Title:

Solar parks as an opportunity to jointly advance climate-change mitigation and biodiversity conservation

Running Title: Solar parks for climate and biodiversity

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Abstract

Anthropogenic climate change is among the most pressing challenges for humanity making carbon-neutral energy production a top priority. Across the globe, solar energy is the single fastest growing energy source with solar parks covering more and more land surface area across many continents. The rise in solar energy production affects terrestrial biodiversity in the areas now occupied by solar parks but our knowledge on the consequences for biodiversity lacks behind the speed of solar-park establishment. This discrepancy likely leads to suboptimal policies regarding solar-park placement, design, and management which, if optimized, could potentially lead to synergies instead of trade-offs between climate-change mitigation and biodiversity conservation. Here, we summarize previous research and remaining knowledge gaps regarding the impacts of solar-park placement, design, and management on biodiversity. If adequately placed, solar parks could increase landscape heterogeneity and habitat connectivity. Solar-park design could enhance microclimate and habitat heterogeneity. Extensive management could make solar parks valuable semi-natural ecosystems for many species of insects, birds, small mammals, amphibians, and reptiles. Based on our assessment of knowledge gaps, we make suggestions for future research. We still lack comprehensive information on solar-park impacts on biodiversity and ecosystem functioning across spatial and temporal scales, and a combined multitrophic, above-belowground perspective. We suggest using standardized, replicated research designs focusing on i) comparing solar parks to adequate, nearby, alternative ecosystem types as well as ii) studying impacts of solar parks across temporal, and iii) spatial scales. Such research would enable comprehensive evaluations of solar-park impacts on biodiversity and would allow policymakers to adequately steer solar-park placement, design and management toward optimizing synergies between renewable energy production (and thus climate change mitigation) and biodiversity conservation for the joint benefit of nature and people.

Keywords: renewable-energy production, photovoltaics, sustainability, ecosystem functioning, land conversion, green energy, habitat connectivity, landscape heterogeneity

Introduction

Anthropogenic climate change is one of the greatest challenges for humanity, with the speed and dimension of observed and projected temperature increase likely being unprecedented in the history of Planet Earth (Calvin et al., 2023). For several years in a row, global average temperatures have exceeded the level of 1.5°C warming, the value that the international community has set as the preferred limit of global warming until the end of the 21st century (UNITED NATIONS, 2015). Given the anticipated negative consequences of progressing climate change, climate-change mitigation and thus the transition to carbon-neutral economies remains a relevant priority in regional, national, and international policies (Calvin et al., 2023). The energy-production sector plays a major role here, as the reduction of fossil-fuel use in all other sectors (traffic, households, industry) crucially depends on the availability of clean electricity (Gielen et al., 2019). Thereby, electricity generation via renewables is not only crucial for climate-change mitigation, but it also contributes to independence from major fossil fuel providers, which, together, makes it a key factor for sustainable prosperity.

In addition to climate change, biodiversity change is the second major environmental crisis of our time (Pettorelli et al., 2021; Pörtner et al., 2023). With the dramatic acceleration of extinction rates, the destruction of natural habitats and the disturbance of ecological functions and services, it has profound consequences for human societies (Cardinale et al., 2012). After land-use change and direct exploitation, climate change has been identified as one of the most important drivers of biodiversity decline (Maxwell et al., 2016), and biodiversity loss can accelerate changes in climatic conditions

(Eisenhauer et al., 2024; Pörtner et al., 2023; Shin et al., 2022). This positive feedback loop, with its reciprocal dependency between a functioning atmosphere and biosphere, highlights the importance of jointly considering both crises and of political, societal, and technological measures that generate win-win-situations for climate and biodiversity.

