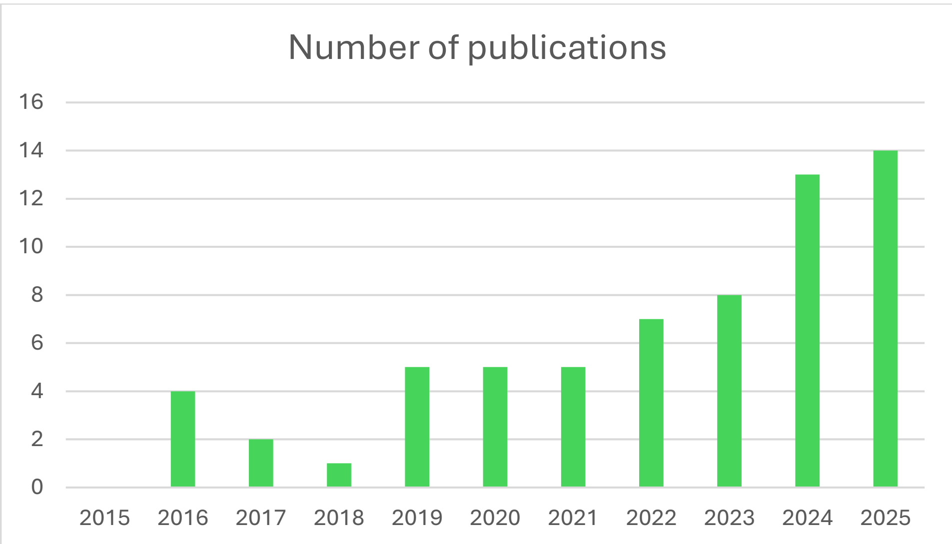


*Figure 1. Number of publications/year*

### *3.3 Primary data sources UK*

The table below details the sources of available data from studies conducted in the UK.

Table 2. Biodiversity features specifically addressed within UK – primary data/guidance

| *Features* | *Details* | *Supporting Literature* |
|---|---|---|
| *Biodiversity - general* | Planning application review - BNG | Benouzid and Simon (2025) |
| | Management approaches | Esteves (2016) |
| | Determinants of planning | Hussain et al (2025) |
| | Comparative study biodiversity | Montag et al (2016) |
| | Biodiversity enhancements - guide | Parker and Monkhouse (2022) |
| | Guidance document - monitoring | Solar Energy UK (2022) |
| | Locations of solar farms | Tinsley et al (2024) |
| *Habitats* | Grassland - review | Carvalho et al (2024) |
| | Local climate effects - grassland | Makaronidou (2020) |
| | Grassland | Stott (2022) |
| *Ecosystem services* | Honeybee – pollinator dependent crops | Armstrong et al (2021) |
| | Combined land use - pollinators | Blaydes et al (2025) |
| | Combined land use – food production | Copping et al (2024) |
| | Combined land use - agrivoltaics | Neesham-McTiernan (2025) |
| | Combined land use | Oudes et al (2021, 2022) |
| | Combined land use | Randle-Boggis et al (2020) |
| *Soils* | Soil carbon | Carvalho et al (2024) |
| | Soil responses | Carvalho et al (2025) |
| *Botany* | Plant responses | Carvalho et al (2025) |
| | Grassland and broadleaved diversity | Montag et al (2016) |
| *Birds* | Impacts on breeding birds | Copping et al (2024) |
| | Management impacts – breeding birds | Copping et al (2025) |
| | Species abundance and diversity | Montag et al (2016) |
| *Bats* | Bat activity/species richness | Montag et al (2016) |
| | Bat activity data | Tinsley et al (2023) |
| *Invertebrates* | Pollinator diversity | Armstrong et al (2021) |
| | Pollinator diversity | Blaydes et al (2021) |
| | Pollinator diversity | Blaydes et al (2022) |
| | Bumblebee populations | Blaydes et al (2023) |
| | Invertebrate diversity and abundance | Montag et al (2016) |

### *3.4 Overall impacts*

The table below details the positive and negative impacts observed on each feature identified from global data sources.

Table 3. Positive and negative impacts identified

| *Features* | *Positive impacts* | *Negative impacts* |
|---|---|---|
| *Biodiversity - general* | Benouzid and Simon (2025) | Ashaf et al (2024) |
| | Esteves (2016) | Matwani & Ojija (2025) |
| | Hussain et al (2025) | |
| | Montag et al (2016) | |
| *Habitats* | Carvalho et al (2024) | Guoqing et al (2021) |
| | Lambert et al (2023) | Makaronidou (2020) |
| | | Xu et al (2024) |
| *Ecosystem services* | Adeh et al (2019) | Guoqing et al (2021) |
| | Armstrong et al (2021) | Hernandez et al (2019) |
| | Blaydes et al (2025) | |
| | Hernandez et al (2019) | |
| | Ludzuweit et al (2025) | |
| | Tölgyesi, C., et al (2024) | |
| | Treasure et al (2025) | |
| *Soils* | Cesar et al (2025) | Carvalho et al (2025) |
| | Zhao et al (2025) | Cesar et al (2025) |
| | Zheng et al (2023) | Lambert et al (2024) |
| | | Makaronidou (2020) |
| | | Neesham-McTiernan (2025) |
| | | Uldriji et al (2023) |
| | | Stott (2017) |
| | | Zhao et al (2025) |
| | | Zheng et al (2023) |
| *Botany* | Lambert et al (2023) | Carvalho et al (2025) |
| | Montag et al (2016) | Cesar et al (2025) |
| | Randall-Boggis et al (2019) | Hernandez et al (2020) |
| | | Xu et al (2024) |
| *Birds* | Barn Owl Trust (2025) | Montag et al (2016) |
| | Copping et al (2025) | Harrison et al (2017) |

| | | |
|---|---|---|
| | Jarčuška, et al (2024) | Smallwood et all (2022) |
| | Montag et al (2016) | Walston et al (2016) |
| | Yuzyk (2024) | |
| *Bats* | Montag et al (2016) | Barre et al (2023) |
| | Szabadi et al (2023) | Harrison et al (2017) |
| | Szoldatits et al (2025) | Montag et al (2016) |
| | | Smallwood et all (2022) |
| | | Szabadi et al (2023) |
| | | Szoldatits et al (2025) |
| | | Tinsley et al (2023) |
| *Invertebrates* | Armstrong et al (2021) | Egri et al (2016) |
| | Barley et al (2025) | Farkas et al (2016) |
| | Blaydes et al (2021) | Grodsky et al (2024) |
| | Blaydes et al (2022) | |
| | Montag et al (2016) | |
| | Tölgyesi, C., et al (2024) | |
| | van der Haas (2019) | |

### *3.5 Review of impacts*

The impacts resulting from the reviewed publications were categorised for discussion into the following categories:

