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Photovoltaic power plants on agricultural land – are they really green?

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Abstract. Photovoltaic systems are a rapidly developing technology that plays a crucial role in the transition to clean energy and the reduction of greenhouse gas emissions. However, it is important to consider their potential impacts on the environment and biodiversity, especially when installing them on agricultural land. The aim of this study is to analyze and assess the impact of photovoltaic power plants (PPPs) on soil properties, microclimate and biodiversity. Renewable energy infrastructure can impact biodiversity in different ways during its construction, operation and maintenance, as well as during decommissioning or re-commissioning. Potential impacts of PPPs on biodiversity include direct morbidity and mortality of wildlife species, habitat loss and degradation, habitat fragmen-tation and barrier effects, habitat alteration or creation, behavioral changes, physiological changes and displacement, infrared wave impacts, impacts on ecosystem services, indirect impacts, and cumulative impacts at the population level. Constructions with photovoltaic panels can affect soil and microclimate conditions by trapping precipitation and atmospheric deposition, changing surface albedo, increasing ground shading, and influencing wind speed. Significant changes in these parameters have been found in all studied locations, which can lead to changes in species composition, richness and diversity. The results obtained for the main negative impacts of PPPs on agricultural lands on the environment can be used to solve a wide range of management tasks such as control over investment proposals in the field of photovoltaics, etc.

Key words: alternative energy sources, renewable energy, environmental impact, soil degradation, biodiversity loss.

Introduction

Bulgaria has a great potential for energy production from photovoltaic power plants (PPPs) with an average radiation of about 1400 kWp/m^2 per year (Markova et al., 2011). The use of local renewable energy sources (RES) is an element of the strategy and policy of the Republic of Bulgaria in the context of European Green Deal (EC, 2021). For these reasons, investor interest is permanently increasing, with expectations that photovoltaics in our country will triple in capacity by 2030, when Bulgaria should achieve a 27% share of renewable energy in total energy consumption. According to the Bulgarian Photovoltaic Association, 2019 marked a boom in solar energy in the EU and over 100% growth in the market (NSI, 2020). Forecasts are for a new record growth in installed capacity of 24.3 GW for 2022 and 26.8 GW for 2023. The boom in projects for the construction of new renewable energy capacities continues. From 2019 to the end of 2022, the applications received for connection to the Electricity System Operator (ESO) for new solar and wind power plants are 3,100 with a total installed capacity of 32,300 MW. For 2023 alone, the number of applications for the construction of new RES is 2,377 with a total installed capacity of 17,500 MW.

These investment intentions, even if not 100% realized, lead to a huge environmental problem, namely the construction of photovoltaic power plants (PPPs) on truly valuable natural territories - protected areas of the Natura 2000 ecological network, agricultural lands and pastures, even dams.

Investment intentions related to the construction of photovoltaic power plants in non-urban areas require procedures for changing the land use of agricultural or forest territory (Velikova, 2012). The new spatial planning preceding the implementation of a photovoltaic power plant itself leads to a loss of area of a given type of territory, a change in the balance of all territories and an increase in anthropogenically influenced territories, which are actually the territories with built photovoltaic parks. It is at the stage of new spatial planning, preceding the implementation of a specific investment proposal, that a high level of environmental protection and compliance with the environmental considerations set out in European and national legislation should be guaranteed. However, in national legislation, there are currently no procedures, algorithms and methodologies to assess the impact of these growing territories with photovoltaic parks on agriculture, natural ecosystems and their potential for providing ecosystem services.

Photovoltaic systems are a rapidly developping technology that plays a crucial role in the transition to clean energy and the reduction of greenhouse gas emissions. However, it is important to consider their potential impacts on the environment and biodiversity, especially when installing them on agricultural land.