While biodiversity should generally profit from climate-change mitigation (Newbold, 2018; Urban, 2024; Warren et al., 2013), the expansion of renewable energy production may have negative consequences for biodiversity. Wind turbines may cause impacts for raptors, bats, and insects (Katzner et al., 2025; Voigt, 2021; Watson et al., 2018) and hydroelectric power plants are imposing barriers to migration pathways of fish and other aquatic species (He et al., 2024). The cultivation of bioenergy crops for biofuels or biogas harms biodiversity via agricultural intensification, or destruction and degradation of natural habitats (Hof et al., 2018; Immerzeel et al., 2014). Finally, photovoltaics, especially solar parks, alter the biophysical conditions of potentially large land areas with subsequent consequences for biodiversity and ecosystem functioning (Rehbein et al., 2020; Figure 4 in: Wright et al., 2026). Overall, these examples illustrate the potentially negative impacts of renewable energy production on biodiversity, which may turn global climate mitigation benefits for biodiversity into negative local effects on species, communities, and ecosystems. This underlines the need for integrated strategies in renewable-energy development, which pursue and prioritise win-win situations for both atmosphere and biosphere. Examples already exist for hydroelectric energy production (Scruton et al., 2007) and offshore wind farms (Werner et al., 2024). Crucial for these overarching sustainability strategies are assessments and an in-depth understanding of renewable-energy related land-use change impacts on biodiversity and ecosystem functioning.

Solar parks and land-use change

Since the first comprehensive studies on global-change stressors (Millennium Ecosystem Assessment, 2005; Sala et al., 2000), land-use change has consistently been identified as one of the most important drivers of biodiversity loss. At the global scale, the most prevalent types of land-use change are conversion of forests to agriculture in the tropics, urbanization and build-up of infrastructure in developed and developing countries as well as the intensification of agriculture (Foley et al., 2005; Vitousek, 1994). With the need for increasing sustainable energy production and the following surge in established solar capacity, another type of land-use change has emerged: the conversion of economically less productive sites (mostly low-fertile agricultural and fallow land, but also forests or brownfields) to energy production. Those conversions range from subtle changes such as shifts in crop selection to bioenergy crops, to the placement of wind turbines within forests and to the construction of ground-mounted solar panels in larger areas, i.e. solar parks (Rehbein et al., 2020; Trainor et al., 2016). Solar parks are the most rapidly growing sector of renewable energy production, with global energy capacities from photovoltaics recently having increased 10-fold within 10 years (Gómez-Catasús et al., 2024). The construction of solar parks represents a drastic change in land use, as it can cover large areas and fundamentally alters the biological and biophysical characteristics of the habitat, even if they are constructed without altering the general habitat type of the site. Hence, effects of solar-park construction could be as relevant and disrupting to biodiversity and ecosystem functioning as e.g. deforestation (Jung et al., 2019).

Countries all over the world have plans to substantially increase their share of renewable energy production with the largest areas of solar-park construction (both in terms of total area being covered and average size of solar parks) having been built in deserts and rangelands, e.g. in North America (Gómez-Catasús et al., 2024; Trainor et al., 2016). The European Union also plans to double the capacity of solar power by 2030 (European Commission & High Representative of the Union for

Foreign Affairs and Security Policy, 2022). In Europe, solar-park construction is happening at smaller scales (Rehbein et al., 2020) and within a very specific context: landscapes in Europe are characterised by relatively small patches of different land-use types, most of which are already anthropogenically altered. Within these heterogeneous landscapes, natural and undisturbed habitats are rare and isolated and typically restricted to marginal and low-productive sites. With solar parks being primarily built on such biodiverse sites in order to avoid trade-offs with agricultural production and other stakeholders in a region (Rehbein et al., 2020), there is an urgent need to identify placement and configuration approaches that are not only least harmful but as beneficial to biodiversity as possible (Tölgyesi et al., 2023). Without a clear evidence-led understanding of the trade-offs and synergies between energy production and biodiversity of solar parks (Fig. 1), especially within heterogeneous landscapes such as those commonly found in Europe, an opportunity to guide this rapidly growing industry is being missed.

Figure 1: Comparison of solar parks with a singular focus on energy production (left) and solar parks synergizing joint benefits for energy, biodiversity, and people (right). Energy-focused solar parks are characterized by strong biophysical alterations via tightly-spaced rows of low panels, strong ecological homogenization, frequent management disturbances and connectivity losses caused by impenetrable fences. We argue that this setup creates strong and unnecessary trade-offs between energy production on the one hand and benefits for biodiversity and people on the other hand. By contrast, placing, building, and maintaining solar parks targeting synergies between energy production, biodiversity, and people could entail maximizing microclimate complexity via higher and widely-spaced panel rows, actively increasing habitat heterogeneity, using extensive management and ensuring habitat connectivity through permeable boundaries.