- Impacts on biodiversity
- Impacts on habitats/soils/vegetation
- Impacts on ecosystem services
- Impacts on bats
- Impacts on birds
- Impacts on invertebrates
- Previous overall impact literature reviews
- Biodiversity Net Gain
- Guidance and information on design and management
- Research gaps and future directions

# 4 Discussion/Review of the literature

***Impacts on biodiversity***

The impacts of solar farms on biodiversity have been addressed by numerous researchers in a variety of areas; some addressing a particular taxa, element or geographic area, some comparing solar facility types and others more broadly combining a selection of taxa to indicate a measure of biodiversity. The key UK focussed biodiversity wide study is described below:

Montag et al (2016) conducted a comparison study of 11 solar farms in the southern region of the UK. They detail that where solar farms actively implement management focussing on wildlife there can be an increase of biodiversity demonstrated across a number of different species. They detailed that management including; utilising a diverse seed mix, conservation grazing/mowing, limiting herbicide use and inclusion of marginal habitats all add to botanical diversity. This botanical diversity then leads to greater abundance and diversity of butterflies, bumblebees and other invertebrates which then makes provision further up the food chain for other species such as birds and bats. The location of solar farms generally within a wider agricultural landscape makes them a haven for other species particularly birds of conservation concern with the ability to provide a mosaic of habitats. During this study the habitat was noted to also have been valued by brown hare, an area that warranted further research.

Many other studies in the UK evidenced solar farms as an opportunity to increase biodiversity on site as part of the specific subject matter they were addressing (Armstrong, et al 2021; Blaydes et al, 2021; 2022; 2023; 2025; Benouzid & Simon, 2025; Esteves, 2016; and Husain et al, 2025).

***Impacts on habitats/soils/vegetation***

Habitat types have been addressed within the literature with a dominance of focus on grassland and agricultural land sitings of solar facilities. In addition to that several studies have looked at the impact of solar farms on soils, hydrology and vegetation.

Some positive impacts included a study by Randall-Boggis et al (2019). The species richness of plants, grasses and eudicot species was found to be significantly higher in the solar parks where management actions had been applied compared with control sites and varied with the action prescribed. Another positive impact was found by Lambert et al (2023) where in tilted tracking photovoltaic systems grassland habitats could be enhanced by improving the water uptake thereby promoting vegetation restoration.

Soils is an area of research that has expanded rapidly however the conclusions are not consistent with each other (Zhao et al, 2025) and impacts of the geographic location of the solar facility not necessarily comparable (Zheng et al, 2023). Negative impacts were detailed by Carvalho et al (2025) where they sampled 32 solar farms across the England and Wales quantifying plant cover, soil nutrients and physiochemical properties of areas of land under and between solar panels as well as on control land adjacent. Plant mass was significantly lower underneath the panels than between or on control land. Soil compaction was also found to be higher under the panels, and the soil organic carbon and particulate organic matter was also lower under the panels. Soil nitrogen was higher under the panels, as was phosphorous. Insights from this on the soil health of solar farms can assist in design and management of options for enhancing both plant cover and soil carbon storage at solar farms in future. However, the previous land use was highlighted as a major factor in the progression of the potential of the land. Previous findings from Makaronidou (2020) were very similar – cooler air and soil temperatures, higher soil moisture content under panels creating local climatic effects. Stott (2017) found both decomposition and productivity under solar panels was suppressed. Uldrijan et al (2023) found solar panels created extreme soil conditions and vegetation responds by increasingly being dominated by tolerant species, opening up opportunity for invasive species. Lambert et al (2024) also found negative impacts on soils in an experimental design in France. Solar panels were found to negatively impact variables related to soil biodiversity and function (pedoclimatic, chemical, microbes and mesofauna).

Cesar and Aken (2025) tested negative impacts of solar panels by evaluating two different solar designs to investigate the trade off between energy yield and soil irradiance. Transparent solar panels were found to provide levels of ground irradiance to promote photosynthesis without increasing the footprint of the solar farm. These could pave a way forward with agrivoltaic schemes and create a healthier soil microclimate allowing solar farms to enhance biodiversity.

Additional research has identified a cooling island effect of solar farms. This has been described by Guoqing et al (2021) and Xu et al (2024). Guoqing investigated how solar farms have potential to alter land surface temperatures by Landsat satellite imagery and confirmed using measurements in the field. They found a cooling effect up to 730m from the solar farms with the temperature cooling 2.3C within the closest 100m area. This finding demonstrates that there is a wider impact to adjoining land which needs to be considered to inform land management and with the expansion of solar farms a need to seriously consider appropriate siting. Xu et al (2024) reported not only the significant land surface cooling effect but also a detrimental effect on vegetation and albedo.

Hussain et al (2025) assessed the situation regarding determinants for planning permission of solar farms at local authority level within the England. Interestingly the environmental impacts of solar farms were found to barely matter for planning (or have likely already been dealt with by the time the proposal reaches the planning stage). In areas that are protected standardised guidance is adhered to however it was noted outside of that it ultimately becomes a decision of the planning authority in question, so there is a degree of inconsistency.

***Impacts on ecosystem services***

The combination of utilising solar power with provision for ecosystem services is an area where the literature is gaining in its evidence base. The concerns over land use are now prompting further investigation into the potential that solar facilities could provide in combination.

Treasure et al (2025) investigated the evidence for positive and negative impacts on ecosystem services globally for the entire life cycle of solar infrastructure from construction through to decommissioning. Within their dataset they found for the UK 22 documented impacts of which 13 were positive and 9 were negative. Those most significant from the wider dataset and applicable to the UK during the operational phase were; positive impacts - enhanced water cycle support, soil erosion regulation and pollination and negative impacts –

maintaining habitats and biodiversity. Positive impacts were more speculative, and further evidence from research across a range of former land uses, climates and ecosystems throughout the phases of the solar farm life stages would be beneficial to fill the data gap. However, the authors demonstrate that with an appropriately designed and managed solar farm there is the potential to enhance ecosystems services throughout the life cycle of the infrastructure project.

Enhancing the provision of ecosystem services using habitat enhancing strategies was modelled by Ludzuweit et al (2025) and found that by integrating vegetation such as grassland, hedges and trees within agrivoltaics that ecosystems service gains could be provided at a rate of 33-88% pollinator supply, 9-22% water retention, 7.5-20% sediment retention and up to 8% carbon storage.

There is a potential competition of land available for food production and energy, and whilst this is a debated topic experimental agrivoltaics experiments have been conducted where aloe vera, tomatoes, maize, pasture grass and lettuce have all successfully been grown under PV panels. Adeh et al (2019) found that the greatest solar PV power potential is achieved from croplands and dual use of this land could be used to address this competition.

