



The impacts of photovoltaic installations on biodiversity



Knowledge synthesis

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BACKGROUND

Solar energy is rapidly being scaled up in a bid to replace fossil fuels, but unlike wind or hydraulic energy, its ecological impact remains unclear. Solar panels and infrastructure can modify ecosystems through habitat loss, wildlife mortality, and the disruption of natural behavioural patterns and local populations. For instance, some insects mistake the reflective surface of solar panels for water and lay their eggs on them (ecological trap). Studies also describe vegetation changes under solar panels due to the creation of new microclimates. Moreover, despite improvements in performance, solar energy systems still require vast land areas, creating a conflict between environmental protection, electricity production and other land uses.

The aim of this paper is to provide a summary of the currently known impacts of photovoltaic (PV) installations on wildlife, as well as recent research on lesser studied or lesser-known aspects that should nonetheless be brought to the attention of the sector (see Table 1).

Observation	Key scientific article
Impact on plant diversity	Gallagher, R. V., Andres, S. E., Stephens, R. E., Hewitt, C., Wintle, B. A., van Leeuwen, S., ... & Adams, V. M. (2025). Impacts of the renewable energy transition on global plant diversity: a review. <i>Plants, People, Planet</i> .
Impact on wildlife	Fleming, P. A. (2025). All that glitters – review of solar facility impacts on fauna. <i>Renewable and Sustainable Energy Reviews</i> , 224, 115995.
Impact on insects	Lec'Hvien, A., Bienvenu, L., Isselin-Nondedeu, F., Bischoff, A., Gros, R., & Schatz, B. (2025). Effects of solar panels and management on pollinators and their interactions with plants in Southern French solar parks. <i>Biological Conservation</i> , 307, 111209.
Impact on agricultural environments	Kocsis, T., de Groot, A., van Beersum, F., Boer, J., Dimmers, W., Laros, I., ... & Fijen, T. (2025). Mixed plant and arthropod biodiversity responses to solar park establishment on former agricultural lands. <i>Journal of Applied Ecology</i> , 62(11), 3078-3091.
Impact on waterbirds	Anderson, C. M., Hopkins, A. P., & Anderson, J. T. (2025). Assessing the impact of solar farms on waterbirds: a literature review of ecological interactions and habitat alterations. <i>Conservation</i> , 5(1), 4.
Impact on semi-arid environments	Iranzo, E. C., Nicolau, J. M., Reiné, R., & Tormo, J. (2025). Current knowledge on novel semi-arid photovoltaic ecosystems, their impacts on biodiversity and implications for the sustainability of renewable energy production. <i>Land</i> , 14(6), 1188.
Impact on agricultural	Schwarz, R., & Ziv, Y. (2025). Shedding light on biodiversity: reviewing existing knowledge and exploring hypothesised impacts of

systems	<p>agrophotovoltaics. <i>Biological Reviews</i>, 100(2), 855-870.</p> <p>Leroy, V., Decocq, G., Noirot-Cosson, P. E., & Marrec, R. (2025). Impacts of punctual solar trackers on soil biodiversity in agricultural lands. <i>Geoderma</i>, 453, 117147.</p> <p>Yan, T., & Wang, Z. (2025). Impact of photovoltaic industry development on grassland ecosystems. <i>Academic Journal of Environment & Earth Science</i>, 7(1), 63-69.</p>
Impact of floating photovoltaics	Oliveira, P. M. B., Almeida, R. M., & Cardoso, S. J. (2025). Effects of floating photovoltaics on aquatic organisms: a review. <i>Hydrobiologia</i> , 852(12), 3155-3170.
Impact on ecosystem services	Treasure, L., Sharp, S. P., Smart, S. S., Parker, G., & Armstrong, A. (2025). Global assessment of solar park impacts on ecosystem services. <i>Progress in Energy</i> , 7(3), 032002.
Limitations and knowledge bias	Lafitte, A., Sordello, R., Ouédraogo, D. Y., Thierry, C., Marx, G., Froidevaux, J., ... & Reyjol, Y. (2023). Existing evidence on the effects of photovoltaic panels on biodiversity: a systematic map with critical appraisal of study validity. <i>Environmental Evidence</i> , 12(1), 25.

CHAPTER 1 – THE MAIN DOCUMENTED IMPACTS OF PV POWER PLANTS ON BIODIVERSITY

As with most types of human infrastructures, renewable energy installations may directly or indirectly harm wildlife and disturb natural ecosystems, either during the extraction of the necessary resources for their production, during their installation (which can last anywhere between 2-3 years)/dismantlement and/or during their operational phase.

These installations therefore contribute to declines in local biodiversity and, in turn, to the global biodiversity crisis. PV energy installations may:

- lead to significant changes and losses of natural habitats, often considered to be one of the most important drivers of biodiversity loss
- represent a cause of wildlife mortality, especially for birds and insects
- impede bird migration
- disrupt plant growth and animal behaviour
- change population composition and diversity
- alter soil quality and ecological functions
- influence habitat use, reproductive and foraging behaviours, and interspecific competition

Current knowledge can be divided into three main categories:

1. The impact on vegetation: less growth under the panels, but sometimes more biomass in drylands, and changes to species composition (some species thrive, at the expense of others).
2. The impact on insects: insects are attracted to polarized light (traps), diversity is lower in very shaded areas. Pollinators (bees, butterflies) are the most studied group.
3. Global impacts: changes in species diversity and abundance near large PV power plants are noted, however, these impacts remain to be quantified. Similarly for the cumulated effects of individual installations which may be greater than the simple addition of individual structures.

Iranzo et al. (2025) noted that, in relation to the DPSIR framework, most studies emphasized “pressure” and “impact” components, while fewer addressed “responses” or underlying “drivers”. The authors provided graphical summaries of the main impacts of PV power plants on microclimate and soil, vegetation, and wildlife. These figures have been reproduced in Appendix 1 of this document.

Actions for improving the coexistence of human activities and biodiversity should alleviate the pressures from these activities, notably those produce the effects described below. It is therefore essential to link pressure and impact to identify possible avenues of action and mitigate undesirable impacts.

CHAPTER 2 - PRESSURE-IMPACT RELATIONSHIPS

Pressure: land-use changes

The greatest pressure on biodiversity from PV installations comes from land-use change, generating habitat loss and fragmentation, and physical barriers (fences, buildings).

The construction and operation of USSE facilities sometimes require the clearing and levelling of large land areas. Vegetation is removed by regular clearing, mowing or herbicide-spraying operations, to prevent panels from being shaded and to reduce the fire risk. Major changes occur during the construction phase, e.g. levelling, soil compaction, removal of the arable layer, tree pruning and removal, and herbicide-spraying. These interventions, whose objectives are to increase the energy yield (shade removal) and reduce the fire risk, degrade the soil and make it prone to erosion.

The transformation of open natural or agricultural habitats into USPV power plants and their infrastructure can disrupt ecosystems and block ecological corridors. High-voltage power lines that connect the power plant to the electricity network can also be insurmountable barriers for certain species from the UV light they emit, which is visible to insects, birds, rodents and other mammals

such as reindeer. The literature shows that many valuable natural areas are impacted by the construction of these facilities, indicating that biodiversity considerations are not sufficiently considered when selecting a site.

These installations have an impact not only on the developed area, but also on adjacent habitats with the development of infrastructure (access roads, electrical equipment, grid cables) that also require the destruction of more areas, cause disturbances and generate pollution (e.g. dust, light pollution, microclimate modification, UV radiation; see below).

The impacts on animals are mortality or injury, migratory route disruption, movement restriction, and avoidance behaviours, which can result in a loss of genetic diversity for populations.

At the landscape scale, solar panels may create a physical barrier for the movement of certain species such as sedentary butterflies (Lec'Hvien et al., 2025).

Fencing around PV fields could disrupt the movement of larger animals, affect habitat connectivity and disrupt migratory routes. This could lead to large-scale effects on populations, and even result in local extinctions (Shwarz et al., 2025).

In plants, repeated disturbances could have long term consequences on communities if the vegetation is systematically cut down before plants reach reproductive maturity. This could impoverish the soil seed bank and inhibit reproduction. There may also be undesirable effects related to the spraying of herbicides, affecting essential functions such as plant growth or plant-pollinator interactions.

The impacts on the soil are variable. Solar farm construction can result in a decline in both soil physical and chemical quality. However, ecologically focused strategic placement of PV panels can positively influence several soil properties, including enhanced soil aggregate stability, increased microbial communities, and elevated organic matter content (Anderson et al., 2025).