The aim of this study is to analyze and assess the impact of some photovoltaic power plants (PPPs) on soil properties, microclimate and biodiversity. Our research hypothesis is as follows: if systematic studies are conducted on the ecological, territorial and landscape aspects of the impact of some PPPs in agricultural areas, the results obtained will allow for the assessment of potential negative impacts, threats and risks for the protection of biodiversity, the ecological balance in natural ecosystems and their potential for providing ecosystem services.

Materials and methods

First step was to perform a literature search to gain an understanding of which type of impacts of the PPPs on environment have been recognized, discussed, measured through empirical data or modelling studies (Petrova et al., 2025). The selection of qualitative and quantitative parameters suitable for the study's objectives to be monitored and analyzed was carried out on the basis of developed impact criteria, each of which allows for an assessment of the nature and scale of the impact in the relevant aspect. For achieving the aim if the study, two groups of indicators were sought - the first group to allow analysis and assessment of the impact of PPPs on the abiotic components of the environment (main ecological factors such as air temperature, light, soil temperature and humidity, soil pH, etc.), and the second group to allow analysis and assessment of the impact of PPPs on habitats and the biodiversity.

The second step included systematic field studies, conducted on the territory of some PPPs in the period June - November 2023 and 2024, aiming to obtain sufficient scientific information in terms of volume, duration and reliability to enable the implementation of the set goals.

Field protocols were completed for each field study, which reflected the quantitative data from the observations and measurements of the abiotic and biotic components' properties.

All measurements were carried out using standardized methods and with the relevant portable specialized equipment, respectively under and above the solar panels, as well as in control areas without panels.

Soil samples were collected, processed and analyzed following the standardized procedures.

Invertebrate fauna was sampled using an entomological bag, with individuals preserved in 75% ethanol and taxonomically identified.

A database was created with the results of the measurements of the selected quantitative and qualitative parameters and impact indicators.

Results and Discussion

Photovoltaic power plants (PPPs) are a key technology for the transition to low-carbon energy. However, the deployment of PV systems requires a significant amount of land, which can present challenges for land-use planning. Some of the most significant environmental impacts of PPPs are related to land use, greenhouse gases (GHG) emissions, soil deterioration, water pollution, chemical pollution (pesticide application), plant change, habitat fragmentation and degradation, etc. (Carullo et al., 2013; Delfanti et al., 2016; Naspetti et al., 2016; Petrova et al., 2025).

In theory, land acquisition for photovoltaic facilities installations can displace other land uses. In some countries, solar energy is used on agricultural or forested land. For example, about 28% of solar energy in California is on agricultural land (cropland and pasture), which is equivalent to about 150 km^2 (Hernandez et al., 2015). In some cases, solar and agricultural production can be co-located, thereby reducing pressure on land use. In other cases, however, solar energy harvested on agricultural land can be at the expense of agricultural production. This can displace agricultural activities elsewhere to meet increasing demand, thus contributing to land use change or pollution far from the PPPs site (Tawalbeh et al., 2021).

Land use refers to the amount and type of land occupied by a PPP, which can affect the natural habitat and biodiversity of the area. Depending on the location, size and design of the photovoltaic power plant, the impact on land use can vary significantly. For example, some PPPs can be integrated into existing buildings or structures, while others require the clearing or cultivation of large areas of land. Some PPPs may also share land with other uses, such as agriculture or grazing, while others may result in the displacement or fragmentation of wildlife habitats (Bošnjaković et al., 2023).

Renewable energy infrastructure can impact biodiversity in different ways during its construction, operation and maintenance, as well as during decommissioning or recommissioning (Petrova et al., 2025). Potential impacts of PPPs on biodiversity include direct morbidity and mortality of wildlife species, habitat loss and degradation, habitat fragmentation and barrier effects, habitat alteration or creation, behavioral changes, physiological changes and displacement, infrared wave impacts, impacts on ecosystem services, indirect impacts, and cumulative impacts at the population level (Herden et al., 2009; Murphy-Mariscal et al., 2018; Whitehead et al., 2017; IFC, 2017; Goodale & Milman, 2019).