Public concerns over land cover required for solar development persist, however data for the actual predictions of land cover required have been limited. Blaydes et al (2025) mapped current solar farm data across the UK and demonstrated that these cover a relatively small area. They determined that the majority of solar farms have been located on either arable land or improved grassland. Calculating an estimate of land required for future ground mounted solar farms (at 100%) for the 2050 target of 90GW would take up a proportion of just 0.72% of UK land and 1.5% of UK agricultural land. Given that solar infrastructure will increase and is likely to be embedded on and within agricultural land, the critical factor is that these solar farms should be used to enhance ecosystem services by providing a combination of land uses, food production and biodiversity conservation. Neesham-McTiernan et al (2025) provides a similar spatial assessment of the UK with an emphasis as to where agrivoltaics could be most beneficial providing large scale solar farms in synergy with agricultural needs.

A UK study investigated the use of solar farms to house honeybee hives by mapping the locations of existing solar farms and overlaying a 1.5km buffer for honeybee foraging. They estimated that if honeybee hives were installed at all existing solar parks in 2017 then the value of ecosystems services provided from pollination of those pollinator dependent crops, soft and top fruits would have reached £5.9 million and could provide many more times that (Armstrong et al, 2021). This could be further enhanced with appropriate planned crop production around areas of solar farms. The authors recommend that enhancing habitat for pollinators be considered further as they offer co-benefits in ecosystem services, land use and economic benefit.

Utilising technology and ecological systems in a mutually beneficial method is going to be key to the future development of solar energy facilities. Hernadez et al (2019) demonstrate that techno-ecological synergies (TESs) are not only feasible across a number of diverse environments but they also can support a number of ecosystems services. They developed a comprehensive framework of 16 TES that provided 20 potential beneficial outcomes.

***Impacts on bats***

The impacts of solar farms on bats are widely disputed and poorly understood, with mixed results reported. A recent study from the United States (Szoldatits, 2025) revealed a species specific difference in response to solar farms at ecovoltaic (combined electricity production and ecosystem services) sites with two species showing higher activity at the sites, where as another two species had no difference to the control sites. Montag et al (2016) conducted a comparative study that evaluated bat activity and diversity between solar plots and control plots. Eight sets of solar and control sites within the UK were surveyed. They found that there was no significant difference in bat species diversity between the two categories overall and when analysing the bat activity overall between all sites there was no significant difference, however there was a significant difference between three of the eight site pairs in number of bat passes per night. They conclude that bats do use solar farms at a comparable but possibly slightly lower level than control plots, although suggest they could provide an excellent foraging habitat that bats could become habituated to using. However, they also highlighted a number of limitations in their methodology that may confound results.

This positive impact of foraging provision was echoed by Szabadi et al (2023) which found a considerable amount of bat activity at solar farms and detected feeding buzzes indicating that the bats are foraging as well as commuting within the solar farms. The species composition at solar farms was observed to be similar to those found in either agricultural habitat or urban areas. In this study in Hungary this comprised primarily of *H. savii*, *N.noctula* and *P.kuhlii*. *Myotis* spp and *B.barbastellus* were not frequently recorded within the solar farms. They conclude that solar farms are particularly advantageous as a foraging opportunity for those bat species that are adapted to anthropogenic environments.

The negative impacts of solar farms have also been discussed recently (Barre et al 2023; Tinsley et al, 2023). Flight and feeding behaviour was studied at nine ground mounted utility size solar farms in the Rhone Vally in France by Barre and colleagues. They recorded three dimensional bat positions using paired sampling design with microphone arrays; one pair within the solar farm and one matched control located outside the solar farm. Echolocation calls were identified to species level where possible and speed of flight and feeding buzz probability was calculated. Strong behavioural impacts were observed on five of seven recorded species. The mean flight speed was found to be significantly higher and the trajectory straighter at solar sites than control sites. In addition, feeding buzz probability was significantly lower at the solar sites than the control sites and indicated that the quality of the foraging habitat was reduced. The researchers suggest that shading from panels may be reducing plant biomass and insect prey availability for the bats, however the authors recommend that further research is undertaken to enable understanding of the mechanism behind these negative impacts. Barre also noted that currently no data is available on the variation in abundance of nocturnal insects in response to solar farms, this would be key in determining availability and suitability of solar farms for foraging bats. Tinsley et al (2023) reported that ground mounted solar PV panels have a significant negative effect on bat activity. The researchers thoroughly compared the levels of bat activity and species richness between 19 operational solar farms spatially paired with 19 control sites within England. Echolocation data was collected via static detectors over a 7-night period at each solar farm and control site. Activity levels were determined by number of calls per hour and whether there was a difference between boundary and field locations and also any difference in species richness by generalised linear mixed effect modelling. The results from this recorded eight species/groups and demonstrated that six of those species/groups (common and soprano pipistrelle, *Nyctallus* spp. *Myotis* spp. *Plecotus* spp. and serotine) had significantly lower activity levels. Implying that they were negatively impacted by solar panels. No difference in species richness was observed. Although useful information, this study provided information at a snap shot of time within the season, within which bat activity is likely to vary widely. In addition to that it was unclear whether the history of the management and relative age of the habitat was accounted for in the comparisons. It furthermore strengthens the need for more research into the impacts of solar panels on bats to understand this potential negative impact. Although the importance of providing an improved habitat surrounding solar farms to increase foraging habitat should be ensured to offset any unavoidable development of solar farms on sites with great feeding potential for bats.

Many studies refer back to the Nature communication publication by Greif and Siemers (2010) where they identified bats used innate echoacoustic cues for recognition of water bodies. This experimental design tested behaviour of 15 species of adult bat over 3 families; Minoptereridaen Verspertilionidae, and Rhinolophidae and in juvenile *M. emarginatus* and found via consecutive drinking attempts that they perceive horizontal acoustical mirrors to be water despite conflicting information. This implies that anthropogenic smooth horizontal surfaces can reflect sound for echolocating bats allowing them to interpretate it as a water body. As solar panels also polarise and reflect light this does highlight another risk to bats.

Fatalities of bats at solar farms was addressed by Smallwood (2022) where numbers were estimated from 11 solar photovoltaic sites were calculated at 0.06 fatalities/MW/year. This was considerably lower than the fatalities of bats found at Concentrated Solar Power (CSP) farms (5.49 fatalities/MW/year) and lower than birds indicating the risk of collision was much greater for birds than bats. However, this is another large gap in the knowledge base, as both activity and fatalities of bats at solar farms is not routinely monitored.

***Impacts on birds***

The fatalities of birds resulting at solar farms investigated by Smallwood (2022) provided a more concerning impact than for bats. The data for numbers of birds between 1982-2018 were analysed at 14 utility scale solar projects in California (11 of which were Photovoltaic

PV). The estimated number of fatalities/MW/year was found to be a mean of 11.61 in PV and 64.61 in found at Concentrated Solar Power (CSP) facilities. These estimates were consistently higher than ever previously reported. Birds were found to collide with solar panels, mirrors, transmission lines, fences and vehicles on site. Smallwood described how collisions with panels may be caused by a 'lake effect' – where birds may perceive a number of closely spaced PV panels as in fact a water body and attempt to land. This is of particular concern for migratory waterfowl and shorebirds. This study saw similar findings to an earlier one by Walston et al (2016) whereby the site with the panels located more closely together found water birds were over-represented within the impact trauma fatalities. The authors here also suggested that the polarising light may be attracting aggregations of insects in turn attracting insectivorous birds.

