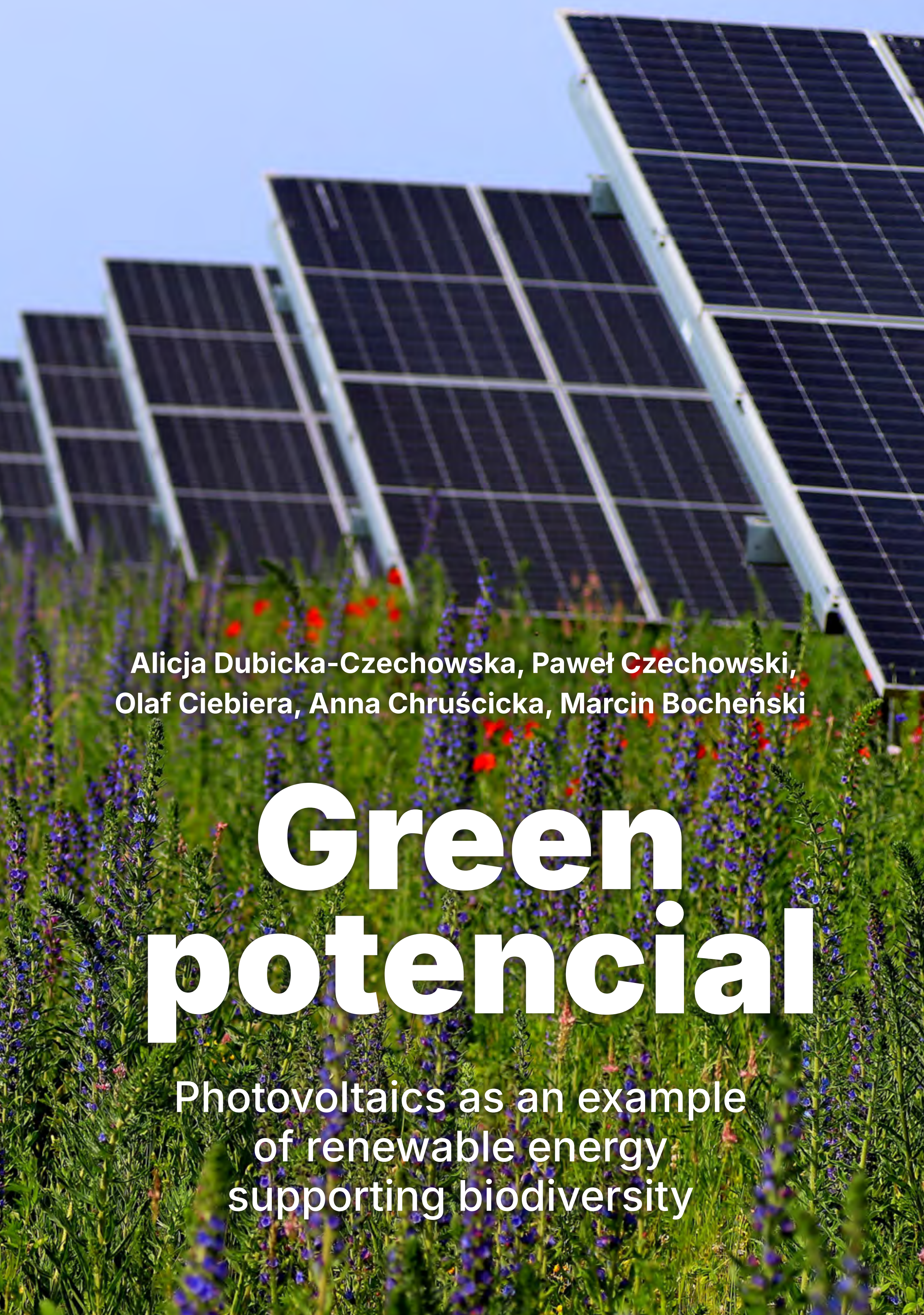

Alicja Dubicka-Czechowska, Paweł Czechowski,
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# Green potencial

## Photovoltaics as an example of renewable energy supporting biodiversity

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## Photovoltaics as an example of renewable energy supporting biodiversity

Zielona Góra – Poznań 2025

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# Contents

**Photo 1.** Sulechów Photovoltaic Farm Complex (photo: O. Ciebiera)

*Ladies and Gentlemen,*

I am pleased to present a comprehensive and one of the first scientific publications summarizing several years of environmental monitoring of flowering meadows sown after the commissioning of photovoltaic farms in the Sulechów municipality.

The Sulechów Photovoltaic Farm Complex is located on a contiguous area of over 60 hectares, with a total installed capacity of nearly 30 MWp. Before construction began, the area where the installation is now located was intensively farmed. Since the panels occupy only half of the photovoltaic farm's area, the remaining land not covered by panels has been designated for the development of biodiversity. During the planning phase of the construction, project teams, with the support of the environmental protection department and naturalists supervising the construction, analysed the possibility of planting native grass and meadow plant species on the site. This initiative aimed to adapt plant mixes to local conditions and support the restoration of the meadow ecosystem.

Since 2021, a flower meadow has been maintained on part of the project, and in 2022, another part of the installation was supplemented with a pasture meadow containing flowering species. From the moment the area was sown, the large area, attractive to many animal species, quickly became populated amidst the surrounding monocultures of crops. Natural processes were restored at a noticeable pace, marking the beginning of our research and monitoring of the restored meadow ecosystem.

The studies conducted during the first two years were highly promising: the area proved to be attractive to various groups of animals, including strictly protected species. To better understand the processes occurring in this area, monitoring efforts continued into early 2023. In collaboration with a team of researchers from the University of Zielona Góra, we focused on analysing biodiversity changes within the Sulechów Photovoltaic Farm Complex. These comprehensive studies covered the functioning of the newly established ecosystem over an entire year.

For the Polenergia Group, collaboration in protecting and restoring ecosystems is an integral part of responsibly implementing investments and creating added value for our projects. This effort is part of broader social engagement and the implementation of a sustainable development strategy for 2023–2030, including the biodiversity strategy adopted in 2024. These documents cover not only active measures to protect the environment in consultation with specialists and transparent sharing of acquired knowledge and experiences but also cooperation with local communities to develop projects supporting biodiversity.

Natural processes are introduced to local school children through Polenergia's "Play Green with Us!®" climate education program. Cyclically invited to the Sulechów Photovoltaic Farm, they have opportunities to learn about animal species and observe the regenerating nature alongside naturalists.

More information about our biodiversity support, conservation efforts, and educational initiatives can be found at esg.polenergia.pl/en.

Since creating our first flowering meadow, similar efforts have been implemented across all photovoltaic farms we have commissioned. We hope our example of ecosystem restoration will inspire similar measures in all large-scale projects of this type. This represents a significant opportunity for nature, where intensive agriculture, the destruction of meadows, and land development contribute to the extinction of valuable species.

Restoring and preserving valuable meadow areas offers not only opportunities for greater natural retention of rainwater but also vast ecosystem services that help counter climate change.

Researchers will discuss the monitoring results and the role of meadow ecosystems in further sections of this publication.

*I invite you to explore it!*

*Iwona Sierżęga*
*Member of the Management Board, Polenergia S.A.*

Polenergia

*Ladies and Gentlemen,*

the initiative undertaken by Polenergia demonstrates how to combine efforts to increase investments in renewable energy sources with the protection of biological diversity.

In the current situation, where the predatory development of our civilization confronts us with a triple planetary crisis, we need comprehensive and diverse actions that address both the climate catastrophe and the mass extinction of species. We must preserve less transformed areas, which, in the context of our continent, means encompassing valuable natural ecosystems with various forms of protection. Equally important are actions in transformed areas where we have an opportunity to improve or even restore ecosystems.

Ecosystem protection and restoration is the main theme of the current UN Decade covering the years 2021–2030. UNEP/GRID-Warsaw's direct response to the UN Decade on Ecosystem Restoration is the launch of the Re:Generation program aimed at rebuilding and preserving ecosystems. One of the project's business partners is Polenergia, which has engaged in supporting four ecologically valuable areas: the Vistula Spit and natural habitats in two nature reserves and the Słowiński National Park. The choice of ecosystems to be supported was determined by the location of Polenergia's operations and the need to protect valuable ecosystems in its vicinity.

Cleaning up the Baltic beaches within the "Vistula Spit" Landscape Park covered more than a ten-kilometer stretch of coastline. This area was selected after consultations with the Pomeranian Landscape Parks Team as the most urgently requiring waste removal. During the cleanup, 140 kg of waste was collected, including 100 kg of mixed waste and 40 kg of plastic packaging.

In the forest reserve "Dolina Kamionki", which protects a complex of ecosystems associated with a river valley along with their characteristic plant species, conservation efforts focused on shaping the appropriate species composition and reducing anthropogenic pressure by eliminating an "illegal" landfill.

In the "Kołacznia" reserve, the only natural habitat in Poland for the yellow azalea, invasive alien species, primarily black cherry and black locust, were eliminated in 2023, and competition from native shrub species was reduced.

Polenergia also supported the removal of another invasive species spreading in the active protection area of the Słowiński National Park by Lake Gardno. Himalayan balsam, one of the most invasive plants in Poland, was eradicated by pulling out entire plants to prevent them from flowering and producing seeds. This procedure must be repeated multiple times due to the characteristics of the species. Invasive species are considered one of the main causes of biodiversity decline and the extinction of native species. Over time, invasive species displace native ones, occupying entire ecosystems and impoverishing their species composition.

Restoring ecosystems is also a significant element of the European Green Deal and a primary objective of the Nature Restoration Law adopted in June 2024. The designated actions include achieving a national upward trend in butterfly populations in grassland areas, increasing the organic carbon content in mineral soils of arable land, and raising the percentage of agricultural land with high-diversity landscape features. Additionally, it aims to boost the population of common farmland birds.

It is essential to remember that activities aimed at preserving biodiversity in areas not covered by any form of nature protection, especially in agricultural regions, present a significant challenge. They require balancing the productive function, ensuring our food security, and the ecosystem function, supporting countless species. However, these two functions are closely interconnected. Agricultural soils will not store carbon or yield the expected crops without a diverse community of organisms. Oilseed, fruit, and vegetable crops require pollinating insects, including butterflies. In agricultural areas—heavily transformed landscapes—our dependence on other species is particularly evident, yet often overlooked.

The development of technology enabling solar energy collection has added a new function to agricultural areas. Photovoltaic farms require space. At the same time, as shown in this publication, they offer a unique opportunity to shape that space. Restoring multi-hectare, species-rich meadow ecosystems has a tremendous environmental impact. Just how significant? You will find out in the publication we present to you. The authors take us into the world of meadows, insects, birds, and bats. A world that needs our care. A world we need.

*I am pleased to recommend reading this publication.*

*Maria Andrzejewska*
*Director General of UNEP/GRID-Warsaw Center,*
*a center affiliated with the United Nations Environment Programme, UNEP*

GRID WARSZAWA | In partnership with UN Environment Programme

# 1. Photovoltaic farms by Polenergia Group

In recent years, there has been a sharp increase in installed photovoltaic capacity. Large-scale photovoltaic farms (PFs), often with capacities in the range of megawatts (MW) or even hundreds of MW, play a key role in the National Power System compared to micro-installations (usually up to 50 kW) and small prosumer installations (a few kW). With their large capacities, these farms can generate significant amounts of electricity, sufficient to power entire regions from a zero-emission renewable source. By the end of 2023, the total capacity of large photovoltaic plants exceeded 1.6 GW, representing a more than 113% year-over-year increase. Polenergia's total photovoltaic farm capacity exceeds 82 MWp, and additional projects, such as PV Szprotawa I and II with a total capacity of 67 MWp, began construction in 2024.

Since the development of this renewable energy segment began, each Polenergia project has undergone environmental inventorying during the pre-investment phase and ecological supervision during construction. Thanks to this best practice, the Polenergia Group minimizes environmental impacts while adding value to projects during the operational phase. Erratic stones collected during construction form valuable biotopes, providing shelter for various reptile, amphibian, insect, and small mammal species.

Besides the meadow ecosystem described in Sulechów, an example of such initiatives is the Strzelino Photovoltaic Farm, which was commissioned in May 2024. Over 1.3 hectares of flowering meadows were sown, and more than 2,000 shrubs were planted, enriching the food base for local birds, insects, and mammals. Properly selected native plant species, adapted to local conditions, are key to successfully restoring local meadow ecosystems, which were established on all photovoltaic farms before they were operational. Additionally, the efforts extend beyond the built projects. Local naturalists conducting oversight propose additional initiatives to benefit nature and local animal species. For example, in forests around the Strzelino Photovoltaic Farm, four nesting baskets for long-eared owls and four kestrel boxes were installed in cooperation with the Ustka Forest District. Two barn owl boxes were also installed on the facades of farm buildings in the Redzikowo municipality. By creating suitable nesting conditions for these predatory birds, the Polenergia Group supports natural mechanisms for controlling rodent populations, positively impacting the complex forest-field ecosystem.

Rapidly developing photovoltaic farm projects are not only a crucial renewable energy source contributing to the energy transition but can also play a significant role in biodiversity restoration as part of the Green Deal.

## The photovoltaic phenomenon

Photovoltaics (PV) is a technology that enables the direct conversion of sunlight into electricity. The process of converting sunlight into electricity in photovoltaic panels is based on the photovoltaic effect. Photovoltaic modules consist of individual cells made of silicon, a semiconductor material. When the cell is illuminated by sunlight, photons (particles of light) strike the semiconductor layer and transfer their energy to the electrons in the material. This energy allows the electrons to overcome their typical position within the atom and move freely within the cell. Each electron knocked out of position by a photon leaves behind a void. This absence of electrons acts as a positive charge. Within the PV cell, an area of positive and negative charge is created, forming a potential difference between the silicon layers (known as the p-n junction), which is necessary to generate electrical current.

Within the p-n junction, an electric field arises, forcing electrons to move in one direction—from the n-layer to the p-layer. The moving electrons flow through the cell as direct current (DC). Combining multiple cells in a panel allows for higher DC power output. Once DC current is generated in photovoltaic panels, it passes through an inverter, which converts it into alternating current (AC) at low voltage (typically 0.8 kV). However, for the current to be efficiently transmitted over long distances and integrated into the national power grid, its voltage must be stepped up to a medium level (15–30 kV) and, in some cases, to high voltage (110 kV or higher).

Large-scale photovoltaic farms differ in technology and parameters, affecting their efficiency and application. Technological advancements in efficiency and panel design have played a significant role, enabling greater energy production from smaller areas. The capacity of large-scale PV installations is expressed in megawatts peak (MWp), indicating the maximum power output of a panel under standard test conditions.

Photovoltaic farms can be installed in various locations and have different applications. Among the main types are:

- **Ground-mounted farms**: Typically large installations on non-productive land such as wastelands, degraded areas, or low-grade agricultural fields (class IV or lower).
- **Building-integrated farms**: Installations on roofs and building facades make efficient use of space, eliminating the need for additional land.
- **Agrophotovoltaics**: Integrating PV plants with agricultural crops allows for simultaneous land use for energy and agriculture; panels are mounted in a way that enables crop cultivation.
- **Micro-installations**: According to the Renewable Energy Sources Act (act of 20 February 2015 on renewable energy sources, Journal of Laws of 2024, item 1361), these are renewable energy installations with a total installed electric capacity not exceeding 50 kW, connected to a power grid with a rated voltage below 110 kV, or with a thermal capacity in cogeneration not exceeding 150 kW, where the

total installed electric capacity does not exceed 50 kW. These installations meet the energy needs of their location (individual and business prosumers).

## Dynamics of photovoltaic farm development in Poland

Electricity production from photovoltaic farms has grown significantly in recent years, illustrating the dynamic development of RES in the national energy system. By the end of 2023, the total capacity of all photovoltaic farm installations reached approximately 11.3 GW, a substantial year-on-year increase (7.7 GW at the end of 2022). This dynamic growth in installed capacity has allowed for a 50% increase in annual electricity production from photovoltaic compared to 2022. Furthermore, it is anticipated that PV capacity in Poland will exceed 28.8 GW by the end of 2024, highlighting the sector's rapid development despite increasing challenges with connection infrastructure.

Statistics also show improvements in farm efficiency over the past few years. Modern photovoltaic farms are designed with smaller areas per unit of power. While a decade ago, the average ratio was 2–3 hectares per 1 MW, today, thanks to more efficient technologies, these values range from 1 to 1.5 hectares per 1 MW. Photovoltaic farm efficiency depends not only on location but also on the technology used.

In recent years, the following innovations have played a key role:

- **Higher energy efficiency**: Solar panel efficiency has significantly improved due to technological advances. In the early 21st century, the average efficiency of solar panels was around 15%. Recently, most monocrystalline solar panels now achieve efficiencies between 19% and 22%, meaning up to 22% of solar energy is converted into electricity. Modern panels feature power outputs of up to 440 watts.
- **Bifacial panels**: Traditional PV panels generate energy only on one side. Bifacial panels also utilize the rear side to capture light reflected from the surface under the panel. This design makes bifacial systems more efficient without increasing their footprint. The average efficiency of bifacial panels is 6–9% higher than single-sided panels.
- **Tracking systems**: Traditionally, panels are mounted in a fixed position facing south. Trackers allow automatic rotation of panels throughout the day, optimizing their angle to the sun. These systems can be single-axis (changing angle horizontally) or dual-axis (changing angle both horizontally and vertically). Using trackers increases system efficiency by 10–25%, depending on location and sunlight conditions.
- **East-west systems**: An alternative to the classic south-facing orientation is the east-west layout, which ensures more stable energy production throughout the day. Although this configuration may not achieve maximum power output at noon, it is particularly valuable in regions with high energy demand during morning and evening hours.

## Challenges and development directions for large-scale photovoltaic farms

The development of large-scale photovoltaic farms involves technological, socio-environmental, and administrative challenges. One of the key issues is location. To minimise environmental impact, farms should be constructed in areas that are less valuable in terms of natural or utilitarian use, such as agricultural land of class IV or lower, degraded areas, or post-industrial sites.

Another challenge is the often outdated grid infrastructure, especially in rural areas where such farms could be built. This poses a significant limitation for new investments and the development of existing facilities. Obtaining the necessary administrative permits also represents a considerable challenge during the implementation of photovoltaic farms. According to the Act on Providing Information on the Environment and Its Protection, Public Participation in Environmental Protection, and Environmental Impact Assessments (dated 3 October 2008, Journal of Laws of 2024, item 1112), the construction of a photovoltaic farm with a built-up area exceeding 2 hectares requires obtaining a decision on environmental conditions. As stipulated by this Act, an application for such a decision must include a Project Information Sheet (KIP), which provides detailed information on the type, characteristics, scale, and location of the investment, as well as basic data on the local environment. At this stage, an inventory is also initiated to assess the environmental value of the site.

The regulation classifies projects into those that are always likely to have a significant environmental impact and those that potentially could. Large-scale photovoltaic farms fall into the latter category, for which conducting an environmental impact assessment is not obligatory.

Authorities reviewing the KIP, such as the Regional Director for Environmental Protection, the State Water Management Authority (Polish Waters), or the State Sanitary Inspector, may deem it necessary to carry out an environmental impact assessment and prepare an Environmental Impact Report (EIA Report) in accordance with the aforementioned Act.

One of the aspects analysed during the environmental impact assessment of a photovoltaic farm is its effect on local biodiversity, particularly regarding the built-up area (covered by panels). Indirect effects on birds of prey are also considered, as the farms may occupy potential hunting grounds.

Two-year studies conducted by the University of Zielona Góra indicate that the implementation of photovoltaic farms not only does not limit foraging opportunities but, when appropriate practices are applied, can also promote biodiversity and increase the richness of animal species inhabiting the investment area, including small mammals that serve as a food base for birds of prey.

The EIA Report enables a comprehensive evaluation of the investment's impact on the environment and the local community, including human health and living conditions, material assets, cultural heritage, and the landscape. It also assesses the risks of major accidents, natural and structural disasters, and outlines possible methods to prevent and mitigate the negative environmental impacts of the project, along with recommendations for monitoring. The analysis considers the investment's impact on individual components during the implementation, operation, and decommissioning phases.

The investment's influence on the local community cannot be overlooked—social acceptance of large photovoltaic farms is crucial for their future. For years, Polenergia Group has been initiating numerous projects designed primarily for and in collaboration with local communities where existing and developing Polenergia projects are located. These initiatives include partnerships aimed at achieving sustainable development goals and collaborative engagement. Polenergia Group treats its responsibility towards the natural environment and local communities as a cornerstone of its long-term development strategy and a key element of its ESG strategy. This underscores its commitment to social engagement and biodiversity support. The main objectives of the strategy include both "developing a due diligence system in the area of biodiversity" and "creating well-being and fostering collaboration with local communities".

Polenergia Group allocates 1% of its consolidated net profit from the preceding financial year to initiatives supporting social engagement. Developing communication strategies and integrating photovoltaic farms with local environmental education significantly improve public perception.

The history of photovoltaic farm development in Poland is not only a story of technological progress but also evidence of how sustainable development can become the foundation of modern energy systems. As Poland transitions into the era of renewable energy sources, the focus must be on technological efficiency and environmental impact. Supporting biodiversity on photovoltaic farm sites contributes to protecting local ecosystems while forming a vital part of the energy transition.

The innovative solutions presented in this scientific publication, exemplified by the Sulechów Photovoltaic Farm Complex, demonstrate that energy production can effectively be combined with environmental stewardship. Through these efforts, photovoltaic farms can serve as producers of green energy and as spaces conducive to the growth of local flora and fauna.

In the face of challenges posed by climate change and increasing energy demand, a responsible approach to photovoltaic farm development will be key to a sustainable future. The following chapters detail how specific biodiversity initiatives undertaken at the Sulechów Photovoltaic Farm Complex contribute to achieving these ambitious goals.

# 2. Research area

The Sulechów Photovoltaic Farm Complex is located south of Sulechów, bordered on the west by the S3 highway, on the north by national road 32, and on the south and east by agricultural lands primarily planted with alfalfa. Geographically, the research area lies within the Central European Lowland province, specifically the South Baltic Lake District sub-province, in the Lubuskie Lake District macroregion and the Łagów Lake District mesoregion (Solon et al., 2018).

Research was conducted within the Sulechów Photovoltaic Farm Complex (Fig. 1), developed in stages since 2019. The first phase involved constructing Sulechów I Photovoltaic Farm with an 8 MW capacity, followed by Sulechów II and III farms, comprising 22 PV installations with a total capacity of nearly 30 MW. The entire complex covers approximately 65.4 hectares and houses nearly 70,000 photovoltaic panels. The estimated energy production corresponds to the annual electricity needs of 16,000 households. The photovoltaic farm consists of support structures with photovoltaic modules mounted at a maximum height of 3 meters above ground level and tilted southward. Additionally, the farm includes inverters and container transformer stations. The entire investment, divided into sectors, is enclosed by a steel mesh fence approximately 2 meters high, topped with barbed wire. The fence does not include a concrete foundation. The farm is equipped with a security system comprising CCTV devices and protective monitoring equipment. Furthermore, two smaller adjacent photovoltaic farms, covering a total area of about 5 hectares, are located east of the primary research site. Due to their proximity and similar characteristics (comparable panel parameters), bird observations from these areas were also included in the research.

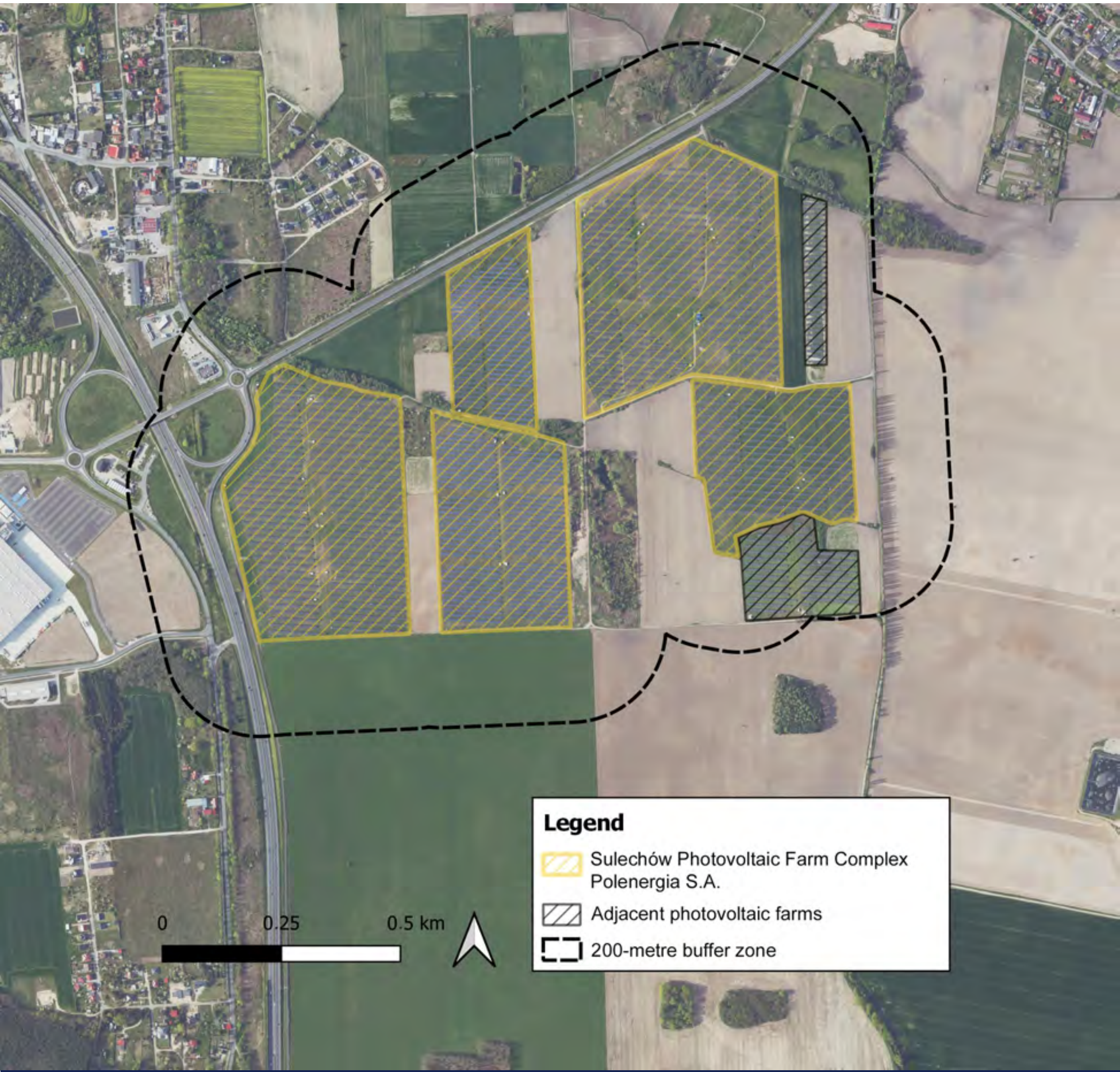


**Figure 1**. Sulechów Photovoltaic Farm Complex – research study area.
Base map source: Main Office of Geodesy and Cartography

# 3. Vegetation on the Sulechów Photovoltaic Farm Complex

Photovoltaic projects in Poland are often located on agricultural (arable land classes IV, V, and VI, nutrient-poor pastures, fallow land) and industrial areas (existing waste heaps or extraction sites left by open-pit mines) and significantly influence the flora and fauna of neighbouring areas. Plant growth is heavily dependent on soil moisture, temperature, and sunlight exposure, which vary across photovoltaic farm areas in time and space.