Current research and knowledge gaps

The functioning of a solar park is reliant on energy produced by the photovoltaic panels, therefore, so long as panel functioning is not impaired, the land surrounding and beneath the panels can be dedicated to biodiversity protection. In response to this, the potential value of solar parks for biodiversity conservation is an increasingly-debated topic (Cali et al., 2022; Treasure et al., 2025), with terms such as ‘ecovoltaic’ (Tölgyesi et al., 2023) and ‘conservoltaic’ (Nordberg & Schwarzkopf, 2023) being coined to highlight the potential to synergise energy production and dedicating land for conservation. This land-sharing perspective provides an opportunity to increase the land area dedicated to nature protection, while keeping the land economically productive (Fig. 1). However, despite the rise in interest in the topic, data on the biological impacts of solar parks are often taxon-specific (e.g., Blaydes et al., 2024), site- or system-specific (e.g., Graham et al., 2021), and are almost exclusively quantified by comparisons with other nearby habitats rather than a more rigorous before-after-control-intervention experimental design (e.g., Jarčuška et al., 2024). As such, the rapidly growing body of research on solar parks is becoming increasingly opaque and difficult to navigate. There is a growing body of evidence that solar parks can have positive (e.g., Golawski et al., 2025), negative (e.g., Tinsley et al., 2023), or mixed (e.g., Kocsis et al., 2025) impacts on biodiversity, depending on the scale, methods, and taxonomic groups studied. A systematic approach is needed to ensure research efforts address the critical issues surrounding solar park placement, design, construction, management and deconstruction, and that research gaps are filled.

Much of the conversation surrounding the potential of solar parks for biodiversity and ecosystem functioning focuses on ecological theories developed for natural ecosystems (Tölgyesi et al., 2023). However, solar parks represent novel artificial landscape elements with limited parallels to natural ecosystems. For example, ground-mounted panels intercept solar radiation and precipitation, creating highly complex microclimate compositions that vary in temperature and water availability across very small distances. While these microclimates are likely to be detrimental to some species (e.g., Zitzmann et al., 2024), this enhanced complexity has the potential to support a diversity of species with varied requirements within a relatively small area. The shelter provided by the panels may furthermore support species persistence under future climate change for mobile species due to the cool refugia produced by the panels which could be used during increasingly frequent extreme weather events (Kerr et al., 2025). Impacts of solar parks on biodiversity may also be highly context dependent. For example, solar-park construction may have particularly strong impacts when constructed in open habitat types such as grasslands, which tend to be exposed and lack substantial shade or shelter. Therefore, the dramatic increase in shelter caused by the panels may have particularly strong impacts on the functioning of grasslands and the persistence of grassland species within the landscape, and yet to date, this impact has not been investigated. For example, the shade produced by panels may impair the functioning of shade intolerant plants but also increase plant species and trait diversity by creating habitat for shade tolerant species. Further, grasslands act as biodiversity hotspots at a global scale (Habel et al., 2013; Murphy et al., 2016; Sankaran, 2009), containing many specialist and endemic species restricted to certain regions or grassland types (Bruchmann & Hobohm, 2010), and are consequently often rare or threatened with extinction. Therefore, solar parks could play a key role in the protection of vulnerable grassland ecosystems under future climate change.

How to build biodiverse and multifunctional solar parks

The opportunities solar parks may provide for biodiversity conservation depend on their placement, design, and management (Fig. 2). Before discussing these aspects in detail, it is worth noting that solar parks could even benefit humans via their potential for recreation, allowing them to experience nature, for example via observing flowering plants, pollinators, or birds not commonly sustained by agricultural habitats surrounding the parks (Tölgyesi et al., 2023). This could be particularly beneficial in densely-populated areas where opportunities to experience biodiversity are comparably limited. In addition to providing recreational benefits, such combined habitat-use for renewable energies and biodiversity maintenance could be leveraged for educational and outreach purposes by illustrating to the wider public how synergies between renewable energy production and conservation can be reached (Fig. 1).