Anderson et al. (2025) stress that in degraded landscapes or intensively managed agricultural areas, solar farms can paradoxically enhance biodiversity. Despite the negative impacts, some studies have found that solar farms support higher bird species richness, diversity, and abundance, particularly for invertebrate eaters and ground foragers, likely due to their increased structural diversity compared to the surrounding landscape. Pollinator species seem to have the most gain from solar installations, with research demonstrating that the inclusion of pollinator plants can increase pollinator abundance threefold over 5 years. Resource-limited agricultural areas often experience enhanced avian biodiversity, as do arid environments when ground-covering vegetation is used, but there is limited research on the impacts on forest and wetland-associated species.

Pressure: biomass “removal”

Avian species are disproportionately affected by mortalities compared to other taxa. Waterfowl and other wetland-dependent species that are nocturnal migrants accounted for almost half of the avian deaths at solar facilities (Anderson et al., 2025). The loss of specific ponds or wetlands in areas converted to solar infrastructure could lead to alterations in migratory routes or breeding patterns of

species exhibiting high breeding and nesting site fidelity. Waterbird mortality varies seasonally, with most events happening during peak migration periods.

Kosciuch et al. (2020) estimated bird fatalities at photovoltaic solar facilities in California and Nevada (USA) at between 1.82 and 2.49 birds per MW per year, which could represent a total of 30,976 to 42,193 bird fatalities per year when extrapolated to the combined total USSE capacity of these two states (17.02 GW).

Anderson et al. (2025) also produced extrapolated estimates that suggest that solar farms are responsible for 37,000-138,000 avian mortality cases annually across the United States. Causes of mortality include burns (from heliostats or concentrated solar projects), collision with infrastructure, electrocution, and entrapment. Some species are particularly sensitive. In this study, mourning doves (*Zenaida macroura*) represented 12.92% of avian mortalities, horned larks (*Eremophila alpestris*) 11.93%, house finches (*Haemorhous mexicanus*) 8.41%, and American coots (*Fulica americana*, waterbird) 2.87%. Extrapolating from studies in the United States, Fleming (2025) estimated that 17.2 million birds die at solar facilities around the world every year.

By comparison, bird-window collisions are an increasingly common occurrence in the United States, with an estimated 100 million to upwards of 1 billion deaths per year. Birds cannot recognize the reflective and transparent glass surfaces as barriers to their movement. Species that migrate during the night are especially at risk (Anderson et al. 2025).

Solar panels may be ecological traps for both prey and predatory species, attracting them to a dangerous environment where they face a higher risk of predation or injury from collision with infrastructure. Finally, predators that hunt in open fields and avoid structurally complex habitats may be excluded from areas with photovoltaic panels, thus reducing natural pest control.

Migratory waterfowl may confuse a large farm of photovoltaic panels for waterbodies (the “lake effect”), increasing their risk of injury or death. Anderson et al. (2025) specify that many studies did not find strong evidence to support the “lake effect”, however a recent study found that while this effect may not lead to significant increases in bird mortality events, diversity at sites with adjacent photovoltaic panels was lower compared to nearby natural wetlands, possibly due to altered migratory routes. These results highlight the importance of not just using mortality as an impact indicator.

Pressure: chemical pollution

The construction and operation of solar farms may involve the release of toxic chemicals, which constitutes another very important pressure on biodiversity. Accidental release of fuels, oils and lubricants can occur during construction and maintenance, and pesticides and herbicides are commonly used to control vegetation. The cleaning of solar panels to remove dust often involves products that are harmful to the environment at high doses, such as brines or salts.

Anderson et al. (2025) highlighted the problem of environmental contamination related to the presence of hazardous chemicals in PV panels. They show that there is a risk related to

monocrystalline and polycrystalline silicon, lead, ethylene vinyl acetate, chlorofluorocarbons, poly/brominated flame retardants, cadmium telluride, copper indium gallium diselenide, nanomaterials, and dyes. When panels are damaged or at the end of life (25-30 years), the leachate can reach 6.6 mg/L (lead) and 43.9 mg/L (copper), exceeding the 5 mg/L regulatory standard. The occurrence of acid rain can lead to increased leaching of the contaminants into surrounding areas. Note that third generation panels contain fewer of the key toxic components than previous generations.

These pollutants can spread by runoff to adjacent ecosystems and over long distances, especially by air and water.

The impacts of pollution are direct and indirect species mortality, poisoning and avoidance behaviours.

Pressure: light pollution

Light pollution from USPV power plants is problematic during certain periods (at night), and by its intensity (blinding glare) and nature (polarized light). PV systems may include artificial lighting for maintenance, creating light pollution in a previously rural habitat, disrupting nocturnal wildlife, and potentially attracting invasive and overabundant species (Shwarz et al. 2025).

Light pollution can affect the biology and ecology of wildlife. Artificial light can disrupt nocturnal wildlife and interfere with navigation, behaviour and physiological processes. Glare from sunlight reflecting off PV panels can temporarily impair vision in both humans and animals, interfering with bird navigation and disrupting migration corridors.

Polarized light, which appears similar to reflections from water surfaces, can attract organisms such as birds, reptiles, amphibians, and insects to the artificial surface, where they may also oviposit. Thus, PV panels can act as ecological traps, resulting in reproductive failures and mortality by collision, as mentioned previously, predation or maladaptive reproduction behaviours.

Horváth et al. (2010) found that PV panels can reflect horizontally polarized light, which is often used by aquatic insects to detect bodies of water. Insects may lay their eggs on these potential ecological traps, which, according to Horváth et al. (2010) could lead to population declines near natural wetlands and water bodies.

Pressure: noise pollution

The construction of PV power plants, which can last between two and three years, generates noise. This disturbance may lead to habitat loss, the exclusion of native species, and the creation of maladaptive environments for migratory species.

Pressure: electromagnetic pollution

PV installations also produce electromagnetic fields that can affect wildlife. Impacts include disruption of the nervous system, circadian rhythms, immune response, and fertility in wild mammals, as well as altered pollination behaviour and efficiency in honeybees.

Pressure: microclimate changes

The construction of PV power plants often involves clearing vegetation from the site. This modifies the local microclimate by reducing evapotranspiration. A heat island effect under the panels can also increase temperatures locally. This may affect relatively sessile organisms (e.g. plants, fungi, microorganisms) in a similar way to crops by benefitting shade-tolerant species while limiting heliophilic species. This modified environment could provide refugia for rare species, potentially mitigating certain impacts of climate change and contributing to soil restoration. Fungal species that thrive in shaded and moist conditions may benefit, with negative consequences on crop yield, thus increasing fungicide use.

Anderson et al. (2025) describe conflicting results regarding the potential for solar farms to induce a heat island effect as a result of changes in albedo. Solar panels also create uneven precipitation distribution. They increase soil water fluctuations, reduce drought, and increase soil water availability due to lower evaporation rates and concentrated water at panel edges. They also increase runoff, with simulations showing that solar panels increase peak discharge 11 times over a reference slope. However, this runoff only has a moderately positive impact when slope-aligned panel placement was used. Furthermore, water runoff is more significantly influenced by the extent of vegetation cover than by the presence of solar panels themselves (Anderson et al. 2025)

Changes to microclimates can also have positive effects on certain species, notably invasive non-native species.

Graham et al. (2021) found that floral abundance increased and bloom timing was delayed in partial shade plots under solar panels, while pollinator abundance and diversity were lower in full shade. The authors established a link between these effects on plant and pollinator communities and changes to microclimate conditions such as air temperature, solar radiation and soil moisture, which can be directly linked to nectar production in plants. Indeed, PV installations can even produce a heat island effect at the scale of the local landscape, with higher humidity levels and night temperatures near these installations.

A study (Lec'hvien et al., 2025) assessing the effects of solar panels on pollinators showed that, across 20 solar parks in the south of France, total pollinator abundance and plant-pollinator interactions decreased by 77% and 86%, respectively, under solar panels compared to controls. For instance, there was a significant reduction in the number of plant-wild bee and plant-hoverfly interactions, and a significant reduction in the number of plant species attracting pollinators. These effects can be explained by the fact that solar panels (1) reduce solar radiation and air temperature during the day, and pollinators avoid shaded and low temperature conditions; (2) affect pollinators

indirectly through effects on plant communities (plant species composition, floral traits, flower density and phenology); and (3) create permanent shade limiting pollen and nectar production, making these areas less attractive to pollinators .