The occurrence of plants on photovoltaic farm areas and issues related to their succession, development, formation of phytosociological communities, ecology, and overall biodiversity are widely discussed in the literature (e.g., Amman 2004, Parker and McQueen 2013, Sinha et al. 2018, Vervloesem et al. 2022, Lafitte et al. 2023, Bena 2024). Authors highlight increased botanical diversity arising from microclimatic differences within photovoltaic farm areas, such as shaded and unshaded sections or wetter and drier environments (Sinha et al. 2018). This botanical diversity leads to a higher number of invertebrate species and their overall abundance, resulting in greater diversity among vertebrate species that can inhabit the farm areas.

Proper vegetation management on a farm reduces environmental impacts across various activities. Above all, vegetation cover reduces soil erosion and air pollution by minimizing dust near the farm during construction. Vegetation, tree rows, shrubbery, and plant-covered fences decrease visual impact in landscape terms and mitigate noise propagation to neighbouring areas. Vegetation prevents rapid soil drying while facilitating easier soil irrigation during heavy rains. Many plant species can accumulate and phytoremediate environmental pollutants (Choi and Lee 2005). Finally, diverse vegetation increases biodiversity among other groups of organisms, from soil bacteria and microorganisms to various groups of invertebrates and terrestrial vertebrates that find niches in fallow land, ruderal areas, crop fields, and edge zones.

The vegetation of the Sulechów Photovoltaic Farm Complex primarily consists of low-growing herbaceous plants, with a very limited presence of shrub thickets, which are found only under power poles (existing infrastructure not connected to the Sulechów Photovoltaic Farm Complex). There are no trees in the area.

From a phytosociological perspective, it is difficult to categorise the vegetation precisely due to the presence of sown flowering meadows between the rows of photovoltaic panels and along the fencing. In certain areas, perennial herbaceous plant communities can be identified, consisting of a mosaic of species from various phytosociological groups, mainly: segetal weeds from the *Stellarietea mediae* class, ruderal communities from the *Artemisietea vulgaris* class, and even fresh meadows from the *Molinio-Arrhenatheretea* class.

Small fragments under power poles (not related to the project, owned by the local operator) contain shrub thickets and small tree clusters from the *Rhamno-Prunetea* class. The taxa present include primarily perennial species, along with annual and biennial plants. The list of plants identified within the Sulechów Photovoltaic Farm Complex includes 104 taxa (scientific names provided per Mirek et al., 2020) (Table 1). No rare plant species listed in the Polish Red Book of Plants and Fungi were recorded. Most species observed in the study area are ruderal or fodder plants commonly found in pastures, fallow lands, wastelands, road verges, and anthropogenic or ruderal areas.

One identified species is legally protected in Poland under partial protection: Sand Immortelle *Helichrysum arenarium*. Furthermore, after the farm's construction, parts of the area were sown with a mix of nectariferous plant seeds, including annual, biennial, and perennial species. Dominant among these were Flax *Linum usitatissimum*, Bird's-foot Trefoil *Lotus corniculatus*, Red Clover *Trifolium pratense*, White Clover *Trifolium repens*, Alfalfa *Medicago sativa*, Crimson Clover *Trifolium incarnatum*, Cornflower *Centaurea cyanus*, Opium Poppy *Papaver somniferum*, Dill *Anethum graveolens*, Borage *Borago officinalis*, and other species 10 taxa with a much smaller presence.

Over the years since the farm's establishment, some plants have disappeared from the area, including Flax *Linum usitatissimum*, Opium Poppy *Papaver somniferum*, Dill *Anethum graveolens*, and Common Sage *Salvia officinalis* . Depending on the region of the farm, the most successfully developing species now include Alfalfa *Medicago sativa*, Viper's Bugloss *Echium vulgare*, Bird's-Foot Trefoil *Lotus corniculatus*, Red Clover *Trifolium pratense*, White Clover *Trifolium repens*, Crimson Clover *Trifolium incarnatum*, Cornflower *Centaurea cyanus*, grasses, and Goldenrod *Solidago* species. Among goldenrods, Canada Goldenrod *Solidago canadensis*, Giant Goldenrod *Solidago gigantea*, and their hybrids were identified. Therefore, in the following parts of this study, the group *Solidago* spp. has been used.

**Table 1.** List of plant species recorded in the Sulechów Photovoltaic Farm Complex.
* Species under partial protection in Poland.

| No. | Scientific name | Common name |
|---|---|---|
| 1 | *Achillea millefolium* L. | Common Yarrow |
| 2 | *Agropyron repens* (L.) P.Beauv. | Couch Grass |
| 3 | *Agrostis capillaris* L. | Common Bent |
| 4 | *Anchusa arvensis* (L.) M. Bieb. | Small Bugloss |
| 5 | *Apera spica-venti* (L.) P.Beauv. | Loose Silky-bent |
| 6 | *Arctium minus* (Hill) Bernh. | Lesser Burdock |
| 7 | *Armeria maritima* (Mill.) Willd. | Thrift |
| 8 | *Artemisia vulgaris* L. | Mugwort |
| 9 | *Berteroa incana* (L.) DC. | Hoary Alyssum |
| 10 | *Borago officinalis* L. | Borage |
| 11 | *Brassica napus* L. | Rapeseed |
| 12 | *Bromus sterilis* L. | Barren Brome |
| 13 | *Calamagrostis epigejos* (L.) Roth | Wood Small-reed |
| 14 | *Capsella bursa-pastoris* (L.) Medik. | Shepherd's Purse |
| 15 | *Carduus acanthoides* L. | Spiny Plumeless Thistle |
| 16 | *Centaurea cyanus* L. | Cornflower |
| 17 | *Cerastium arvense* L. s. s. | Field Mouse-ear |
| 18 | *Chelidonium majus* L. | Greater Celandine |
| 19 | *Chenopodium album agg.* L. | Lamb’s Quarters |
| 20 | *Cichorium intybus* L. | Chicory |
| 21 | *Cirsium arvense* (L.) Scop. | Creeping Thistle |
| 22 | *Cirsium vulgare* (Savi) Ten. | Spear Thistle |
| 23 | *Convolvulus arvensis* L. | Field Bindweed |
| 24 | *Corynephorus canescens* (L.) P.Beauv. | Grey Hair-Grass |
| 25 | *Crepis tectorum* L. | Narrowleaf Hawksbeard |
| 26 | *Dactylis glomerata* L. | Cock's-foot |
| 27 | *Daucus carota* L. | Wild Carrot |
| 28 | *Echinochloa crus-galli* (L.) P.Beauv. | Barnyard Grass |
| 29 | *Echium vulgare* L. | Viper's Bugloss |
| 30 | *Erigeron annuus* (L.) Pers. | Annual Fleabane |
| 31 | *Erigeron canadensis* (L.) Cronquist | Canadian Fleabane |
| 32 | *Erodium cicutarium* (L.) L'Hér. | Common Stork's-bill |
| 33 | *Euonymus europaeus* L. | European Spindle |
| 34 | *Euphorbia cyparissias* L. | Cypress Spurge |
| 35 | *Fallopia convolvulus* (L.) Á. Löve | Black Bindweed |

| No. | Scientific name | Common name |
|---|---|---|
| 36 | *Filago arvensis* L. | Field Cudweed |
| 37 | *Fumaria officinalis* L. | Common Fumitory |
| 38 | *Geranium pusillum* Burm. F. ex L. | Small-flowered Crane's-bill |
| 39 | *Glechoma hederacea* L. | Ground Ivy |
| 40 | *Helichrysum arenarium* (L.) Moench | Dwarf Everlast* |
| 41 | *Hellianthus annuus* L. | Common Sunflower |
| 42 | *Heracleum sphondylium* L. | Hogweed |
| 43 | *Hieracium umbellatum* L. | Narrowleaf Hawkweed |
| 44 | *Holcus lanatus* L. | Yorkshire Fog |
| 45 | *Hypochaeris radicata* L. | Cat's Ear |
| 46 | *Jacobaea vulgaris* L. | Common Ragwort |
| 47 | *Jasione montana* L. | Sheep's-bit |
| 48 | *Lactuca serriola* L. | Prickly Lettuce |
| 49 | *Lamium purpureum* L. | Red Dead-nettle |
| 50 | *Lapsana communis* L. s. s. | Nipplewort |
| 51 | *Leucanthemum vulgare* Lam. s. s. | Oxeye Daisy |
| 52 | *Linum usitatissimum* L. | Flax |
| 53 | *Lolium perenne* L. | Perennial Ryegrass |
| 54 | *Lotus corniculatus* L. | Bird's-foot-trefoil |
| 55 | *Matricaria maritima* L. subsp. *inodora* (L.) Dostál | Scentless Mayweed |
| 56 | *Medicago lupulina* L. | Black Medick |
| 57 | *Medicago sativa* L. | Alfalfa |
| 58 | *Melandrium album* (Mill.) Garcke | White Campion |
| 59 | *Melilotus albus* Medik. | White Sweet Clover |
| 60 | *Myosotis arvensis* (L.) Hill | Field Forget-me-not |
| 61 | *Onobrychis viciifolia* Scop. | Sainfoin |
| 62 | *Origanum majorana* L. | Sweet Marjoram |
| 63 | *Papaver argemone* L. | Long-headed Poppy |
| 64 | *Papaver rhoeas* L. | Common Poppy |
| 65 | *Papaver somniferum* L. | Opium Poppy |
| 66 | *Pastinaca sativa* L. | Wild Parsnip |
| 67 | *Petrorhagia prolifera* (L.) P.W. Ball & Heywood | Proliferous Pink |
| 68 | *Phacelia tanacetifolia* Benth. | Lacy Phacelia |
| 69 | *Plantago lanceolata* L. | Ribwort Plantain |
| 70 | *Poa pratensis* L. | Smooth Meadow-grass |
| 71 | *Polygonum aviculare* L. | Knotgrass |
| 72 | *Potentilla argentea* L. s.s. | Hoary Cinquefoil |

| No. | Scientific name | Common name |
|---|---|---|
| 73 | *Ranunculus repens* L. | Creeping Buttercup |
| 74 | *Raphanus raphanistrum* L. | Wild Radish |
| 75 | *Rumex acetosella* L. | Sheep's Sorrel |
| 76 | *Rumex acetosa* L. | Common Sorrel |
| 77 | *Sambucus nigra* L. | Black Elder |
| 78 | *Sanguisorba minor* Scop. | Salad Burnet |
| 79 | *Senecio jacobaea* L. | Common Ragwort |
| 80 | *Senecio vernalis* Waldst. & Kit. | Eastern Groundsel |
| 81 | *Senecio vulgaris* L. | Groundsel |
| 82 | *Setaria glauca* (Poir.) Roem. & Schult. | Yellow Foxtail |
| 83 | *Silene latifolia* L. | White Campion |
| 84 | *Solidago* sp. | Goldenrod |
| 85 | *Tanacetum vulgare* L. | Tansy |
| 86 | *Taraxacum officinale* coll. | Common Dandelion |
| 87 | *Thlaspi arvense* L. | Field Pennycress |
| 88 | *Tragopogon pratensis* L. s. s. | Meadow Salsify |
| 89 | *Trifolium arvense* L. | Hare's-foot Clover |
| 90 | *Trifolium aureum* Pollich | Large Hop Trefoil |
| 91 | *Trifolium dubium Sibth.* | Lesser Trefoil |
| 92 | *Trifolium hybridum* L. | Alsike Clover |
| 93 | *Trifolium incarnatum* L. | Crimson Clover |
| 94 | *Trifolium pratense* L. | Red Clover |
| 95 | *Trifolium repens* L. | White Clover |
| 96 | *Urtica dioica* L. | Stinging Nettle |
| 97 | *Verbascum nigrum* L. | Dark Mullein |
| 98 | *Verbascum thapsus* L. | Great Mullein |
| 99 | *Veronica verna* L. | Spring Speedwell |
| 100 | *Vicia cracca* L. | Tufted Vetch |
| 101 | *Vicia sativa* L. | Common Vetch |
| 102 | *Vicia villosa* L. | Hairy Vetch |
| 103 | *Vicia grandiflora* Scop. | Large-flowered Vetch |
| 104 | *Viola arvensis* Murray | Field Pansy |

# 4. Selected groups of insects

## Introduction

The modern world is characterised by advanced technological thought and a rapid pace of change, which significantly impacts the surrounding environment. New investments often lead to a decrease in environmental value, and sometimes even its complete degradation. To maintain homeostasis, all elements must remain in balance, as they are interdependent and can function properly only under these conditions. The introduction of investments managed sustainably in areas where such balance has been disrupted may partially compensate for the degraded environment and thus increase its biodiversity. However, this is only true when investments are carried out thoughtfully and with care for the environment. In such cases, they mitigate negative actions and sometimes even enhance the ecological value of a given area. Examples of such activities include the construction and sustainable management of photovoltaic farms.

In an era of increasing demand for renewable energy sources, photovoltaic farms have become an integral part of the landscape of modern agriculture. Beyond energy production, they have been observed to significantly impact the natural environment. The way they are designed and managed determines whether the area they occupy will become barren land or an unexpected island of biodiversity. This is of great importance, especially for insects, whose extinction rate has accelerated in recent decades (Forister et al. 2019, Wagner 2020, Dicks et al. 2021). Insects often go unnoticed and unappreciated, yet they play a crucial role in many aspects of the natural environment. They are responsible for decomposing organic matter, are an important part of food chains, and, most importantly, provide the free service of pollinating wild and cultivated plants (Quintero et al. 2010, Stein et al. 2017). Research conducted in the Sulechów Photovoltaic Farm Complex has shown that photovoltaic farms serve as habitats for numerous pollinating insect species, which is significant for crops located nearby. Insects find sources of food, shelter, and for some species, development sites. Similar conclusions have been presented by other researchers in studies conducted across Europe (Blaydes et al. 2021, 2022). Supporting insects in solar farm areas is particularly important on agricultural land characterised by minimal biodiversity, often due to monoculture farming, the removal of trees, shrubs, and hedges, and the use of chemical plant protection agents. Such areas do not provide adequate living conditions for most flora and fauna representatives, as there is insufficient food supply and limited development opportunities (Dirzo et al. 2014, Powers & Jetz 2019). Sustainable management of photovoltaic farms in such spaces makes them important “hotspots” of biodiversity, significantly improving habitat conditions for many flora and fauna representatives. However, inappropriate location and improper management of photovoltaic farms can pose risks to insects. Therefore, it is recommended that farms be built in unproductive, degraded areas with low agricultural value, while avoiding construction on natural or semi-natural habitats with high biodiversity. Improper land management, including the use of chemical herbicides and plant protection agents, depletion of plant cover, and soil erosion, poses a serious threat to insects and all invertebrates, which form the foundation of the functioning ecosystem. This chapter presents the synergy between technology and nature, where modern photovoltaic installations, when properly managed, create new environments that support insect life. Furthermore, it illustrates how, with minimal effort, the area of a photovoltaic farm can be used to preserve species diversity. Additionally, practical methods of their establishment and management are presented, based on scientific research conducted on existing farms worldwide. We hope that our work will raise awareness among all those involved in the broadly understood solar energy sector and transform the image of large-scale photovoltaic farms, turning them into small oases of biodiversity.

The study aimed to conduct a preliminary assessment of selected insect groups inhabiting the Sulechów Photovoltaic Farm Complex. Additionally, it compared the habitat potential of areas planted with nectariferous plants (as part of farm management) to those that underwent spontaneous vegetation succession.

## Methods

The inventory of selected insect groups within the Sulechów Photovoltaic Farm Complex was conducted from April to August in 2023 and 2024. A total of 20 field inspections were carried out during this period, with two inspections each month. Observations were conducted under favourable weather conditions, on sunny and warm days. The primary focus was on two groups of pollinating insects: bees *Anthophila, Apiformes* and butterflies *Rhopalocera*. Preliminary observations of insects from other systematic groups, such as grasshoppers *Orthoptera*, mantises *Mantodea*, and other Hymenoptera, were also made. These additional observations prioritised rare, protected, or faunistically significant species.

The primary method for assessing species diversity and abundance involved counts conducted along five designated linear transects (Fig. 2). Each transect measured 200 metres in length and 2 metres in width (1 metre on each side). Walking a single transect took up to 60 minutes, with observations conducted between 9:00 AM and 5:00 PM. Surveys on individual transects were performed in random order. Two inspections were conducted each month (from April to August in both 2023 and 2024). Insects were identified alive based on intimate work with macro photographic documentation. Species that are difficult to distinguish in flight were caught with an entomological net, immediately photographed and released, under the permission of the Regional Director of Environmental Protection (Decision WPN-I.6401.138.2023.AK, dated 20 March 2023).

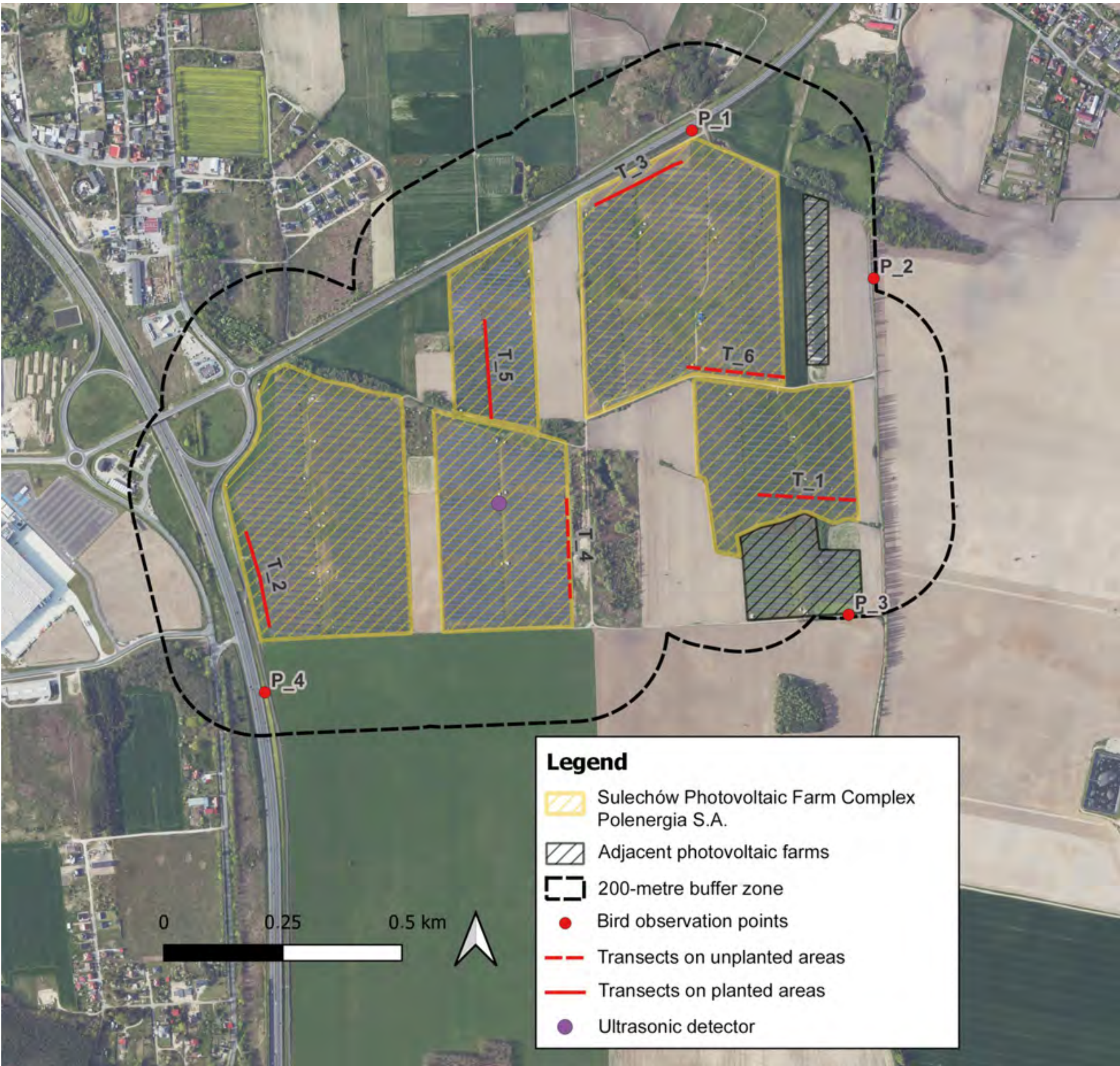


**Figure 2**. Linear transects, bird observation points, and the location of the ultrasonic detector within the study area.
Base map source: Main Office of Geodesy and Cartography

To compare the habitat potential of areas planted with nectariferous/polleniferous plants to those undergoing spontaneous vegetation succession, counts were conducted along six linear transects (five previously described and one additional transect). Observations were conducted on three transects from each habitat type (planted—Photo 2, and unplanted—Photo 3). In addition to recording observed insects, all flowering plants were documented. Plants were determined either in situ or during desk work based on photographic documentation.

**Photo 2.** Photovoltaic farm area planted with flowers for pollinators (photo: A. Dubicka-Czechowska)

**Photo 3.** Photovoltaic farm area undergoing spontaneous plant succession
(photo: A. Dubicka-Czechowska)

# Results

## Bees Anthophila, Apiformes

In Poland, 488 species of bees have been recorded (Banaszak 2004; Banaszak et al. 2013; Wendzonka 2014; Motyka & Bystrowski 2016; Pawlikowski et al. 2016; Twerd 2020; Wendzonka et al. 2020, 2022a, b; Borański et al. 2021; Kierat 2024), classified into six families: Plasterer Bees Colletidae, Leafcutter Bees Megachilidae, Mining Bees Andrenidae, Apidae Bees, Sweat Bees Halictidae, and Melittid Bees Melittidae. In temperate climates, they play the role of the most efficient pollinators of both wild and cultivated plants.

Within the Sulechów Photovoltaic Farm Complex, 42 species of bees were identified (Table 2), representing all systematic families, along with the domesticated Honey Bee *Apis mellifera*.

Bees, regardless of species, require the same basic conditions for survival: an adequate food base, nesting sites, and sometimes specific materials for constructing their nests. The research demonstrated that the study area provides access to a wide variety of blooming flowers, which serve as sources of pollen and nectar throughout the vegetative season. This enables various bee species to thrive despite their diverse dietary preferences (Photo 4).

**Photo 4.** A high diversity of nectar and pollen producing plant species significantly supports pollinating insects (photo: A. Dubicka-Czechowska)

**Table 2.** List of bee species recorded directly within the Sulechów Photovoltaic Farm Complex and their conservation status in Poland: PP – partial protection; ERLB – European Red List of Bees: NT – near threatened, DD – data deficient, LC – least concern; PRB – Polish Red Book of Animals, Invertebrates: EX – extinct; PRL – Polish Red List of Endangered and Threatened Animals: EX – extinct, VU – vulnerable.

| No. | Species | Conservation status |
|---|---|---|
| Plasterer Bees (Colletidae) | | |
| 1 | Early Colletes *Colletes cunicularius* | ERLB-LC |
| 2 | Bare-saddled Colletes *Colletes similis* | ERLB-LC |
| Mining Bees (Andrenidae) | | |
| 3 | Gwynne's Mining Bee *Andrena bicolor* | ERLB-LC |
| 4 | Yellow-legged Mining Bee *Andrena flavipes* | ERLB-LC |
| 5 | White-bellied Mining Bee *Andrena gravida* | ERLB-LC |
| 6 | Orange-tailed Mining Bee *Andrena haemorrhoa* | ERLB-LC |
| 7 | Ashy Mining Bee *Andrena cineraria* | ERLB-LC |
| 8 | Clarke's Mining Bee *Andrena clarkella* | ERLB-LC |
| 9 | Black Mining Bee *Andrena pilipes* | ERLB-LC |
| 10 | Wilke's Mining Bee *Andrena wikella* | ERLB-LC |
| Sweat Bees (Halictidae) | | |
| 11 | Orange-footed Furrow Bee *Lasioglossum xanthopus* | ERLB-NT |
| 12 | Sweat Bees *Lasioglossum* spp. | |
| 13 | Large Blood Bee *Sphecodes albilabris* | ERLB-LC |
| Melittid Bees (Melittidae) | | |
| 14 | Clover Melitta *Melitta leporina* | ERLB-LC |
| 15 | Pantaloon Bee *Dasypoda hirtipes* | ERLB-LC |
| Leafcutter and Mason Bees (Megachilidae) | | |
| 16 | Gold-fringed Mason Bee *Osmia aurulenta* | ERLB-LC |
| 17 | Rape Mason Bee *Osmia brevicornis* | ERLB-LC |
| 18 | Red Mason Bee *Osmia bicornis* | ERLB-LC |
| 19 | Blue Mason Bee *Osmia caerulescens* | ERLB-LC |
| 20 | Banded Mud Bee *Megachile ericetorum* | ERLB-LC |
| 21 | Patchwork Leafcutter Bee *Megachile centuncularis* | ERLB-LC |
| 22 | Coastal Leafcutter Bee *Megachile maritima* | ERLB-DD |
| 23 | Willughby's Leafcutter Bee *Megachile willughbiella* | ERLB-LC |
| 24 | Large-headed Resin Bee *Heriades truncorum* | ERLB-LC |
| 25 | Viper's Bugloss Mason Bee *Hoplitis adunca* | ERLB-LC |
| 26 | Sharp-tailed Bees *Coelioxys* sp. | ERLB-LC |
| Apidae | | |
| 27 | Hairy-footed Flower Bee *Anthophora plumipes* | ERLB-LC; PP |

| No. | Species | Conservation status |
|---|---|---|
| 28 | Brown-banded Carder Bee *Bombus humilis* | ERLB-LC; CzL-VU; PP |
| 29 | Garden Bumblebee *Bombus hortorum* | ERLB-LC; PP |
| 30 | Tree Bumblebee *Bombus hypnorum* | ERLB-LC; PP |
| 31 | Red-tailed Bumblebee *Bombus lapidarius* | ERLB-LC; PP |
| 32 | White-tailed Bumblebee *Bombus lucorum* | ERLB-LC; PP |
| 33 | Common Carder Bee *Bombus pascuorum* | ERLB-LC; PP |
| 34 | Early Bumblebee *Bombus pratorum* | ERLB-LC; PP |
| 35 | Red-Shanked Carder Bee *Bombus ruderarius* | ERLB-LC; PP |
| 36 | Red-tailed Cuckoo Bee *Bombus rupestris* | ERLB-LC |
| 37 | Large Garden Bumblebee *Bombus ruderatus* | ERLB-LC; PRL-VU; PP |
| 38 | Shrill Carder Bee *Bombus sylvarum* | ERLB-LC; PP |
| 39 | Buff-tailed Bumblebee *Bombus terrestris* | ERLB-LC; PP |
| 40 | Violet Carpenter Bee *Xylocopa violacea* | ERLB-LC; PRB-EX; PRL-EX; PP |
| 41 | Painted Nomad Bee *Nomada fucata* | ERLB-LC |
| 42 | Nomad Bees *Nomada* sp. | |

Most of the bees observed in the study area are polylectic species, meaning they collect food (pollen and nectar) from various plant genera and species. Additionally, species with specific food specialisations or those entirely dependent on particular flowers were also recorded. These include the Pantaloon Bee *Dasypoda hirtipes* and the Slender Plasterer Bee *Colletes similis*, which are primarily associated with Asteraceae; the Viper's Bugloss Mason Bee *Hoplitis adunca*, which is faithful to Viper's Bugloss *Echium vulgare*; the Clover Mellita *Melitta leporina*, associated with Fabaceae, particularly lucerne *Medicago* spp.; the Wilke's Mining Bee *Andrena wikella*, associated with Fabaceae; the Clarke's Mining Bee *Andrena clarkella*, associated with Salicaceae; the Rape Mason Bee *Osmia brevicornis*, associated with Brassicaceae; and the Banded Mud Bee *Megachile ericetorum*, associated with Fabaceae.