Yuzyk (2024) conducted a literature review focussing on summarising the global evidence on the impact of solar farms on birds. The findings conclude that to date the impact of solar on birds has a deficit of data and that so far evidence varies widely across different territories when addressing the aspects such as abundance, species composition and activity. Generally, bird diversity declines in areas with large solar infrastructure however CSP farms often support more species than in agricultural land. Bird mortality was demonstrated to be by collision with solar infrastructure (and burns from CSP plants), however much lower rates at PV. This mortality was higher at locations near wetlands or migratory routes making emphasis on location considerations key in future. Rooftop PV systems were suggested as a more biodiversity friendly alternative for birds.

Recently Copping et al (2024) addressed the impacts on birds within solar farms within the Fens, UK. Surveying six sites they found through their bird habitat evaluation modelling that the overall impact of solar energy on breeding bird habitat is expected to be small. In fact, where Nature Based Solutions are used in combination with woodland, Red and Amber listed Birds of Conservation Concern populations may see the largest increases in habitat availability, with only the farmland specialists seeing a decrease. This echoes previous findings of Montag et al (2016) that overall a higher diversity and abundance of birds of conservation concern utilise solar plots when compared with control plots. They also found that despite the fact skylarks would not nest within the solar farm they will forage within the area and on their study two of the sites have significantly higher numbers of foraging skylarks than in the control plots, making them part of their territory. The authors conclude that solar farms may be able to provide a haven for declining species; notable species that they found only on solar plots included kestrel, stock dove, tawny owl, willow warbler and mallard. The use of solar farms by raptors is another area that warrants further research alongside longworth trapping studies to investigate the abundance and diversity of small mammals present.

The Barn Owl Trust (2024) has stated how ground mounted solar can indeed be beneficial to barn owls particularly where the vegetation underneath is maintained as rough grassland. It provides an opportunity for the barn owls to perch hunt from the solar panels which are of appropriate height and pose no danger to the owls.

The lack of design with a combined focus of energy production and wildlife were noted by Jarcuska et al (2024) where they recorded bird diversity at 32 solar parks all designed exclusively for electricity production. They found that solar parks provided habitat supporting greater total bird species richness and diversity, richness and abundance of insectivorous birds overall, whilst within grassland solar parks ground foragers were greater than their grassland control plots. However, had wildlife been a consideration during the design phase an even greater positive impact could have been achieved.

***Impacts on invertebrates***

The impacts on invertebrates have been a more thoroughly researched area within the solar infrastructure landscape. Generally, the consensus is that solar farms could provide a haven for invertebrates and make a concerted effort to conserve a number of species particularly pollinators. Positive impacts have been evidenced in the UK for butterflies, honeybees, bumblebees, hoverflies and moths (Blaydes, 2024).

Armstong et al (2021) made the case that solar farms could be a viable method to boost pollinator populations with honeybees in particular utilising them to for essential ecosystem services to fruit crops or oilseed. They also suggest that pollination service benefits should be included within the planning stage of solar farms.

In a modelling study within the UK Blaydes et al (2022) demonstrated that management of solar farms was key to supporting densities of bumble bees. Those managed as wildflower meadows throughout rather than just margins (or grassland) could double the number of foraging bumblebees in the surrounding landscape. They investigated how the shape, size and management alongside landscape context influenced ground nesting bumble bee density, nest density and nest productivity both inside existing solar farms and the surrounding landscape. The shape and size and landscape had little impact on bumble bee density within the solar farm however large, elongated resource rich solar farms were most effective at increasing density in the surrounding landscape. Field data however is essential to test these findings.

Randall-Boggis et al (2019) found significantly greater abundance of butterflies was observed in solar parks managed with grazing and meadows compared to control sites. There was a significantly higher abundance of bees associated with solar parks manged by planting or maintaining wild flower and nectar seed meadows compared to control sites. Species richness of butterflies and bees was greater in solar parks compared to control sites, however they found that management actions had no significant difference to the species richness. An experimental study in solar parks in Hungary (Tölgyesi et al, 2024) found that introducing a species rich grassland could increase total plant richness and grassland species richness more than the control sites and had higher species richness of pollinators - hoverflies and wild bees.

A couple of literature reviews focussed on discrete management practices for invertebrates (Barley et al 2025; Blaydes et al 2021) and found a difference in opinion. Barley summarises how energy infrastructure such as solar and rights of way could provide ideal opportunities for conservation of insects. They discuss how co-locating high quality insect habitat within infrastructure (which is generally within farming landscapes) can jointly meet both conservation needs with agricultural production needs. Blaydes assessed 185 articles for details on how 27 management interventions in Europe can enhance pollinator biodiversity. From this assessment of evidence, they then provided recommendations of improvements to solar farm management to enhance pollinator biodiversity by utilising considered management practices, provision of foraging and reproductive resources, and increasing the heterogeneity, connectivity and microclimatic variation of the landscape within them.

Polarising light from the solar panels and its impacts on aquatic invertebrates has been reported by several researchers. Egri et al (2016) in a study conducted in Budapest found that horizontally polarised light even ten times dimmer was more attractive in the springtail *Podura aquatica* than unpolarised light. Fakas et al (2016) also found the same response in two mayfly species where horizontally polarised light was consistently found more attractive than vertically polarised or unpolarised light in study in Hungary. Here they detailed that the avoidance of weak vertical polarised light from aquatic vegetation allows them to avoid the edges of water bodies and lay eggs appropriately in the water. The negative effect of attraction of polarised light from solar panels has also previously been reported to initiate oviposition behaviour in mayflies (Ephemeroptera), stoneflies (Trichoptera), dolichopodid dipterans, and tabanid flies (Tabanidae), where solar panels were found to reflect far more than natural water sources (Horvath et al, 2010). Siting of solar farms near water bodies warrants further consideration on its impact on aquatic invertebrate populations.

Negative impacts were also demonstrated on tenebrionid beetles in a study in the Mojave Desert where the more intensive solar development using bulldozing had significant effects on the beetle abundance, species richness and diversity (Grodsky et al, 2024). This family of beetles has 20,000 species worldwide with 47 species in Britain.

***Previous overall impact literature reviews***

There have been numerous literature reviews of available data conducted regarding solar farms impacts on biodiversity so far - 21 were reviewed just during this literature review. These reviews have covered a range of topics regarding the impacts including; general biodiversity (Esteves, 2016; Lafiitte et al, 2023; Matwani & Ojija, 2025; Meletiou et al, 2019; Taylor et al, 2019), birds (Yuzyk, 2024), invertebrates (Barley et al, 2025; Blaydes et al, 2021), soils (Carvalho et al, 2024; Vaughan & Brent, 2024), vegetation/hydrology/agrivoltaics (Nordberg et al, 2021; Vaughan & Brent, 2024; Walston et al, 2022; Yavari et al, 2022), artificial habitats (Boscarino-Gaetano et al, 2024), wildlife behaviour (Chock et al, 2020) general ecology (Dhar et al, 2020) and ecosystem services (Oudes et al, 2022). Some of these have been discussed within their relevant field as above.