At the landscape level, the deployment of PPPs can fragment habitats and create barriers to species movement. Habitat fragmentation occurs when a continuous habitat is divided into isolated patches of remnant habitat due to conversion or disturbance (Wilson et al., 2015). This results in both a smaller total habitat area and changes in the spatial configuration of the habitat (Berger-Tal & Saltz, 2019). Habitat fragmentation is associated with reduced species richness, edge effects, compromised ecosystem function and population isolation, and reduced genetic exchange (Haddad et al., 2015; Fahrig, 2003). The construction of PPPs on grasslands and meadows destroys the habitats of many species of mammals, birds, amphibians, and reptiles. For example, they could disturb larks, buntings, meadow-larks and others that nest in open areas such as grasslands and meadows. Other taxa, such as salamanders, may also be negatively affected by the barrier effect created by power lines (Cecala et al., 2014).

Constructions with PV panels can also affect soil and microclimate conditions by trapping precipitation and atmospheric deposition, changing surface albedo, increasing ground shading, and influencing wind speed (Hernandez et al., 2014). Due to the albedo effect, for example, nighttime temperatures in a rural solar installation have been found to be 3–4°C higher than those in the wild (Barron-Gafford et al., 2016). Due to the insulating effect of shading and airflow, spring and summer soil temperatures were 0.5–4°C lower in summer and higher in winter compared to control sites without collectors (Wu et al., 2014). Similarly, a study at a UK PPPs observed summer cooling of up to 5.2°C and drying under PV panels compared to gaps between PV panels rows and control areas (Armstrong et al., 2016).

Summary information from a systematic review of the scientific literature on the potential impacts of photovoltaic parks on biodiversity is presented in Table 1. Some results from the field measurements of abiotic parameters in studied PPPs in Bulgaria during the period 2023-2024 – illuminance intensity, air temperature, soil temperature, soil moisture, soil pH, are presented in Table 2 and Table 3, aiming just to illustrate the intensity of impact. Some of the obtained and processed results regarding the biodiversity of invertebrates on the territory of the studied PPPs are presented in Table 4.

Table 1. Summary of potential impacts on biodiversity of photovoltaic power plants (PPPs) and associated power lines (according to OECD, 2024).

Potential impacts on biodiversity	Photovoltaic panels	Electricity lines
Direct mortality and morbidity	Bird collision with panels	Bird strike with power lines Electrical shock of birds, mammals, reptiles
Habitat loss and/or degradation	Clearance and management of vegetation where PV panels are installed Change in surface water flows	Clearance and management of vegetation under overhead cables Clearance of vegetation and removal of soil for underground cables
Habitat fragmentation and barrier effects	Physical barrier Fragmentation of populations	Physical barrier
Habitat modification/creation (potentially positive or negative impacts on biodiversity depending on context)	Microclimatic changes created by PV panels (e.g. shading) can alter species composition, richness and diversity Panels can provide nesting sites or shelter for some bird, arthropod and plant species	The poles are used for nesting and foraging by some bird species The lines provide a corridor for the movement of some species through the landscape
Behavioral changes, species displacement and physiological changes	Avoidance of solar installations during construction or operation Attraction to solar installations (e.g. attraction of aquatic insects to polarized light; waterfowl mistake panels for water)	Power line avoidance by birds and some mammals (effective habitat loss) Effects of electromagnetic fields on behavior (attraction/avoidance), physiology and navigation (Temporary) displacement due to noise during construction
Potential impacts from invasive alien species	Invasive alien species may be introduced during construction and colonize more easily due to vegetation clearing practices, mowing, etc.	Colonization and spread of invasive species along power lines
Impacts on ecosystem services (potentially positive or negative impacts on biodiversity depending on context)	Impact on carbon sequestration, nutrient and hydrological cycles, pollination, habitat provision, water and food supply, and cultural values	
Indirect impacts	Impacts may arise if agriculture is displaced Displacement of energy sources with higher greenhouse gas emissions, thereby helping to mitigate climate-related impacts Reduced pressure on ecosystems in developing countries by facilitating alternative livelihoods (e.g., cessation of charcoal production, reduction of slash-and-burn agriculture)	Increased fire risk Increased deforestation and hunting through easier access Displacement of more greenhouse gas-intensive energy sources, thereby helping to mitigate climate change Reduced pressure on ecosystems in developing countries by facilitating alternative livelihoods (e.g., phasing out charcoal production, reducing slash-and-burn agriculture)
Cumulative and population-level impacts	Population-level effects likely for some sensitive species (e.g., grassland birds in the US) due to cumulative impacts of multiple energy developments	Cumulative impacts on populations of sensitive species due to collision and electrocution Cumulative habitat loss and fragmentation