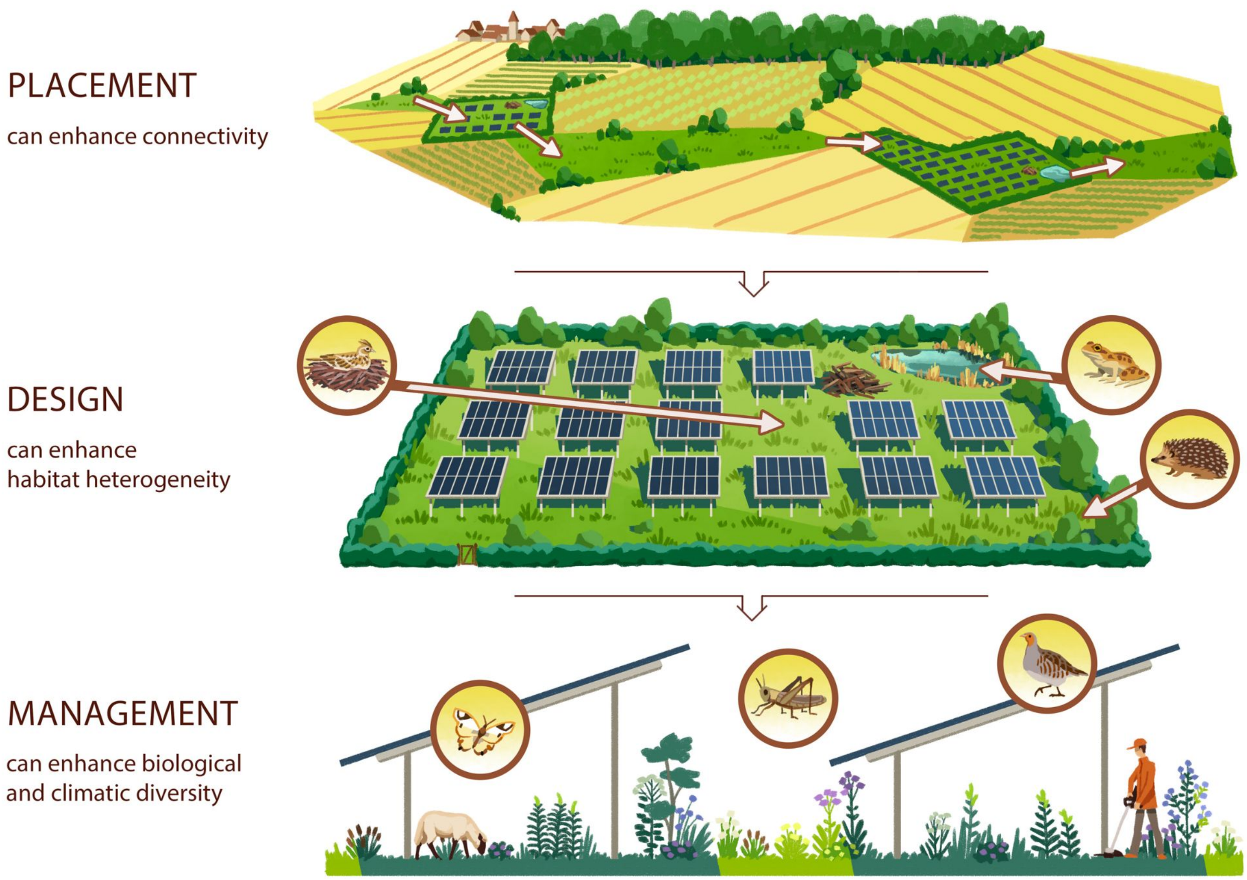

Figure 2: Benefits to biodiversity related to solar park placement (top), design (middle), and management (bottom). Careful placement of single or groups of solar parks can enhance habitat connectivity for mobile species in a matrix of non-suitable habitats where biodiversity-friendly solar parks connect otherwise too-far spaced natural or semi-natural habitats. Solar-park design can benefit biodiversity by providing additional extensively-managed grassland habitat but also via microhabitats, such as larger gaps between panels, water bodies, deadwood, sandy, or rocky areas. Such elements increase habitat heterogeneity at the landscape scale and increase habitat value for multiple species of insects, birds, small mammals, amphibians, or reptiles. Solar-park management with grazing or reduced mowing, can enhance biological and climatic diversity in these semi-natural systems and benefit certain species of insects and birds. In particular, species which require refugia from climatic extremes, which are adapted to extensive management, or benefit from grazing-induced vegetation heterogeneity will profit.