The most recent literature review published this month by Fleming (2025) described five key mechanisms explaining the attractiveness or avoidance of solar facilities by birds, bats and invertebrates, detailed below:

- Lost, altered and novel habitat
- Evaporation ponds
- Increased foraging opportunities
- Concentrated solar energy
- Solar panels represent large expanse of smooth flat surfaces

Dealing with Concentrated Solar Power (CSP) and Solar Photovoltaic (PV) systems separately through a thorough review of 101 articles they found that both positive and negative impacts had been reported. Contrasting results were found for impacts over the species groups particularly with birds where species richness was reported to be less, no difference and more at solar facilities within various studies.

A little discussed factor in the future of renewable energy siting was addressed by Ashraf et al (2024) whereby they reviewed literature for evidence of where species range shifts from climate change impacts have been considered. They discovered within a data set of 157 publications (between 1997 and 2022) that whilst 93% of these addressed biodiversity, only 18.4% considered the role of climate change on biodiversity and furthermore only 1.9% of these investigated the role of climate change as a driver to range shifts for biodiversity/taxonomic group or species of interest. This lack of data is an area where research should be focussed to provide as climate change threatens the range of more of our species.

Delahay and Sherman (2023) summarised the published evidence to date regarding the impacts of solar farms on biodiversity and found a total of 57 articles comprising of 33 published papers, 15 reports and 9 miscellaneous grey literature items. Although their search utilised a twenty year period from 2002 to 2022 the increase in articles rose dramatically in the last three years of that search period. This demonstrates that the evidence base for impacts on biodiversity is rapidly increasing and will enable these considerations to inform future planning and management of solar farms. However, they concluded that currently empirical data is still vastly lacking to enable comprehensive best practice guidance on enhancing solar sites for biodiversity or avoidance of impacts on species.

Natural England previously published an evidence review by Harrison et al (2017) stating how concerning the lack of evidence there is on the ecological impact of solar farms. Taylor et al (2019) conducted their second comprehensive review of research into the ecological impacts of ground mounted solar sites in the UK and found in the 5 years intervening little had changed. Between these and all subsequent reviews the case remains the same, they detail the lack of data and consistently identify a range of key areas for further research – however despite the recent influx (refer to Figure 1) to date not many of these key focus areas have been addressed.

***Biodiversity Net Gain***

Benbouzid and Simon (2025) reviewed 30 planning application submissions in the UK and assessed biodiversity net gain. The study highlighted the issue that there are areas within the NPPF that allow for differing interpretations between planning authorities. They did demonstrate through a case study that a biodiversity net gain of up to 70% can be achieved and suggest that more explicit criteria and consultation prior to application would enhance biodiversity and provide renewable energy in an integrated nature positive approach.

There was no significant evidence published of the potential for solar farms to provide Biodiversity Net Gain although many positive impacts on biodiversity have been described.

***Guidance and information on design and management***

A collaboration between Lancaster University and the University of York developed a Solar Park Impacts on Ecosystem Services (SPIES) decision support tool (DST) in 2019 described by Randall-Boggis et al (2020). This comprised an assessment of 704 pieces of evidence including 457 peer reviewed journal articles assessing the impact of land management on ecosystem services. This tool was tested with operational solar parks and then validated with nine further solar parks. Use of this could further assist in future plans for solar farms.

Parker & Monkhouse (2022) and Solar Energy UK (2022) have published guidance on increasing biodiversity and recommendations on how to monitor it. These documents provide a host of information for solar farms and provide essential reading prior to design to assist with planning and life span of the project. The Before-After-Control-Impact (BACI) approach – this examines the conditions before (pre-construction) and after (post-construction) of the site whilst also comparing a Control site with the Impact site and then attributing the ecological changes due to the impact (Green, 1979; Stewart-Oaten et al, 1986) should be employed to facilitate the recommended monitoring. Sinha et al (2018) have also described best practices for improving biodiversity at utility scale solar facilities evidenced by biological monitoring efforts at the Topaaz project, California. This case study details design features to enhance the environment for endangered species with management systems to combine increase in biodiversity with effective operation of the site.

Designs must also account for the lifecycle emissions, land use and community impact. Solar whilst having lower operational emissions does however have a larger land footprint than wind systems. Although the Copping et al (2024) study demonstrated that renewable energy deployment in terms of solar requires relatively little land and impacts on food production would be minimal. Tinsley et al (2024) having reviewed the spatial locations of solar farms within England reiterate the importance of revolving research around biodiversity and solar farms is not only incorporated into decision making of the operational design but that monitoring is completed for the whole lifespan of the solar farms to assess impacts. Barley et al (2025) acknowledge the gaps in research around co-locating habitat with solar infrastructure and detail the urgency of action to generate more insect conservation gains, given the exponential growth in this energy sector. This requires site specific planning as well as plant and pollinator monitoring to become successful.

Although there is an immediate need for ground mounted solar, data provided from University College London (UCL) to CPRE has identified that consideration of alternative locations for installing solar panels such as on new buildings, existing warehouses and car parks could provide 40-50GW, representing more than half the national target of 70GW (CPRE, 2023). This is another factor that should be considered within the planning system.

## 5 Research gaps and future directions

The impacts of ground mounted solar on biodiversity overall and for individual species groups is an area that is still vastly lacking in empirical evidence. Furthermore, evidence for specific countries with similar climate, legislation and best practice guidance is a requirement to develop the sector in a more consistently nature positive route.

Considerations of the impacts of ground mounted solar panels on both plants and soils must be contextualised to the local conditions and factored before, during and after the development of the solar farm (Carvalho et al 2025). In addition, other variables such as previous land use, land management the inter-panel gap, panel height and angles should all be addressed in further research to maximise positive biodiversity outcomes. Further research into the variability of the diversity of plants in association with the microclimate variability under the panels, between panels and in control areas away from panels as well as comparing between within and outside solar parks is critical (Makaronidou, 2020).

The necessity for further research into wildlife-solar facilities behavioural interactions was highlighted by Chock et al (2020) to inform on how to site, design and operate solar facilities whilst reducing negative impacts. This will require collaboration between sectors and a more systematic and standardised approach to monitoring before, during and after solar farm construction and operation with appropriate control sites.