A significant presence of plants from the families Lamiaceae, Fabaceae, and Boraginaceae was observed on the farm. Among the listed plant genera, the Hairy-footed Flower Bee *Anthophora plumipes* and numerous Bumblebee Species *Bombus* showed strong associations. This likely explains the large number of bumblebee species (12) recorded, accounting for nearly one-third of all species documented in the country (Pawlikowski & Pawlikowski 2012). These included common species such as the Garden Bumblebee *Bombus hortorum*, Tree Bumblebee *B. hypnorum*, Red-tailed Bumblebee *B. lapidarius*, Common Carder Bee *B. pascuorum*, Buff-Tailed Bumblebee *B. terrestris*, Early Bumblebee *B. pratorum*, Red-shanked Carder Bee *B. ruderarius*, and Shrill Carder Bee *B. sylvarum*. The White-tailed Bumblebee, which is also a common species, was observed much less frequently. Females of this species bear a resemblance to females of the Buff-tailed Bumblebee *B. terrestris*, the Cryptic

Bumblebee *B. cryptorum*, and the Northern White-tailed Bumblebee *B. magnus*. This species was identified primarily based on observations of male individuals.

Rare bumblebee species observed during the study included the Brown-banded Carder Bee *Bombus humilis* (Photo 5) and the Large Garden Bumblebee *B. ruderatus*. The former was observed in significant numbers, with sightings of females, males, and young queens, suggesting that this species may have been breeding on the farm or in its immediate vicinity. However, no nests were found. In the Lubusz Voivodeship, the Brown-banded Carder Bee is primarily associated with meadows, though occasional observations have been made in anthropogenic environments such as parks, gardens, and railway verges. The Large Garden Bumblebee *B. ruderatus*, on the other hand, was recorded on three occasions, with all observations being of males. In the Lubusz Voivodeship, this species is primarily associated with extensive meadows in the Warta and Noteć river valleys. It is also rarely encountered in smaller river valleys, transitional habitats, and occasionally on agricultural land within the rural landscape (Dubicka & Czechowski 2020).

**Photo 5.** A rare species – the Brown-Banded Carder Bee *Bombus humilis* – frequently observed at the Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska)

Bees, in addition to food, also require suitable nesting sites. Most species nest in the ground, digging burrows, using existing tunnels, or various other natural cavities. During the study, nesting of several bee species was confirmed. Nests were located on exposed soil patches, primarily along access roads, near transformer station buildings, in numerous rodent burrows, and in vertical sandy walls formed near badger burrows. Active nests of the Buff-tailed Bumblebee *Bombus terrestris* and the Red-tailed Bumblebee *B. lapidarius* were found in abandoned rodent burrows. Nests of the Early Colletes *Colletes cunicularius* and numerous nests of Sweat Bees Halictidae were also observed (Photo 6).

**Photo 6.** A female Sweat Bee *Lasioglossum* sp. digging a nest at the Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska)

Additionally, species potentially capable of nesting within the Sulechów Photovoltaic Farm Complex were identified. These included mining bees such as the Gwynne's Mining Bee *Andrena bicolor*, Yellow-legged Mining Bee *A. flavipes*, Orange-tailed Mining Bee *A. haemorrhoa*, Ashy Mining Bee *A. cineraria*, White-bellied Mining Bee *A. gravida*, Clarke's Mining Bee *A. clarkella*, and the Black Mining Bee *A. pilipes*. Species with other nesting preferences were also recorded, such as the Gold-fringed Mason Bee *Osmia aurulenta*, which nests in abandoned snail shells, and several species of Leafcutter Bees *Megachile* spp., which nest in hollow plant stems, dead wood tunnels, or on stones.

The farm provides only limited development sites for species with such habitat requirements, mainly in the form of dry plant stems, such as those of umbellifers Umbelliferae, thistles *Cirsium* spp., and mulleins *Verbascum* spp. Moreover, the farm area includes two "bee hotels", which have been sparsely occupied by mason bees such as the Red Mason Bee *Osmia bicornis*, Blue Mason Bee *Osmia caerulescens*, Viper's Bugloss Mason Bee *Hoplitis adunca* (Photo 7), and *Heriades* species.

**Photo 7.** Sealed nest of the Viper's Bugloss Mason Bee *Hoplitis adunca* from the Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska)

Bees often require additional materials from the nearby area to construct, line, or seal their nests. These materials include cut fragments of various leaves and flower petals, plant fluff, resin, clay, sand, or small stones. The study area provides all of the materials mentioned above.

Several species of bees that are nest parasites of their hosts were also identified in the study area. These included the Painted Nomad Bee *Nomada fucata*, the Red-tailed Cuckoo Bee *Bombus rupestris*, and bees from the genus *Coelioxys*. The presence of parasitic species can be considered an indicator of a strong host population.

The study also recorded a significant number of bee species (13) under legal protection. These included the Hairy-footed Flower Bee *Anthophora plumipes*, the Violet Carpenter Bee *Xylocopa violacea* (Photo 8), and the following bumblebees: the Brown-banded Carder Bee *Bombus humilis*, Garden Bumblebee *B. hortorum*, Tree Bumblebee *B. hypnorum*, Red-tailed Bumblebee *B. lapidarius*, White-tailed Bumblebee *B. lucorum*, Common Carder Bee *B. pascuorum*, Early Bumblebee *B. pratorum*, Red-shanked Carder Bee *B. ruderarius*, Large Garden Bumblebee *B. ruderatus*, Shrill Carder Bee *B. sylvarum*, and Buff-tailed Bumblebee *B. terrestris*.

**Photo 8.** A male Violet Carpenter Bee *Xylocopa violacea*, a protected species, at the Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska)

## Butterflies Rhopalocera

In Poland, 167 species of butterflies have been recorded (Buszko & Nowacki 2017), belonging to six families: Skippers *Hesperiidae*, Swallowtails *Papilionidae*, Whites *Pieridae*, Blues *Lycaenidae*, Metalmarks *Riodinidae*, and Brush-footed Butterflies *Nymphalidae*.

During the research conducted within the Sulechów Photovoltaic Farm Complex, 32 butterfly species were identified (Table 3), some of which successfully breed in the area. This diversity represents 19% of Poland's butterfly fauna and 34% of those documented in the Lubusz Voivodeship (Buszko & Nowacki 2017). Most of the observed species are widespread, often abundant, and common. Based on available literature (Blab & Kudrna 1982; Beneš et al. 2002), the recorded butterflies can be assigned to several ecological groups. Ubiquitous species associated with a wide range of habitats dominated (47%), with a similar share of mesophilic species linked to open and transitional areas (44%). Additionally, two species were classified as xerothermophilic, and one as hygrophilic.

**Table 3.** List of butterfly species recorded within the Sulechów Photovoltaic Farm Complex and their conservation status in Poland. Conservation status: SP – strict protection, PP – partial protection, PRB – Polish Red Book of Animals, Invertebrates, PRL – Polish Red List of Endangered and Threatened Animals, LR – lower risk, VU – vulnerable, LC – least concern. Ecological groups: M – Mesotrophs; U – Ubiquists; X – Xerophytes; H – hygrophilic.

| No. | Species | Conservation status | Ecological group |
|---|---|---|---|
| Skippers Hesperiidae | | | |
| 1 | Essex Skipper *Thymelicus lineola* | | M |
| 2 | Small Skipper *Thymelicus sylvestris* | | M |
| 3 | Large Skipper *Ochlodes sylvanus* | | U |
| Swallowtails Papilionidae | | | |
| 4 | Scarce Swallowtail *Iphiclides podalirius* | PRB-VU; PRL-VU; PP | X |
| 5 | Old World Swallowtail *Papilio machaon* | PRL-LC | U |
| Pieridae – whites and yellows | | | |
| 6 | Wood White *Leptidea* sp. | | M |
| 7 | Orange-tip *Anthocharis cardamines* | | M |
| 8 | Large White *Pieris brassicae* | | U |
| 9 | Green-Veined White *Pieris napi* | | U |
| 10 | Small White *Pieris rapae* | | U |
| 11 | Pale Clouded Yellow *Colias hyale* | | U |
| 12 | Brimstone *Gonepteryx rhamni* | | M |
| Lycaenidae – blues, coppers, and hairstreaks | | | |
| 13 | Large Copper *Lycaena dispar* | PRB-LR; PRL-LC; SP | H |
| 14 | Small Copper *Lycaena phlaeas* | | U |

| No. | Species | Conservation status | Ecological group |
|---|---|---|---|
| 15 | Sooty Copper *Lycaena tityrus* | | M |
| 16 | Scarce Copper *Lycaena virgaureae* | | M |
| 17 | Brown Hairstreak *Thecla betulae* | | M |
| 18 | Short-tailed Blue *Cupido argiades* | | M |
| 19 | Holly Blue *Celastrina argiolus* | | M |
| 20 | Brown Argus *Aricia agestis* | | X |
| 21 | Common Blue *Polyommatus icarus* | | U |
| Nymphalidae – brush-footed butterflies | | | |
| 22 | Queen Of Spain Fritillary *Issoria lathonia* | | U |
| 23 | Weaver's Fritillary *Boloria dia* | | M |
| 24 | Red Admiral *Vanessa atalanta* | | U |
| 25 | Painted Lady *Vanessa cardui* | | U |
| 26 | Peacock *Inachis io* | | U |
| 27 | Comma *Polygonia c-album* | | M |
| 28 | Wall Brown *Lasiommata megera* | | U |
| 29 | Chestnut Heath *Coenonympha glycerion* | | M |
| 30 | Small Heath *Coenonympha pamphilus* | | U |
| 31 | Meadow Brown *Maniola jurtina* | | U |
| 32 | Marbled White *Melanargia galathea* | | M |

Of the 32 identified species, only two are protected. Among those under strict protection, the Large Copper *Lycaena dispar* (Photo 9) was recorded. This butterfly is also listed in Annexes II and IV of the Habitats Directive and in the *Polish Red Data Book of Animals: Invertebrates* as a species of Lower Risk (LR) (Głowaciński & Nowacki 2004) and on the Polish Red List of Threatened and Endangered Animals as Least Concern (LC) (Buszko & Nowacki 2002). There is a strong likelihood that this butterfly breeds within the farm area, as evidenced by observations of both sexes and the presence of host plants for its larvae (several species of sorrels, *Rumex* spp.).

The second protected species is the Scarce Swallowtail *Iphiclides podalirius*, which is partially protected in Poland. It is also listed in the *Polish Red Data Book of Animals: Invertebrates* as a Vulnerable species (VU) (Głowaciński & Nowacki 2004) and on the Polish Red List of Threatened and Endangered Animals as Vulnerable (VU) (Buszko & Nowacki 2002). Its caterpillars feed on trees and shrubs from the rose family *Rosaceae*, often on Blackthorn *Prunus spinosa* and, in Lubusz Voivodeship, on Black Cherry *Prunus serotina*. Butterflies observed within the studied area are likely breeding outside the farm complex in locations where their host plants are present. In recent years, this species has been increasingly widespread in Lubusz Voivodeship and across the country (Gajda et al. 2020, Sielezniew & Sielezniew 2024).

**Photo 9.** A female Large Copper Butterfly *Lycaena dispar*, a protected species, at the Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska)

Additionally, one species listed on the Polish Red List of Threatened and Endangered Animals was recorded: the Old World Swallowtail *Papilio machaon*, classified as Least Concern (LC) (Buszko & Nowacki 2002). The Old World Swallowtail is associated with open landscapes such as meadows, clearings, and fallow lands, and is considered a common species (Buszko & Masłowski 2015).

Several other noteworthy species, not protected or included in lists of threatened taxa, were also observed. These are butterflies characteristic of specific habitats, considered uncommon, rarely seen, forming small populations, or having a limited range in the country. Three such species were recorded within the farm area:

The Brown Hairstreak *Thecla betulae*, which is widespread in Poland but not often encountered, usually seen individually (Buszko & Masłowski 2015).

The Short-tailed Blue *Cupido argiades*, which is expanding its range and/or returning to previously occupied sites. In Lubusz Voivodeship, it has been observed at an increasing number of locations over the last 20 years (Gajda et al. 2020).

The Wall Brown *Lasiommata megera*, which is widespread in Poland but exhibits fluctuations in abundance across different years. In Lubusz Voivodeship, it is not commonly found (Gajda et al. 2020, Czechowski et al., unpublished data).

## Other selected insect groups

The study also identified the presence of "noteworthy" insects from other systematic groups within the study area. Table 4 lists rare, protected, and faunistically interesting species (e.g., invasive species). Among them, European Mantis *Mantis religiosa*, (Photo 10) was observed on several occasions. This strictly protected species has been expanding its range in Poland in recent years, moving northward and westward (Żurawlew et al., 2022). However, its reproduction within the study area could not be confirmed.

**Photo 10**. A protected insect species – the European Mantis *Mantis religiosa* – at the Sulechów Photovoltaic Farm Complex (photo: P. Czechowski)

**Table 4.** List of rare insect species from other taxonomic groups recorded in the Sulechów Photovoltaic Farm Complex and their conservation status in Poland: SP – strict protection, PP – partial protection; PRB – Polish Red Book of Animals, Invertebrates: EN – endangered, VU – vulnerable; PRL – Polish Red List of Endangered and Threatened Animals: CR – critically endangered, NT – near threatened.

| No. | Species | Conservation status |
|---|---|---|
| Mantises Mantodea | | |
| 1 | European Mantis *Mantis religiosa* | PRB-EN, PRL-CR; SP |
| Orthopterans Orthoptera | | |
| 2 | Sickle-bearing Bush-cricket *Phaneroptera falcata* | PRL-NT |
| 3 | Italian Locust *Calliptamus italicus* | PRB-EN, PRL-CR |
| 4 | Blue-winged Grasshopper *Oedipoda caerulescens* | PRL-NT |
| 5 | Field Cricket *Gryllus campestris* | PRL-NT |
| Thread-waisted wasps Sphecidae | | |
| 6 | Golden Digger Wasp *Sphex funerarius* | |
| Scoliid wasps Scoliidae | | |
| 8 | Six-spotted Scoliid Wasp *Scolia sexmaculata* | |
| 9 | Hairy Scoliid Wasp *Scolia hirta* | PRB-VU |
| Invasive species | | |
| 10 | Box Tree Moth *Cydalima perspectalis* | |
| 11 | Buffalo Treehopper *Stictocephala bisonia* | |

Among Orthopteran insects, several species listed in red lists were recorded. the Italian Locust *Calliptamus italicus*, classified as Endangered (EN) in the *Polish Red Data Book of Animals: Invertebrates* (Liana, 2004) and Critically Endangered (CR) on the Polish Red List of Threatened and Endangered Animals (Liana, 2002), was noted. This species occurs in two regions of Poland and is currently expanding, being common in the Lubusz Voivodeship. Three other Orthopteran species found in the study area—Sickle-bearing Bush-cricket *Phaneroptera falcata*, Blue-winged Grasshopper *Oedipoda caerulescens*, and Field Cricket *Gryllus campestris*—are listed as Near Threatened (NT) on the Polish Red List (Liana, 2002).

Historically, the Sickle-bearing Bush-cricket was primarily found in southeastern Poland but is now observed throughout the country (Żurawlew et al., 2017). The other two species are widely distributed across Poland. The Red-winged Wasp *Sphex funerarius*, listed in Table 4, was once considered rare but has become increasingly numerous and widely distributed in recent years (e.g., Szymkiewicz & Szymkiewicz, 2014). Similarly, two listed species of Digger Wasps *Sphex* spp. have expanded their range and are now found in many new locations within the country (e.g., Smolis et al., 2019).

Invasive insect species were also recorded during the study, including the Box Tree Moth *Cydalima perspectalis*, which likely arrived from neighbouring areas, and the Buffalo Treehopper *Stictocephala bisonia*, whose status remains uncertain.

Further entomological studies are needed to obtain a complete picture of the insect diversity in the study area.

The research also enabled a comparison of the habitat potential of planted and unplanted areas (with nectariferous plants) within the farm.

In the planted areas (transects), a total of 52 nectar- and pollen-producing plant species were recorded, compared to 41 species in the unplanted areas (Table 5).

**Table 5.** Comparison of the species composition of nectar- and pollen-producing plants (potential food base for pollinating insects) in unplanted and planted areas within the Sulechów Photovoltaic Farm Complex.

| No. | Plant species | Unplanted areas | Planted areas |
|---|---|---|---|
| 1 | Ribwort Plantain *Plantago lanceolata* | + | + |
| 2 | White Campion *Silene latifolia* | | + |
| 3 | Small-flowered Cranesbill *Geranium pussilum* | + | + |
| 4 | Ground-ivy *Glechoma hederacea* | | + |
| 5 | Small Bugloss *Anchusa arvensis* | + | + |
| 6 | Cornflower *Centaurea cyanus* | | + |
| 7 | Common fumitory *Fumaria officinalis* | | + |
| 8 | Lacy Phacelia *Phacelia tanacetifolia* | | + |
| 9 | Field Pansy *Viola arvensis* | + | + |
| 10 | Greater Celandine *Chelidonium majus* | + | + |
| 11 | Proliferous Pink *Petrorhagia prolifera* | + | + |
| 12 | Common Stork's-bill *Erodium cicutarium* | + | + |
| 13 | Creeping Buttercup *Ranunculus repens* | | + |
| 14 | Red Dead-nettle *Lamium purpureum* | + | + |
| 15 | Sheep's-bit *Jasione montana* | + | |
| 16 | Oxeye Daisy *Leucanthemum vulgare* | + | + |
| 17 | Dwarf Everlast *Helichrysum arenarium* | + | |
| 18 | Bird's-foot Trefoil *Lotus corniculatus* | + | + |
| 19 | White Clover *Trifolium repens* | + | + |
| 20 | Alsike Clover *Trifolium hybridum* | | + |
| 21 | Lesser Trefoil *Trifolium dubium* | + | |
| 22 | Crimson Clover *Trifolium incarnatum* | | + |
| 23 | Golden Clover *Trifolium aureum* | | |
| 24 | Red Clover *Trifolium pratense* | + | + |
| 25 | Meadow Salsify *Tragopogon pratensis* | | + |

| No. | Plant species | Unplanted areas | Planted areas |
|---|---|---|---|
| 26 | Mouse-ear Hawkweed *Pilosella officinarum* | + | + |
| 27 | Common Yarrow *Achillea millefolium* | + | |
| 28 | Salad Burnet *Sanguisorba minor* | | + |
| 29 | Wild Marjoram *Origanum vulgare* | + | + |
| 30 | Black Medick *Medicago lupulina* | | + |
| 31 | Alfalfa *Medicago sativa* | + | + |
| 32 | Nipplewort *Lapsana communis* | + | + |
| 33 | Prickly Poppy *Papaver argemone* | | + |
| 34 | Common Poppy *Papaver rhoeas* | + | + |
| 35 | Wild Carrot *Daucus carota* | + | + |
| 36 | Dandelion *Taraxacum* sp. | + | + |
| 37 | Goldenrod *Solidago* spp. | + | |
| 38 | Field Forget-me-not *Myosotis arvensis* | + | + |
| 39 | Yellow Sweet Clover *Melilotus officinalis* | | + |
| 40 | Borage *Borago officinalis* | | + |
| 41 | Spear Thistle *Cirsium vulgare* | | + |
| 42 | Creeping Thistle *Cirsium arvense* | + | + |
| 43 | Hawk's-beard *Crepis* sp. | + | + |
| 44 | Silver Cinquefoil *Potentilla argentea* | + | |
| 45 | Field Bindweed *Convolvulus arvensis* | + | + |
| 46 | Hairy Cat's Ear *Hypochaeris radicata* | + | + |
| 47 | Spring Speedwell *Veronica verna* | + | + |
| 48 | Annual Fleabane *Erigeron annuus* | + | + |
| 49 | Hedge Bedstraw *Galium mollugo* | | + |
| 50 | Hoary Alyssum *Berteroa incana* | + | + |
| 51 | Scentless Mayweed *Tripleurospermum inodorum* | + | + |
| 52 | Field Mouse-ear *Cerastium arvense* | + | + |
| 53 | Rapeseed *Brassica napus* var. *napus* | + | |
| 54 | Eastern Groundsel *Senecio vernalis* | + | + |
| 55 | Common Ragwort *Jacobaea vulgaris* | + | + |
| 56 | Sainfoin *Onobrychis viciifolia* | | + |
| 57 | Shepherd's Purse *Capsella bursa-pastoris* | + | + |
| 58 | Large-flowered Vetch *Vicia grandiflora* | + | |
| 59 | Hairy Vetch *Vicia villosa* | + | + |
| 60 | Common Vetch *Vicia sativa* | | |
| 61 | Cypress Spurge *Euphorbia cyparissias* | | + |
| 62 | Viper's Bugloss *Echium vulgare* | | + |

The percentage of flower coverage was significantly higher in the planted transects, averaging 60% (range: 20–100%), compared to 20% (range: 10–30%) in the unplanted areas. Similarly, the species diversity of pollinating insects was greater in the planted areas, with 41 species recorded, compared to 24 species in the unplanted areas (Table 6).

**Table 6.** Summary of pollinating insect species recorded in unplanted and planted areas within the Sulechów Photovoltaic Farm Complex.

| No. | Pollinating insect species | Unplanted areas | Planted areas |
|---|---|---|---|
| 1 | Green-veined White *Pieris napi* | + | + |
| 2 | Large White *Pieris brassicae* | | + |
| 3 | Small White *Pieris rapae* | + | + |
| 4 | Sooty Copper *Lycaena tityrus* | + | + |
| 5 | Small Copper *Lycaena phlaeas* | + | + |
| 6 | Queen of Spain Fritillary *Issoria lathonia* | + | + |
| 7 | Brimstone *Gonepteryx rhamni* | + | + |
| 8 | Plasterer Bee *Colletes* sp. | + | |
| 9 | Willughby's Leafcutter Bee *Megachile willughbiella* | | + |
| 10 | Banded Mud Bee *Megachile ericetorum* | | + |
| 11 | Brown Argus *Aricia agestis* | | + |
| 12 | Common Blue *Polyommatus icarus* | + | + |
| 13 | Gold-fringed Mason Bee *Osmia aurulenta* | | + |
| 14 | Red Mason Bee *Osmia bicornis* | | + |
| 15 | Rape Mason Bee *Osmia brevicornis* | | + |
| 16 | Pantaloon Bee *Dasypoda hirtipes* | + | + |
| 17 | Marbled White *Melanargia galathea* | | + |
| 18 | Hairy-footed Flower Bee *Anthophora plumipes* | + | + |
| 19 | Meadow Brown *Maniola jurtina* | + | + |
| 20 | Yellow-legged Furrow Bee *Lasioglossum xanthopus* | | + |
| 21 | Sweat Bee *Lasioglossum* sp. | + | + |
| 22 | Ashy Mining Bee *Andrena cineraria* | | + |
| 23 | Clark's Mining Bee *Andrena clarkella* | + | |
| 24 | Yellow-legged Mining Bee *Andrena flavipes* | + | + |
| 25 | Honey Bee *Apis mellifera* | + | + |
| 26 | Red Admiral *Vanessa atalanta* | | + |
| 27 | Painted Lady *Vanessa cardui* | | + |
| 28 | Peacock *Aglais io* | + | + |
| 29 | Clover Melitta *Melitta leporina* | | + |

| No. | Pollinating insect species | Unplanted areas | Planted areas |
|---|---|---|---|
| 30 | Small Heath *Coenonympha pamphilus* | + | + |
| 31 | Pale Clouded Yellow *Colias hyale* | + | + |
| 32 | Sharp-tailed Bee *Coelioxys* sp. | + | |
| 33 | Large Garden Bumblebee *Bombus ruderatus* | | + |
| 34 | Red-tailed Bumblebee *Bombus lapidarius* | + | + |
| 35 | Early Bumblebee *Bombus pratorum* | | + |
| 36 | Garden Bumblebee *Bombus hortorum* | + | + |
| 37 | Tree Bumblebee *Bombus hypnorum* | | + |
| 38 | Red-shanked Carder Bee *Bombus ruderarius* | | + |
| 39 | Shrill Carder Bee *Bombus sylvarum* | | + |
| 40 | Common Carder Bee *Bombus pascuorum* | | + |
| 41 | Brown-banded Carder Bee *Bombus humilis* | | + |
| 42 | *Bombus sensu stricto* | + | + |
| 43 | Red-tailed Cuckoo Bee *Bombus rupestris* | + | |
| 44 | Violet Carpenter Bee *Xylocopa violacea* | | + |
| 45 | Orange Tip *Anthocharis cardamines* | + | + |

## Summary

The ecological studies conducted within the Sulechów Photovoltaic Farm Complex revealed a relatively rich fauna of pollinating insects. Among the two thoroughly studied groups, 42 species of bees and 32 species of butterflies were identified. The inventory of bees included 13 species under partial protection, while the butterflies included one species under strict protection and one under partial protection.