The placement of solar parks

To eliminate trade-offs between solar parks and both agriculture as well as conservation areas, selection of suitable sites is key (Tölgyesi et al., 2023). In regions such as Europe, where unutilized space is limited, there is a high chance that agriculturally productive sites are spared. Concerns have been raised that this will come at the cost of permanent grasslands which, coincidentally, are often key biodiversity areas, especially under low management intensity (Schils et al., 2022). At the same time, there is a high potential for solar parks to support and promote biodiverse communities at the landscape scale through increased habitat heterogeneity and habitat connectivity (Fig. 2, top panel). Even if solar parks might not be suitable as permanent habitat for some species, they can still increase habitat connectivity by serving as stepping stones (Blaydes et al., 2024; Cali et al., 2022; Korányi et al., 2023). For example, solar parks could act as resting areas for birds and other migrating animals (cf. Hovick et al., 2017). At the regional level, the strong microclimatic variation within solar parks could enable species constrained by thermal requirements to more effectively track their climate niche under climate change (Lenoir et al., 2017). Solar parks of high habitat quality could connect isolated or fragmented populations and hence improve gene flow, support metapopulation dynamics, and ultimately support population persistence (Ibagon et al., 2022).

Especially in landscapes dominated by agriculture, solar parks have the potential to benefit the broader landscape via spill-over effects into adjacent habitats (Hamřík et al., 2026). Spill-over of pollinators or predators and the respective services of pollination and pest control will depend on the communities established in the park and on the similarity between the ecological communities in the park as the donor system and in adjacent recipient systems (Michalko & Birkhofer, 2021; Tölgyesi et al., 2023).

To leverage those positive effects of solar parks at the landscape level, their design and the availability of additional landscape components or microhabitats need to be considered.

The design of solar parks

The three key components of solar-park design, which create biodiversity impacts and opportunities, are the photovoltaic panels, the land underneath and around the panels, and the park border (Fig. 1, Fig. 2, middle panel). For photovoltaic panels, their composition and arrangement can be modified; particularly panel height, distance between the panels, and the angle of the panels. Panel height determines the possible structure of the vegetation beneath. The panels must not be shaded by vegetation, and so taller panels would mean that vegetation could be cut less frequently, and the vegetation could grow taller between cuts. This would reduce management costs, disturbance intensity, and increase ground shading to further reduce water loss, soil erosion, and maintain cooler soil microclimates (Song et al., 2013). The increased vegetation height would also result in a more complex three-dimensional microhabitat for species to occupy. Panel height also alters air flow, with taller panels showing improved efficiency (Smith et al., 2022), hence benefiting both energy production and microclimate complexity. Distance between the panels and their angle will alter the amount of light reaching the ground, which alters vegetation productivity, soil moisture, and microclimate complexity. As plant communities are known to differ beneath versus between panels (Uldrijan et al., 2022), with shifts from annual shade-tolerant to perennial drought-tolerant species (Uldrijan et al., 2022, 2023), changes in the distance between the panels would alter the proportion of these plant communities within the solar park landscape. This fragmentation of plant communities may increase the risk of invasion by non-natives (Uldrijan et al., 2023), however to date this has not been investigated in solar parks. A key consideration would be that increasing the distance between the panels would reduce panel density, therefore reducing energy yield per area, resulting in more land being converted to solar parks in order to achieve energy-production requirements. Changes to panel angle may also alter their efficiency should it reduce their exposure to solar radiation. There are growing bodies of evidence that highlight the abiotic impacts of panel composition, for example comparing ground shading between tracking versus fixed panels (Pinos et al., 2026), and how panel angle interacts with or disrupts wind flow (Jiang et al., 2021). However, to date, little work has linked these changes to ecosystem processes or climate resilience (for example, whether the shade produced by panels is used as refugia during heatwaves, or can support communities with a greater diversity in thermal sensitivity than an otherwise more thermally homogenous landscape), and therefore the opportunity for customisation of panel composition to achieve biodiversity outcomes remains unclear.