Conversely, Iranzo et al. (2025) showed that in arid environments, the shade from PV panels can create a cool island effect that may extend to the outer perimeter of the power plant, potential providing a thermal refuge. Shading and precipitation captured by panels can also promote increased soil water retention, in turn leading to increased biomass and species richness of adjacent vegetation, particularly in water-limited ecosystems. In cropland or pasture settings, solar panels add structural complexity, shading and shelter that can provide microenvironmental and habitat diversity, in turn supporting greater plant biodiversity compared to control sites such as arable fields.

A study from the Netherlands (Kocsis et al., 2025) compared non-shaded and partially shaded areas in relatively recent (<4 years) solar park conversions, intensive grasslands, and semi-natural extensive grasslands. The problem with this study is that it excluded the large cover of shaded areas beneath panels (mean 73% of surface with panels in Dutch solar parks). Nevertheless, in the areas considered, solar parks had higher plant diversity than intensive grasslands, and floral resources and vascular plant species richness that were similar to those of extensive grasslands. This may be due to the phenomenon of disturbance-mediated colonization of species-poor environments, which is used in ecosystem restoration, or to the fact that some parks have been resown with seed mixtures to increase plant diversity. As a result of floral resource availability, overall bee and hoverfly species richness and abundance in solar parks are similar to those in extensive grasslands and much higher than intensive grasslands. Butterflies, however, do not benefit, showing no significant difference in abundance between solar parks and intensive grasslands. This may be because many species prefer semi-natural low-productivity vegetation, which recent solar parks with an intensive management history may not yet provide. Furthermore, butterflies are more mobile than wild bees and hoverflies, making them more likely to forage in surrounding agricultural fields, where exposure to agrochemicals can negatively affect their development, fecundity and lifespan. It is known that butterfly communities in solar parks are compositionally distinct from those in grasslands, likely reflecting incomplete or spatially variable colonization.

Soil-emergent arthropod biomass and abundance were lower in solar parks (despite the abundant floral resources) than in intensive grasslands, suggesting that other characteristics of solar parks may limit abundance (panels likely create microclimatic conditions, e.g. altered water availability and evaporation rates). Overall richness was similar across habitats, but species composition differed with more heterogeneous communities in solar parks and extensive grasslands than in intensive grasslands. Coleoptera were especially abundant and diverse in intensive grasslands, reflecting their adaptability to intensive management. 17 species were regularly found in solar parks, 11 of which were linked to wet grassland conditions. This suggests that Dutch solar parks create distinct ecological conditions resembling wet grassland habitats. Community composition was highly variable across solar parks and related to park-specific features such as panel configuration, row spacing, margin size, soil type, vegetation management, and surrounding landscape elements.

Pressure: invasive non-native species

The disturbance caused when installing and operating large solar parks can create niche space for opportunistic alien plant species to colonize before native vegetation can recover. Native to invasive-dominated transitions are also possible via changes to fire regimes resulting from accidental ignitions. PV structures could attract invasive or overabundant species, which might exploit the disturbed area. These structures might serve as perching sites for predators, increasing predation pressure, but also providing natural pest control. These changes may drive the loss of plant species and their associated animal species.

CHAPTER 3- AGRIVOLTAIC SYSTEMS

Shwarz et al. (2025) showed that PV panels above agricultural land may alter the microclimate differently from panels installed over bare ground. Key differences include shade, temperature, pH and humidity under the panels.

They reported that photosynthetically active radiation (PAR) under agrophotovoltaic (APV) panels is 30-75% lower compared to unshaded areas, especially during the morning and in the summer, and is influenced by various factors, including time of day, latitude, season, module type, tilt angle, installation height and spacing between arrays.

Soil temperature under stilt-mounted APV systems is typically lower due to shading, which can be beneficial during hot periods but may delay crop maturation in cooler seasons. Soil moisture in APV systems tends to be lower than in open fields in temperate climates during the winter, but higher in semi-arid regions, where APV systems enhance water-use efficiency.

Air temperatures are generally lower under APV panels compared to bare-ground-mounted PV panels. Relative humidity tends to be higher under the panels of APV systems than in open fields, especially during winter.

APV structures reduce wind speed and serve as windbreaks, potentially reducing soil erosion. Some APV arrays have rainwater-harvesting systems that collect water from the panels, cleaning them from dust, and redistributing it for irrigation of the crops below. This optimizes water usage and removes the need to use pollutant chemicals for dust removal.

Implications for agriculture vary and depend on local conditions as well as on adaptations and management practices in the park, e.g. the presence of resources for agrobiodiversity, grazing, etc.

APV systems can result in delayed crop development, where growth under shade leads to taller, slower growing plants. Their impact on agricultural yield varies, with potential reductions in cooler seasons, especially in temperate climates, or for shade-intolerant crops. Conversely, yield increases have been reported in hot, dry climates (e.g. in the summer months or desert climates) and windy sites, or for shade-tolerant crops.

The selection of crops and the configuration of PV panels (e.g. angle, height, and orientation) are crucial in optimizing both agricultural and electrical yields. The impact of PV panels could be reduced by having stilt-mounted panels, thus reducing the microclimatic effect.

The authors mention that chemical pollution risks are potentially lower in APV systems due to the presence of vegetation reducing dust and thus the need for dust-repellent chemicals. They summarize the effects of APV systems on biodiversity in a table (see Appendix 2).

Leroy et al. (2025) examined the impact of solar trackers (on 7 m-high masts similar to isolated trees or electricity poles) installed two to seven years before the survey (after the effects of construction had dissipated), focusing on winter wheat and hay meadows, and soil decomposers (earthworms, springtails, woodlice, and microbial activity). One limitation of this study was its focus on atypical PV structures that are very different from traditional installations (horizontal panels). Under this configuration, farming practices (soil tillage intensity, fertilization, mowing intensity) remain the main determinant of biodiversity patterns, outweighing the influence of solar trackers whatever the taxa or land cover type considered.

Measurements in four winter wheat fields confirmed that soil and air temperatures were significantly lower and soil moisture was higher near the tracker than at 35 m from the tracker. Plant species richness was greater at the base of the tracker mast (which may be explained by the fact that there is limited agricultural management and no cultivated crops within one to three metres around the mast, allowing weeds to develop and offer a refuge to soil organisms, in the same way as green or agro-ecological infrastructures).

By contrast, areas near the tracker had lower soil organic matter and nitrogen content due to the absence of fertilisers. Contrary to expectations, the study found little soil compaction close to the tracker (the compaction caused by the installation work had faded out over time, or the action of soil organisms such as earthworms had loosened the soil surface, or the direct vicinity of the tracker may not be compacted by the repeated passage of vehicles, contrarily to the rest of the field).

Yan and Wang (2025) studied 10 fixed plots in the five years before and after the construction of a PV power station. Results showed that the average vegetation cover before construction was 84.4 % while after construction, it was 31.9 %, 56.4 % and 77.2 % in the construction zone, buffer zone, and control area, respectively. The decrease in vegetation cover may be due to the indirect impact of construction activities, vehicle traffic and human disturbance on the surrounding ecosystem. Although small, the decline in vegetation cover in the control area may be attributed to the combined effects of natural climate change and human activities such as grazing.

The authors confirm that soil moisture in the construction area is lower after construction than before construction, which they explain by a reduction in surface water evaporation and precipitation infiltration alongside changes to surface runoff and soil structure resulting in a decrease in soil water retention capacity. In terms of species diversity, results showed high diversity before construction, indicating that the ecosystem is relatively stable, and a decrease of 70.8% of this diversity after construction due to the direct destruction of vegetation habitats by the laying of PV panels and infrastructure construction.

Agrophotovoltaic systems are a promising solution to the food-energy-environment nexus, but their impacts on biodiversity are complex, multidimensional, and largely hypothetical at this stage. APV systems have the potential to increase land production (by up to 70 %), prevent the further destruction of natural habitats, minimize land disturbance (stilt-mounted systems), reduce the risk of chemical pollution, create refugia for rare species, and mitigate the effects of climate change.

However risks exist, such as the variability of the effects depending on the ecological context and the species' characteristics, the risk of acting as ecological traps for prey and predators, their potential attractiveness for invasive species, habitat fragmentation (fencing), exclusion of certain species (predators in open fields, heliophilous species), and complex interactions with farming practices (pesticide spraying, vegetation management).