Other insect groups observed within the farm complex included the strictly protected European Mantis *Mantis religiosa*.

The farm area had previously been partially planted with pollinator-friendly plant mixtures, resulting in a relatively diverse composition of pollen- and nectar-producing plants. The comparison of planted and unplanted areas showed that the species diversity and abundance of plants and pollinating insects were significantly lower in the unplanted areas.

In conclusion, the research indicates that the current management practices within the Sulechów Photovoltaic Farm Complex are appropriate and provide a rich food base for many pollinator species. The flora in the study area includes host plants for the larvae of various butterfly species. Additionally, the farm area offers favourable conditions for the development (nest construction) of numerous ground-nesting bee species.

# 5. Amphibians and reptiles

Land designated for photovoltaic farms can serve as potential habitats for amphibians and reptiles, provided that suitable features used by herpetofauna exist within or near them, such as ponds, small water bodies, piles of stones or sand, and that access to the farm is not obstructed, for example, by a concrete fence foundation. For amphibians, the presence of water bodies with clean, usually shallow water, free from large numbers of fish, is crucial—particularly those with lush riparian vegetation or partially gravelled bottoms along their shores.

Amphibians also require the presence of meadows, fallow land, deciduous or mixed forests, and tree stands in the vicinity, as these habitats are frequently used during the post-breeding period. A specific type of "fallow land" can be found within the Sulechów Photovoltaic Farm Complex, where herbaceous vegetation is maintained. Within this area, a single amphibian species—the Common Toad—was recorded (Photos 11 and 12).

**Photo 11**. Common Toad *Bufo bufo* at the Sulechów Photovoltaic Farm Complex (photo: O. Ciebiera)

**Photo 12**. Mating Common Toads *Bufo bufo* near a water reservoir located between sections of the Sulechów Photovoltaic Farm Complex (photo: O. Ciebiera)

Individuals were observed burrowing in the grass and migrating across different parts of the farm, with their primary concentration around the water body situated between its sections. In this pond and in adjacent ones located to the north and north-east, populations of the following amphibian species were recorded, based on acoustic monitoring and direct observations of migrating individuals (Table 7).

The network of ditches and water bodies in the area of the Photovoltaic Farm Complex is favourable for amphibian migration towards the south and south-east. Species mentioned above are likely to use the farm area to move between these water bodies (Figure 3). The central ponds are the largest and feature a particularly diverse range of habitats, shoreline structures, and aquatic vegetation. However, during the study, degradation and infilling with rubble were observed in the pond located to the west of the road (Figure 3). The remaining ponds, although smaller, are equally important within the region's water system.

**Table 7.** List of amphibian species recorded within the Sulechów Photovoltaic Farm Complex and their conservation status in Poland: SP – strict protection, PP – partial protection, N2000 – species listed in Annex II of the Habitats Directive.

| No. | Species | Conservation status |
|---|---|---|
| 1 | Edible Frog *Pelophylax esculentus* | PP |
| 2 | Common Frog *Rana temporaria* | PP |
| 3 | Moor Frog *Rana arvalis* | SP |
| 4 | Smooth Newt *Lissotriton vulgaris* | PP |
| 5 | Fire-bellied Toad *Bombina bombina* | SP, N2000 |
| 6 | European Tree Frog *Hyla arborea* | SP, N2000 |
| 7 | Common Toad *Bufo bufo* | PP |

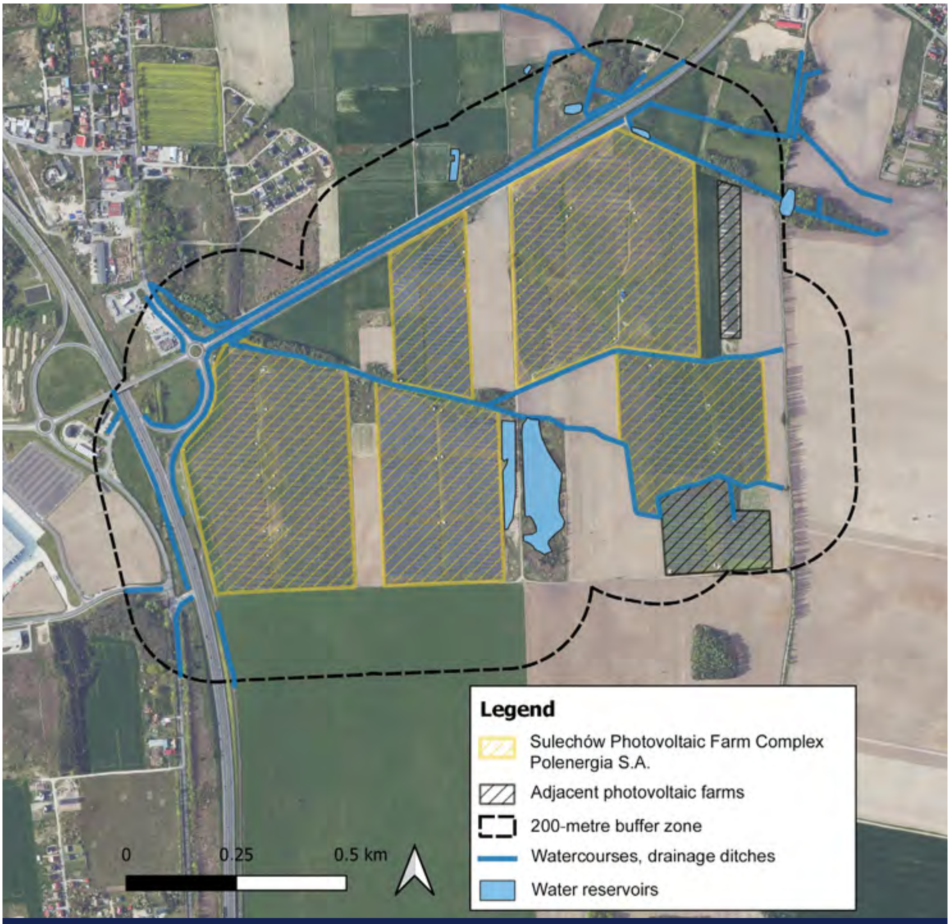


**Figure 3**. Layout of ditches and water reservoirs in the Sulechów Photovoltaic Farm Complex area. Base map source: Main Office of Geodesy and Cartography

The smallest “northern” pond retains water year-round (Photo 13), unlike the eastern pond within a wooded area, which dries out in the summer. Two of the largest ponds, situated north of National Road 32, are permanent water bodies with year-round water retention. The drainage ditches, however, only carry water periodically.

**Photo 13**. Water reservoir located at the northern boundary of the Sulechów Photovoltaic Farm Complex (photo: O. Ciebiera)

The reptile species recorded within the Sulechów Photovoltaic Farm Complex include the Sand Lizard (Photo 14). Other reptile species, namely the Viviparous Lizard, the Slow Worm, and the Grass Snake, were observed outside the farm’s boundaries but in its immediate vicinity, along the edges of wooded areas and near damp ditches and water bodies. The Sand Lizard readily utilised intentionally created stone piles within the Photovoltaic Farm Complex, as well as areas surrounding transformers and abandoned infrastructure on the ground (e.g., frames, panels, tanks, etc.). Beyond these areas, it was also found on the embankments of roads S3 and DK 32.

**Photo 14**. Sand Lizard *Lacerta agilis* readily inhabiting the open areas of the Sulechów Photovoltaic Farm Complex (photo: O. Ciebiera)

All the reptile species mentioned above are subject to partial protection under the Regulation of the Minister of the Environment of 16 December 2016 on species protection of animals (Journal of Laws, 2022, item 2380).

Amphibians are the most threatened group of vertebrates, with population declines observed worldwide (Luedtke et al., 2023). The most significant causes of this decline include habitat change and degradation, landscape fragmentation, UV radiation, road collisions, and diseases caused by viruses (Greenberg & Palen, 2019). These factors prevent amphibians from reproducing in clean waters in various regions of the world, particularly in areas where agriculture is highly intensified, and forest, water body, and wetland degradation is progressing.

As a result, integrating key amphibian habitats to ensure connectivity and facilitate easier dispersal is crucial and requires action across various spatial planning and nature conservation strategies. The same applies to reptiles: according to European Commission data (eea.europa.eu/data-and-maps/figures/trends-of-european-amphibians-reptiles, online access; accessed: 26.07.2024), over 41% of reptile populations show a declining trend, while the status of more than 13% remains uncertain.

It is therefore worth considering whether and how photovoltaic farms can support local amphibian and reptile populations within the mosaic of Poland's diverse environments. Proper planning, farm siting, and biodiversity management can undoubtedly provide positive benefits for reptiles—firstly, by at least not contributing to population declines, and secondly, by facilitating population growth when additional conservation measures are implemented within the farms.

Photovoltaic farms, being enclosed areas inaccessible to humans and free from agricultural activities, are devoid of pollutants such as pesticides, herbicides, and fertilisers. With naturally occurring or intentionally introduced native plant species, these areas can serve as attractive hunting and foraging grounds for amphibians. Additionally, maintaining local water bodies—and in some cases, restoring or constructing new ponds designed to support amphibians—offers an effective means of aiding local populations and expanding and maintaining a broader ecological connectivity network.

Such measures are already being implemented on some photovoltaic farms in Germany, where shallow water bodies have been created specifically for the Green Toad (Peschel, 2010).

# 6. Birds

## Introduction

The observed growth of photovoltaic energy in Poland and globally impacts the natural environment and can affect its various elements on an increasingly large scale. These impacts extend to avifauna as well (e.g., DeVault et al., 2014; Jenkins et al., 2015; Harrison et al., 2017; Taylor et al., 2019; Kosciuch et al., 2020; Lafitte, 2023). However, assessing the actual effects of photovoltaic installations on birds and their habitats is challenging. This is primarily due to the variability in baseline data collected from diverse facilities located in different regions and habitats (reviewed in Pięta, 2020).

The construction of large-scale photovoltaic farms can lead to negative effects, such as reducing the spatial diversity of bird communities. This occurs when agricultural land is withdrawn from production or when elements of the agricultural landscape are simplified (e.g., removal of marginal habitats, shrubs, and hedgerows). These changes can reduce the spatial heterogeneity of bird habitats (Pięta, 2020—analysis of 32 documents on the potential effects of photovoltaic farms on birds).

Photovoltaic farms can also have positive impacts, provided their location and biological structure are carefully planned. Properly sited farms, especially in areas not intensively used by birds, can create alternative foraging grounds (e.g., grassy patches and shrubs between panels and sectors) and nesting sites (e.g., nests on support structures) (Tryjanowski & Łuczak, 2013).

Monitoring data from photovoltaic farms collected by the Leipziger Institut für Energie indicate that such areas are often used as breeding habitats by farmland birds, such as the Yellowhammer and Skylark. Additionally, solar panel structures have been used for nesting, for instance, by White Wagtails (cited in Pięta, 2020).

Well-designed and managed photovoltaic farms located in intensively used and biologically impoverished agricultural landscapes can become important biodiversity hotspots. These farms create microhabitats that serve as vital nesting and foraging sites for various bird species. Research from Germany highlights the positive role of peripheral farm areas and spaces between panel sectors. These areas are frequently used as hunting and feeding grounds by many bird species (multiple examples from Germany, cited in Pięta, 2020).

Studies show that photovoltaic farms can positively impact overall biodiversity. However, this depends on the willingness of investors to engage in environmental consultations. While construction activities inevitably interfere with existing flora and fauna, a well-planned investment can improve environmental quality and even create new, more diverse habitats for many plant and animal species.

Ultimately, such measures, combined with an existing network of biotopes, contribute to increased biodiversity in the area, which positively affects local bird populations (Pięta, 2020).

For every investment, it is crucial to assess potential losses and benefits for local bird populations, particularly with regard to sensitive, key, or rare species.

# Methods

## Breeding bird surveys

Breeding bird surveys within the Sulechów Photovoltaic Farm Complex were conducted between April and June 2023. A total of seven surveys were completed. Observations involved recording all birds present within the farm area and categorising their occurrence (breeding or likely breeding species) based on behaviours such as singing, courtship displays, foraging, and nest building.

## Surveys of birds of prey

Birds of prey observations were carried out from April 2023 to April 2024, with 39 surveys conducted during this period. Observations were spaced approximately ten days apart each month, although in some cases, poor weather conditions required rescheduling to ensure meaningful results.

Four observation points were designated within the farm area (Fig. 2) to maximise visual coverage of the photovoltaic farm and its surrounding areas (e.g., neighbouring fields and nearby roads). Each observation session lasted one hour per point, resulting in four hours of observation per survey. Sessions began in the morning (8:00–10:00) and concluded in the early afternoon (12:00–14:00).

During birds of prey surveys, every observation was recorded, noting the location, species, number of individuals, sex/age (if identifiable), and the nature of the bird's activity. Observation categories included:

- **Location Type:** Photovoltaic farm area, roads, fields, other (e.g., nearby ponds, wooded areas, tree rows).
- **Behaviour:** Hunting, resting/perching, local or migratory flight. For resting/perching birds within the farm, the specific resting site was noted (e.g., panels, fences, power lines/poles, transformer buildings).

## Comprehensive bird monitoring

From April 2023 to May 2024, during surveys focused on breeding birds and birds of prey, all avifauna (migratory, overwintering, and roving birds) were also observed. For every bird observed within the farm area or its immediate surroundings (up to 200 metres from the photovoltaic farm's edge), its status was recorded. In total, 40 survey days were conducted.

# Results

From April 2023 to April 2024, 106 bird species were recorded within the Sulechów Photovoltaic Farm Complex and its immediate vicinity (up to 200 metres from the photovoltaic farm's boundary).

## Breeding bird species within the Sulechów Photovoltaic Farm Complex

In 2023, 13 bird species were confirmed or likely to have bred within the Sulechów Photovoltaic Farm Complex (inside the fenced area, between the panels) (Table 8). Additionally, in 2024, a nesting attempt by the Tree Sparrow was recorded.

**Table 8.** Composition and abundance of breeding bird fauna within the Sulechów Photovoltaic Farm Complex. Status in Poland (Chodkiewicz et al. 2015): VA – very abundant, A – abundant, MA – moderately abundant; conservation status: SP – strictly protected, BD – species listed in Annex I of the Birds Directive.

| No. | Species | Number of territories | Density (p./10 ha) | Dominance (%) | Status in Poland | Conservation status |
|---|---|---|---|---|---|---|
| 1 | Red-backed Shrike *Lanius collurio* | 2 | 0.3 | 3.5 | A | SP, BD |
| 2 | Skylark *Alauda arvensis* | 30 | 4.6 | 52.6 | VA | SP |
| 3 | Crested Lark *Galerida cristata* | 1 | 0.2 | 1.8 | MA | SP |
| 4 | Barred Warbler *Curruca nisoria* | 1 | 0.2 | 1.8 | MA | SP, BD |
| 5 | Common Whitethroat *Curruca communis* | 1 | 0.2 | 1.8 | A | SP |
| 6 | Whinchat *Saxicola rubetra* | 1 | 0.2 | 1.8 | A | SP |
| 7 | European Stonechat *Saxicola rubicola* | 2 | 0.3 | 3.5 | MA | SP |
| 8 | Northern Wheatear *Oenanthe oenanthe* | 2 | 0.3 | 3.5 | MA | SP |
| 9 | Common Blackbird *Turdus merula* | 1 | 0.2 | 1.8 | A | SP |
| 10 | Tree Sparrow *Passer montanus* | 1 | 0.2 | 1.8 | A | SP |
| 11 | Yellow Wagtail *Motacilla flava* | 1 | 0.2 | 1.8 | A | SP |

| No. | Species | Number of territories | Density (p./10 ha) | Dominance (%) | Status in Poland | Conservation status |
|---|---|---|---|---|---|---|
| 12 | Common Linnet *Linaria cannabina* | 2 | 0.3 | 3.5 | A | SP |
| 13 | Corn Bunting *Emberiza calandra* | 8 | 1.2 | 14.0 | A | SP |
| 14 | Yellowhammer *Emberiza citrinella* | 4 | 0.6 | 7.0 | VA | SP |
| Total | | 57 | 8.6 | 100.0 | | |

Three species—the Blackbird, Red-backed Shrike, and Common Linnet—had breeding territories partially located within the farm. The nests of the remaining 11 species (including Skylark, Crested Lark, Barred Warbler, Common Whitethroat, Whinchat, European Stonechat, Northern Wheatear, Tree Sparrow, Yellow Wagtail, Corn Bunting, and Yellowhammer) were located within the farm for at least some pairs.

The Skylark was the most numerous breeding species within the farm, with 30 pairs recorded (Photo 15), representing 53.6% of the entire breeding assemblage. Other dominant species (each exceeding 5% of the total) included the Corn Bunting (14.3%) and Yellowhammer (7.1%). The remaining species collectively accounted for 25.0% of all territories.

**Photo 15**. Skylark *Alauda arvensis* nest situated among vegetation at the Sulechów Photovoltaic Farm Complex (photo: P. Czechowski)

A total of 56 bird territories were recorded within the farm area, resulting in a density of 8.6 territories per 10 hectares.

Due to the environmental characteristics of photovoltaic farms (predominance of open spaces, limited shrubs and trees), ground-nesting or low vegetation-nesting birds dominated the assemblage, representing 82.1% of territories across seven species (Skylark, Crested Lark, Whinchat, Stonechat, Yellow Wagtail, Corn Bunting, and Yellowhammer).

The next group included four shrub-nesting species (Red-backed Shrike – Photo 16, Barred Warbler, Common Whitethroat, and Common Linnet). The Northern Wheatear nested in stone piles located within the farm (Photo 17), while the Tree Sparrow preferred nesting boxes or cracks/holes in buildings.

The breeding bird community included two species listed in Annex I of the EU Birds Directive: the Red-backed Shrike and the Barred Warbler. Their presence highlights the potential of photovoltaic farms to support species of conservation concern when properly managed.

**Photo 16**. A female Red-backed Shrike *Lanius collurio* – a breeding species at the Sulechów Photovoltaic Farm Complex. Birds frequently perched on power plant infrastructure, such as fencing (photo: P. Czechowski)

**Photo 17.** Northern Wheatear *Oenanthe oenanthe* – nesting in rock piles and using solar panels as singing perches (photo: P. Czechowski)

## Breeding bird species in the vicinity of the Sulechów Photovoltaic Farm Complex

The habitat mosaic surrounding the Sulechów Photovoltaic Farm Complex, comprising open areas (fields, fallow lands), small woodlands, tree alleys, shrub strips and clusters, as well as aquatic environments such as ponds, supports a relatively rich and diverse avifauna. Within a 200-metre buffer zone around the farm, 56 bird species were recorded as breeding (Table 9).

Habitat preferences of breeding birds:

- **Forest birds** (39.3%): Species associated with woodland habitats included Woodpeckers, Golden Oriole, Tits, Leaf Warblers, Sylviid Warblers, Wren, Starling, Thrushes, and Chaffinch.

- **Farmland birds** (33.9%): Species linked to agricultural landscapes included the Common Quail, Red-backed Shrike, Skylark, Common Whitethroat, Whinchat, Yellow Wagtail, Goldfinch, and Yellowhammer.
- **Birds of anthropogenic and broad habitats**: Some species, such as the Tree Sparrow and White Wagtail), nested in a wide range of habitats, including areas influenced by human activity.

The avifauna in the vicinity of the farm was dominated by widespread species classified in Poland as common or very common, accounting for 59% of all identified species. Another group comprised moderately common birds (27% of the assemblage). Among the birds classified as scarce breeders in the country, eight species were identified (14% of the assemblage).

Additionally, five species breeding near the farm are listed in Annex I of the Birds Directive: Common Crane, Marsh Harrier, Red-backed Shrike, Woodlark, and Ortolan Bunting.

**Table 9.** Composition and abundance (selected species) of breeding bird fauna in the immediate vicinity of the Sulechów Photovoltaic Farm Complex. Abundance: number – number of pairs, + – species present without a recorded number. Habitat type: UA – urban areas, I – other, L – forested areas (forest and woodland birds), R – agricultural landscape birds, W – water and wetland birds. Status in Poland (Chodkiewicz et al. 2015): VA – very abundant, A – abundant, MA – moderately abundant, S – scarce. Conservation status: SP – strictly protected, GS – game species, BD – species listed in Annex I of the Birds Directive.

| No. | Species | Abundance (selected species) | Habitat type | Status in Poland | Conservation status |
|---|---|---|---|---|---|
| 1 | Mallard *Anas platyrhynchos* | 2 | W | MA | GS |
| 2 | Common Quail *Coturnix coturnix* | 1 | A | MA | SP |
| 3 | Little Grebe *Tachybaptus ruficollis* | 2 | W | S | SP |
| 4 | Common Wood Pigeon *Columba palumbus* | + | F/UA | A | GS |
| 5 | Common Cuckoo *Cuculus canorus* | + | O | MA | SP |
| 6 | Water Rail *Rallus aquaticus* | 1 | W | S | SP |
| 7 | Common Moorhen *Gallinula chloropus* | 1–2 | W | S | SP |
| 8 | Eurasian Coot *Fulica atra* | 2 | W | MA | GS |
| 9 | Common Crane *Grus grus* | 1 | W | S | SP, BD |
| 10 | Western Marsh Harrier *Circus aeruginosus* | 1 | W | S | SP, BD |
| 11 | Common Buzzard *Buteo buteo* | 1 | F | MA | SP |
| 12 | Eurasian Wryneck *Jynx torquilla* | 1 | F | MA | SP |
| 13 | European Green Woodpecker *Picus viridis* | 1 | F | S | SP |
| 14 | Lesser Spotted Woodpecker *Dryobates minor* | 1 | F | S | SP |
| 15 | Great Spotted Woodpecker *Dendrocopos major* | + | F | A | SP |
| 16 | Eurasian Golden Oriole *Oriolus oriolus* | + | F | A | SP |
| 17 | Red-backed Shrike *Lanius collurio* | 8–10 | A | A | SP, BD |

| No. | Species | Abundance (selected species) | Habitat type | Status in Poland | Conser-vation status |
|---|---|---|---|---|---|
| 18 | Marsh Tit *Poecile palustris* | 1 | F | MA | SP |
| 19 | Eurasian Blue Tit *Cyanistes caeruleus* | + | F | A | SP |
| 20 | Great Tit *Parus major* | + | F/UA | VA | SP |
| 21 | Eurasian Penduline Tit *Remiz pendulinus* | 1 | W | S | SP |
| 22 | Woodlark *Lullula arborea* | 1 | F | A | SP, BD |
| 23 | Skylark *Alauda arvensis* | + | A | VA | SP |
| 24 | Crested Lark *Galerida cristata* | 2 | A | MA | SP |
| 25 | Savi's Warbler *Locustella luscinioides* | 1 | W | MA | SP |
| 26 | Icterine Warbler *Hippolais icterina* | + | A | A | SP |
| 27 | Marsh Warbler *Acrocephalus palustris* | + | A | A | SP |
| 28 | Eurasian Reed Warbler *Acrocephalus scirpaceus* | 2 | W | MA | SP |
| 29 | Great Reed Warbler *Acrocephalus arundinaceus* | 1 | W | MA | SP |
| 30 | Willow Warbler *Phylloscopus trochilus* | + | F | VA | SP |
| 31 | Common Chiffchaff *Phylloscopus collybita* | + | F | A | SP |
| 32 | Long-tailed Tit *Aegithalos caudatus* | 1 | F | MA | SP |
| 33 | Eurasian Blackcap *Sylvia atricapilla* | + | F | VA | SP |
| 34 | Garden Warbler *Sylvia borin* | 1 | F | A | SP |
| 35 | Lesser Whitethroat *Curruca curruca* | + | A/UA | A | SP |
| 36 | Common Whitethroat *Curruca communis* | + | A | A | SP |
| 37 | Eurasian Wren *Troglodytes troglodytes* | + | F | A | SP |
| 38 | Common Starling *Sturnus vulgaris* | + | F/UA | A | SP |
| 39 | European Robin *Erithacus rubecula* | + | F | A | SP |
| 40 | Common Nightingale *Luscinia megarhynchos* | 3 | A/UA | MA | SP |
| 41 | Whinchat *Saxicola rubetra* | 3 | A | A | SP |
| 42 | European Stonechat *Saxicola rubicola* | 2 | A | MA | SP |
| 43 | Song Thrush *Turdus philomelos* | + | F | A | SP |
| 44 | Common Blackbird *Turdus merula* | + | F/UA | A | SP |
| 45 | Tree Sparrow *Passer montanus* | + | UA | A | SP |
| 46 | Yellow Wagtail *Motacilla flava* | + | A | A | SP |
| 47 | White Wagtail *Motacilla alba* | + | UA | A | SP |
| 48 | Common Chaffinch *Fringilla coelebs* | + | F | VA | SP |
| 49 | European Greenfinch *Chloris chloris* | + | A/UA | A | SP |
| 50 | Common Linnet *Linaria cannabina* | + | A | A | SP |
| 51 | European Goldfinch *Carduelis carduelis* | + | A/UA | A | SP |
| 52 | European Serin *Serinus serinus* | + | UA | A | SP |
| 53 | Corn Bunting *Emberiza calandra* | + | A | A | SP |

| No. | Species | Abundance (selected species) | Habitat type | Status in Poland | Conser-vation status |
|---|---|---|---|---|---|
| 54 | Yellowhammer *Emberiza citrinella* | + | A | VA | SP |
| 55 | Ortolan Bunting *Emberiza hortulana* | 1 | A | MA | SP, BD |
| 56 | Common Reed Bunting *Emberiza schoeniclus* | + | A/W | A | SP |

## Avifauna of water bodies adjacent to the Sulechów Photovoltaic Farm Complex

Within the two ponds located between sections of the Sulechów Photovoltaic Farm Complex, 12 species characteristic of wetland habitats were recorded (Table 9). These included species strictly associated with aquatic environments: Mallard – 2 pairs, Little Grebe – 2 pairs, Moorhen – 1–2 pairs, and Coot – 2 pairs.

Additionally, species linked to reed habitats were also breeding: Water Rail – 1 pair, Marsh Harrier – 1 pair, Savi's Warbler – 1 pair, Sedge Warbler – 2 pairs, Great Reed Warbler – 1 pair, Reed Bunting – 1–2 pairs.

A pair of Penduline Tits, which favour water bodies and rivers for nesting, were also observed constructing nests in trees near the ponds. Additionally, in 2023, a pair of Common Cranes likely nested in the area, as 1–2 individuals were consistently observed near the ponds.