The second component of solar-park design that could be manipulated is the land underneath and around the panels. During construction, soil clearing, compacting, and levelling, as well as the removal of vegetation and topsoil poses massive disturbance to the soil, disrupting the composition of the local ecological community. Therefore, following construction, efforts can be made to either restore the ecosystem back to its previous state, or to create entirely novel ecosystems that may perform better in the solar-park setting (Tölgyesi et al., 2023). One of the most important decisions influencing solar park habitat quality is the choice of the target plant community to be established (Tölgyesi et al., 2023). Plant communities can be altered or controlled through seed mixtures (Tölgyesi et al., 2023), resulting in novel community compositions that consist of both sun and shade tolerant plants. Decades of research into plant-diversity effects on non-plant biodiversity and ecosystem functioning from biodiversity-ecosystem functioning experiments (Isbell et al., 2018; Weisser et al., 2017) and realworld systems (Duffy et al., 2017; van der Plas, 2019) provide strong evidence that more diverse plant communities enable overall higher biodiversity (Scherber et al., 2010), ecosystem multifunctionality (Dietrich et al., 2024; Meyer et al., 2018), and stability to extremes (Isbell et al., 2015). Therefore, the choice of a target plant community in solar parks considerably impacts overall biodiversity in the park. As the land between the panels is largely unused space, there is also the opportunity to dedicate land to biodiversity improvement or species-specific support, for example by constructing ditches, building water bodies, or rock and deadwood piles (Fig 2, middle panel). Such specific support would be highly context-dependent and would require focused study within relevant systems to understand how target species interact with solar parks. Such research could determine when and where these strategies are appropriate.

The last component is the border of the solar park. Parks are typically fenced to reduce the risk of damage or vandalism to solar-park equipment. These fences can inhibit wildlife movement through the landscape, specifically for larger-bodied animals, and may therefore have negative consequences for habitat connectivity (Fig. 1). However, this can be mitigated through creating small gaps in the fence or between the fence and ground or choosing a suitably wide gauge that wildlife could pass through while excluding people (Cypher et al., 2021). There are also possible benefits of fencing for disturbance-sensitive wildlife such as ground-nesting birds (Ikuta & Blumstein, 2003). While, to date, there are no studies investigating the impact of fencing on species occupying or moving through solar parks, fencing has been used successfully for conservation purposes in other contexts, such as predator exclusion zones (Malpas et al., 2013), inhibiting the movements of invasive species (Young & VanderWerf, 2024), and even providing biodiversity benefits that spill out into the wider landscape

(Tanentzap & Lloyd, 2017). Therefore, with appropriate site selection and design, the use of fencing around solar parks could serve similar purposes. There are also alternatives to traditional fencing, such as the use of hedgerows, which provide additional habitat and can act as permeable barriers for wildlife. In some cases, local communities may be concerned about the visual impact of solar parks near settlements, which can be alleviated through the construction of natural barriers such as earthen banks or tall vegetation to act as screening. These structures further alter local conditions by artificially changing the vegetation and topographical structure of the landscape and provide further microclimate complexity. Therefore, the impacts of these structures may be particularly pronounced in otherwise homogenous landscapes, however this has not yet been investigated.

Overall, the design of solar parks can dramatically alter within-park conditions. For wildlife, but particularly small organisms such as insects, movement between sun and shade, areas of different vegetation compositions and structures, from sheltered borders to exposed central areas over such small distances means a high diversity of microhabitats could support diverse communities (Fig. 1, Fig. 2 bottom panel). The enhanced microclimate complexity can provide refugia during extreme heat or cold events and support climate-resilient populations. Solar-park design therefore offers an opportunity to create novel ecosystems uniquely rich in microclimatic refugia and vegetation complexity through carefully considered and evidence-led design.

The management of solar parks

After establishing and designing a solar park, another aspect with a high potential to maintain and even maximize biodiversity and ecosystem functioning and services is their management (Fig. 2, bottom panel). While the selection of what to sow in solar parks at construction affects plant communities from the start, long-term management components will determine which species will be sustained over time. Via long-term management, we can adjust and maintain specific habitat types surrounding the solar panels, create habitat and microclimatic heterogeneity (Adler et al., 2001), and establish conditions allowing for high above-belowground biodiversity (Le Provost et al., 2021) or habitat optimisation for target taxa (van Noordwijk et al., 2017).