From the literature review the following areas have been highlighted numerous times as critical research gaps to address and inform our rapid expansion into delivering solar across the UK:

- Experimental studies of optimising plant diversity between and beneath panels
- Experimental studies of impacts of polarised light on birds and invertebrates
- Experimental long term data on wildlife impacts from UK solar farms using BACI approach
- Evidence of Biodiversity Net Gain provision from solar projects
- Quantifying the impact of polarising light pollution on migratory routes

- Monitoring (all species) – from pre-construction through to decommissioning
- Bats in situ data on impacts – foraging, orientation, drinking attempts, collision
- Birds in situ data on impacts – feeding, nesting, perching, collision
- Invertebrates – attraction to panels (aquatic and oviposition), abundance, nocturnal species (bat prey species), pest predator invertebrate species
- Impacts on other species – reptiles, brown hares, small mammals, birds of prey
- Climate change impacts on species range distribution mapped against solar
- Impacts of historical land use on soils

## 6 Conclusion

Large scale ground mounted solar infrastructure can have varying impacts on a wide range of species. The negative impacts on biodiversity have been demonstrated as being;

- fragmentation and loss of habitat (current or climate change driven range of species)
- polarising of light resulting in alteration of behaviour – attracting species
- changes in soil health
- bird collisions
- reduced foraging for bats

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More positive impacts are the potential;

- enhanced invertebrate habitat - therefore increasing foraging sources for insectivores
- increased pollination for ecosystem services
- provision of mosaic of habitats relatively undisturbed for many species
- opportunity for agrivoltaics

Many of these positive and negative impacts overlap with inconclusive findings for each. From this review of research published 2015-2025 it has been found that there is still a substantial gap in evidence of the ecological impacts of ground mounted solar facilities. With regards to the UK only 8 publications provide any empirical evidence with key indicator species groups bats, birds, and invertebrates. Globally evidence has conflicting opinions on the level and direction of the impact on biodiversity on key features. However, there is a general consensus that solar farms offer an opportunity for biodiversity enhancement, with thoughtful planning, management and monitoring in place. Numerous studies have made suggestions for design and management at solar facilities to increase biodiversity within them and there are two published best practice documents in the UK which detail management and monitoring recommendations. However further research is critical to fully understanding the impacts of solar on biodiversity and the case has been made repeatedly for more BACI assessments to be made to aid the development of this evidence base.

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Zheng, J., Luo, Y., Chang, R. and Gao, X. (2023). An observational study on the microclimate and soil thermal regimes under solar photovoltaic arrays. *Solar Energy*, 266, pp.112159–112159. doi:https://doi.org/10.1016/j.solener.2023.112159.

## 8 Appendix

| Authors | Title | Journal | Publication date | Item type | DOI | Design/ Management | Impact on Features | Primary data | Region |
|---|---|---|---|---|---|---|---|---|---|
| Adeh, E.H., et al | Solar PV Power Potential is Greatest Over Croplands | Scientific Reports | 2019 | Journal article | 10.1038/s41598-019-47803-3 | Yes | Ecosystem services | Yes | USA |
| Armstrong, A., et al | Honeybee pollination benefits could inform solar park business cases, planning decision and environmental sustainability targets | Biological Conservation | 2021 | Journal article | 10.1016/j.biocon.2021.109332 | Yes | Ecosystem services, invertebrates (pollinators) | Yes | England |
| Ashraf, U., et al | Aligning renewable energy expansion with climate-driven range shifts | Nature Climate Change | 2024 | Journal article - review | 10.1038/s41558-024-01941-3 | Yes | Biodiversity | No | Global |

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|---|---|---|---|---|---|---|---|---|---|
| Barley, T.A., et al | A stitch in time: integrating energy infrastructure into the fabric of conservation habitats | Current Opinion in Insect Science | 2025 | Journal article - review | 10.1016/j.cois.2025.101358 | Yes | Invertebrates (pollinators) | No | Global |
| Barre, K., et al | Insectivorous bats alter their flight and feeding behaviour at ground mounted solar farms | Journal of Applied Ecology | 2023 | Journal article | 10.1111/1365-2664.14555 | Yes | Bats | Yes | France |
| Benbouzid,I and Simon, D | Evaluating the potential for improving biodiversity in solar farms | Royal Holloway University | 2025 | PDF Research Report | evaluating-the-potential-for-improving-biodiversity-in-solar-farms.pdf | Yes | Biodiversity | Yes | UK |
| Blaydes, H., et al | Opportunities to enhance pollinator biodiversity in solar parks | Renewable and Sustainable Energy Reviews | 2021 | Journal - review | 10.1016/j.rser.2021.111065 | No | Insects (pollinators) | No | Europe |

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|---|---|---|---|---|---|---|---|---|---|
| Blaydes, H., et al | Solar park management and design to boost bumble bee populations | Environmental Research | 2022 | Journal article | 10.1088/17 48- 9326/ac584 0 | Yes | Invertebrates (pollinators) | Yes | UK |
| Blaydes, H., et al | On-site floral resources and surrounding landscape characteristics impact pollinator biodiversity at solar parks | Ecological Solutions and Evidence | 2023 | Journal article | 10.1002/2688-8319.12307 | Yes | Invertebrates (pollinators) | Yes | UK |
| Blaydes, H., et al | Shedding light on land use change for solar farms | Progress in Energy | 2025 | Journal article | 10.1088/2516-1083/adc9f5 | No | Ecosystem services – agricultural land use | Yes | UK |
| Boscarino-Gaetano, R., et al | Creating wildlife habitat using artificial structures: a review of heir efficacy and | Biological Reviews | 2024 | Journal article - review | 10.1111/brv.13095 | Yes | Biodiversity | No | Global |

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|---|---|---|---|---|---|---|---|---|---|
| | potential use in solar farms | | | | | | | | |
| Carvalho, F., et al | Enhancing soil carbon in solar farms through active land management: a systematic review of the available evidence | Environmental Research | 2024 | Journal article - review | 10.1088/2752-664X/ad8ce4 | Yes | Soil | No | UK |
| Carvalho, F., et al | Plant and soil responses to ground-mounted solar panels in temperate agricultural systems | Environmental Research | 2025 | Journal article | 10.1088/1748-9326/ada45b | Yes | Soil, plants | Yes | UK |
| Cesar, I., & Van Aken, B.B., | Evaluation method and module design for cost-effective compliance with irradiance guidelines to | EPJ Photovoltaics | 2025 | Journal article | 10.1051/epjpv/2025003 | Yes | Soil | Yes | Netherlands |

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|---|---|---|---|---|---|---|---|---|---|
| | maintain soil quality in solar parks | | | | | | | | |
| Chock, R.Y., et al | Evaluating potential effects of solar power facilities on wildlife from an animal behaviour perspective | Conservation Science and Practice | 2020 | Journal article | 10.1111/csp2.319 | Yes | Wildlife - behaviour | Yes | Global |
| Copping, J.P., et al | Ambitious onshore renewable energy deployment does not exacerbate future UK land-use challenges. | Cell Reports Sustainability | 2024 | Journal article | 10.1016/j.crsus.2024.100122. | Yes | Land use, food production, birds | Yes | UK |
| Copping, J.P., et al | Solar farm management influences breeding bird responses in an arable- | Bird Study | 2025 | Journal article | 10.1080/00063657.2025.2450392 | Yes | Birds | Yes | UK |