CHAPTER 4 – FLOATING PHOTOVOLTAIC SYSTEMS

Oliveira et al. (2025) carried out a systematic review of the literature on the ecological impacts of floating photovoltaic (FPV) systems on freshwater and marine aquatic environments. Their search yielded a limited number of studies (24 selected in total) on the topic, which were all published within the last six years. Studies were primarily carried out in small-scale artificial ecosystems in China and Taiwan, where most of the aquaculture production occurs. The most studied organisms were algae and photosynthetic bacteria, in their capacity as bioindicators of water quality. There was a tendency for reduced primary production. This effect increased with coverage area but was not significant until 20 % coverage. The authors suggest a critical threshold of 30 % coverage. Four studies found reduction in algae biomass, chlorophyll-a concentration, growth rate and photosynthetic pigments. One study found inconsistent results regarding biomass of primary producers in scenarios from 0 to 100 % coverage, and another found higher chlorophyll-a values in wetlands covered with PV panels compared with other types of wetlands in the same area (however, without knowing if these values were already higher before the installation).

Two studies reported decreased growth rates for cultured algae below semi-transparent PV panels but increased photosynthetic activity due to reduced photoinhibition. Indeed, light reduction does not necessarily reduce phytoplankton photosynthetic activity and could even increase their biomass by reducing the biomass of macrophytes, which compete with phytoplankton for light and nutrients. PV panels can also cause a reduction in water temperature and wind mixing, although their effects have not been studied. There is an apparent consensus that FPV panels control algae and cyanobacteria, especially in the case of systems that face harmful algal blooms. There are few studies on other groups of organisms, however, one study based on a modelling approach reported water treatments to be potentially inefficient in maintaining protozoans and bacteria populations at a safe level for human consumption when coverage is over 30 % in a reservoir (NB: the mean coverage area of currently installed FPV plants in freshwater ecosystems is around 34 %). Two studies reported reduced abundance, diversity and richness of rotifer communities and bacterial communities in subsidence wetland areas in China caused by reduced light incidence. Rotifer communities seemed to be affected by changes in water temperature and chlorophyll-a, which could affect reproduction and interactions with prey and predators.

Most studies evaluating effects on aquatic organisms focused on fish and crustaceans and on the growth of cultured animals under PV panels. It was reported that the bacterial community present under the PV panels could enhance the health and growth of cultured shrimps, as well as hinder algal bloom development. Conflicting results on production and growth rate have been reported in fish. Decreased water temperature below the PV panels has been associated with physiological effects, both negative (on fish feeding habits) and positive (from reduced heat stress for fish and crustaceans during summer temperatures), as well as several effects on crabs' tissue colour, muscles and organs, and a shortened spawning period for fish.

The available studies reported a decrease in diversity and an increase in abundance of aquatic birds, suggesting that PV panels cause a homogenizing effect in bird communities, favouring vegetation gleaners that could use the panels as shelter and hindering diving birds by blocking their access to water. FPV farms, including at sea, can favour species that take advantage of the panels, for instance by preying on animals attached or aggregating around the floating structures.

One study detected the release of aluminium and zinc from tubes and caps made from polyethylene after 2 weeks, but no tests were executed on living beings. However, one study reported crystalline silicon panel leachates could cause deformities and reduce the survival rate of *Danio rerio* (zebrafish) and *Daphnia magna*. Crystalline silicon is the dominant technology for PV panels, which is why more research is needed on these toxic effects.

FPV setups can serve as substrate for different groups of aquatic organisms such as Annelida, Arthropoda, Bryozoa, Chlorophyta, Chordata, Cnidaria, Entoprocta, Nemertea, Ochrophyta, Platyhelminthes and Rhodophyta. This leads to competition interactions for shelter and other resources. Around 11 % of the taxa found on the floaters were non-native, although more studies are needed to find out how FPV setups can affect the dispersal of invasive species.

CHAPTER 5 – IMPACTS ON ECOSYSTEM SERVICES

Treasure et al. (2025) carried out a systematic review of the impacts of solar energy installations (solar panels, agrivoltaic systems) on 11 ecosystem services (ES). Data was derived from field studies, modelling studies, speculative evidence, and expert opinion. The authors provide contextualized examples to illustrate their point. Results are mixed: some ES clearly benefit from solar installations, whereas others are negatively affected. These impacts are variable and depend on climate, ecosystem type, and management practices. Note that there is uncertainty around many estimates, due to, among other things, the variability of environmental conditions and the difficulty in isolating the precise causes of observed impacts.

Maintaining habitats and biodiversity

Negative evidence	61%	Significant
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Positive evidence	39 %	Evenly distributed across climate and ecosystem types
Evidence quality	Evenly distributed between strong and weak quality	Mixed evidence level
Climate variability	Homogeneous	Evenly distributed across climate and ecosystem types
Solar park (SP) life cycle phase	Construction	More degradation during the construction phase (initial habitat loss)

Negative impacts

Negative impacts	Description
Habitat loss or fragmentation (<50% of negative evidence)	<p>Actual or potential loss of habitat due to SP expansion</p> <p>Degradation of habitat corridors and barriers to animal movement</p> <p>Overlap of SPs with conservation areas and rare wildlife habitats</p> <p><i>Example:</i></p> <p><i>Loss of grey-crowned babbler (Pomatostomus temporalis) habitat and nest removal prior to SP construction in Australia</i></p>
Changes to community composition (~25% of negative evidence)	<p>Lower species diversity and abundance under panels</p> <p><i>Examples:</i></p> <p><i>In Oregon, USA, areas under panels had lower floral abundance and insect species richness and diversity compared to controls</i></p> <p><i>Bat behaviour: bat activity was reduced at SPs in Hungary and the UK, presumed due to the loss of foraging habitats</i></p>
Species mortality and welfare (~15% of negative evidence)	<p>Mortality caused by collision, accidents, burns...</p> <p><i>Examples:</i></p> <p><i>Avian mortalities at SPs estimated at 2.49 to 11.61 birds MW⁻¹yr⁻¹ in the Southwestern US</i></p> <p>Considerable uncertainty due to the difficulty in attributing a definitive cause of mortality</p> <p>Increased mortality of aquatic birds and insect species attributed to polarized light</p> <p>Concerns have been raised around potential future damage to wildlife due to the disposal of solar panels during dismantlement</p>
Effects on photosynthesis and	Reduction in photosynthetically active radiation (PAR) under solar panels

productivity	Decrease in productivity, biomass production and vegetation cover
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Positive impacts

Positive impacts	Description
Improved species richness and diversity (~67% of positive evidence)	<p>Habitat enhancement, protection or provision through:</p> <ul style="list-style-type: none"> ○ Co-location with vegetation ○ Wildflower planting ○ Provision of shade ○ Integration with the local landscape <p><i>Examples:</i></p> <p><i>In central Asia, tenebrionid beetle diversity was significantly higher within a SP compared with an ungrazed site, although this difference was marginal</i></p> <p><i>In China, increased plant species richness and diversity were observed under panels and between rows of panels</i></p>
Species survival and welfare	<p>Birds using SP infrastructure for shelter, perches, foraging and nesting in South Africa and USA</p> <p><i>Example:</i></p> <p><i>In the Mojave Desert, seed bank survival for desert annuals increased under shade and an increased number of the Mojave woolly sunflower (Eriophyllum mohavense, a rare species) survived to maturity, likely attributable to reduced evapotranspiration in the shade</i></p> <p>Impacts varied with species, habitat and weather conditions, highlighting the importance of site characteristics</p>

Studies showed no significant impact on:

- Abundance, species richness or community composition

Example: no change was found in the abundance and community structure of beetles in China; no change in the richness or diversity of flowers between shade levels in the US

- Habitat size, corridors and animal movement

Example: In California, mitigation corridors were deemed sufficient to maintain connectivity of Mojave Desert tortoise (Gopherus agassizii) populations

- Bird injuries, mortalities or attraction to polarized light in Australia, South Africa and the United States

Food provision

Negative evidence	47 %	Not significant
Positive evidence	53 %	
Evidence quality	Strong for the majority	Solid evidence level

Negative impacts

Negative impacts	Description
Reduction in crop yield (~67% of negative evidence)	<p>Crops sensitive to lower PAR: wheat, maize, soybean</p> <p><i>Examples:</i></p> <p><i>South Korea – the yield of sesame, soybean and rice crops was reduced by up to 30%</i></p> <p><i>France – apples within an agrivoltaic orchard had 24% lower dry matter content (reduced quality)</i></p> <p>Delays to crop growth and maturity:</p> <p><i>Examples:</i></p> <p><i>South Korea – grapes grown under solar panels exhibited slower growth</i></p> <p><i>France – reductions in growth rate of lettuces and cucumbers attributed to the reduced light and altered soil temperature</i></p> <p>Most evidence for negative impacts is from temperate climates, where potential benefits from shade may be less apparent</p>
Land use changes	<p>Trade-off between food and energy production</p> <p>Potential risks for food security</p>