Table 2. Some results from abiotic parameters measurements of the air in PPPs in 2024.

Date	Air measurements above PV panels		Air measurements below PV panels		Air measurements with no PV panels (control)	
	Illuminance	Temperature	Illuminance	Temperature	Illuminance	Temperature
August	99100 lux	51°C	2820 lux	35.5°C	91700 lux	48°
October	81000 lux	31°C	3260 lux	29.5°C	81200 lux	40°

Table 3. Some results from abiotic parameters measurements of the soil in PPPs in 2024.

Month	Soil measurements below PV panels			Soil measurements with no PV panels (control)		
	Humidity	Temperature	pH	Humidity	Temperature	pH
August	62%	25.1°C	6.31	52.2%	30.8°C	7.34
October	65.9%	15.3°C	6.82	73.3%	21.4°C	8.07

Table 4. Some results for the biodiversity in one of the studied PPPs in August 2024.

Plot	number	Phylum	Class	Order	Family	Genus
Control	4	Mollusca	Gastropoda	Styllomatophora	Hygromiidae	Helicella
	82	Arthropoda	Insecta	Hymenoptera	Formicidae	Formica
	2	Arthropoda	Insecta	Hemiptera	Miridae	
	2	Arthropoda	Insecta	Hemiptera	Nabidae?	
	2	Arthropoda	Arachnida	Araneae	Thomisidae	Xysticus
	307	Arthropoda	Insecta	Hemiptera	Aphididae	?
	2	Arthropoda	Malacostraca	Isopoda	Oniscidae	
	2	Arthropoda	Insecta	Diptera	Drosophilidae	
	2	Arthropoda	Insecta	Hemiptera	Cicadellidae	
	1	Arthropoda	Insecta	Thysanoptera	?	
	1	Arthropoda	Insecta	Coleoptera	Chrysomelidae	
	1	Arthropoda	Insecta	Hymenoptera	Eulophidae	Hemiptarsenus
	1	Arthropoda	Insecta	Diptera	Chironomidae	
	1	Arthropoda	Insecta	Orthoptera	?	
Total	**410**					
Around PV panels	22	Insecta	Hymenoptera	Formicidae	Formicinae	Formica
	2	Insecta	Orthoptera	Acrididae	Acridida	Calliptamus
	1	Insecta	Orthoptera	Acrididae	Acridida	Acridia
	1	Insecta	Hymenoptera			Formica
	2	Insecta	Hemiptera	Miridae		Calliptamus
	1	Arachnida	Araneae			Acridia
Total	**49**					

Changes in soil and microclimatic conditions can lead to changes in species composition, richness and diversity (Tanner et al., 2014). For example, a study of a PPP in the UK found that species diversity and plant biomass were lower under photovoltaic sectors, partly due to differences in soil and air temperature (Armstrong et al., 2014). In some contexts, the shading effect of PV panels can be beneficial, for example when used to preserve crops during heat waves and droughts (Barron-Gafford et al., 2016) or by providing shade and shelter for some arthropods (Suuronen et al., 2017) and bird species (Visser et al., 2019). If vegetation is allowed to regrow between the panels, solar facilities could also provide nesting opportunities (Visser et al., 2019). Further evidence on microclimatic changes associated with PPPs in different contexts and the resulting impacts on species and ecosystem services could help optimize the design of PV facilities with a view to their positive effect on biodiversity.