Relevant management of solar parks managed as grassland habitat includes mowing, grazing, and maintaining target plant communities via re-seeding. Those activities have well-studied effects on grassland biodiversity and ecosystem functioning. For mowing, the timing and frequency of cuts (Berger et al., 2024; Georgi et al., 2023; Halbritter et al., 2015; Proske et al., 2022), as well as cutting height and mower type (Bruppacher et al., 2016; Hartlieb et al., 2024; Hecker et al., 2022; Humbert et al., 2010; Von Berg et al., 2025) are key aspects to take into account. For grazing, livestock identity (Rook et al., 2004; Vickery et al., 2001), grazing intensity (Hu et al., 2019), and the timing and duration of grazing events (Wrage et al., 2011) influence above-belowground biodiversity and ecosystem functioning. Finally, long-term maintenance of a specific target plant community could be achieved via re-seeding or supplementing solar-park grasslands via hay transfer from nearby target communities.

In summary, a targeted management of grasslands in solar parks holds massive potential for maintaining and increasing local biodiversity and ecosystem functioning, across taxa and trophic levels, above and below the ground. However, typical management of grasslands may not be applicable to solar parks. Panel composition will impact the type of machinery that can be used, creating differences in management intensity between and under the panels, or livestock behaviour may differ between and under the panels, resulting in heterogenous grazing intensity. To date, little work has explored how grassland management can be tailored to increase biodiversity in solar parks.

The way forward – addressing knowledge gaps on biodiverse and multifunctional solar parks

Despite continued increases in solar park cumulative capacity and an accompanying increase in scientific studies on their impacts (Gómez-Catasús et al., 2024), we still lack comprehensive information on how they impact biodiversity and ecosystem functioning in cross-scale, combined above-belowground, multitrophic systems, including their impacts on surrounding habitats and their potential to assist landscape-scale and regional habitat connectivity. While single studies can provide an in-depth assessment of relatively isolated aspects of this question (e.g., the suitability of solar parks varying in between-panel distance for a specific ground-nesting bird species), we need combined, integrative, and replicated studies to synthesize our understanding of solar-park impacts on biodiversity and ecosystem functioning. Much of the previous research has seemingly focused on a small number of parks, a small subset of species, or on very specific technical aspects of solar-park construction, which limits our capacity to generalise these findings.

We need standardized research replicated across multiple solar parks covering a wide range of environmental (e.g., climatic and soil) conditions. Previous studies have focused on single solar parks (e.g., Graham et al., 2021) or seemingly random clusters of solar parks in a region (e.g., Blaydes et al., 2024). But only well-replicated frameworks across relevant environmental gradients and study designs with adequate controls, i.e. BACI – before-after-control-impact – designs (see Christie et al., 2019) will allow us to obtain meaningful generalizations on how solar parks impact biodiversity and ecosystem functioning. A central aspect of BACI design is a valid or informative point of comparison. Compared to a never fertilized, twice-mown pristine grassland, solar parks might not be a very convincing example for biodiversity conservation. However, compared to an agricultural field, they might appear as a pinnacle of diversity and ecosystem functioning. Adequate points of comparison need to encompass a variety of scales which is important for our understanding of ecological responses (Dixon Hamil et al., 2016; Martin, 2018) and for our ability to scale up from small-scale effects (e.g., below or between panels) to areas covering multiple panel rows over single parks, and then up to the landscape level. Hence, to comprehensively assess the potential value of solar parks, we need integrative research across a range of scales; from the directly affected areas under and directly surrounding the panels, beyond the fence into adjacent habitats, the surrounding landscape, and the regional level (Fig. 2).