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|---|---|---|---|---|---|---|---|---|---|
| | dominated landscape | | | | | | | | |
| Delahay R. and Sherman, D. | A summary of the published evidence on the impacts of solar farms on biodiversity | EDF Renewables Report | 2023 | Report - review | Solar-Panels-and-Wildlife-Review-2019.pdf | No | Biodiversity Multi species | No | Temperate regions |
| Dhar, A., et al | Perspectives on environmental impacts and a land reclamation strategy for solar and wind energy systems. | Science of the total environment | 2020 | Journal article - review | 10.1016/j.scitotenv.2019.134602 | No | Biodiversity Birds | Yes | Global |
| Egri, Á., et al | Polarization sensitivity in Collembola: an experimental study of polarotaxis in the water-surface-inhabiting | Journal of Experimental Biology | 2016 | Journal article | 10.1242/jeb.139295 | Yes | Aquatic invertebrates | Yes | Hungary |

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|---|---|---|---|---|---|---|---|---|---|
| | springtail,*Podura aquatica*. | | | | | | | | |
| Esteves, A.M.R., | Untapping the full potential of solar farms in the UK: Different Approaches to Management | Instituto Politecnico de Braganca (Portugal) | 2016 | Dissertation - review | ProQuest Dissertations & Theses, 2016. 30207618 | Yes | Biodiversity | No | UK |
| Farkas, A., | Mayflies are least attracted to vertical polarization: A polarotactic reaction helping to avoid unsuitable habitats | *Physiology & Behavior* | 2016 | Journal article | 10.1016/j.physbeh.2016.05.009 | Yes | Aquatic invertebrates | Yes | Hungary |
| Fleming, P.A. | All that glitters – Review of solar impacts on fauna | Renewable and Sustainable Energy Reviews | 2025 | Journal article – review | 10.1016/j.rser.2025.115995 | Yes | Birds, bats, wildlife | No | Global |

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|---|---|---|---|---|---|---|---|---|---|
| Guoqing, L., et al | Ground-mounted photovoltaic solar parks promote land surface cool islands in arid ecosystems | Renewable and Sustainable Energy Transition | 2021 | Journal article | 10.1016/j.rset.2021.100008 | Yes | Habitat | Yes | China, United States |
| Grodsky, S.M., et al | Mixed responses of tenebrionid beetles to solar energy development in the Mojave Desert | Journal of Arid Environments | 2024 | Journal article | 10.1016/j.jaridenv.2024.105243 | Yes | Insects | Yes | United States |
| Harrison, C., et al | Evidence review of the impact of solar farms on birds, bats and general ecology | Natural England report NEER012 | 2017 | Report – evidence review | Evidence review of the impact of solar farms on birds, bats and general ecology 2016 - NEER012 | No | Birds, bats, biodiversity | No | Global |
| Hernandez,R.R., et al | Techno-ecological synergies of solar energy produce outcomes that mitigate global change | Nature Sustainability | 2019 | Research article | 10.1038/s41893-019-0309-z | Yes | Ecosystem services | Yes | Global |

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|---|---|---|---|---|---|---|---|---|---|
| Hernandez,R.R., et al | Simulated photovoltaic solar panels alter the seed bank survival of two desert annual plant species | Plants | 2020 | Research article | 10.3390/plants9091125 | No | Plants | Yes | United States |
| Hussain, M.M., et al., | "Here comes the sun": Determinants of solar farm planning at local authority level in England. | Energy Research & Social Science | 2025 | Research article | 10.1016/j.erss.2024.103916 | Yes | Biodiversity | Yes | England |
| Jarčuška, B., et al | Solar parks can enhance bird diversity in agricultural landscape | Journal of Environmental Management | 2024 | Journal article | 10.1016/j.jenvman.2023.119902 | No | Birds | Yes | Slovakia |
| Lafitte, A., et al | Existing evidence on the effects of photovoltaic panels on biodiversity: a | Environmental Evidence | 2023 | Journal article - review | 10.1186/s13750-023-00318-x | No | Biodiversity – wild terrestrial and semi- | No | Global |

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|---|---|---|---|---|---|---|---|---|---|
| | systematic map with critical appraisal of study validity | | | | | | aquatic species | | |
| Lambert, Q., et al | Photovoltaic power stations: an opportunity to promote European semi-natural grasslands? | Frontiers in Environmental Science | 2023 | Journal article | 10.3389/fenvs.2023.1137845 | Yes | Grasslands, soils | Yes | France |
| Lambert, Q., et al | Effects of habitat restoration and solar panels on soil properties and functions in solar parks | Applied soil ecology | 2024 | Journal article | 10.1016/j.apsoil.2024.105614 | No | Soil | Yes | France |
| Ludzuweit, A., et al | Enhancing ecosystem services and biodiversity in agrivoltaics through habitat- | Renewable and Sustainable Energy Reviews | 2025 | Journal article | 10.1016/j.rser.2025.115380 | No | Ecosystem services Insects (pollinators) | Yes | Germany |

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|---|---|---|---|---|---|---|---|---|---|
| | enhancing strategies | | | | | | | | |
| Makaronidou, M., | Assessment on the local climate effects of solar photovoltaic parks | ResearchGate | 2020 | PhD thesis | 10.17635/lancaster/thesis/1019 | No | Grassland | Yes | UK |
| Matwani, J., and Ojija, F., | Exploring the link between energy resources and global biodiversity. | Sustainable Social Development | 2025 | Journal article - review | 10.54517/ssd3245 | No | Biodiversity | Yes | Global |
| Meletiou, A., et al | EU renewable energy policies, global biodiversity, and the UN SDGs | Centre for Ecology & Hydrology, UK | 2019 | Report - review | (PDF) EU renewable energy policies, global biodiversity, and the UN SDGs-A report of the EKLIPSE project | No | Biodiversity | No | Global |
| Montag, H., et al | The Effects of Solar Farms on Local Biodiversity: A comparative study | Clarkson & Woods and Wychwood Biodiversity | 2016 | Report | Clarkson & Woods | Yes | Botany, invertebrates, birds, bats, biodiversity | Yes | UK |

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|---|---|---|---|---|---|---|---|---|---|
| Neesham-McTiernan, T.H., et al | The spatial potential for agrivoltaics to address energy-agriculture land use conflicts in Great Britain | Applied Energy | 2025 | Journal article | 10.1016/j.apenergy.2025.125527 | Yes | Botany, combined land use - agrivoltaics | Yes | UK |
| Nordberg, E.J., et al | Designing solar farms for synergistic commercial and conservation outcomes | Solar Energy | 2021 | Journal - review | 10.1016/j.solener.2021.09.090 | Yes | Biodiversity | No | Global |
| Oudes, D., and Stremke, S., | Next generation solar power plants? A comparative analysis of frontrunner solar landscapes in Europe | Renewable and Sustainable Energy Reviews | 2021 | Journal article | 10.1016/j.rser.2021.111101 | No | Ecosystem services | Yes | Europe but some UK case studies |
| Oudes, D., et al | Towards a typology of solar energy | Energy Research & Social Science | 2022 | Journal article – | 10.1016/j.erss.2022.102742 | Yes | Ecosystem services | Yes | Europe but some UK case studies |