Positive impacts

Positive impacts	Description
<p>Improved growth and yield (~86% of positive evidence)</p>	<p>Benefits were strongly influenced by climate, crop selection and array design</p> <p>Notable benefits in climates with high levels of solar radiation:</p> <ul style="list-style-type: none"> ○ Increased shade ○ Higher soil moisture ○ Improved water use efficiency (WUE) <p><i>Examples:</i></p> <p><i>In Arizona (agrivoltaic): a 65 % increase in WUE and double the fruit production over 1,000 hours</i></p> <p><i>Cherry tomatoes (Solanum lycopersicum var. cerasiforme): higher yield compared to unshaded crops</i></p> <p><i>Irrigated vegetable crops: savings of 14 % - 29 % of evapotranspired water</i></p> <p>In temperate climates, yields were found to increase in drier years</p> <p><i>Example:</i></p> <p><i>A Belgian study – modelled crop yields increased by 12 % in 2022 (a drier year)</i></p>
<p>General benefits of agrivoltaics (~14% of positive evidence)</p>	<p>Improvements to food system resilience</p> <p>Increased diversity of crops grown</p> <p>Pollination benefits to surrounding crops</p> <p>Increased overall land use efficiency</p>
<p>Welfare of livestock</p>	<p><i>Examples:</i></p> <p><i>USA – the body temperature of cows shaded by solar panels was lower through reduced heat stress</i></p> <p><i>The liveweight of lambs under solar panels was comparable to those that grazed in open pastures, despite a higher stocking density</i></p> <p>However, tracker, vertical or bifacial systems can have potentially negative impacts (more light can reduce yields)</p>

Studies found no significant difference in:

- fruit production of jalapeños grown within the shade of an AVS and in full sun

- milk production in cows (although respiration rates were lower in cows provided with solar panel shade)

Climate regulation

Negative evidence	54 %	Homogeneous data
Positive evidence	46 %	Homogeneous data
Evidence quality	50 % strong / 50 % weak	

Negative impacts

Negative impacts	Description
Increase in air temperature (~50% of negative evidence)	<p>Largely in hotter, drier regions</p> <p>Above panels or exposed areas within SPs: increased heat transfer</p> <p>Higher panel temperatures leading to convection heat dissipation</p> <p>At night or during winter: panels may retain heat and contribute to elevated air temperatures under panels</p> <p>Modelling studies have predicted localized increases in air temperature</p> <p>A quarter of the evidence showed a reduction in albedo associated with solar panels (more apparent in desert environments)</p>
Reduction in soil carbon (~25% of negative evidence)	<p>Due to a reduction in the growth of herbaceous species, a decrease in soil moisture, or an increase in salinity and pH</p> <p>Negative impact on climate regulation</p> <p><i>Concrete examples:</i></p> <p><i>France, China, Italy: reduced soil total and/or organic carbon within SPs compared to controls</i></p>
Other negative impacts	<p>Reduced precipitation following the hypothetical construction of large-scale SPs</p> <p>Speculation on the general degradation of climate regulation</p>

Positive impacts

Positive impacts	Description
Reduction in air temperature (~50% of positive)	<p>Potential mitigation of climate change</p> <p><i>Variable depending on context:</i></p>

<p>evidence)</p>	<p>During the day, directly under panels: air temperature can decrease as the shade reduces the amount of incoming solar radiation; this trend is more pronounced in spring and summer when ambient temperatures are higher</p> <p>“Cool island” effect: panels remove a proportion of incoming solar energy as electricity</p> <p>At night: temperatures under panels can remain lower than ambient</p> <p>Grasslands vs deserts: cooling at SPs may occur where the difference in albedo is less pronounced</p> <p><i>Example:</i></p> <p><i>Suuronen et al. – lower daily air temperature under panels in a fixed-mount system compared to gaps and the surrounding Chilean desert; differences less pronounced in a tracker system</i></p> <p>Additional benefits: wetland creation and vegetation planting may reduce air temperatures</p>
<p>Increase in soil carbon (~25% of positive evidence)</p>	<p>Mostly predictions (without field data)</p> <p>Landscaping SP degraded lands with native vegetation may promote soil carbon sequestration</p> <p>A few field studies observed increases in soil carbon following SP installation with links to vegetation cover</p> <p><i>Example:</i></p> <p><i>In the USA – vegetated solar areas had higher soil carbon compared to bare areas</i></p>
<p>General enhancement of climate regulation</p>	<p>Substantial reduction in carbon emissions for solar PV compared to other energy sources</p>

Some studies found no significant differences in:

- air temperature
- meteorological variables and carbon fluxes
- soil carbon (possibly due to site characteristics or insufficient time since construction)

Soil quality regulation

Negative evidence	55 %	Homogeneous data
Positive evidence	45 %	Homogeneous data
Significance	88% significant	Solid evidence level
Climate variability	Negative impacts in temperate climates, positive impacts in arid and dry climates	

Negative impacts

Negative impacts	Description
Degradation of physical soil quality	<p>Compaction from machinery during SP construction: Anaerobism, waterlogging, nutrient depletion, reduced fertility</p> <p>Changes in soil temperature influencing plant growth, development and nutrient uptake, microbial community composition and decomposition of organic matter</p> <p><i>Example:</i></p> <p><i>South Korea (agrivoltaic) and China (arid region): higher soil temperature under panels</i></p>
Soil chemistry	<p>Soil nutrient concentrations, including nitrogen, negatively impacted by topsoil stripping and removal of vegetation cover. Low nitrogen concentrations can limit soil organic matter accumulation</p> <p>Increases in soil salinity have been found with adverse effects on plant growth</p> <p><i>Example:</i></p> <p><i>France and Italy: lower nitrogen under panels and a corresponding decrease in soil organic matter (SOM)</i></p> <p>Higher levels of toxic chemicals (lead, chlorine), potentially the result of leaking from panels</p> <p>Contamination with transformer oil during SP construction</p>
Soil biological quality	<p>Substantial reduction in soil microorganism biomass and the abundance of mites, springtails, fungi and gram-negative bacteria</p> <p><i>Example:</i></p>

	<i>Italy – general reduction in soil microbial activity attributed to adverse environmental conditions: reduced soil moisture, higher temperature, increased salinity, reduced organic matter</i>
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Positive impacts

Positive impacts	Description
Reduction in soil temperature	<p>At SPs in more arid regions or those experiencing increased droughts</p> <p>Mitigates the effects of climate change when temperatures may be close to thresholds for vital plant-soil processes: productivity, decomposition, seed germination</p> <p><i>Examples:</i></p> <p><i>Evidence in China, France, and arid regions confirming a reduction in temperature</i></p>
Enhancement of soil chemical and biological quality	<p>Increases in soil nitrogen and organic matter (China)</p> <p>Management promoting biocrust formation (key component for soil formation in desert ecosystems)</p> <p>Potential restoration of degraded dryland ecosystems</p>
General enhancement of soil formation and fertility (6% of positive evidence)	Improve soil health in certain conditions

Studies showed no differences in certain soil parameters between SPs and controls: soil temperature, nutrients and pH, bacteria and fungi.