## Avifauna using the Sulechów Photovoltaic Farm for foraging

The Sulechów Photovoltaic Farm served as a foraging and resting site for various bird species. These included: birds breeding within the farm, species breeding in the immediate vicinity, and birds arriving from more distant areas, including the surrounding agricultural landscape and urbanised zones.

In addition, this group included migratory and/or overwintering species, with a total of 93 species recorded. The use of the photovoltaic farm for foraging and resting was noted for 42 species (including breeding birds within the farm). Another 23 species were observed in the immediate vicinity of the farm (up to 200 metres), including ponds, fields, fallow lands, tree stands, and shrubbery.

Table 10 provides an overview of the recorded avifauna, detailing foraging and/or resting species, excluding the breeding birds listed in Table 8. Non-breeding species observed in the vicinity of the farm are also included in this table.

**Table 10.** Composition of bird fauna utilising the Sulechów Photovoltaic Farm Complex (foraging, resting), excluding breeding species. Additionally, the "Farm surroundings" column lists non-breeding bird species observed in the immediate vicinity. Conservation status: SP – strictly protected, PP – partially protected, GS – game species, BD – species listed in Annex I of the Birds Directive.

| No. | Species | Farm area | Farm surroundings | Conservation status |
|---|---|---|---|---|
| 1 | Common Pheasant *Phasianus colchicus* | | + | GS |
| 2 | Feral Pigeon *Columba livia* forma *urbana* | | + | PP |
| 3 | Eurasian Collared Dove *Streptopelia decaocto* | | + | SP |
| 4 | Common Swift *Apus apus* | + | | SP |
| 5 | Northern Lapwing *Vanellus vanellus* | | + | SP |
| 6 | Common Snipe *Gallinago gallinago* | | + | SP |
| 7 | Green Sandpiper *Tringa ochropus* | | + | SP |
| 8 | White Stork *Ciconia ciconia* | + | | SP, BD |
| 9 | Grey Heron *Ardea cinerea* | | + | PP |
| 10 | Western Marsh Harrier *Circus aeruginosus* | + | | SP, BD |
| 11 | Eurasian Sparrowhawk *Accipiter nisus* | + | | SP |
| 12 | Northern Goshawk *Accipiter gentilis* | + | | SP |
| 13 | Red Kite *Milvus milvus* | + | | SP, BD |
| 14 | Black Kite *Milvus migrans* | + | | SP, BD |
| 15 | Rough-legged Buzzard *Buteo lagopus* | + | | SP |
| 16 | Common Buzzard *Buteo buteo* | + | | SP |
| 17 | Long-eared Owl *Asio otus* | | + | SP |
| 18 | Common Kingfisher *Alcedo atthis* | | + | SP, BD |
| 19 | Common Kestrel *Falco tinnunculus* | + | | SP |
| 20 | Peregrine Falcon *Falco peregrinus* | | + | SP, BD |
| 21 | Great Grey Shrike *Lanius excubitor* | + | | SP |
| 22 | Eurasian Jay *Garrulus glandarius* | | + | SP |
| 23 | Eurasian Magpie *Pica pica* | | + | PP |
| 24 | Common Raven *Corvus corax* | | + | PP |
| 25 | Hooded Crow *Corvus cornix* | | + | PP |
| 26 | Eurasian Blue Tit *Cyanistes caeruleus* | + | | SP |
| 27 | Great Tit *Parus major* | + | | SP |
| 28 | Common House Martin *Delichon urbicum* | + | | SP |
| 29 | Barn Swallow *Hirundo rustica* | + | | SP |
| 30 | Sand Martin *Riparia riparia* | + | | SP |
| 31 | Goldcrest *Regulus regulus* | | + | SP |
| 32 | Eurasian Wren *Troglodytes troglodytes* | + | | SP |
| 33 | Common Starling *Sturnus vulgaris* | + | | SP |

| No. | Species | Farm area | Farm surroundings | Conservation status |
|---|---|---|---|---|
| 34 | European Robin *Erithacus rubecula* | + | | SP |
| 35 | Black Redstart *Phoenicurus ochruros* | + | | SP |
| 36 | Mistle Thrush *Turdus viscivorus* | | + | SP |
| 37 | Song Thrush *Turdus philomelos* | + | | SP |
| 38 | Redwing *Turdus iliacus* | | + | SP |
| 39 | Fieldfare *Turdus pilaris* | | + | SP |
| 40 | Dunnock *Prunella modularis* | | + | SP |
| 41 | Grey Wagtail *Motacilla cinerea* | | + | SP |
| 42 | White Wagtail *Motacilla alba* | + | | SP |
| 43 | Common Chaffinch *Fringilla coelebs* | + | | SP |
| 44 | Brambling *Fringilla montifringilla* | + | | SP |
| 45 | Eurasian Bullfinch *Pyrrhula pyrrhula* | | + | SP |
| 46 | European Greenfinch *Chloris chloris* | + | | SP |
| 47 | Common Redpoll *Acanthis flammea* | | + | SP |
| 48 | European Goldfinch *Carduelis carduelis* | + | | SP |
| 49 | European Serin *Serinus serinus* | + | | SP |
| 50 | Eurasian Siskin *Spinus spinus* | | + | SP |
| 51 | Common Reed Bunting *Emberiza schoeniclus* | + | | SP |

These observations underline the significance of the Sulechów Photovoltaic Farm Complex not only as a breeding habitat but also as a valuable foraging and resting site for a diverse array of bird species, including migratory and overwintering populations.

Of the 42 bird species observed within the Sulechów Photovoltaic Farm Complex, 38 species (insectivores, granivores, corvids (*Corvidae*), birds of prey, shrikes (*Laniidae*), and the White Stork) were recorded foraging on the ground, in herbaceous vegetation, and shrubs. Birds of prey, white storks, and shrikes hunted rodents (Photo 18), reptiles, and/or insects present within the farm.

Additionally, four species: Barn Swallow, House Martin, Sand Martin, and Common Swift foraged directly above the farm (over the panels), preying on flying insects.

The birds of prey species recorded included: Common Buzzard, Rough-legged Buzzard, Red Kite, Black Kite, Marsh Harrier, and Common Kestrel. These birds of prey primarily hunted rodents but also preyed on insects. White storks and shrikes (Great Grey Shrike and Red-backed Shrike were also observed hunting rodents and insects. In particular, the Great Grey Shrike established caches (spiked prey) on the farm's fence mesh (Photo 19).

**Photo 18**. Rodent found in the Sulechów Photovoltaic Farm Complex – a common prey for birds of prey (photo: A. Dubicka-Czechowska)

**Photo 19**. A vole impaled on the farm's fence – a Great Grey Shrike's *Lanius excubitor* food cache (photo: O. Ciebiera)

During migration and wintering periods, large flocks of birds representing dozens of species were regularly observed. The largest foraging flocks on the farm included: Starling, Chaffinch, Yellowhammer, Goldfinch, Common Linnet, Reed Bunting, and Barn Swallow (Photo 20). Smaller flocks of Brambling (Photo 21) and European Greenfinch were also noted.

Several species used the farm during spring and autumn migration, including: Black Redstart, White Wagtail, European Robin, Song Thrush, and Tits, such as the Great Tit and Blue Tit. Around the farm, large flocks of Ravens, Fieldfares, Redwings, Tree Sparrows, and occasional flocks of Common Redpolls were observed foraging.

**Photo 20**. Mixed flock of birds foraging in autumn on the seeds of vegetation growing at the Sulechów Photovoltaic Farm Complex (photo: P. Czechowski)

**Photo 21**. A flock of Yellowhammers *Emberiza citrinella* and Bramblings *Fringilla montifringilla* (two birds on the left) observed in winter (photo: P. Czechowski)

The avifauna of the Sulechów Photovoltaic Farm Complex and its surroundings was further enriched by birds observed in flight during migrations or post-breeding dispersal. This group included several species such as: Golden Plover, Caspian Gull, Black Stork, Great White Egret, Lesser Spotted Eagle, Jackdaw, and Red Crossbill.

## Use of the Sulechów Photovoltaic Farm infrastructure by birds

The infrastructure of the Sulechów Photovoltaic Farm Complex (fencing, panels, frames, cameras, transformer buildings) served as resting spots, hunting perches, and singing platforms for 32 bird species (Table 11, Photo 22).

**Table 11.** Species composition of birds using the infrastructure of the Sulechów Photovoltaic Farm Complex. Type of activity: P – perching, R – resting, S – singing site, F – foraging. Conservation status: SP – strictly protected, PP – partially protected, BD – species listed in Annex I of the Birds Directive.

| No. | Species | Type of activity | Conservation status |
|---|---|---|---|
| 1 | Eurasian Sparrowhawk *Accipiter nisus* | P | SP |
| 2 | Red Kite *Milvus milvus* | P,R | SP, BD |
| 3 | Common Buzzard *Buteo buteo* | P,R | SP |
| 4 | Rough-legged Buzzard *Buteo lagopus* | P,R | SP |
| 5 | Common Kestrel *Falco tinnunculus* | P,R,F | SP |
| 6 | Red-backed Shrike *Lanius collurio* | P,R,F | SP, BD |
| 7 | Great Grey Shrike *Lanius excubitor* | P,R,F | SP |
| 8 | Eurasian Magpie *Pica pica* | R | PP |
| 9 | Common Raven *Corvus corax* | R | PP |
| 10 | Eurasian Blue Tit *Cyanistes caeruleus* | R,F | SP |
| 11 | Great Tit *Parus major* | R,F | SP |
| 12 | Eurasian Skylark *Alauda arvensis* | R,S | SP |
| 13 | Crested Lark *Galerida cristata* | R,S | SP |
| 14 | Barn Swallow *Hirundo rustica* | R | SP |
| 15 | Common Whitethroat *Curruca communis* | R,S | SP |
| 16 | Common Starling *Sturnus vulgaris* | R | SP |
| 17 | Black Redstart *Phoenicurus ochruros* | R,F | SP |
| 18 | Whinchat *Saxicola rubetra* | R,S | SP |
| 19 | European Stonechat *Saxicola rubicola* | R,S | SP |
| 20 | Northern Wheatear *Oenanthe oenanthe* | R,S | SP |
| 21 | Common Blackbird *Turdus merula* | R,S | SP |
| 22 | Eurasian Tree Sparrow *Passer montanus* | R | SP |
| 23 | Yellow Wagtail *Motacilla flava* | R,S | SP |
| 24 | White Wagtail *Motacilla alba* | R | SP |
| 25 | Common Chaffinch *Fringilla coelebs* | R | SP |
| 26 | Brambling *Fringilla montifringilla* | R | SP |
| 27 | European Greenfinch *Chloris chloris* | R | SP |
| 28 | Common Linnet *Linaria cannabina* | R | SP |
| 29 | European Goldfinch *Carduelis carduelis* | R | SP |
| 30 | Corn Bunting *Emberiza calandra* | R,S | SP |
| 31 | Yellowhammer *Emberiza citrinella* | R,S | SP |
| 32 | Common Reed Bunting *Emberiza schoeniclus* | R | SP |

**Photo 22**. Corn Bunting *Emberiza calandra* frequently using elements of the farm's infrastructure, such as cameras, as singing perches (photo: P. Czechowski)

**Solar Panels:** All 32 species were observed using the panels, making them the most frequently utilised infrastructure. Panels were regularly used as hunting perches, feeding locations, and resting spots by two bird of prey species, the Common Buzzard and the Common Kestrel. Shrikes, including the Great Grey Shrike and the Red-Backed Shrike, also frequently perched on the panels. Ravens and, less often, Magpies were observed resting on the panels. Additionally, panels were used as singing platforms by Skylarks, Crested Larks, Yellowhammers, Blackbirds, Common Whitethroats, Whinchats, European Stonechats, and Corn Buntings.

**Fencing and Monitoring Cameras:** Fencing was the second most commonly used infrastructure element. For example, Great Grey Shrikes were observed using the fence mesh to create food caches (spiked prey). Monitoring cameras were less frequently used but were popular perches for corn buntings and kestrels.

## Use of the Sulechów Photovoltaic Farm area by birds of prey

During annual observations conducted at the Sulechów Photovoltaic Farm Complex, nine species of birds of prey were identified (Table 12). This group included birds flying over the farm, foraging within the farm area, and resting or perching on elements of the farm's infrastructure. A total of 640 individual birds were recorded across 540 observations. The most frequently observed species was the Common Kestrel (Photo 23), comprising 41.7% of all observations within the farm, followed by the Common Buzzard (Photo 24) at 41.3%. The remaining species accounted for 17.0% of observations, with the Red Kite (6.3%) and Marsh Harrier (4.6%) being the most frequently encountered among them.

**Table 12.** List of birds of prey observed directly within the Sulechów Photovoltaic Farm Complex from April 2023 to April 2024. N obs. – number of observations, % obs. – percentage of all observations, N ind. – number of individuals, % ind. – percentage of all individuals.

| No. | Species | N obs. | % obs. | N ind. | % ind. |
|---|---|---|---|---|---|
| 1 | Northern Goshawk *Accipiter gentilis* | 7 | 1.3 | 7 | 1.1 |
| 2 | Eurasian Sparrowhawk *Accipiter nisus* | 11 | 2.0 | 11 | 1.7 |
| 3 | Common Buzzard *Buteo buteo* | 223 | 41.3 | 274 | 42.8 |
| 4 | Rough-Legged Buzzard *Buteo lagopus* | 3 | 0.6 | 3 | 0.5 |
| 5 | Marsh Harrier *Circus aeruginosus* | 25 | 4.6 | 36 | 5.6 |
| 6 | Common Kestrel *Falco tinnunculus* | 225 | 41.7 | 260 | 40.6 |
| 7 | White-tailed Eagle *Haliaeetus albicilla* | 1 | 0.2 | 1 | 0.2 |
| 8 | Black Kite *Milvus migrans* | 11 | 2.0 | 12 | 1.9 |
| 9 | Red Kite *Milvus milvus* | 34 | 6.3 | 36 | 5.6 |
| Total | | 540 | 100.0 | 640 | 100.0 |

In terms of individual counts, the Common Buzzard was the most numerous species with 274 individuals (42.8% of all recorded birds), followed by the Kestrel with 260 individuals (40.6%). Among the less frequently observed species, the most numerous were the Marsh Harrier and Red Kite, each with 36 individuals (5.6%).

The majority of observations involved single birds (87.2%). Instances of two birds accounted for 9.3% of all observations, involving four species: Common Buzzard, Kestrel, Marsh Harrier, and Black Kite. Observations of three to six birds made up 3.5% of all records. The maximum number of individuals observed at the same time on the farm was six Buzzards (6 September 2023) and four Kestrels (three separate occasions: 22 June, 20 July, and 2 August 2023). Additionally, three Marsh Harriers were observed on three occasions (11 May, 4 July, and 20 July 2023), and three Red Kites were recorded on one occasion (15 August 2023).

Of the 540 observations of birds of prey at the farm complex, 81.3% (77.5% of individuals) showed a direct association with the farm, including hunting within the farm area, perching, or resting on farm infrastructure. Among these observations,

**Photo 23**. Common Kestrel *Falco tinnunculus* – the most frequently observed bird of prey at the Sulechów Photovoltaic Farm Complex. Kestrels regularly used various elements of farm infrastructure as perches and resting sites (power lines, solar panels) (photo: P. Czechowski)

**Photo 24**. Common Buzzard *Buteo buteo* – the second most frequently observed bird of prey at the farm. Buzzards were often seen perching and resting on solar panels (photo: P. Czechowski)

53.5% (54.6% of individuals) were related to hunting activities, while 46.5% (45.4% of individuals) involved resting or perching on farm infrastructure such as solar panels, fences, and cameras. The remaining 18.8% of observations (22.5% of individuals) involved birds flying over the farm without interacting with it. These included birds in active flight, either on local movements (18.3% of farm observations, 22.2% of individuals) or during migration (0.4% of observations, 0.3% of individuals).

Direct use of the farm area (hunting, resting/perching) was observed in eight species: Northern Goshawk, Eurasian Sparrowhawk, Common Buzzard, Rough-Legged Buzzard, Marsh Harrier, Black Kite, Red Kite, and Kestrel. All eight species were noted hunting within the farm, while five species (Sparrowhawk, Common Buzzard, Rough-Legged Buzzard, Red Kite, and Kestrel) also utilized the infrastructure. The distribution of observations and the number of individuals using the farm as a hunting ground are presented in Table 13, while the number of observations and individuals resting/perching are detailed in Table 14.

**Table 13.** Number of observations and individuals of birds of prey using the Sulechów Photovoltaic Farm Complex as a hunting ground. N obs. – number of observations, % obs. – percentage of observations, N ind. – number of individuals, % ind. – percentage of individuals.

| No. | Species | N obs. | % obs. | N ind. | % ind. |
|---|---|---|---|---|---|
| 1 | Marsh Harrier *Circus aeruginosus* | 13 | 5.1 | 21 | 7.7 |
| 2 | Northern Goshawk *Accipiter gentilis* | 6 | 2.4 | 6 | 2.2 |
| 3 | Black Kite *Milvus migrans* | 6 | 2.4 | 7 | 2.6 |
| 4 | Red Kite *Milvus milvus* | 28 | 11.0 | 28 | 10.3 |
| 5 | Eurasian Sparrowhawk *Accipiter nisus* | 21 | 8.3 | 2 | 0.7 |
| 6 | Common Buzzard *Buteo buteo* | 48 | 18.9 | 53 | 19.6 |
| 7 | Rough-Legged Buzzard *Buteo lagopus* | 2 | 0.8 | 2 | 0.7 |
| 8 | Common Kestrel *Falco tinnunculus* | 130 | 51.2 | 152 | 56.1 |
| Total | | 254 | 100.0 | 271 | 100.0 |

**Table 14.** Number of observations and individuals of birds of prey using the Sulechów Photovoltaic Farm Complex for resting/perching. N obs. – number of observations, % obs. – percentage of observations, N ind. – number of individuals, % ind. – percentage of individuals.

| No. | Species | N obs. | % obs. | N ind. | % ind. |
|---|---|---|---|---|---|
| 1 | Eurasian Sparrowhawk *Accipiter nisus* | 1 | 0.5 | 1 | 0.4 |
| 2 | Common Buzzard *Buteo buteo* | 119 | 58.3 | 131 | 58.2 |
| 3 | Rough-Legged Buzzard *Buteo lagopus* | 1 | 0.5 | 1 | 0.4 |
| 4 | Common Kestrel *Falco tinnunculus* | 82 | 40.2 | 91 | 40.4 |
| 5 | Red Kite *Milvus milvus* | 1 | 0.5 | 1 | 0.4 |
| Total | | 204 | 100.0 | 225 | 100.0 |

Resting and/or perching birds of prey (five species – Table 14) were observed on various elements of the photovoltaic farm's infrastructure, including panels, fences, buildings, and electricity poles/lines crossing the farm area. The distribution of observations and individual birds seen on specific infrastructure elements is shown in Figure 4. The use of specific infrastructure elements by the two most numerous species (Common Buzzard and Kestrel) is illustrated in Figures 5 and 6.

Monthly observations during the annual study period recorded between two and seven species of birds of prey at the farm, with the highest diversity noted between April and June and in August (Figure 7). From April to October, the distribution of observations and bird numbers was very similar. Birds of prey were least frequently observed during the winter months from December to March.

The presence of the two most numerous species within the farm showed distinct patterns. The number of observations and individual counts of the Common Buzzard increased from August, peaking and remaining high through January (Figure 8), reflecting post-breeding dispersal, migration, and overwintering. For the Kestrel, a rise in observations and individual counts was evident from April to October (Figure 9), likely associated with the return of birds to nesting sites (buildings and infrastructure in Sulechów), their consistent use of the farm as a foraging area for adults feeding chicks, and the presence of juvenile birds from June/July onwards.

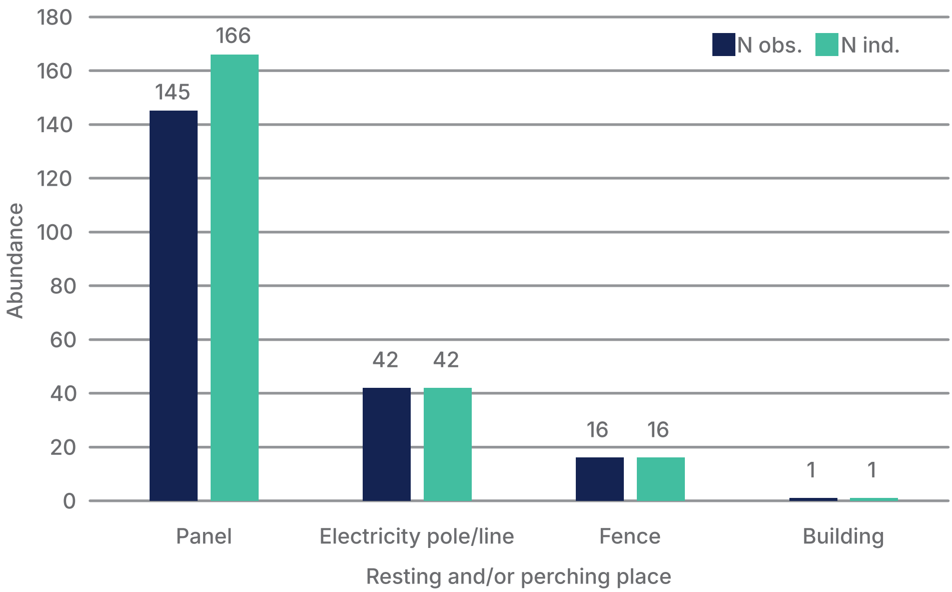


**Figure 4**. Distribution of observations and individuals of birds of prey (all species combined) seen on various elements of the Sulechów Photovoltaic Farm Complex infrastructure. N obs. – number of observations, N ind. – number of individuals

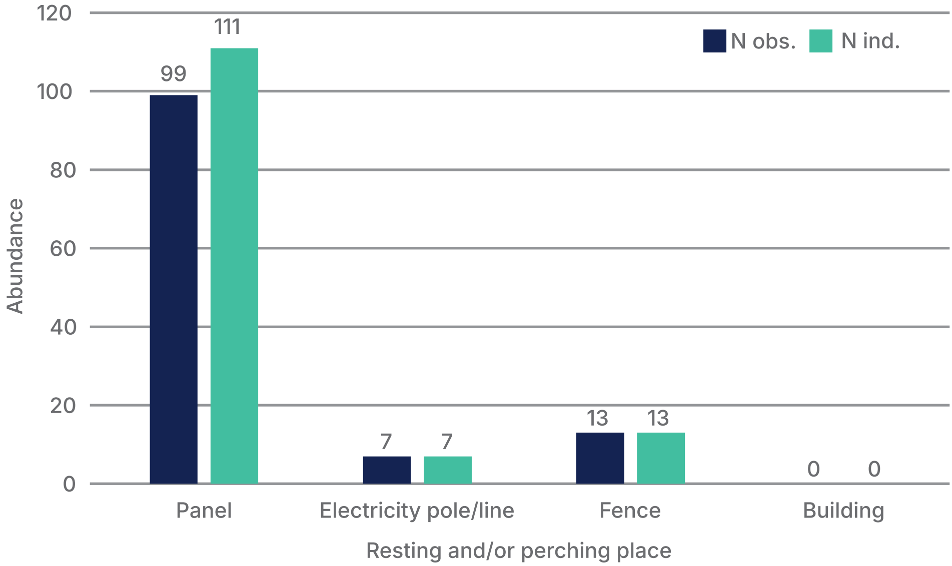


**Figure 5**. Distribution of observations and individuals of Common Buzzards *Buteo buteo* seen on different elements of the Sulechów Photovoltaic Farm Complex infrastructure. N obs. – number of observations, N ind. – number of individuals

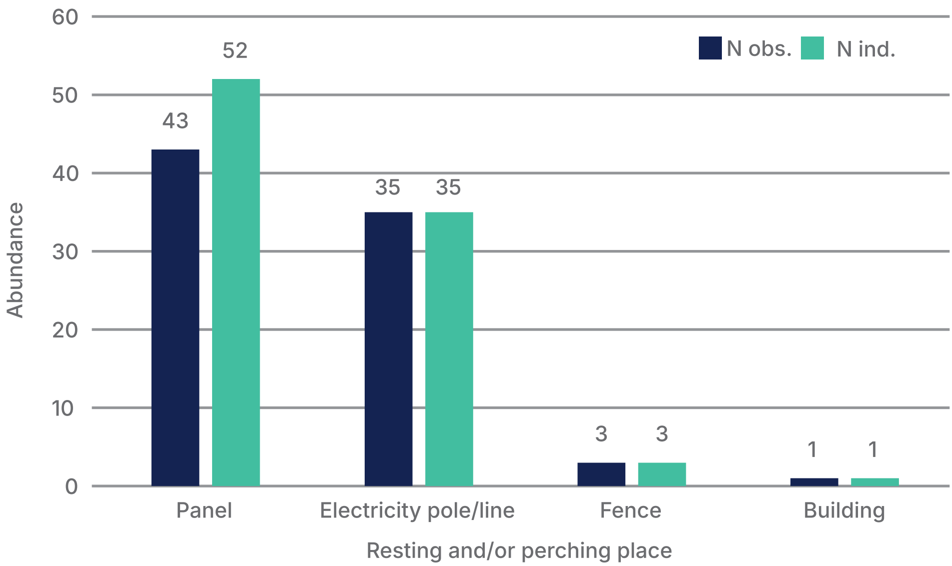


**Figure 6**. Distribution of observations and individuals of Common Kestrels *Falco tinnunculus* seen on different elements of the Sulechów Photovoltaic Farm Complex infrastructure. N obs. – number of observations, N ind. – number of individuals

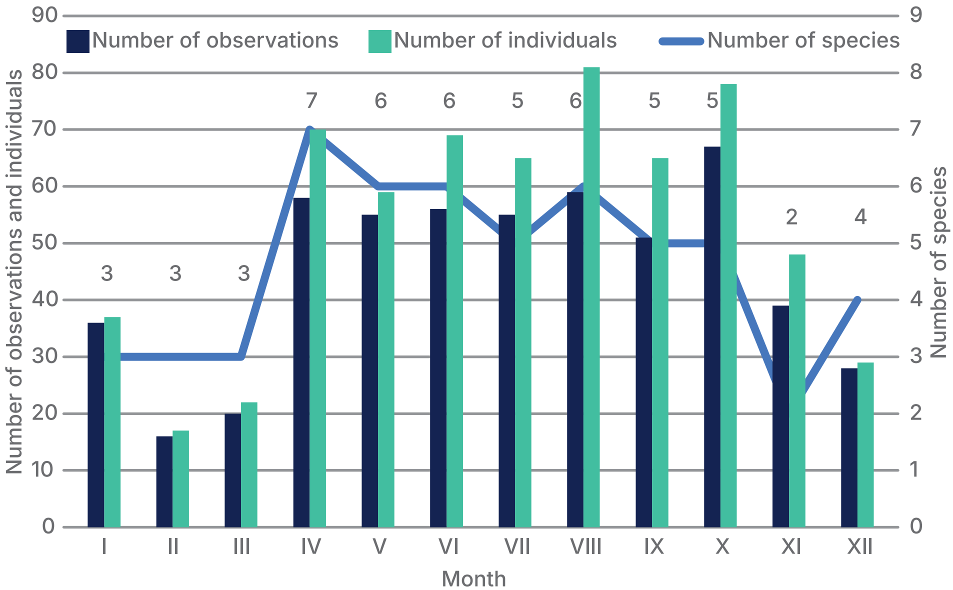


**Figure 7**. Monthly distribution of observations, individuals, and species of birds of prey recorded in the Sulechów Photovoltaic Farm Complex