In addition, we need to study solar parks throughout their entire life cycle, i.e. from before construction until years after their disassembly, to better understand the temporal dynamics of their impacts. Construction of solar parks causes heavy disturbance to soil and vegetation, which may provide suitable habitat for early successional or highly disturbance-reliant species that might otherwise be scarce in well-established habitats or static landscapes. Early successional habitats can contain high biodiversity, and often highly distinct communities and species that are restricted to such habitat types (Prach & Pyšek, 1999; Sandoval et al., 2019). However, they are poorly studied, and even less so in the context of solar park life cycles (Zaplata & Dullau, 2022). Following the initial disturbance, communities in solar parks will transition over time (Jung et al., 2019) resulting in a highly dynamic land-use type, where findings may vary drastically depending on park age.

Solar parks may attract wildlife but impact performance in different ways across their life cycle; the observation of a bird species singing in a solar park at a given point in time does not necessarily provide information about its breeding success (Hemmer et al., 2025). Stable performance over time cannot be projected from a single time point. Therefore, without long-term information, we cannot be sure if solar parks act as a sink or could, over time, represent a source for certain populations. How ecosystems initially respond and then transition over time throughout the solar park life cycle remains unclear and requires dedicated study.

Lastly, to achieve a comprehensive understanding of how solar park placement, design, and management impact biodiversity and ecosystem functioning, we need to consider greater taxonomic diversity because solar park establishment causes heavy soil disturbance, affecting both above- and below-ground ecosystems. Most previous research has focused on aboveground biodiversity or, if belowground perspectives were employed, they are commonly restricted to abiotic changes or respiration, and rarely comprehensively assess soil biodiversity and ecosystem processes (but see Menta et al., 2023). Given the importance of soil biodiversity both as a part of global biodiversity (Anthony et al., 2023) and for its role in terrestrial ecosystem functioning (Delgado-Baquerizo et al., 2020), we need this integrative above-belowground perspective to comprehensively understand how solar parks impact the habitat they are covering. Moreover, we need to explicitly combine taxa at multiple trophic levels and functional roles into assessments of solar-park impacts (Eisenhauer et al., 2019; Seibold et al., 2018). Many studies focus on specific subsets of taxa, e.g. arthropod pollinators, to assess the effect of solar parks on specific ecosystem processes and services such as pollination (Blaydes et al., 2024; Walston et al., 2018). While this specific information is valuable, such a rather narrow focus prevents a broader, integrative assessment across different trophic levels and the range of ecosystem processes they are involved in, from decomposition via herbivory to pest control and pollination (Wilson, 1987). Without established guidelines on solar-park placement, design, and management, conclusions drawn from single taxa may have unintended consequences.

Integrating ecological knowledge into decision making

From an overarching political or legal conservation perspective, a comprehensive understanding of whether and how solar parks may benefit species, biodiversity and ecosystem functioning, will help in designing optimal compensation regulations. Currently, compensation measures do not, or only to a limited degree, consider the actual potential of the transformed areas themselves for benefiting biodiversity, but are usually based on purely area-related aspects, which rely on static legal or administrative regulations. More flexible or case-specific, empirically based compensation measures that consider actual management measures within the solar park might instead contribute to synergies between energy production and biodiversity. Releasing solar park developers from costly compensation measures for specific target species outside solar parks would free resources for biodiversity-friendly design and management of solar parks. This would result in solar parks that, in addition to providing green energy, meaningfully contribute to the maintenance of biodiversity and ecosystem processes. However, for designing such case-specific compensation regulations, comprehensive, independent long-term monitoring and assessment efforts, such as those outlined here, are needed to provide the required knowledge base on the effects of park placement, design, and management measures on a range of biodiversity and ecosystem function aspects.

Conclusions

Human societies depend on both biodiversity and its services and on sustainable energy production. To comprehensively assess the threats and services of solar parks for biodiversity, we need a more standardized and broader assessment of their ecological impacts and potential for biodiversity conservation. Most of all, we should avoid establishing parks for energy production while accepting potential biodiversity threats or services as a collateral damage or accidental benefits. Instead, we need more targeted efforts for actively leveraging their potential to simultaneously serve both energy production and biodiversity conservation. Solar parks represent an opportunity to tackle some of the most pressing challenges humanity is facing via mitigating both the climate and the biodiversity crisis. However, achieving this synergy relies on empirical evidence. With the global boom in solar-park development, it is critical that well-designed and thorough research is conducted to address the research gaps we have highlighted.

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