Water cycle support

Positive evidence	67 %	Significant
Negative evidence	33 %	In the minority but notable

Evidence quality	70 % strong, 30 % weak	Relatively solid evidence level
Favourable conditions	Positive impacts mainly associated with temperate climates, agricultural ecosystems, and the operational phase	Predominantly agricultural data

Negative impacts

Negative impacts	Description
Increased water scarcity	Use of water for panel washing Especially critical in dry climates
Reduction in soil moisture under panels	Predominantly due to diverted rainfall by solar infrastructure Homogeneous effect depending on the type of climate and ecosystem

Positive impacts

Positive impacts	Description
Higher soil moisture (~60% of positive evidence)	The shade of solar panels reduced evaporation and the collection of precipitation along the edges of the panel frames These effects were observed in arid zones and more temperate zones and may become particularly apparent in drier spring and summer months in temperate climates
Future opportunities	Potential for enhancement of water cycle by reducing water requirements for panel washing and reusing washing water for irrigation of agrivoltaic crops Rainwater harvesting

Biomass materials provision

Positive evidence	59 %	Homogeneous data
Negative evidence	41 %	Evenly distributed data
Evidence quality	66 % strong, 34 % weak	Relatively solid evidence level

Negative impacts

Negative impacts	Description
Decreased plant productivity (~67% of negative evidence)	The shade of solar panels led to reductions in aboveground net primary productivity and biomass of forage grassland Variation in outcomes depending on array design, soil moisture, seasonal and diurnal variations in light and temperature
Reduced provision of raw materials	Scale of impacts varying with location, construction, and site management practices <i>Example:</i> <i>Reduced access to firewood for inhabitants living near SPs in Rajasthan, India</i>

Positive impacts

Positive impacts	Description
Increases in quantity and quality of biomass	<i>Example:</i> <i>Oregon (USA) – pasture: biomass increased by 90%</i> Increased forage quality and digestibility
Adaptation of SP management to enhance raw materials provision	Growth of biofuel crops within SPs <i>Example:</i> <i>Rosemary, thyme and alfalfa (Medicago sativa) cultivation within “PV gardens” in Italy</i>

Soil erosion regulation

Positive evidence	83 %	Highly significant
Negative evidence	17 %	Weak minority
Evidence quality	52% strong, 48% weak	Mixed evidence level
Favourable conditions	Agricultural ecosystems, operational phase	

Negative impacts

Negative impacts	Description
Increased erosion due to channelling of the water	Creation of rills and gullies underneath panels
Soil disturbance	Topsoil stripping Impact on vegetation and soil properties, including its erodibility

Positive impacts

Positive impacts	Description
Reduced soil erosion overall	Across a range of climates and ecosystem types, although this effect is likely more beneficial in arid regions through increased vegetation cover (root binding) reducing wind and water erosion
Rainfall interception	Rainfall interception and reduced runoff rates Panels may intercept rainfall and weaken splash erosion

Recreation and aesthetic interactions

Negative evidence	65 %	Not significant
Positive evidence	35 %	Significant minority
High confidence	45 %	
Low confidence	55 %	Limited data with much uncertainty

Negative impacts

Negative impacts	Description
Visual impact	Especially in natural areas Implications for local wellbeing, community acceptance and tourism <i>Example:</i> <i>A survey of locals in the Jaén province (southern Spain) found that the least popular options for installation of renewable energy were tourist areas, amid fears that the infrastructure would make the landscape less attractive for tourists</i>

Positive impacts

Positive impacts	Description
Prospective enhancement	<p>When there is scope to manage the vegetation to enhance aesthetics or when SPs provide benefits to locals:</p> <ul style="list-style-type: none"> ○ Recreational activities ○ Community gatherings ○ Vantage points <p><i>Example:</i></p> <p><i>In Italy, proposal to create “photo-ecological gardens” (green spaces within urban areas that generate electricity). These may improve mood and reduce stress and anxiety.</i></p>

Pollination regulation

Positive evidence	80 %	Significant
Negative evidence	20 %	Minority
Evidence quality	20 % strong, 80 % weak	Weak evidence level, most of the evidence is speculative, based on opinion or modelling
Empirical evidence	Lacking	Research needed
Favourable conditions	Temperate climates, operational phase	

Negative impacts

Negative impacts	Description
Loss of pollinator habitat	<p>Changes in pollinator community composition due to:</p> <ul style="list-style-type: none"> ● SP expansion ● Potential impacts on pollinator fitness and movement <p><i>Example:</i></p> <p><i>Oregon (USA) – pollinator abundance, diversity and</i></p>

	<i>richness were lower under panels compared to gaps between rows and controls, possibly linked to the lower number of bloom units in the shade</i>
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Positive impacts

Positive impacts	Description
Enhancement via management decisions and practices	<p>SPs managed with native vegetation and wildflowers</p> <ul style="list-style-type: none"> • More floral resources for pollinators • Improved habitat compared to prior land use <p><i>Example:</i></p> <p><i>USA – where water is limited, late season foragers may benefit from delayed bloom-timing observed in gaps between rows of panels</i></p> <ul style="list-style-type: none"> • Actions to enhance ES are increasingly incorporated into SP management plans • Industry guidance and legislative initiatives to make SPs pollinator-friendly

Pest and disease regulation

Negative evidence	54 %	Homogeneous data
Positive evidence	46 %	Evenly distributed data
Evidence quality	77% weak	Weak evidence level
Variability	Homogeneous depending on climate/ecosystem/phase	Limited data

Negative impacts

Negative impacts	Description
Increase in invasive species and pests	<p>Mainly associated with construction and management</p> <p><i>Invasion examples:</i></p> <p><i>Mexican poppy (Argemone mexicana) and mesquite</i></p>

	<p><i>(Prosopis julif)</i> became invasive at a SP construction site in South Africa</p> <p>Shade tolerant species – common stork’s-bill (<i>Erodium cicutarium</i>) and Arabian schismus (<i>Schismus arabicus</i>) – increased in a SP in the Mojave Desert</p>
Impact on human health	<p>Risk of infection and exposure to electric and magnetic fields</p> <p><i>Example:</i></p> <p>Infections of construction workers after grading land harbouring the soil-borne fungal pathogen <i>Coccidioides immitis</i></p>

Positive impacts

Positive impacts	Description
Hypothetical positive impacts on pest and disease regulation	<p>Two-thirds of the evidence were general references to hypothetical enhancement of biological control, human health and crop pest predation.</p> <p>Evidence was weak and associated with co-location of SPs with vegetation or sustainable integration into the landscape</p>

Flood regulation

Positive evidence	31 %	Not significant
Negative evidence	69 %	Represented the majority of impacts
Evidence quality	100% weak	Very weak evidence level. Lack of field data, additional research is needed

Negative impacts

Negative impacts	Description
Increased runoff	<p>Interception of rainfall by impervious solar panels</p> <p><i>Example:</i></p> <p>A modelling study found that long-term reductions in surface roughness under solar panels resulted in increased runoff, thus the potential for increased</p>

	<p><i>flooding</i></p> <p><i>Concrete example: runoff volume was higher after SP construction due to increased inflow of rainwater which exceeds the infiltration capacity of the soil</i></p>
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Positive impacts

Positive impacts	Description
Potential enhancement of flood regulation	<p>Constructing SPs on arable land and converting the landcover to grassland:</p> <ul style="list-style-type: none"> • Increased soil stability • Increased vegetation cover • More effective infiltration
Creation of pollinator habitat	<p>When converting unfavourable environments (intensively farmed arable land) to grassland, with the establishment of native vegetation or nectar-producing species</p>

Chapter 6 - Knowledge gaps and methodological bias

Temporal scale

Studies on the characteristics of vegetation in PV power plants are generally conducted over a short timeframe, both in terms of the time after the construction of power plant and during the data collection phase.

We observe a lack of long-term studies on the effects and the evolution of communities. Certain processes respond more quickly than others: changes in plant and animal species composition can be observed just after construction, while other processes (changes in soil physicochemical properties, response of soil organisms, water infiltration or runoff) require longer timescales to emerge and should be monitored over the long term.

Spatial scale

Most studies on the impacts of PV installations were carried out in arid environments (particularly in the southwestern United States). There are limited data on wetlands, even though these systems have very high biodiversity. Moreover, the five studies examining the interaction between waterfowl and solar infrastructure only focused on mortality rates, and none investigated the impact on ecosystem services (Anderson et al. 2025). The poorly understood impact of solar farms in heavily

forested and wetland areas necessitates evaluating their potential adverse effects on migratory birds and waterfowl in coastal regions, as large-scale solar installations may increase avian mortality.

Monitoring is usually carried out at the scale of the installation, while there is insufficient research at the scale of the landscape or the ecosystem. The cumulative environmental impacts of existing and planned renewable energy projects should be considered, both prior to construction and during the operational phase.

Taxonomic and ecological coverage

Most research on the impact on wildlife focused on birds and pollinators, while other animal groups were much less studied.

Reports generally only considered very basic aspects (richness and abundance) without considering functional aspects, species interactions, effects on behaviour, selective value, or population dynamics. Pioneer species may initially increase richness or diversity, but this effect is transient, and more generally, some changes can be detected early while others are only visible in the long run.

There is a lack of studies on the functional diversity of species on solar farms. For instance, there may be an initial increase in invertebrate specialists and ground foragers, but there is also the potential loss of other niche specialists. The question of functional diversity (i.e. the ecological role of organisms) is crucial but often neglected (Anderson et al., 2025). Reports on the physiological and phenological outcomes in wild plant species are insufficient. Moreover, studies rarely examine the effects on vertebrates, including their physiology and behaviour.