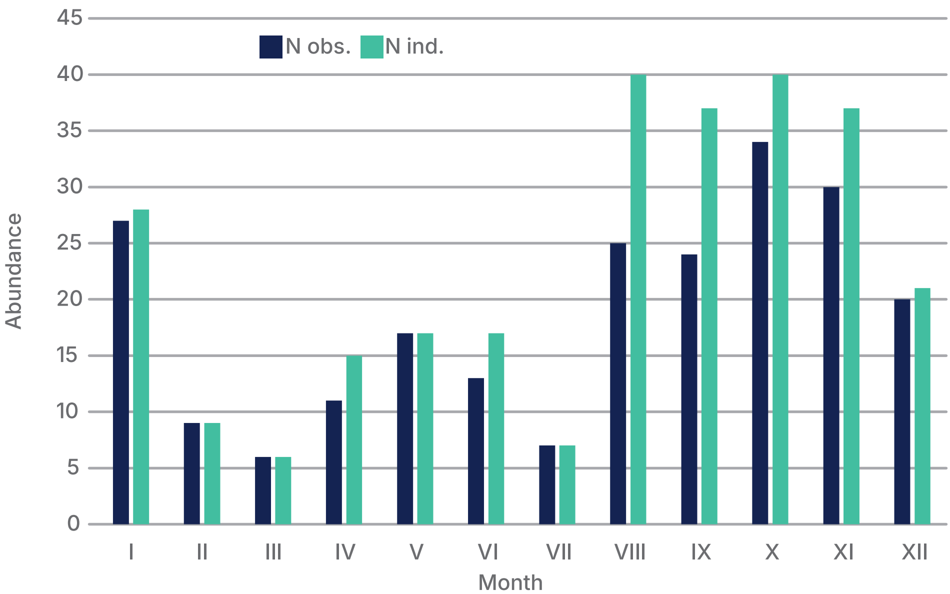


**Figure 8**. Monthly distribution of the number of observations (N obs.) and individuals (N ind.) of Common Buzzards *Buteo buteo* in the Sulechów Photovoltaic Farm Complex

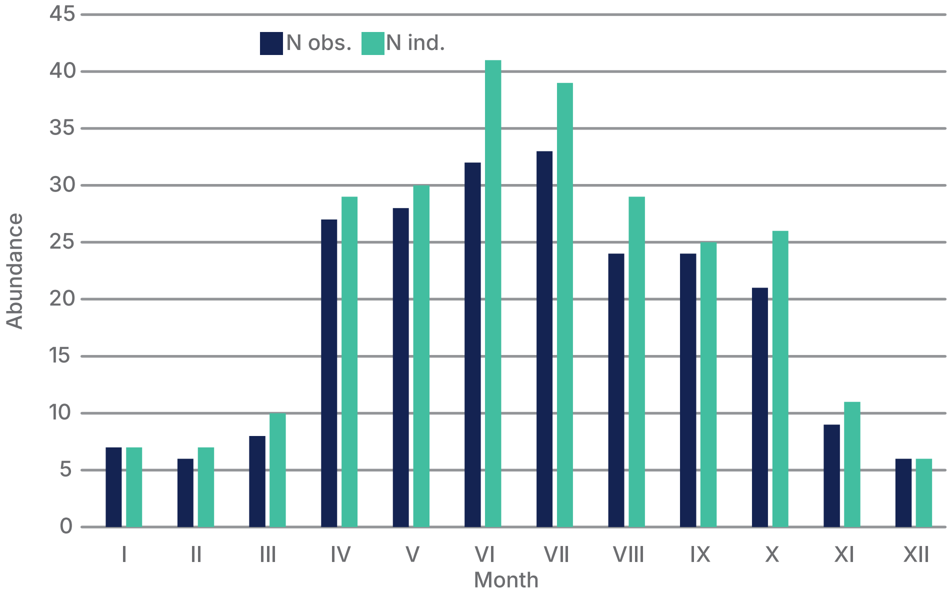


**Figure 9**. Monthly distribution of the number of observations (N obs.) and individuals (N ind.) of Common Kestrels *Falco tinnunculus* in the Sulechów Photovoltaic Farm Complex

## Summary


Over the course of year-long field observations from April 2023 to May 2024, 106 bird species were recorded in the Sulechów Photovoltaic Farm Complex and its vicinity, including 58 breeding species. Fourteen species were confirmed as breeding within the farm boundaries, while an additional 44 species bred in the immediate surroundings. The Skylark was the most abundant breeding species on the farm.

The species composition observed on the farm is typical for agricultural landscapes with limited shrub coverage. Ground-nesting birds, as well as those nesting in dense vegetation or shrubs, dominated the breeding avifauna. Common and very common species in Poland formed the majority of the assemblage.

The two ponds located between farm sections were identified as valuable habitats, increasing avian diversity by hosting several water bird species.

In addition to breeding avifauna, 48 non-breeding bird species were observed within the area of the Photovoltaic Farm Complex and adjacent lands. These included species that visited from nearby areas as well as migratory and/or wintering birds.

A total of 42 species (including breeding birds on the farm) used the Photovoltaic Farm Complex as a foraging or resting site. During migration and wintering periods, larger flocks of several species were regularly observed. The photovoltaic farm

infrastructure (fencing, panels, frames, cameras, buildings) served as resting spots, lookout points, and singing perches for 32 species.

Within the Sulechów Photovoltaic Farm Complex, nine species of birds of prey were recorded. The most frequently and abundantly observed species were the Common Buzzard, Common Kestrel, Red Kite, and Marsh Harrier. Up to six Buzzards and four Kestrels were observed at the farm at any one time. Direct use of the farm area was noted in 81.3% of observations, involving birds hunting (foraging) or resting/perching on farm infrastructure such as power lines, poles, panels, fences, and buildings.

The recorded activity of birds of prey on the farm was high, with the level of farm usage comparable to that of surrounding areas (nearby fields and roadside verges). This is primarily due to the easy availability of prey, particularly rodents.

The good management practices at the Sulechów Photovoltaic Farm, including the maintenance of suitable habitats with appropriate vegetation, have fostered the development of diverse ecological networks. This has resulted in a rich avifauna, representing various bird families and ecological groups.

The monitoring data confirm that well-managed photovoltaic farms can provide critical habitats for local bird populations. The farm area supports nesting for several species, serves as a consistent foraging ground for insectivores and granivores, and provides hunting grounds for birds of prey.

The findings align with similar studies on photovoltaic farms near Zgorzelec (five farms studied in 2022–2023), where 94 bird species were recorded. In the Zgorzelec farms, 58 species bred within a 100-metre buffer, with 30 species nesting directly within the farms. At the Sulechów farm, 106 species were observed, including 58 breeding species within a 200-metre buffer and 14 species nesting directly on the farm.

Both sites were dominated by bird species associated with open areas and limited shrub coverage. However, neither study included pre-construction bird community data, making it difficult to assess changes in avifaunal diversity following the transition from agricultural to photovoltaic use.

# 7. Mammals

Human activities increasingly intensify their impact on natural environments, leading to biodiversity loss at multiple levels. Land use for urban development, agriculture, transportation, and non-renewable energy extraction has resulted in habitat fragmentation and transformation, significantly affecting mammalian populations (Burton et al., 2024). For some species, these environmental changes can lead to the complete disappearance of local populations.

One strategy to mitigate this impact involves the development and preservation of ecological corridors—intact systems that connect habitat patches within a region's landscape. At the same time, some mammal species exhibit adaptability to anthropogenic environments, demonstrating plasticity in their choice of foraging, breeding, resting, and migration sites. For example, increasing observations of Moose *Alces alces*, Roe Deer *Capreolus capreolus*, Eurasian Wild Boar *Sus scrofa*, and Red Fox *Vulpes vulpes* in urban areas highlight this adaptability. However, these interactions often result in human-wildlife conflicts, as animals seek ecological niches for survival in increasingly complex, human-altered ecosystems.

Over the past decade, Poland has seen significant growth in renewable energy production, particularly on agricultural lands such as fields, meadows, pastures, and fallow lands. While wind farms primarily cause localised land alterations near turbine foundations and construction sites, photovoltaic (solar) farms occupy large areas and, when enclosed by continuous fencing, may hinder the migration of large mammals.

To minimise this impact, it is recommended to divide large solar farms into smaller units with separate enclosures. These areas can provide attractive environments for mammals, offering shelter and foraging grounds. The reduced human presence due to fencing also benefits wildlife populations.

Administrative bodies responsible for managing wildlife and planning regional development (e.g., local spatial plans or integrated investment strategies) should account for the varying sensitivities of mammal species to human-wildlife interactions across gradients of anthropogenic influence. Proper planning can balance the needs of wildlife conservation with renewable energy development, ensuring ecological corridors remain intact and supporting diverse mammalian populations within these landscapes.

The study on the mammalian fauna of the Sulechów Photovoltaic Farm Complex focused on identifying mammal species that utilize the farm area for various purposes and at different intensities. The primary methods of inventory included:

- **Direct observations:** Monitoring active animals, their tracks, droppings, feeding marks, and remains.
- **Roadkill surveys:** Recording animals killed by vehicles or left by predators along roads.
- **Shelter searches:** Identifying hiding spots and breeding colonies, especially for bats.

**Photo 25**. Ultrasonic detector placed in a bird box in the central part of the Sulechów Photovoltaic Farm Complex (photo: O. Ciebiera) (see Figure 2)

Fieldwork was conducted from April 2023 to May 2024. A Bushnell trail camera was deployed across multiple locations on the farm, operating continuously throughout the study period.

Bat activity was recorded through echolocation calls between 6 April 2023 and 15 November 2023 and again from 15 March 2024 to 5 April 2024. A Wildlife Acoustics EM3+ detector was installed at the centre of the farm, approximately 4 metres above ground level and 2 metres above the top of the photovoltaic panels (Photo 25).

The bat detector recorded ultrasonic echolocation calls, which were automatically filtered and stored for analysis using the Kaleidoscope software by Wildlife Acoustics Inc. The recordings were cross-referenced with relevant literature (e.g., Sachanowicz & Ciechanowski, 2005; Russ, 2012 & 2021; Barataud, 2015). Each detected bat flight or a continuous sequence of echolocation signals from a single individual (1 impulse to 5 seconds) was counted as one activity unit. The monitoring studies covered a full year, which was divided into specific phenological periods. The Period of Departure from Hibernation Sites (I) was defined as 15 to 31 March, the Spring Migration and Formation of Breeding Colonies (II) as 1 April to 30 May, the Breeding Period as 1 June to 31 July, the Dissolution of Breeding Colonies and Beginning of Autumn Migration, Swarming (III) as 1 August to 15 September, the Autumn Migration Period (IV) as 16 September to 31 October, and the Beginning of Hibernation (VI) as 1 to 15 November. Additionally, during selected nights, observations of the farm area were conducted using an infrared (IR) camera to determine how bats utilise the space above the photovoltaic panels.

The mammalian fauna of the Lubusz Voivodeship includes 72 species (Ważna et al., 2008), influenced by the region's geographical diversity, land use, and state of natural habitats. Within the Sulechów Photovoltaic Farm Complex, 21 mammal species were identified, along with individuals from three genera: Hedgehogs *Erinaceus*, Long-eared Bats *Plecotus*, Mouse-eared Bats *Myotis* (Table 15).

**Table 15.** List of mammal species recorded within the Sulechów Photovoltaic Farm Complex and their conservation status in Poland: SP – strictly protected, PP – partially protected, N2000 – species listed in Annex II of the Habitats Directive. PRB – Polish Red Data Book of Animals: LC – least concern, NN – species with undefined threat status.

| No. | Species | Conservation status |
|---|---|---|
| 1 | Hedgehog *Erinaceus* sp. | PP |
| 2 | European Mole *Talpa europaea* | PP |
| 3 | Common Shrew *Sorex araneus* | PP |
| 4 | Daubenton's Bat *Myotis daubentonii* | SP |
| 5 | Natterer's Bat *Myotis nattereri* | SP |
| 6 | Bats of the *Myotis* genus (Mouse-eared Bats) | SP |
| 7 | Common Noctule *Nyctalus noctula* | SP |
| 8 | Common Pipistrelle *Pipistrellus pipistrellus* | SP |
| 9 | Soprano Pipistrelle *Pipistrellus pygmaeus* | SP |

| No. | Species | Conservation status |
|---|---|---|
| 10 | Nathusius' Pipistrelle *Pipistrellus nathusii* | SP |
| 11 | Parti-coloured Bat *Vespertilio murinus* | SP, PRB-LC |
| 12 | Serotine Bat *Eptesicus serotinus* | SP |
| 13 | Western Barbastelle *Barbastella barbastellus* | SP, N2000, PRB-NN |
| 14 | Bats of the *Plecotus* genus (Long-eared Bats) | SP |
| 15 | Bats of the *Nyctalus* + *Vespertilio* + *Eptesicus* group | SP |
| 16 | European Hare *Lepus europaeus* | |
| 17 | European Water Vole *Arvicola amphibius* | PP |
| 18 | Common Vole *Microtus arvalis* | |
| 19 | Striped Field Mouse *Apodemus agrarius* | |
| 20 | Red Fox *Vulpes vulpes* | |
| 21 | European Badger *Meles meles* | |
| 22 | Beech Marten *Martes foina* | |
| 23 | Roe Deer *Capreolus capreolus* | |
| 24 | Wild Boar *Sus scrofa* | |

## Hedgehog *Erinaceus* sp.

Hedgehogs belong to the order Erinaceomorpha. In Poland, two subspecies or species, depending on classification, occur: Western Hedgehog, and Eastern Hedgehog.

Both species are found in the Lubusz Voivodeship (Ważna et al., 2008) and differ genetically and in their ranges. In Europe, hedgehog populations are declining due to habitat changes caused by human activity and high road mortality (Williams et al., 2018; Zacharopoulu et al., 2022). Hedgehogs inhabit deciduous forests with dense undergrowth, parks, gardens, and orchards, often found at the edges of built-up areas. Their diet primarily includes earthworms, snails, insects, eggs and chicks of ground-nesting birds, small rodents (whose nests they dig out), and some plant material.

On the Sulechów Photovoltaic Farm, hedgehogs were observed in the western part near a vegetated watercourse (Photo 26). Hedgehogs benefit from the shaded areas under photovoltaic panels, although they were not observed in the central part of the installation. Likely, they utilise ecotonal areas and may dig into vole burrows, which are abundant on the farm. Hedgehogs can move through the farm's fencing via burrows created by other animals, gaps in the mesh, or under gates.

In agricultural landscapes, hedgehogs use designed shrub corridors but require access to larger wooded patches, orchards, or parks for refuge and foraging.

**Photo 26**. Hedgehog *Erinaceus* sp. – occasionally found at the Sulechów Photovoltaic Farm Complex (photo: P. Czechowski)

## Mole *Talpa europaea*

The Mole occurs throughout Poland and inhabits a wide range of habitats. It is most common in lowland meadows, deciduous forests, and arable land. Acidic soils, which are unfavourable for earthworm populations (their primary food source), can limit their distribution (Fellowes et al., 2020). Moles avoid waterlogged, stony, or sandy soils, where tunnel construction is challenging or impossible.

Moles are territorial and can create tunnels at a speed of 12–15 metres per hour. Their tunnels are shallow in summer and deeper in winter. Unlike many other mammals, moles do not hibernate. They are often found in urban environments, such as parks and lawns, where their presence is marked by visible molehills, though the animals themselves are rarely seen.

In the agricultural landscape, moles prefer areas near mixed forests, wide dirt roads, or paved roads with broad vegetated shoulders. These areas provide shelter among roots and foraging grounds in adjacent fields.

**Photo 27**. European Mole *Talpa europaea* readily inhabits the farm area, using agricultural fields as feeding grounds (photo: O. Ciebiera)

On the Sulechów Photovoltaic Farm, molehills were observed both within the installation and immediately outside the fencing, in neighbouring fields used for growing cereals and maize (Photo 27). This pattern aligns with observations of moles in transitional zones between cultivated land and vegetated ecotones.

## Common Shrew *Sorex araneus*

The Common Shrew is widespread throughout Poland, typically inhabiting deciduous and mixed forests with dense undergrowth, river valleys, meadows, field groves, parks, and orchards. Due to habitat homogenisation and the chemicalisation of agriculture, which reduces invertebrate populations, its numbers are believed to be declining in agricultural areas across Europe (Dokulilová & Suchomel, 2017). The common shrew feeds mainly on earthworms, insects, snails, and spiders and serves as an excellent bioindicator of ecosystem quality.

During the study, a single deceased individual was observed on a road between farm sections near water bodies and shrubs. Although the immediate area under the photovoltaic panels does not appear particularly suitable for shrews, the surrounding areas with trees, shrubs, and nearby woodlands, especially those with water bodies, provide favourable habitats.

## Bats Chiroptera

The Sulechów Photovoltaic Farm Complex is situated in a mosaic landscape combining agricultural (to the south and east) and anthropogenic areas (to the north, bordering Sulechów, and to the west, adjacent to the S3 expressway). Within and around the farm, a variety of habitats provide diverse resources for bats, including: water bodies and streams with rich riparian vegetation that support abundant insect populations, tree rows and roadside vegetation, offering shelter and potential roosting sites, and nearby field groves with diverse tree ages and species, including Scots pine *Pinus sylvestris*, alder *Alnus* sp., and oak *Quercus* sp. This habitat diversity enhances the attractiveness of the area for bats, which rely on such environments for foraging, roosting, and commuting. The study aimed to assess the degree to which bats utilise the space within the Sulechów Photovoltaic Farm Complex. Particular attention was given to evaluating how bats interact with the farm's infrastructure and surrounding habitats.

Using the applied method of detecting echolocation calls, a total of 12,127 bat activity units were recorded throughout the study period (Table 16). The dominant species was the Common Noctule, accounting for 68.9% of detections, followed by pipistrelles: the Common Pipistrelle – 11.2%, Nathusius' Pipistrelle – 7.7%, and the Soprano Pipistrelle – 5.6%. Other taxa collectively made up 6.6% of the activity and were recorded sporadically (Table 16, Fig. 10).

**Table 16.** Bats recorded in the Sulechów Photovoltaic Farm Complex.

| No. | Species | Number of recordings | Share [%] |
|---|---|---|---|
| 1 | Western Barbastelle ***Barbastella barbastellus*** | 7 | 0.1% |
| 2 | Serotine Bat ***Eptesicus serotinus*** | 147 | 1.2% |
| 3 | Daubenton's Bat ***Myotis daubentonii*** | 40 | 0.3% |
| 4 | Greater Mouse-eared Bat *Myotis myotis* | 10 | 0.1% |
| 5 | Natterer's Bat ***Myotis nattereri*** | 2 | 0.0% |
| 6 | Bats of the ***Myotis*** genus (Mouse-eared Bats) | 9 | 0.1% |
| 7 | Common Noctule ***Nyctalus noctula*** | 8360 | 68.9% |
| 8 | Bats of the ***Nyctalus*** + ***Vespertilio*** + ***Eptesicus*** group | 289 | 2.4% |
| 9 | Nathusius' Pipistrelle ***Pipistrellus nathusii*** | 935 | 7.7% |
| 10 | Common Pipistrelle ***Pipistrellus pipistrellus*** | 1354 | 11.2% |
| 11 | Soprano Pipistrelle ***Pipistrellus pygmaeus*** | 684 | 5.6% |
| 12 | Bats of the ***Plecotus*** genus (Long-eared Bats) | 11 | 0.1% |
| 13 | Parti-coloured Bat ***Vespertilio murinus*** | 279 | 2.3% |
| Total | | 12127 | 100.0% |

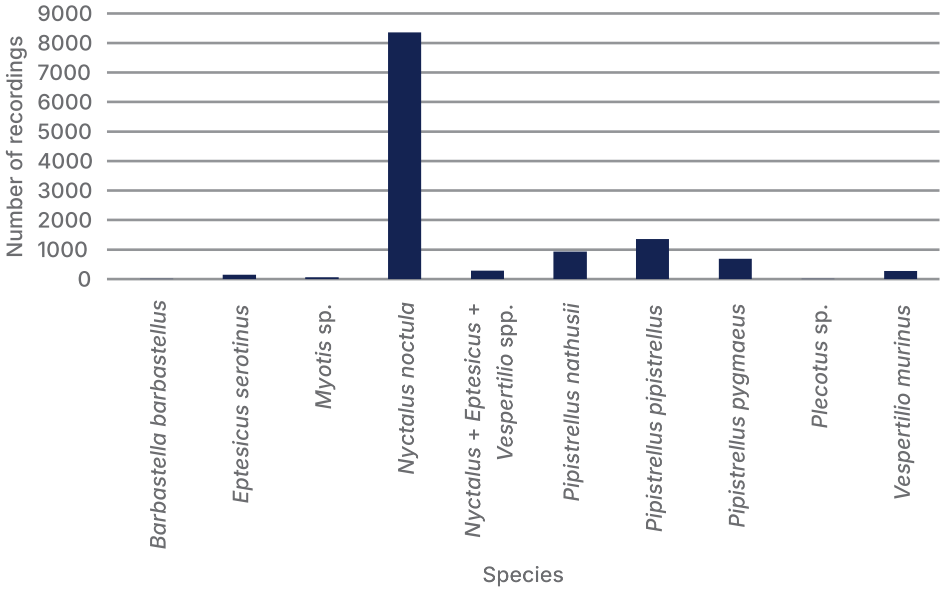


**Figure 10**. Species composition of bats at the Sulechów Photovoltaic Farm Complex

The species composition and number of bat activity units within the Photovoltaic Farm Complex are typical for the mosaic agricultural landscape of the Lubusz Voivodeship. The Common Noctule is associated with forests, river valleys, large parks, and gardens, where it establishes breeding colonies. It is widespread throughout the country, hibernating in tree cavities, rock crevices, and caves.

During the summer, it primarily inhabits tree hollows, building attics, and bird and bat boxes. Females form maternity colonies ranging from seven to around 200 individuals, while males live solitarily or in small colonies during the summer. For foraging, noctules prefer river valleys, meadows and pastures, areas near large bodies of water, forest clearings, and spaces near streetlights. They forage up to 20 km or more from their roosts and undertake long-distance seasonal migrations. Occasionally, they migrate in large groups during the day (Sachanowicz & Ciechanowski 2005; Furmankiewicz & Gottfried 2009).

Other species that extensively utilised the Photovoltaic Farm Complex were Pipistrelles: the Common, Nathusius', and Soprano Pipistrelles. These species are widespread throughout the country and share a key characteristic: their foraging habitats. Pipistrelles forage readily over water bodies, meadows, agricultural areas, rural settlements, near streetlights, along roads, and in forest clearings.

The highest number of bats within the Photovoltaic Farm Complex was observed during the period of breeding colony dissolution and swarming, between 1 August and 15 September (Fig. 11). The peak bat activity, with 510 activity units, was recorded during the night of 6–7 August. This increase is attributed to the movement of young bats leaving maternity colonies located in nearby tree stands, forests, buildings, and other structures. These juveniles begin exploring available habitats, learning to forage and familiarising themselves with the area.

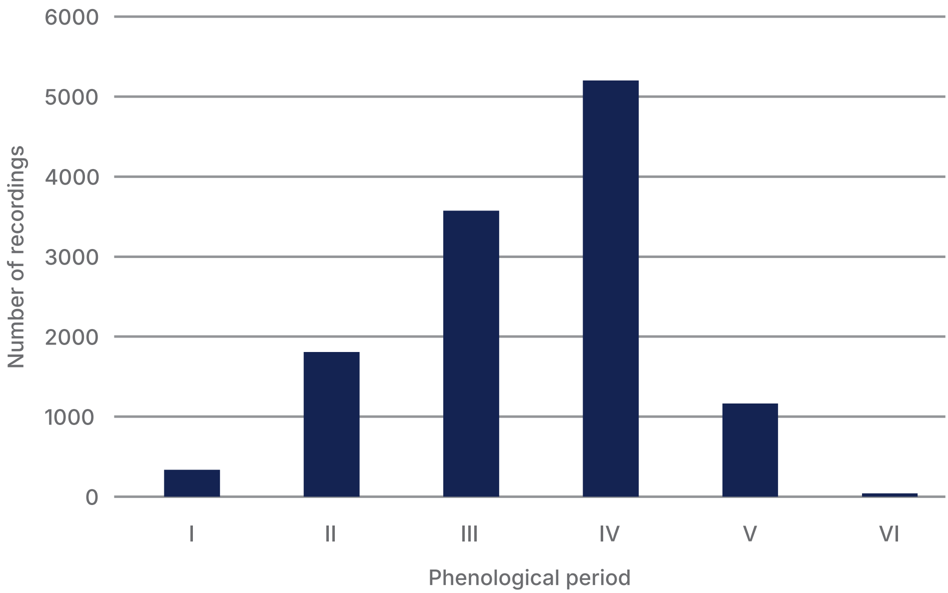


**Figure 11**. Bat activity in different phenological periods in the Sulechów Photovoltaic Farm Complex. Phenological periods: I – emergence from winter hibernation (15–31 March), II – spring migration and colony formation (1 April–30 May), III – breeding (1 June–31 July), IV – colony dispersal and early autumn migration, swarming (1 August–15 September), V – autumn migration (16 September–31 October), VI – early hibernation (1–15 November)

Observations using an infrared (IR) camera revealed that bats foraged directly above the panels at various heights, ranging from 1 metre to several metres above the panels, with particular activity near drainage ditches and tree stands. Some individuals were also observed foraging at lower levels between the rows of panels. No bat hibernation sites or maternity colonies were found within the farm area.

The impact of photovoltaic panels on biodiversity has been a subject of discussion among various authors (Jessel & Kuler 2006; Herden et al. 2012; Harrison et al. 2017). On the one hand, photovoltaic panels have a positive effect on biodiversity in agricultural areas, particularly where species diversity has been replaced by large-scale monoculture farming, without causing adverse effects (Herden et al. 2012). On the other hand, land-use changes, habitat fragmentation, fencing, alterations in land cover, and hydrological changes can negatively impact ecosystems and populations (Hernandez et al. 2014; Pizzo 2011; Gielen et al. 2019; Tinsley et al. 2023).