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|---|---|---|---|---|---|---|---|---|---|
| | landscapes: Mixed-production, nature based and landscape inclusive solar power transitions | | | review and case studies | | | | | |
| Parker, G., and Monkhouse, J., | Realising the Biodiversity Potential of Solar Farms – A Practical Guide | Naturesave Insurance | 2022 | Practical guide | realising-the-biodiversity-potential-of-solar-farms.pdf | Yes | Biodiversity | No | UK |
| Randle-Boggis, R.J.,et al | Realising co-benefits for natural capital and ecosystem services from solar parks: A co-developed, evidence-based approach | Renewable and Sustainable Energy Reviews | 2020 | Journal article | 10.1016/j.rser.2020.109775 | Yes | Ecosystem services | Yes | UK |
| Sinha, P., et al | Best Practices in Responsible Land Use for Improving | Case Studies in the Environment | 2018 | Journal article | 10.1525/cse.2018.001123 | Yes | Biodiversity | Yes | USA |

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|---|---|---|---|---|---|---|---|---|---|
| | Biodiversity at a Utility-Scale Solar Facility | | | | | | | | |
| Smallwood, K.S. | Utility-scale solar impacts to volant wildlife | Journal of Wildlife Management | 2022 | Jornal article | 10.1002/jwmg.22216 | No | Birds, bats | Yes | USA |
| Solar Energy UK | A Standardised Approach to Monitoring Biodiversity on Solar Farms | Solar Trade Association | 2022 | Guidance | Ecological-Monitoring-Guidance-2022.pdf | Yes | Biodiversity | No | UK |
| Stott, H.L. | Microclimatic and diversity controls on UK grassland carbon cycling | Lancaster University | 2017 | PhD thesis | 2017HeatherStottPhD.pdf | No | Grasslands | Yes | UK |
| Szabadi, K.L., et al | The use of solar farms by bats in mosaic landscapes: Implications for conservation | Global Ecology and Conservation | 2023 | Journal article | 10.1016/j.gecco.2023.e02481 | No | Bats | Yes | Hungary |

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|---|---|---|---|---|---|---|---|---|---|
| Szoldatits et al | Bat Activity at Ecovoltaic Solar Energy Developments in the Midwestern United States | Not peer review published | 2025 | Preprint research paper | Bat Activity at Ecovoltaic Solar Energy Developments in the Midwestern United States | No | Bats | Yes | USA |
| Taylor, R., et at | Potential ecological impacts of ground-mounted photovoltaic solar panels | BSG Ecology | 2019 | Report - literature review | Solar-Panels-and-Wildlife-Review-2019.pdf | No | Biodiversity, bats, birds, aquatic invertebrates | No | Global |
| Tinsley, E., et al | Renewable energies and biodiversity: Impact of ground-mounted solar photovoltaic sites on bat activity | Journal of Applied Ecology | 2023 | Journal article | 10.1111/1365-2664.14474 | Yes | Bats | Yes | UK |
| Tinsley, E., et al | The location of solar farms within England's ecological landscape: | Journal of Environmental Management | 2024 | Journal article | 10.1016/j.jenvman.2024.123372 | Yes | Biodiversity | Yes | England |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Implications for biodiversity conservation | | | | | | | | |
| Tölgyesi, C., | Introducing the first ecovoltaic parks of Hungary: a reconciliation between solar development and nature conservation, | EGU General Assembly | 2024 | Poster/ presentation | 10.5194/egusphere-egu24-2933 | Yes | Ecosystem services | Yes | Hungary |
| Treasure, L., et al | Global assessment of solar park impacts on ecosystem services | Progress in Energy | 2025 | Journal article - review | 10.1088/2516-1083/addfa4 | Yes | Ecosystem services | No | Global |
| Uldrijan, D., et al | Bioindication of Environmental Conditions Using Solar Park Vegetation | Environments | 2023 | Journal article | 10.3390/environments10050086 | Yes | Soil, botany | Yes | Czech Republic |

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|---|---|---|---|---|---|---|---|---|---|
| van der Haas, I., | Solar park biodiversity: pollinator abundance in different locations with seed mixtures | AERES University of Applied Sciences, Almere | 2019 | PDF Research Report | Solar park biodiversity:pollinator-abundance-in-different-locations-with-seed-mixtures.pdf | Yes | Insects (pollinators) | Yes | Netherlands |
| Vaughan, A., and Brent, B,. | Agrivoltaics for small ruminants: A review | Small Ruminant Research | 2024 | Journal article - review | 10.1016/j.smallrumres.2024.107393 | Yes | Ecosystem services, soils | No | Global |
| Walston, L.J., et al | A preliminary assessment of avian mortality at utility-scale solar energy facilities in the United States. | Renewable Energy | 2016 | Journal article | 10.1016/j.renene.2016.02.041 | Yes | Birds | Yes | USA |
| Walston, L.J., et al | Opportunities for agrivoltaic systems to achieve synergistic food-energy-environmental needs and | Frontiers in sustainable food systems | 2022 | Journal article - review | 10.3389/fsufs.2022.932018 | Yes | Ecosystem services, biodiversity | No | Global |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | address sustainability goals. | | | | | | | | |
| Xu, Z., et al | A global assessment of the effects of solar farms on albedo, vegetation and land surface temperature using remote sensing | Solar Energy | 2024 | Journal article | 10.1016/j.solener.2023.112198 | Yes | Habitat, vegetation | Yes | Global |
| Yavari, R., et al | Minimizing environmental impacts of solar farms: a review of current science on landscape hydrology and guidance on stormwater management | Environmental Research: Infrastructure and Sustainability | 2022 | Journal article - review | 10.1088/2634-4505/ac76dd | Yes | Soil, plants, hydrology | Yes | USA |

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|---|---|---|---|---|---|---|---|---|---|
| Yuzyk, A.V., | Global Insights of the Impact of Solar Power Plants on Bird Populations | Biodiversity, Ecology and Experimental Biology | 2024 | Journal article - review | 10.34142/2708-5848.2024.26.1.06 | No | Birds | No | Global |
| Zhao, L., et al | Soil microbial networks' complexity as a primary driver of multifunctionality in photovoltaic power plants in the northwest region of China | Frontiers in Microbiology | 2025 | Journal article | 10.3389/fmicb.2025.1579497 | No | Soil | Yes | China |
| Zheng, J., et al | An observational study on the microclimate and soil thermal regimes under solar photovoltaic arrays | Solar Energy | 2023 | Journal article | 10.1016/j.solener.2023.112159 | No | Soils | Yes | China |