This type of knowledge is essential when trying to reduce or compensate for the impacts of these installations. When ecosystem restoration is envisaged, it is crucial to treat the factors that have led to the ecosystem's degradation, otherwise such efforts will be ineffective.

Lack of studies and methodological gaps

The effects of electromagnetic pollution are difficult to establish because of a lack of assessment methods and thus remain controversial.

The actual effects of solar farms may not be fully known because they are often assessed without accounting for the absorptive properties of impervious surfaces, leading to inaccurate estimates of water infiltration and an overestimation of runoff (Anderson et al. 2025).

To test the impact of agrophotovoltaic systems, there is a need for large-scale studies that cover different types of crops (cereals, oilseed crops, sugar beet, potato), grasslands (meadows and pastures), and a wider range of soil types and bioclimatic regions, and in all types of installations (ground-mounted arrays).

The effects of floating PV panels on primary producers can be complex. In addition, there is a lack of studies on their impact on ecological interactions, and how this can affect trophic cascades in freshwater ecosystems.

To this day, there are not enough studies to understand if and how PV panels affect the growth and production of aquaculture organisms. Potential research questions for future studies on the impact of APV systems on biodiversity are suggested in Appendix 3.

We also lack studies on the ecological interactions between groups of aquatic organisms, such as competition, predator-prey dynamics, and the possible effects of trophic cascades. Moreover, all studies of aquatic organisms were carried out in Asia, thus limiting the generalization of the results. In addition, most research focused on small-scale artificial freshwater ecosystems, limiting our understanding of the impacts on a large scale or over the long term. More studies on aquatic organisms are needed so that knowledge can keep pace with the rapid development of the floating solar industry.

Lack of scientific monitoring

Post-installation monitoring of ecosystem evolution is not systematically carried out, which means that certain impacts and the validity of certain measures cannot be clearly established. Biodiversity indices should include the functional and structural characteristics of local communities.

Many studies lack robust experimental protocols, which limits before/after comparisons. In addition, impacts should be compared to a reference state or area, providing a baseline value against which the impact is measured.

Most observations are made in first world countries (Europe, USA), while regions with high solar potential (such as Africa, Southeast Asia) are far less studied.

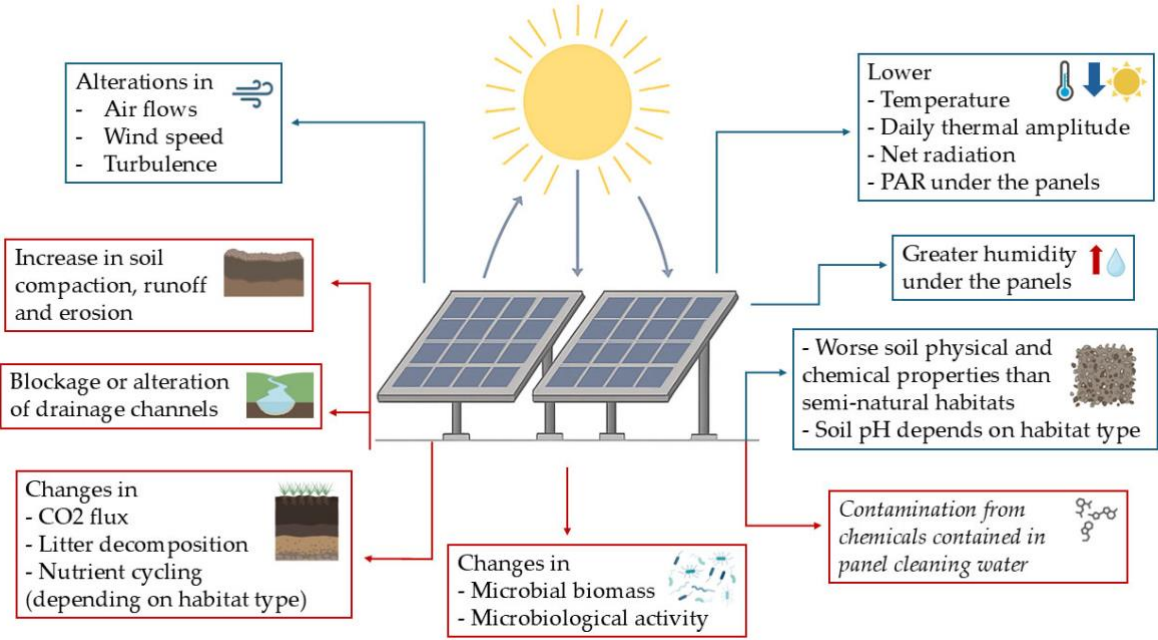
Moreover, 15% of studies contain methodological errors (inadequate controls, confounding factors, etc.).

We also lack data on bats, non-flying mammals, amphibians, and reptiles, even though these taxa are often most affected by habitat loss.

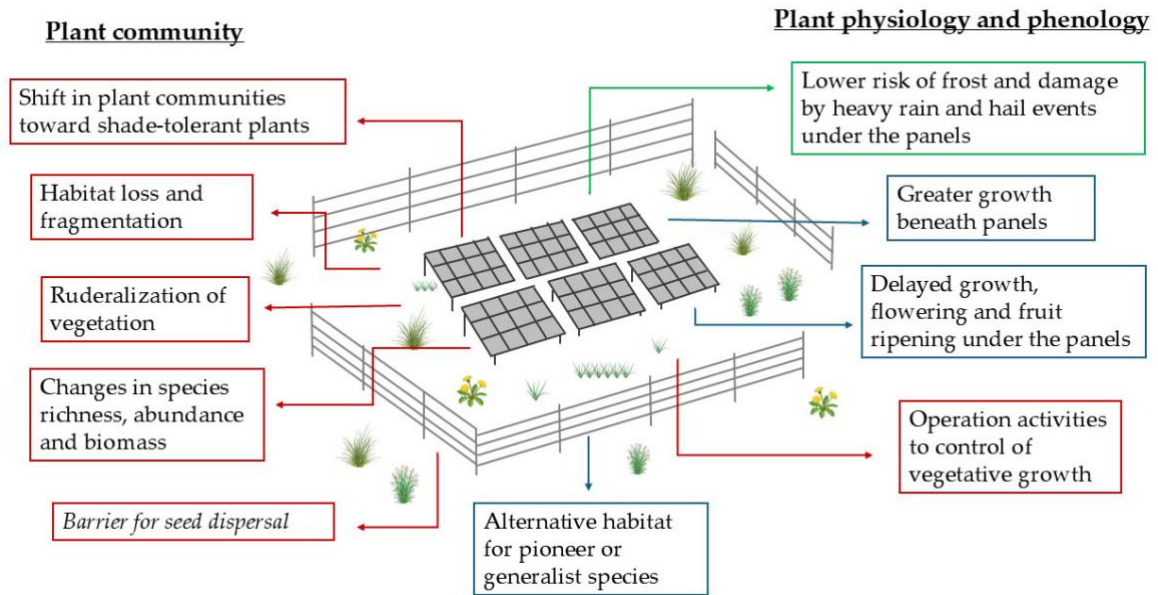
The authors also highlight the lack of studies on floating PV installations, solar thermal panels, and the effects of chemical or noise pollution during construction.

APPENDIX

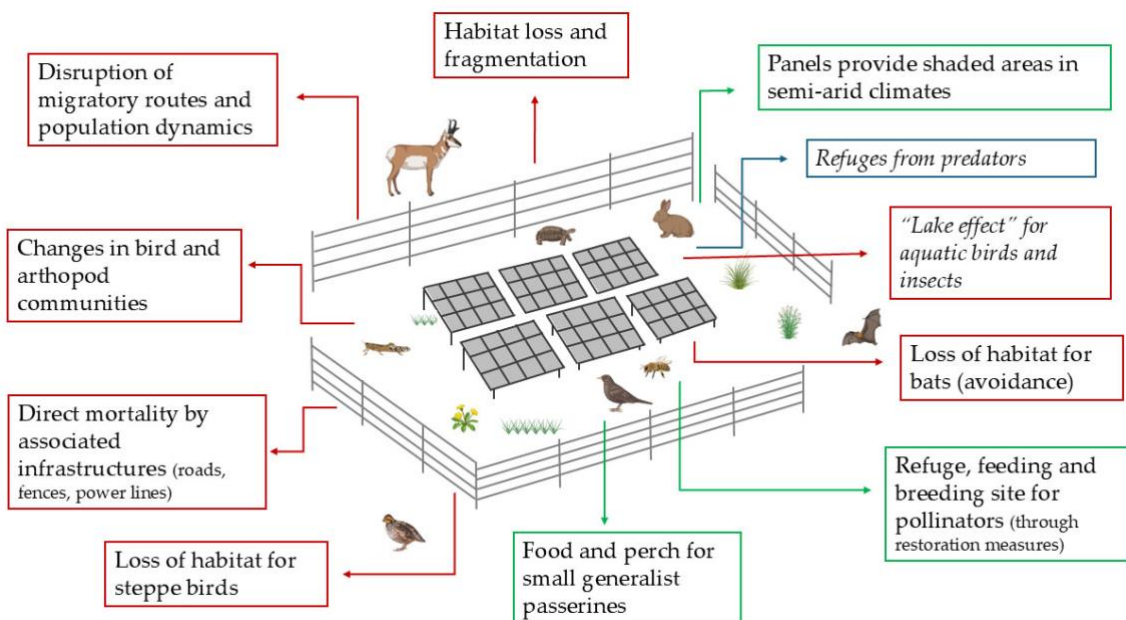
Appendix 1: Graphical summaries of the main impacts of PVPs on microclimate and soil (a), vegetation (b), and wildlife (c). Reproduced from Iranzo et al. (2025).