Scientific evidence suggests that photovoltaic panels reflect polarised light, which can attract insects, and consequently, birds and bats (Horváth et al. 2009, 2010). This is beneficial for bat populations: hunting above the panels, where food is more abundant, reduces energy expenditure and may, for example, make it easier for female bats to feed their young, thereby increasing reproductive success.

On the other hand, recent research in the UK by Tinsley et al. (2023) indicates that photovoltaic farms located in agricultural landscapes may negatively impact the activity of most bat species studied, leading to habitat loss and fragmentation of foraging and commuting areas. This research focused on common species such as those from the Pipistrelles *Pipistrellus*, Noctules *Nyctalus*, Long-Eared Bats *Plecotus*, and Mouse-Eared Bats *Myotis* genera, which are also widespread in Poland.

However, other studies conducted by Szabadi et al. (2023) in Hungary show that species adapted to human-altered environments—such as the Common Noctule *Nyctalus noctula*, Savi's Pipistrelle *Hypsugo savii*, and Kuhl's Pipistrelle *Pipistrellus kuhlii*—readily use photovoltaic farms, demonstrating their adaptability to modern landscapes.

Some scientific studies suggest that photovoltaic farms create increased shading beneath the panels and reduce plant biomass, which directly affects the biomass of flying invertebrates over the farm, ultimately leading to a decline in bat foraging activity (Tinsley et al. 2023; Barré et al. 2024). Thus, large-scale ground-mounted photovoltaic farms in areas that are attractive for bat foraging are likely to degrade habitat quality (due to reduced insect biomass), potentially affecting local bat populations.

In contrast, the situation is different when farms are located in areas subject to intensive agricultural practices (e.g., intensive farming regions), as seen in the case of the Sulechów Photovoltaic Farm Complex. Here, farm infrastructure combined with biodiversity-supporting measures can enhance local natural resources. Research shows that species diversity is higher in less intensively farmed fields that also serve as insect habitats (Duelli et al. 1999), while arthropod populations are lowest in areas of highly intensive agriculture (Benton et al. 2002).

Key factors contributing to the decline of insect populations in agricultural landscapes include the simplification of crop diversity, large-scale monoculture farming, and particularly the use of pesticides. Against the backdrop of monocultural landscapes dominated by large-scale crops such as maize, the presence of photovoltaic farms with well-managed greenery, wildflower meadows, fallow areas, shelter vegetation, and ecotonal boundary vegetation can provide important areas for invertebrate development and, consequently, serve as significant foraging grounds for bats.

One anticipated effect of photovoltaic farms on bats is the potential for mortality due to collisions with panels. Young bats may occasionally mistake photovoltaic panels for water surfaces, which could lead to collisions. However, such incidents are rare, as research shows that some bat species can distinguish between water surfaces and other reflective surfaces based on texture (Greif & Siemers, 2010; Russo et al., 2012; Greif et al., 2017).

During the research conducted at the Sulechów Photovoltaic Farm, detailed searches for collision victims did not uncover any dead birds or bats, suggesting that such impacts are minimal or absent in this specific context.

## European Hare *Lepus europaeus*

The European Hare is a widely distributed mammal in Poland, primarily inhabiting open agricultural landscapes. It utilises permanent grasslands and a mosaic of fields featuring winter cereals and rapeseed. Changes in agriculture, including increased mechanisation, pesticide use, and habitat transformation, have led to a decline in its European population. This downward trend is also observed in Poland (Gryz & Krauze-Gryz 2022). The main contributing factors include the expansion of field sizes, crop homogenisation (particularly large-scale maize monocultures), removal of areas with wild vegetation, and pesticide use (Sliwinski et al. 2019).

To provide suitable habitats and enhance biodiversity in agricultural fields, "wild-flower strips" are implemented. These strips have been shown to effectively support local hare populations, offering a foundation for the recovery of the European population (Sliwinski et al. 2019). Wildflower strips cover 5–10% of a field's area and are situated among the fields. They consist of various annual and perennial plant species that produce pollen and nectar. Their primary purpose is to increase the diversity of pollinating insects and overall biodiversity.


**Photo 28**. European Hare *Lepus europaeus* is a common species at the Sulechów Photovoltaic Farm Complex

A photovoltaic farm, when appropriately maintained, can serve as a type of "wildflower strip". Despite being fenced, it can act as a refuge for European Hares. Studies conducted at the Sulechów Photovoltaic Farm Complex confirm the hare's year-round presence across all sections of the farm (Photo 28). Hares can easily access the farm by using gaps between the ground and the fence or by passing under entrance gates. Individual hares were observed resting under the panels on hot days, seeking shade and protection from aerial predators.

## Rodents Rodentia

Among the rodents identified within the Photovoltaic Farm Complex, Voles *Microtus* sp. were dominant, with the Common Vole *Microtus arvalis* being the most frequently recorded species. Other rodents included the striped Field Mouse *Apodemus agrarius* and a single individual of the Water Vole *Arvicola amphibius*. The latter is typically associated with wetland areas, lake shores, and riverbanks, and its presence is likely due to the water bodies located between sections of the photovoltaic farm.

The striped field mouse was recorded throughout the farm, although it showed a preference for more humid areas, ecotones, and the edges of the farm. Similar to voles, it can occur in large numbers, causing damage to crops.

However, the most numerous group of mammals within the Photovoltaic Farm Complex were voles, whose burrows and tunnels were found across the entire area. Voles are common in Poland's agricultural landscape, mainly occupying semi-natural habitats such as fallow land, roadsides, field edges, hedgerows, grassy strips along watercourses, stubble fields, and meadows. They play a vital role in ecosystems due to their high reproductive potential (up to seven litters per year, with 4–12 young per litter, which can themselves reproduce within two months). However, they are often preyed upon by a variety of predators, including foxes, Weasels, Stoats *Mustela erminea*, birds of prey (e.g., Common Buzzards and Kestrels), owls (e.g., Barn Owls and Long-Eared Owls), shrikes, storks, martens, and domestic dogs and cats.

Voles are considered pests in agricultural fields, as large populations can invade crop areas, particularly cereals. They primarily feed on green plant parts, seeds, tubers, and roots, storing up to 2 kg of food for the winter. Interestingly, a high vole population density can lead to vegetation loss in a given area. This occurs when predator populations are insufficient to significantly reduce vole numbers, prompting the voles to relocate in search of new habitats. For this reason, efforts to support bird and owl populations on and near photovoltaic farms are essential.

To assess the intensity of vole activity, studies were conducted in three habitat types: the photovoltaic farm, road verges, and a field sown with alfalfa. The relative intensity of habitat use by voles was estimated by counting the number of burrow entrances per 100 m². Several random study plots were selected within each habitat type and surveyed in April 2024. The presence of voles was confirmed by detecting fresh plant clippings or droppings (following the method described by Jareño et al., 2014), after which burrow entrances were located and counted across each plot. The results are presented in Table 17.

This indirect method of assessing habitat use does not provide precise vole population numbers but clearly demonstrates the extent to which each habitat is utilised. Voles were confirmed to be present in all habitat types, with the highest average number of burrow entrances recorded on the photovoltaic farm, followed by road verges, and the lowest on the alfalfa field (Table 17).

**Table 17.** Intensity of habitat use by voles *Microtus* sp. in three habitat types.

| Habitat type | Number of surveyed plots of 100 $m^2$ | Total number of detected burrow entrances | Minimum | Maximum | Mean | SD |
|---|---|---|---|---|---|---|
| Roadside verges of S3 and DK 32 | 30 | 843 | 0 | 132 | 28.1 | 31.86 |
| Alfalfa | 32 | 226 | 0 | 36 | 7.1 | 8.3 |
| Sulechów PFC | 54 | 3222 | 11 | 146 | 60.8 | 27.81 |

The intensive use of the Photovoltaic Farm Complex by voles is due to the lack of agricultural activities on the site (the ground is not ploughed but only mowed with light machinery). Voles are active year-round and throughout the day. They live in colonies, digging burrows and deep tunnels, and create visible paths on the ground surface.

## Red Fox *Vulpes vulpes*

The Red Fox has adapted exceptionally well to human-transformed environments, ranging from forested and field-meadow areas to urbanised city landscapes. In Poland, it is found throughout the entire country. While it typically inhabits a selected environment, it can also lead a nomadic lifestyle. Adult individuals maintain territories, the size of which varies depending on habitat quality. Territory size ranges from 0.30 $km^2$ to 8.6 $km^2$ (Goszczyński 2002), depending on the availability of food resources. A territory is usually occupied by an adult male and one or two females with their young. Families and solitary individuals live in ground dens, often maintaining emergency dens within their territory. A single den may be used by multiple generations.

Red foxes are omnivores and scavengers, with a highly varied diet. They primarily feed on small rodents such as voles and mice, but their diet also includes bird eggs, insects, reptiles, and fruits.

Within the Sulechów Photovoltaic Farm Complex and its vicinity, one family of red foxes has been observed. Their dens are located in various parts of the farm, mainly in the northern section, although the foxes traverse different sections of the farm without significant difficulty. They easily pass under the fencing or use gaps in it.

The photovoltaic farm provides the foxes with a safe refuge and access to an abundant food supply.

## European Badger *Meles meles*

The European Badger is a carnivorous mammal from the mustelid family, widespread throughout Poland. Its preferred habitat is deciduous and mixed forests with dense undergrowth. Badgers are omnivorous and may live in social groups of several to a dozen individuals.

Their territory can span several dozen hectares. Badgers build extensive burrow systems with multiple entrances, which can be passed down through generations. These burrows may have several emergency exits or even dozens in special cases.

At least one badger burrow, inhabited by two adult individuals, was identified within the farm (Photo 29). The burrow is located between rows of photovoltaic panels, but the badgers roam the surrounding areas in search of food.


**Photo 29**. European Badger *Meles meles* digging deep burrows at the Sulechów Photovoltaic Farm Complex

## Stone Marten *Martes foina*

The Stone Marten is widespread throughout Poland and closely resembles the Pine Marten *Martes martes*, which predominantly inhabits older deciduous and mixed forests. Stone martens, however, occupy diverse habitats, ranging from parks and wooded areas to open landscapes and urban environments. They are solitary animals, with individuals maintaining well-defined territories marked by droppings left in visible locations, such as large stones or fallen trees. Stone martens were observed on the farm and in its immediate vicinity. They were noted searching for food among the photovoltaic panels but primarily remained near humid areas with existing tree cover, such as those around the pond and drainage ditches.

## Roe Deer *Capreolus capreolus*

The Roe Deer is widely distributed throughout Poland, inhabiting both forested areas and open landscapes, including agricultural fields, meadows, and fallow lands. This highly adaptable species is also capable of utilising parks and gardens in urban centres (Jasińska et al., 2022). It thrives in a mosaic of small wooded patches, meadows, and agricultural areas.

**Photo 30**. Roe Deer *Capreolus capreolus* observed in the Sulechów Photovoltaic Farm Complex (photo: P. Czechowski)

Roe Deer lead a sedentary lifestyle and are active throughout the day, typically living in family groups. They were regularly observed within the Sulechów Photovoltaic Farm Complex (Photo 30). On one occasion, a female with a fawn and a male were spotted directly among the panels. On hot days, the panels provided shade and shelter for the deer.

The roe deer remained year-round in one of the farm's sections in the eastern area. Due to gaps in the fencing, they were able to migrate freely in both directions, making the farm a safe and suitable habitat. The existing vegetation, including alfalfa and a mix of meadow species, provided an adequate foraging base for this species.

## Eurasian Wild Boar *Sus scrofa*

The Wild Boar is commonly found throughout Poland in forests, agricultural areas, and even urban environments. It is increasingly observed on the outskirts and in city centres, actively searching for food. Within the Sulechów Photovoltaic Farm Complex, wild boars were not directly observed, but signs of their presence, such as rooting sites, tracks, and droppings, were detected near the farm, directly along the fencing.

Additionally, Domestic Cats *Felis catus* were observed both within the photovoltaic farm and its surroundings. Their presence can significantly impact the local fauna, including insects, reptiles, small mammals, and birds.

It is also highly likely that several other mammal species inhabit the area. These include the Weasel *Mustela nivalis*, which primarily hunts voles, abundant on the farm, the Raccoon *Procyon lotor*, an invasive and omnipresent species, and other small mammals from the Micromammalia group.

In summary, the Sulechów Photovoltaic Farm Complex provides an attractive habitat for various mammal taxa, serving as a foraging ground and, for some species, a shelter and breeding site. Moreover, it does not act as a barrier for the movement of large mammals due to the division of the area into fenced sectors corresponding to different parts of the farm.

# 8. Impact on the landscape

The landscape is one of the most important elements of our surrounding space. It is a multidimensional concept, encompassing both natural and anthropogenic elements that collectively shape the visual and spatial characteristics of a given area. Various components coexist and interact within it, such as landforms, vegetation, hydrological networks, and built structures. The landscape is also defined as the overall visual impression we perceive when looking at an area. This can include views of mountains, forests, agricultural fields, cities, or coastlines. It comprises everything we see around us—natural features such as trees, rivers, and hills, as well as human-made elements like buildings, roads, and bridges. The landscape is an integral part of human living environments: it influences our health, well-being, and quality of life, shaping our experiences and memories.

The significance of the landscape for humans is multifaceted. Firstly, it fulfils ecological functions, serving as a habitat for numerous plant and animal species while regulating water and material cycles. Secondly, it has cultural and historical dimensions, acting as a repository of cultural heritage and collective memory. Lastly, it holds immense aesthetic value, influencing our perceptions and emotions, which in turn affect mental and physical health.

Although the landscape is an integral part of our daily lives, it often goes unnoticed until some form of change occurs. Such changes can result from human activities, such as urbanisation, industrialisation, or agricultural intensification, which may lead to landscape degradation. These processes often result in the loss of biodiversity, environmental pollution, spatial fragmentation, and the disappearance of unique landscape features. Poor spatial planning and a lack of care for cultural and natural heritage can lead to the loss of a place's distinctive characteristics, negatively impacting the quality of life for residents. It is at such moments that we begin to realise how profoundly the landscape influences our lives and how crucial its preservation is.

Protecting the landscape is therefore essential to maintaining a balance between socio-economic development and the conservation of natural environments and cultural heritage. Efforts in this area include sustainable spatial planning that considers the needs of nature and landscape protection, as well as public education and the promotion of pro-ecological attitudes. By doing so, it becomes possible to preserve the unique landscape values for future generations, which directly contributes to the quality of life and the health of society.

## Development of concepts

The term *landscape* is complex and has numerous definitions. It is widely used across various disciplines, including landscape architecture and spatial planning, and has been the subject of many syntheses (e.g., Ostaszewska, 2002; Wolski, 2002; Chmielewski, 2008; Pietrzak, 2010; Richling & Solon, 2011).

Integrating different approaches to defining the term, the landscape can be understood as a segment of geographical space characterised by a specific structure of natural and cultural elements that are functionally interconnected (Żarska, 2011). This space depends on the presence of humans, who observe it, shape it through their actions (or inaction), and assign it personal meaning (feelings associated with it, memories, etc.). As a result, the landscape is not a fixed, unchanging concept. It continuously evolves under the influence of human presence and cannot be objectively evaluated without considering its role for the people living within it.

The structure and functioning of the landscape are perceived through multiple senses, meaning that every landscape has its own smell, taste, sound, and appearance. Moreover, landscapes change over time and space. Many researchers emphasise the evolution of landscapes, which are shaped by natural forces and anthropogenic pressure (Badora, 2011).

Polish law also describes the concept of the landscape in various acts and regulations. Notably, the *Act of 27 March 2003 on Spatial Planning and Development* and the *Act of 24 April 2015 on Amending Certain Acts in Relation to Strengthening Landscape Protection Tools* define the landscape as "a space perceived by people that contains natural elements or products of civilisation shaped by natural forces or human activity".

This definition focuses on the visual aspect of the landscape, simplifying it to a collection of vistas within a specific area as perceived by an observer. From their perspective, the landscape encompasses the earth's surface viewed from a particular vantage point, forming what is known as a view.

The human perspective plays a critical role in assessing landscape impact. Changes to a view's structure caused by human activity (e.g., implementing a project) determine both the assessment process and its outcomes.

The view surrounding an observer can be divided based on its influence:

- **First zone (I):** Up to 200 metres from the observer, this zone is perceived multisensorially and has the greatest influence on the overall landscape perception.
- **Second zone (II):** Beyond 200 metres, this zone forms the background of the view and is perceived visually only.

Research suggests that proximity influences our reaction to a view. The closer we are to a feature, the more likely we are to respond positively or negatively, with a stronger emphasis on the immediate surroundings (Wojciechowski, 1986). Other studies indicate that humans perceive stereoscopically up to approximately 1,200 metres (Middleton, 1957; Meienberg, 1966), where the observer experiences the strongest impact.

Landscape perception is also influenced by individual observer characteristics, making it highly subjective. Beyond the foreground, where an object may dominate, elements in the background and distant planes may be visible but do not necessarily draw attention.

The concept of *view range* is another critical aspect of landscape perception. Lange (1990) noted that the closer an obstacle is to the observer, the more it restricts the field and range of view. This observation is particularly significant in urban areas and near tall vegetation. Such considerations are essential for understanding how different elements shape human perception of the landscape.

## The impact of photovoltaic farms on the landscape—Case study: Sulechów Photovoltaic Farm Complex

The impact of photovoltaic installations on the landscape is one of several environmental and social considerations associated with such investments, alongside concerns like noise, infrasound, electromagnetic field emissions, land surface transformations, and effects on biocenoses. Landscape-related risks stemming from photovoltaic farm development are subject to identification and mitigation under the frameworks of environmental protection, cultural heritage preservation, and spatial planning laws, all aligned with sustainable development principles (Badora, 2017).

The landscape encompasses natural and cultural elements, their physical composition, historical and visual aspects, and human perception of the whole. This discussion focuses primarily on the visual impact of photovoltaic installations on the landscape. The analysis included a GIS-based assessment of the area's visual range and visualisations of the photovoltaic farm created using WindPro 4.0 software (EMD, 2023), incorporating the actual dimensions of the installation. The results were compared to the existing state to determine whether pre-implementation analyses reflected the real-world impact.

## Landscape characteristics of the Sulechów Photovoltaic Farm Complex and surroundings

The Sulechów Photovoltaic Farm Complex is located in the Łagów Lakeland mesoregion. The area features a vast plateau separated from the Oder River valley by a steep escarpment. It is a rolling landscape shaped by glacial and fluvioglacial processes, characterised by subglacial troughs, kettle holes, and small denudational valleys with flat floors (Nowaczyk, 1978).

The local landscape primarily consists of a mosaic of farmland, meadows, wetlands, natural watercourses, forests (mostly pine-dominated coniferous habitats), and one of the largest stands of Black locust (*Robinia pseudoacacia*) in Poland, near Nowy Świat and Górzykowo. Deciduous forests, mainly riparian woodlands, are concentrated in the Oder River valley. Industrial areas on the outskirts of Sulechów and their associated vegetation also contribute to the landscape.

The region features a well-developed transport network. To the west, the farm is bordered by the S3 expressway, while to the north, it adjoins National Road 32 (DK32). The photovoltaic farm and its adjacent areas are heavily human-altered, significantly influencing the surrounding landscape's character. Farmlands in the area were artificially created for agricultural production, resulting in an anthropogenic landscape dominated by transformed areas interspersed with natural elements.

The primary landscape functions of the area are provisioning (agricultural production) and industrial-energy functions. The composition of the open landscape is predominantly shaped by the interiors of the agricultural landscape—cultivated fields interspersed with anthropogenic features such as nearby industrial facilities or road junctions. These landscape interiors are enclosed by forested areas, tree stands, and adjacent transport corridors, some of which are elevated above the surrounding terrain.

The Sulechów Photovoltaic Farm Complex is situated on relatively flat terrain with no prominent hills or elevations, at an altitude of approximately 80–85 metres above sea level. There are no distinctive landforms in the area. The visual landscape backdrop consists of a mosaic of land-use forms: agricultural fields, clusters of vegetation and tree stands, watercourses, and, from a broader perspective, compact forest areas, industrial facilities, and scattered residential buildings (Photo 31).

**Photo 31**. View of the Sulechów Photovoltaic Farm Complex facing north (photo: O. Ciebiera)

Field margins separating the individual fields feature both dense tree stands and shrub clusters as well as isolated trees and shrubs. In-field vegetation, roadside trees, and shrubs along roads and local watercourses provide a relatively varied character to the landscape and create visual barriers.

According to the Landscape Audit of the Lubusz Voivodeship (Lubuskie Voivodeship Board, 2024), the visual environment of the Sulechów Photovoltaic Farm Complex and its surrounding areas falls within Landscape Unit No. 966. This is classified as a natural-cultural landscape: rural, with a predominance of mosaically distributed agricultural land forming medium-sized fields (Subtype B6d).

The dominant landscape features near the farm include a high-voltage power line (110kV Sulechów–Wolsztyn) supported by tall lattice towers, and, to a lesser extent, viaducts and embankments of nearby elevated transport routes. Within the investment area and its immediate surroundings, there are no significant viewpoints or valuable visual axes.

## Area visibility

The simulation of the area visibility range for the Sulechów Photovoltaic Farm Complex was conducted using GIS tools, employing a digital terrain model (DTM) and a digital surface model (DSM) in accordance with the method developed by the authors. Similar methodologies for visibility analysis have been described in publications such as *Challenges and Tools in Landscape Protection* edited by Daniel Lisek (2023) and *Assessment of the Impact of Photovoltaic Farms on the Landscape: Methodological Recommendations* by Ansee Consulting (2022).

An analysis based on the DTM of the hypsometric map for the planned project and its surroundings revealed that the photovoltaic farm is located in an expansive, relatively flat area with minor elevation differences (usually around 5 metres, with a maximum of 8 metres).

In addition to topography, land cover significantly impacts the landscape and the visibility of specific elements within it. An analysis based on the DSM for the Sulechów Photovoltaic Farm and its surroundings showed that numerous local features serve as visual barriers, reducing visibility. These include:

- **Vegetation:** Tree and shrub clusters, often isolated, located along field boundaries, watercourse banks, and wetland edges.
- **Anthropogenic structures:** Elevated road embankments (mainly for the S3 expressway and DK32 highway), viaducts, and transport junctions.

For the analysis, the maximum height of farm components was set at 3 metres above ground level, with the observer’s eye level assumed at an average height of 1.6 metres. A map showing the visibility range simulation results is presented in Figure 12.

The analysis results indicate that the installation is prominently visible within the landscape, primarily in the central part of the Photovoltaic Farm Complex, specifically from the open agricultural fields and the accompanying rural roads located south of the photovoltaic farms. The solar panels are also clearly visible from certain sections of roads surrounding the farm area. In other locations, the visibility is at most moderate.

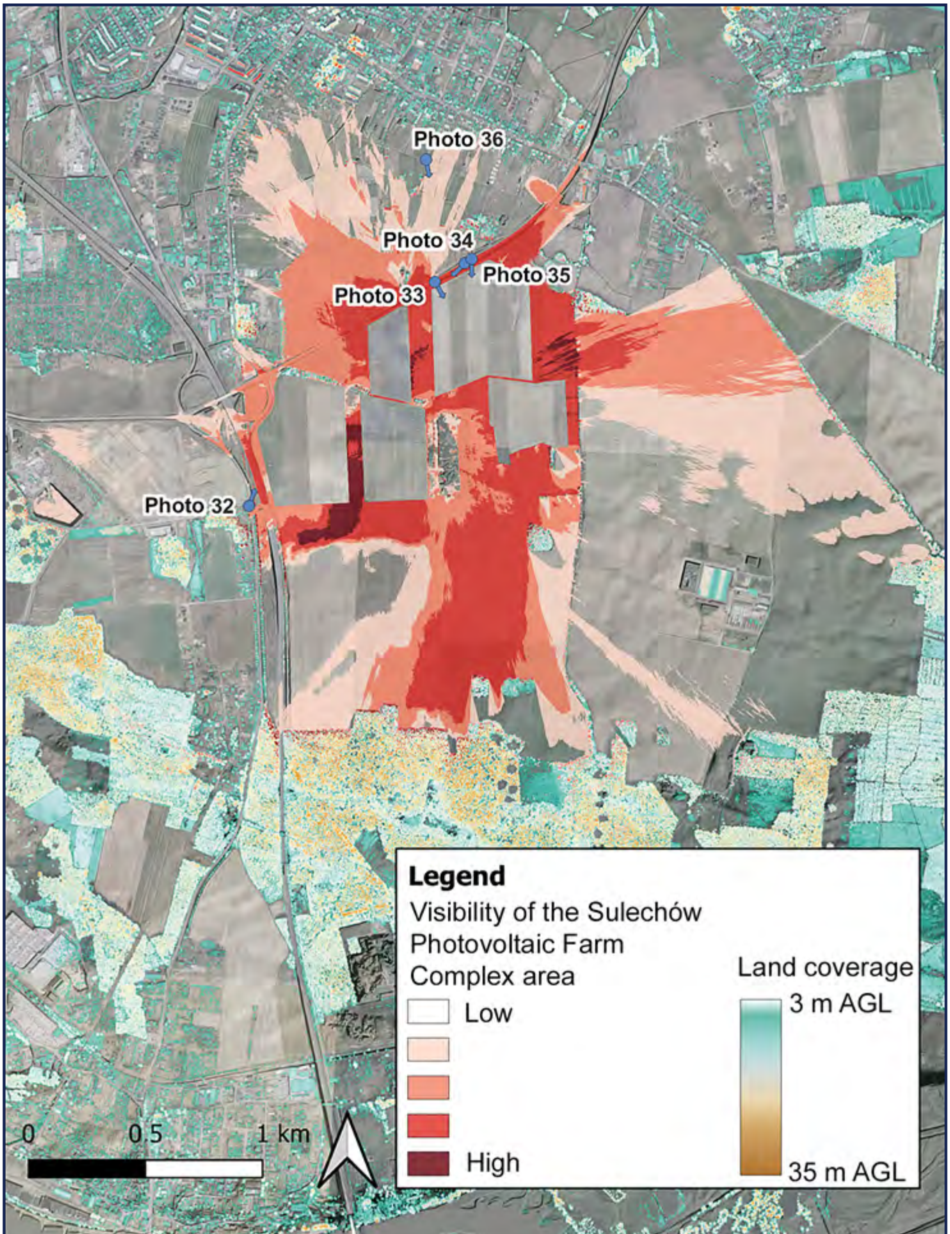


**Figure 12**. Area visibility map of the Sulechów Photovoltaic Farm Complex

Key factors in reducing the visibility of the panels include the embankments of neighbouring roads (mainly the S3 highway, but also sections of DK32), which, as in the case of the S3, almost entirely block the view of the photovoltaic panels, significantly reducing their visibility on the western side of the S3. Local vegetation, mainly in the form of isolated tree clusters and groves, also plays an important role in reducing visibility, either diminishing or completely obscuring the visual impact.