The construction and operation of PPPs may induce behavioral responses for certain species. Potential responses include avoidance of (or attraction to) noise, light, and physical structures, and changes in feeding, competition, and reproductive patterns. Such responses, which may be temporary or permanent, may affect energy expenditure and predation risk, potentially reducing fecundity and increasing mortality in wildlife (Murphy-Mariscal et al., 2018). Therefore, changes in wildlife behavior induced by PPPs could negatively impact populations and ecological communities. Few studies have examined behavioral changes and species displacement induced by solar facilities. However, evidence suggests that solar power plants may displace species through both habitat destruction and avoidance behavior (effective habitat loss). For example, a study in South Africa found that birds were much more abundant (141.9 birds/km) and species-rich (51 species) in the surrounding grassland than in the solar field (1.27 birds/km; 22 species) (Jeal et al., 2019). Another study found that bird species richness (and to a lesser extent density) in the largest photovoltaic facility in South Africa was lower than the boundary zone and adjacent untransformed land (Visser et al., 2019).

While some species avoid photovoltaic power installations, others may be attracted to them. For example, preliminary research suggests that PPPs may be "ecological traps" for insects. Aquatic insects may be attracted to the polarized light reflected from PV panels, confusing the panels with water surfaces. The increased concentration of insects may then attract insectivorous birds and bats (Kagan et al., 2014). Attracting insects to PV panels may have adverse effects on ecosystems, especially when PPPs are located near water basins (Horváth et al., 2009, 2010).

Installation of PPPs could facilitate the introduction or spread of invasive alien species (IAS) through two main pathways – the first is direct and the second is indirect. First, the construction and maintenance of PV facilities involves the movement of components, equipment and people, each of which provides a potential vector for the species. Second, habitat degradation or loss during construction or operation can reduce ecosystem resilience and thus facilitate the colonization or spread of IAS. In California, for example, invasive grasses have been found to persist after mowing (removal of above-ground vegetation) (Grodsky & Hernandez, 2020).

If ecosystems function properly, they provide us with many of the products and services we take for granted. Plants capture and transform the sun's energy, making it available to other life forms. Bacteria and other organisms break down organic matter in the soil into nutrients that plants can use. Bees and other pollinating insects are key contributors to maintaining ecosystems and biodiversity. The lack of pollinators threatens many plant species, as well as the organisms that are directly or indirectly associated with these plants. Many agricultural crops are also at risk. The deployment of PPPs could affect the supply and access to ecosystem services. Potentially affected are sustaining services such as soil formation and nutrient cycling, regulating services such as climate and hydrology, material services such as water and food supply, and cultural services such as recreational activities, aesthetic and spiritual values (Sánchez-Zapata et al., 2016).

In some contexts, with proper siting, design, and management, PV facilities could enhance several ecosystem services while helping to combat climate change and meet energy needs (Randle-Boggis et al., 2020; Walston et al., 2021). For example, compared to pre-construction agricultural land use, PPPs in the Midwest of the United States that restore and manage native grasslands can increase pollinator availability by 300%, carbon storage potential by 65%, sediment retention by more than 95%, and water retention by 19% (Walston et al., 2021).

Conclusions

The results obtained for the main negative impacts of photovoltaic power plants on the environment can be used to solve a wide range of management tasks such as:

- control over investment proposals in the field of renewable energy sources,
- setting requirements for a more detailed assessment of the degree of impact/ecological assessment of the potential risk to biodiversity, landscape, protected areas and sensitive areas;
- adding new indicators to the environmental assessment, based on the ecosystem approach and

related to the potential risks to natural ecosystems and the ecosystem services provided by them;

- requirements for planning measures for their sustainable management, etc.

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