(a) Graphical summary of the main impacts of PVPs on microclimate and soil. Red arrows and boxes indicate negative effects. Blue arrows and boxes indicate effects that are either neutral, undefined, or variable, depending on the context. Italics indicate potential impacts identified by the literature but not proven to date.



(b) Graphical summary of the main impacts of PVPs on vegetation. Red arrows and boxes indicate negative effects. Green arrows and boxes indicate positive effects. Blue arrows and boxes indicate effects that are either neutral, undefined, or variable, depending on the context. Italics indicate potential impacts identified by the literature but not proven to date.



(c) Graphical summary of the main impacts of PVPs on wildlife. Red arrows and boxes indicate negative effects. Green arrows and boxes indicate positive effects. Blue arrows and boxes indicate effects that are either neutral, undefined or variable, depending on the context. Italics indicate potential impacts identified by the literature but not proven to date.

Appendix 2: Impacts of APV on biodiversity, effects and mechanisms (Shwarz et al., 2025)

Shwarz et al. (2025) summarized in a table the proposed effects and pathways by which agrophotovoltaic (APV) systems are hypothesized to affect biodiversity. The table details the potential effects of APV systems based on existing literature on the impacts of utility-scale PV (USPV) power plants on biodiversity, the effects of APV systems on agricultural crops, and the hypothesized effect (positive/negative /mixed) these may have on biodiversity.

Altered variable	APV feature causing impact	Taxa impacted	Impact	Likely route of impact	Outcome	Potential effect on biodiversity
Land change, habitat conversion and destruction	Installing APV systems on existing agricultural fields	All	Positive	Prevention of further natural habitat conversion Providing shade, shelter and water access	<ul style="list-style-type: none"> Increased shelter availability Refugia for rare species 	Positive
			Negative	Agroecological microhabitat conversion	<ul style="list-style-type: none"> Changed species composition, diversity and abundance Increased local extinction 	Negative
Physical structure	APV panels, stilts, fences, supporting structures, added artificial habitat structures	Prey species	Positive	Protection from predators	<ul style="list-style-type: none"> Increased shelter and nesting site availability 	Positive
		Non-native species/local overabundant species	Positive	Creation of favourable microclimatic conditions Protection from	<ul style="list-style-type: none"> Establishment Range expansion Becoming agricultural pests 	Negative

				predators	<ul style="list-style-type: none"> • Increased predation on local wildlife • Increased competition with local wildlife 	
		Flying species	Negative	Collision with structures	<ul style="list-style-type: none"> • Reduced natural pest control 	Negative
		Predator species	Positive	Creation of perching sites	<ul style="list-style-type: none"> • Increased predation pressure 	Negative
	Supporting structures (power lines emitting UV light)	Insects, birds, rodents and large mammals	Negative	<p>Avoidance of APV systems</p> <p>Avoidance of power line perimeter</p>	<ul style="list-style-type: none"> • Reduced natural pest control • Reduced movement ability • Reduced habitat connectivity 	Negative
	Fences	Large flightless species	Negative	Reduced habitat connectivity	<ul style="list-style-type: none"> • Disrupted migratory routes • Reduced genetic diversity 	Negative
Pollution	Artificial light at night	Nocturnal species	Negative	Disruption of circadian rhythm	<ul style="list-style-type: none"> • Behavioural changes • Species composition changes 	Negative

		Non-native species/local overabundant species	Positive	Increased food availability Penetration of novel environments	<ul style="list-style-type: none"> • Increased predation on local wildlife • Increased competition with local wildlife 	Negative
	Glare	Birds	Negative	Disruption of navigation abilities	<ul style="list-style-type: none"> • Interruption of migration flyways 	Negative
	Polarized light	Birds, reptiles, amphibians and insects	Negative	Attraction to PV panel (mistaken as water body)	<ul style="list-style-type: none"> • Collision with structures • Reproductive effort wasted • Increased predation 	Negative
	Electromagnetic field generated by grid cables	Wild mammals	Negative	Physiological effects	<ul style="list-style-type: none"> • Damage to the nervous system • Disruption to circadian rhythm • Changes to heart functions • Impaired immunity and fertility • Genetic and developmental problems • Changed species composition, diversity 	Negative
	Fuels, oils, lubricants, dust suppressants					

					<ul style="list-style-type: none"> and abundance • Local extinction • Runoff to adjacent habitats 	
Microclimate changes	Arid and mesic environments	Shade-tolerant plant, fungal and microorganism species	Positive	<p>Increased soil moisture</p> <p>Reduced photosynthetically active radiation</p> <p>Reduced soil temperature</p> <p>Reduced air temperature</p> <p>Increased relative humidity</p>	<ul style="list-style-type: none"> • Altered growth rates and patterns • Later or earlier seasonal blooming • Fewer or more annual seasonal blooming events • Modified nutrient content • Refugia for rare species • Mitigation of climate change effects • Increased competition with crops • Increase in natural enemies and pathogens 	Positive
					<ul style="list-style-type: none"> • Increased use of pesticides and herbicides 	Negative

		Shade-intolerant plant, fungal and microorganism species	Negative		<ul style="list-style-type: none"> • Changed species composition • Exclusion by competition • Local extinction 	Negative
		Animal species	Positive/negative		<ul style="list-style-type: none"> • Changed behaviour • Changed phenology • Changes in life-history traits 	Positive/negative
		Pollinators	Positive/negative		<ul style="list-style-type: none"> • Altered activity patterns • Changed foraging behaviour • Altered pollination efficiency 	Positive/negative
		Non-native species/local overabundant species	Positive		<ul style="list-style-type: none"> • Becoming established • Expanding ranges • Becoming agricultural pests • Increased predation on local wildlife • Increased competition with local wildlife 	Negative

Appendix 3

Shwarz et al. (2025) suggested potential research questions for future studies on the effects on biodiversity of agrophotovoltaic (APV) systems:

Small-scale effects

- (1) How do changes in physical and/or biological conditions imposed by APV structures affect biodiversity?
- (2) What mechanisms and relationships are promoted or depressed in APV systems compared to agroecological ecosystems?
- (3) Do species interactions change in APV fields and surrounding environments?
- (4) What are the effects of APV systems on functional groups (e.g. predators, pollinators, decomposers, pathogens) and their interactions?

Large-scale effects

- (5) How do any effects on biodiversity change in APV systems across different geographic zones, climates and habitat types?
- (6) What are the complex, large-scale spatial effects of APV structures on macroecological processes (e.g. species distributions, dispersal, migration patterns)?
- (7) How is global warming predicted to impact the effects of APV systems on biodiversity and on vulnerable species across different habitat types?
- (8) Is ecovoltaics superior to APVs in promoting biodiversity, ecosystem functioning and ecosystem services across habitats?

Technical and agricultural aspects of APV systems

- (9) Do any crops grown in APV systems benefit biodiversity and surrounding ecosystems more than others?
- (10) How do the supporting structures of APV systems (e.g. fencing, grid cables, stilts) impact biodiversity?
- (11) Do different PV panel technologies (e.g. semi-transparent panels, sun-tracking technologies) affect biodiversity differently?
- (12) What wildlife-friendly practices minimise negative impacts and enhance positive impacts of APVs on biodiversity, and on vulnerable taxa?
- (13) How can research-based planning of APV systems (e.g. geographic location, system layout, surveys of the types of species and habitats present, addition of artificial habitat structures) enhance biodiversity?