The visibility range analysis further indicates that parts of the farm are clearly visible from certain points up to approximately 950 metres away (from the agricultural fields to the south). However, for most of the area surrounding the Photovoltaic Farm Complex, the panels will be only minimally visible from about 200–300 metres, becoming progressively less visible with increasing distance. On the western side of the S3 and in parts of the northern side of DK32, the presence of visual barriers means that the photovoltaic panels become invisible from distances of approximately 100 metres or more.

For area-wide visibility analyses, data from the available numerical terrain coverage models are utilised. However, this method introduces a margin of error, as the information may not always be up-to-date and depends on the scale and methodology of its generation.

An additional method for illustrating the visual impact of the installation involves creating visualisations based on photographs taken during field inspections within and around the farm area. These photographs present the most current natural and cultural state of the area, providing an initial understanding of the landscape's character and its functions. The photographs are then supplemented with scaled sections of photovoltaic panels and fencing to give an approximate impression of the installation's dimensions and its integration into the local landscape.

In the case of the Sulechów Photovoltaic Farm Complex, the installation has already been present in the landscape for a considerable period. Subsequent pages compare the results obtained from the analysis (visualisations) with photographs showing the post-construction appearance of the farm (Photos 32–36).

As observed, despite its large surface area, the photovoltaic farm occupies only a small portion of the landscape from the perspective of routes and viewpoints, drawing little attention from observers.


**Photo 32**a. Visualisation (photo: M. Bocheński, compiled by A. Chruścicka)


**Photo 32**b. Post-implementation state (photo: M. Bocheński)

**Photos 32a and 32b.** View facing north, on the western side of the S3 expressway. Photovoltaic panels are partially visible but mostly obscured by the road embankment. The presence of the embankment and its vegetation significantly limits the visibility of the farm from the western side of the S3 road, in some places completely blocking it.

**Photo 33**a. Visualisation (photo: M. Bocheński, compiled by A. Chruścicka)

**Photo 33**b. Post-implementation state (photo: M. Bocheński)

**Photos 33a and 33b.** View facing south from the verge of national road DK32. Photovoltaic panels are clearly visible but occupy only a small portion of the landscape, not obstructing the horizon.

**Photo 34**a. Visualisation (photo: M. Bocheński, compiled by A. Chruścicka)

**Photo 34**b. Post-implementation state (photo: M. Bocheński)

**Photos 34a and 34b.** View facing west from the verge of national road DK32 on its northern side. Photovoltaic panels are clearly visible but occupy only a small portion of the landscape, not obstructing the horizon.

**Photo 35**a. Visualisation (photo: M. Bocheński, compiled by A. Chruścicka)

**Photo 35**b. Post-implementation state (photo: M. Bocheński)

**Photos 35a and 35b.** View facing south from the verge of national road DK32 on its northern side. Photovoltaic panels are clearly visible but occupy only a small portion of the landscape, not obstructing the horizon.

**Photo 36**a. Visualisation (photo: M. Bocheński, compiled by A. Chruścicka)

**Photo 36**b. Post-implementation state (photo: M. Bocheński)

**Photos 36a and 36b.** View facing south towards open areas near the boundary of the built-up area in Kruszyn. Photovoltaic panels are barely visible on the horizon due to the significant distance and obstruction by vegetation and the embankment of road DK32.

## Conclusions and summary

Thanks to local visual barriers, the impact of the Sulechów Photovoltaic Farm Complex on the landscape is significantly limited, reducing potential negative aesthetic perceptions among the local population and visitors. Despite the farm's location in a transformed area dominated by agricultural fields and surrounded by industrial facilities, roads, and other anthropogenic structures, natural barriers such as tree and shrub clusters, as well as artificial ones like road embankments and industrial buildings, effectively diminish its visibility from nearby areas regularly used by residents. The Sulechów Photovoltaic Farm demonstrates that it is possible to adopt a sustainable approach to developing renewable energy infrastructure while preserving landscape values.

The visual impact of photovoltaic farms on the landscape is a constant effect (present throughout the operational lifespan of the installation) and unavoidable (although it can be minimised). However, there are numerous analytical methods that can be used during the planning stage to preliminarily determine factors such as the intensity and extent of the impact, as well as to identify potential receptors of the anticipated changes in the landscape.

As demonstrated by the results of the analyses above, the assumptions made during these studies are reflected in reality and can be effectively applied to assess the impact of photovoltaic farms on the landscape.

# 9. Best practices—how to increase biodiversity on photovoltaic farms

## Investment planning

When considering the environmental impact of photovoltaic farms, it is crucial to find a balance between environmental protection, sustainable land use, and the need to produce clean energy. This requires a holistic approach that incorporates ecological, economic, and social aspects at both the planning and operational stages of these installations.

Careful planning and design of photovoltaic farms, aimed at minimising their environmental impact, primarily focus on locating them in non-productive, degraded, or low-value agricultural areas. The choice of location is a critical factor in determining the subsequent impact of the farm on the environment (Photo 37). Photovoltaic farms should not be established in ecologically valuable areas, such as Natura 2000 sites designated for the protection of habitats and bird species. Any development in such areas must be preceded by a thorough assessment of potential environmental changes and their impact on the conservation objectives of the Natura 2000 site. Photovoltaic farms must not be constructed in national parks, nature reserves, ecological sites, landscape-nature complexes, documentation sites, or natural monuments.

**Photo 37**. Choosing the right location for the investment is a key factor in the later impact of the photovoltaic farm (photo: O. Ciebiera).

In the case of landscape parks, protected landscape areas, and Natura 2000 sites, a more detailed analysis is provided in Chapter 10 of this publication. Building such projects on biologically diverse lands, including meadows, grasslands, peatlands, or transitional ecosystems, is always detrimental to nature and to crops near potential farms. It is essential to recognise that no investment, regardless of effort, can match the complexity of natural ecosystems. Nor is it possible to fully restore the biodiversity levels characteristic of such ecologically valuable areas.

Photovoltaic farms can be located on already degraded or heavily human-altered lands, such as expressway and highway verges, former military training grounds or infrastructure, post-mining spoil heaps, and reclaimed waste disposal sites. Secondarily, they may also be established on agricultural land, particularly on low-quality soil (classes IV–VI), such as fallow land and large-scale monoculture crops (e.g., maize).

Another important aspect in planning such investments is the management of the land around the panels, along transportation routes, and near fencing. Ensuring the appropriate vegetation structure within photovoltaic farms is a key stage in their planning (Photo 38). It is important to remember that without soil, there can be no vegetation, and without vegetation, the soil loses its physical and chemical properties. Depleting the vegetation layer rapidly leads to soil erosion caused by rainfall and wind.

**Photo 38**. Proper vegetation management is essential for increasing biodiversity and protecting soil from erosion – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

Therefore, appropriate land management for photovoltaic farms is essential, with the best approach based on the physical properties of the soil. Factors such as fertility, water retention, and exposure to sunlight must be considered. Universal solutions are often ineffective; for instance, sowing species-rich meadow species on sandy soils with low water retention will not achieve the intended results. Land management must be carefully planned to create a largely self-sustaining environment that does not require additional interventions, such as irrigation.

In heavily degraded areas, soil fertility can be improved through the use of phytoremediation plants, which enhance soil structure. These include valuable nectar plants that also serve as an excellent food source for pollinators. With such management, the soil can gain an additional 20 cm of humus over several decades (Kasztelewicz & Szwed 2010). Soil improvement plants include species that fix nitrogen and produce large amounts of biomass, such as Comfrey *Symphytum officinale*, Clover *Trifolium* spp., Alfalfa *Medicago* spp., Pea *Pisum* sp., Bean *Phaseolus* sp., Oats *Avena* sp., and Rapeseed *Brassica napus*. Phytoremediation also increases water infiltration into the soil.

When planning such investments, it is essential to consider global trends supporting pollinators (e.g., the European Commission's A New Deal for Pollinators, 2023), which may eventually influence national legislation. A notable example is the global trend of developing photovoltaic farms as pollinator-friendly spaces. This involves managing farms to provide pollinators with a rich, season-long food base and suitable development habitats. In some countries (e.g., the USA), legislative changes have already been implemented to mandate such practices (Terry 2020).

## Introducing vegetation to photovoltaic farms

Planting, maintaining, and periodically tending vegetation is an excellent approach for managing the unique environment of photovoltaic farms. Such vegetation must possess several key characteristics beneficial to the farm's conditions. Firstly, plants grown under the panels must demonstrate significant tolerance to shade, while those in other areas of the farm should tolerate direct sunlight. Additionally, selected species should have slow growth rates, remain relatively short at maturity, and require minimal maintenance.

The use of native species naturally occurring in the region is strongly recommended. Depending on the vegetation management approach (mowing, grazing, or even cultivating selected species), the choice of herbaceous plant mixtures must be tailored to the farm's design and green space management. The plants should also be easy to maintain and have long-term durability. It is important to implement practices such as mowing and systematic reseeding to prevent the areas from being overrun by undesirable or invasive species.

Introducing green belts, wildflower meadows, and even low-growing trees and shrubs, strategically planted in appropriate areas, is a beneficial idea. These vegetation features should not interfere with energy production and will serve as ecological compensation areas.

Prompt land management following the construction phase is also crucial. Neglecting this can lead to the uncontrolled spread of highly undesirable plants, such as holoagrophytes—non-native plants established in natural habitats. These include invasive and foreign species that pose a threat to local biodiversity, such as Canadian goldenrod *Solidago canadensis*, Giant goldenrod *S. gigantea*, Canadian fleabane *Conyza canadensis*, Sosnowski's hogweed *Heracleum sosnowskyi*, and others.

In rare cases, refraining from planting may also be a viable option, but only in areas where sand grassland or heathland communities naturally thrive.

A well-thought-out planting/seeding and biodiversity management plan should be tailored to the specific characteristics of the project, taking into account individual factors such as the availability of water bodies, ecological corridors, local flora and fauna, and the land use in adjacent areas. The herbaceous seed mix should come from local, certified sources to ensure the development of local biodiversity.

## Application of agrotechnical practices

Selected agricultural practices, when applied with appropriate frequency, such as mowing and reseeding, have a positive impact on maintaining native seeds and root structures in the soil. These practices minimise the risk of wind and water erosion while increasing the likelihood of natural land reclamation (Sinha et al., 2018).

The farm area should be mowed, but infrequently and in a phased manner. A more detailed analysis of mowing/grazing methods that enhance biodiversity while minimising the presence of invasive plants is discussed in the section on insects in the guide "Maintaining Green Spaces".

Additionally, when mowing larger sections of the area, it is essential to start from the centre of the farm and move outward. This approach gives animals, such as birds and their chicks or small mammals, the chance to escape.

Introducing periodic land-use changes can also support the development of meadow species. For instance, rotational grazing by livestock and mowing the farm area could follow a schedule such as one year of grazing followed by two years of mowing. This cyclical approach fosters biodiversity and supports sustainable vegetation management.

## Integration with organic farming

Creating synergy between energy production and sustainable agriculture can bring numerous tangible benefits for all parties involved. The land of photovoltaic farms can successfully be used for cultivating specific crops (agrivoltaics) while simultaneously installing photovoltaic panels on fields in such a way that agricultural practices can still be carried out. This requires appropriate panel height and spacing, burying transmission infrastructure at adequate depths, and selecting suitable crops and land management methods for the area beneath the panels.

Agrivoltaics is particularly advantageous for dual land use, especially in regions where agricultural land is becoming scarce. Research shows that yields of certain crops can be comparable in partially shaded areas to those obtained in open fields. For instance, Broccoli *Brassica oleracea* var. *italica* was experimentally cultivated over several growing seasons (Chae et al., 2022).

Selecting shade-tolerant crops or those with a high tolerance for partial shading (accounting for the apparent movement of the sun during the day and seasons) can prove economically viable. Additionally, photovoltaic farms can host crops that tolerate high sunlight and occasional water deficits. Examples include some plants commonly referred to as “herbs” (e.g., Oregano *Origanum vulgare*, Sage *Salvia officinalis*, and Basil *Ocimum basilicum*), which are nectar-rich plants and thus expand the available food base for pollinators (Photo 39).

**Photo 39**. Many plant species can be successfully cultivated on photovoltaic farms, including kitchen herbs such as common oregano *Origanum vulgare* – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

Other crops suitable for cultivation on photovoltaic farms, in addition to those mentioned above, include:

- **Vegetables:** Cabbage *Brassica oleracea* var. *capitata*, Spinach *Spinacia oleracea*, Celery *Apium graveolens* var. *rapaceum*, Peppers *Capsicum* spp., Lettuce *Lactuca* spp., Beets *Beta vulgaris*, Potatoes *Solanum tuberosum*, Radishes *Raphanus sativus* var. *sativus*, Tomatoes *Solanum lycopersicum*, Garlic *Allium sativum*.
- **Fruits:** Strawberries *Fragaria × ananassa* Duchesne, Blueberries *Vaccinium corymbosum*, Raspberries *Rubus idaeus*.
- **Herbs:** Oregano *Origanum vulgare*, Sage *Salvia officinalis*, and Basil *Ocimum basilicum*.

These crops are particularly suited to agrivoltaic systems due to their ability to tolerate partial shading, intense sunlight, or occasional water shortages.

Research and examples from multiple studies (Beck et al., 2012; Marrou et al., 2013; Barron-Gafford et al., 2019; Sekiyama & Nagashima, 2019; Thompson et al., 2020; Hudelson et al., 2021; Weselek et al., 2021; Chae et al., 2022; Martins, 2024) illustrate the potential of agrivoltaics to optimise land use while supporting biodiversity and sustainable agriculture.

Collaboration with local "organic" farmers promotes this type of agriculture and positively influences public perception of photovoltaic investments among local communities. Additionally, organising joint initiatives, such as "green certification" programs for products from photovoltaic farms that support biodiversity, promotes organic food and raises environmental awareness.

When considering honeybee farming on photovoltaic farms, it is important to account for its potential negative impact on wild species populations. Due to the large size of honeybee colonies (with tens of thousands of individuals in a single hive), they pose significant competition for food resources. In areas with insufficient nectar sources (flowering plants), wild species face severe food deficits. Therefore, introducing hives with honeybees to areas with a limited food base is a mistake. Additionally, honeybees carry numerous pathogens that can infect wild species, further reducing the biodiversity of other bee populations.

## Creating "green corridors"

On large-scale monoculture plantations, increasingly characteristic of modern agriculture, photovoltaic farm networks can form "green corridors." These farms, built at short distances from each other and managed sustainably, connect fragments of habitats that are friendly to fauna. This enables animals to disperse more easily, migrate between habitats, and exchange genetic material.

## Monitoring and evaluation

A crucial element of all implemented changes is regularly tracking their impact on biodiversity within the farm. The primary goal of monitoring is to identify potential threats to plants and animals and to enable early interventions to minimise negative effects. An effective solution is to prepare a biodiversity management plan for the farm. This strategic document outlines actions to reduce the investment's negative impacts on biodiversity and plans to enhance it.

## Education and raising ecological awareness

Photovoltaic farms can serve not only as energy production sites but also as important educational centres, inspiring care for the planet. In an era of growing ecological awareness, these farms offer opportunities for practical learning about sustainable development, biodiversity, and the benefits of supporting it. By organising workshops, school field trips, and programs for local communities, they engage people in conservation efforts. A good example is the annual educational event "Bee Day", organised by the Sulechów Photovoltaic Farm Complex manager, aimed at nearby schools.

The following section of this chapter discusses detailed practices aimed at specific animal groups (insects, birds, amphibians/reptiles, mammals) and landscape protection.

## Insects

### Planting green areas

The green areas of photovoltaic farms should be planted with mixtures of nectar- and pollen-rich plants, tailored to the physical conditions of the site. It is essential to consider soil quality and class, sunlight exposure, and water retention. Selecting the right flora for the geological and meteorological conditions can expand the food base and positively influence insect species diversity.

A key aspect of creating vegetation is the proper selection of plant species. It is imperative to use native and/or cultivated species that bloom alternately, ensuring a continuous food supply for insects throughout the growing season (ideally from March to October). For this reason, seed mixtures must have a diverse species composition. Areas sown with nectar-rich plant mixtures provide a greater number of flowering plants, thereby serving as "dining areas" for pollinators (Blaydes et al., 2024) (Photo 40).

**Photo 40**. Photovoltaic farm areas serve as an excellent food base for insects – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

Another good practice is to leave small areas of the investment site for spontaneous succession of ruderal plants. These plants quickly colonise fallow land, provide valuable food sources for a large number of insects, are entirely self-sufficient, and do not require additional interventions.

Non-planted areas have lower plant diversity and density but support common and native species that serve as host plants, particularly for many butterfly species. To enable spontaneous succession, some parts of the site should be left as fallow land, meaning they should not be subjected to maintenance or gardening activities, although mowing may be necessary if invasive plants appear.

For the modified area to undergo successful spontaneous succession, at least 30% of its surface should consist of semi-natural or natural habitats. Therefore, edges adjacent to forests, tree clusters, shrubs, hedgerows, field paths, roadsides, and water bodies, including their surroundings, should be preserved.

One particularly valuable habitat, especially for many butterfly species, is Blackthorn Shrubs or Hedges *Prunus spinosa*, as blackthorn serves as a host plant for the caterpillars of numerous butterflies.

If there is an insufficient number of preserved semi-natural or natural habitats, planting is necessary. In the case of reforestation efforts on neighbouring areas, their potential can be enhanced by including trees such as Linden *Tilia* sp., Maple

*Acer* sp., and Rowan *Sorbus* sp. Additionally, shrubs such as raspberry or blackberry *Rubus* sp. can be planted.

## Maintaining green areas

To maintain a balance between renewable energy production and creating suitable conditions for insects, green areas on photovoltaic farms require a well-designed mowing or extensive grazing plan. This approach ensures efficient energy production by preventing vegetation from overgrowing the panels. Additionally, it protects the area from the encroachment of shrubs and trees and provides a food base for insects throughout the growing season.

It is essential to carry out mowing infrequently and in a phased manner. The mowing plan should identify critical zones where vegetation height must be kept low to ensure energy production. These zones should be mowed in stages, once during the growing season, after 15 June (Photo 41). This means mowing every other row along the panel arrays and all access paths.

**Photo 41**. Mown areas of the most intensively used sections (communication paths and vegetation under the panels) – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

The mown plant material should be left on-site or nearby for three weeks to allow eggs laid by insects, such as butterflies, to hatch and larvae to develop. After this period, the cut material should be carefully collected to prevent the formation of thatch (old, decaying grass), which over-fertilises the soil and harms small flowering plants. The remaining sections can be mown after a minimum of four weeks.

This phased mowing method helps preserve some of the food base for insects, maintain host plants needed for larval development, and allow seeds to mature. At the end of the growing season (September–October), maintenance mowing can be performed on managed areas, such as access paths and zones along the panels. The mowing should be done at a height of 10–15 cm, preferably using sickle bar mowers.

Additionally, certain areas that do not require frequent mowing should be identified. These areas are best mowed every other year at the start of the growing season. This approach allows dry stems of tall plants to remain, providing potential nesting sites and habitats for insect pupation (Photo 42).

**Photo 42**. Leaving unmown sections increases the availability of potential development sites for insects – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

Extensive grazing can also be implemented on photovoltaic farms, limiting the number of animals per unit area. For instance, in the case of sheep grazing, the recommended density is five animals per hectare. A higher density may deplete the food base for insects, which relies on a variety of flowering plant species.

The grazing area should be divided into paddocks and made available to animals in rotation. This allows previously grazed vegetation to regenerate, ensuring the sustainability of the grazing system and maintaining the ecological balance.

If invasive plants colonise the area, these zones should be marked for targeted management, with specific approaches depending on the plant species. Goldenrods *Solidago* spp., which are among the most common invasive species on solar farms (Photo 43), should be controlled through strategic mowing. Goldenrods should be mown at the beginning of flowering to prevent seed formation. Mowing should be repeated whenever new plants appear. The best results are achieved with double mowing (early June and September) over a period of 3–4 years (Mariańska et al., 2023).

**Photo 43**. Invasive alien species of goldenrods *Solidago* spp. – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

For other invasive species, such as Rugosa rose *Rosa rugosa*, Knotweeds (*Reynoutria* spp.), and Hogweeds: *Heracleum sosnowskyi* and *Heracleum mantegazzianum*, although not present at the Sulechów Photovoltaic Farm Complex, management involves mowing immediately after the emergence of young shoots and excavating their underground parts. Mowing should be repeated as soon as new shoots grow back.

A different approach is required for invasive Balsams *Impatiens* spp., which have been identified at the Sulechów Photovoltaic Farm Complex (Photo 44). These should be uprooted rather than mown. Manual removal of entire plants, including roots, is the most effective method. Uprooted plants must immediately be bagged and transported off-site, as they can regenerate through adventitious roots if left behind. The plants should then be either incinerated at a biomass facility or composted under strict supervision. Composting requires layering the plants with soil and allowing complete decomposition over 2–3 years.

**Photo 44**. Invasive alien species – Small balsam *Impatiens parviflora* – frequently inhabits shaded areas beneath the panels – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

A key consideration when managing invasive plants is the seed bank in the soil. Therefore, the elimination of invasive species should begin during the construction phase of the photovoltaic farm. The earlier removal starts, the sooner invasive species can be eradicated from the site.

Another essential aspect of green space management is the prohibition of chemical herbicides and pesticides. Instead, biological pest control can be successfully applied if necessary (e.g., when crops are grown on the farm). This approach utilises natural enemies of pest insects, such as predators, parasites, or pathogens, to regulate pest populations. It is a safe alternative that minimises the use of harmful chemical pesticides.

Maintaining high biodiversity is the best method for preventing pest outbreaks, as a diverse ecosystem supports natural pest antagonists. Supporting this approach involves cultivating a variety of plant species, which reduces pest populations by creating a heterogeneous environment that favours natural predators. Additionally, planting specific plant species in proximity can yield desired effects, such as deterring pests or attracting their natural enemies.

## Providing development sites for insects

Development sites for insects often surprise with their simplicity and ingenuity. In many cases, they do not require any human intervention to provide nesting spaces. For butterflies, leaving host plants for caterpillars is often sufficient. More than 80% of wild bee species found in the country nest in the ground, digging their own burrows or using various natural openings and burrows of small mammals. Exposed, compacted soil, particularly along access paths and near transformer station buildings, offers significant potential for colonisation by certain bee species (Photos 45 and 46).

**Photo 45**. Fragments of exposed, compact, and sunlit soil are readily colonised by numerous bee species – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

**Photo 46**. Ground nests established within the Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

Numerous rodent burrows on farms are the first choice for many bumblebee species. Those that do not nest underground readily build nests under dense clumps of grass. To create favourable conditions for insect development, it is essential to maintain a mosaic of habitats. Leaving elements such as dead wood, areas that are not mowed or grazed (retaining dry stems), embankments, small mounds, or piles of stones provides development sites for a wide variety of species.

## “Insect hotels”

Ready-made structures marketed as “bee hotels” or “insect houses” (Photo 47) are available for creating nesting spaces for insects. Similar nesting aids designed for butterflies are also found. However, understanding the biology of these insects shows that such “houses” cannot fulfil their intended role. These structures should primarily be viewed as educational tools rather than essential nesting aids.

They primarily highlight the importance of supporting insects and sometimes inspire people to expand their knowledge of insect biology. Therefore, placing such structures on farm premises can be beneficial, especially for educational activities.

**Photo 47**. "Insect hotels" mainly serve an educational role, highlighting the need to support pollinators – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

Although "bee hotels" are sometimes inhabited, they are mainly used by common bee species with flexible habitat preferences. Given the current sharp decline in biodiversity, it is worth questioning whether supporting the most common species is appropriate.

Additionally, "insect hotels" are quickly subjected to pressure from parasitic species and are often used by birds as a food source, with nesting insects being consumed. Such structures also require periodic inspections and replacement of degraded components.

## Stones

A good idea for increasing habitat potential is leaving large boulders in areas away from communication paths and creating stone piles (Photo 48). These provide microhabitats offering development sites, shelter, and hunting areas for various insect species. They are also readily used by other fauna representatives. To construct such a pile, the first step is selecting a suitable location. It should be sunny to provide warmth but may also have shaded areas. Placing the pile near plants, especially flowering ones, will increase insect interest.

**Photo 48**. Stone piles positively contribute to increasing biodiversity on photovoltaic farm areas – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

The materials for construction should consist of natural stones sourced from the nearby area or the investment site, supplemented with porous stones, such as limestone. It is important that the pile is built with stones of various sizes and shapes, as this creates more crevices and niches. Adding materials such as clay, leaves, grass, or dead wood into the pile will further increase its attractiveness. The height and width of the pile should depend on the available space, although larger piles may attract more species. The most important considerations are that the pile is stable and safe.

## Creating water reservoirs and lagoons

Water reservoirs on farm areas significantly enhance biodiversity, as many insect species use them for development. However, creating small water reservoirs can be challenging when there are no natural terrain depressions that fill with water. All artificial reservoirs require numerous interventions to retain water; otherwise, they dry out very quickly (Photo 49). This must be considered during the investment planning stage, with a thorough analysis of whether the area has potential for creating a water reservoir or at least a small lagoon for insect development.

**Photo 49**. When designing water reservoirs and lagoons, it is crucial to consider the land's potential for retaining water in such structures – Sulechów Photovoltaic Farm Complex (photo: A. Dubicka-Czechowska).

To create development sites for insects, it is essential to maintain a mosaic of habitats and preserve fragments of unmown areas, which provide access to host plants and dry stems of tall plants. Exposed or sparsely vegetated soil, embankment slopes, brambles, clusters of sedges, moss patches, dead wood, stone piles, old trees, and lagoons—all of these can serve as potential development sites for insects.

Implementing all the measures described above can significantly improve living conditions for insects on photovoltaic farm areas, while also increasing ecological awareness and promoting sustainable development.

## Amphibians and reptiles

Native species of amphibians absolutely require water for reproduction. To enrich photovoltaic farm areas with various amphibian species, it is necessary to maintain existing water reservoirs or create artificial ones and facilitate amphibian migration to and from these sites. These could be small ponds, even up to 1 hectare in size, with both deeper and shallower areas and a diversified shoreline to increase microhabitats used by amphibians for egg-laying, resting, etc. Maintaining such a reservoir is crucial, ensuring proper water balance and cleanliness, as these are fundamental factors determining the development of amphibians in a given location (Kazimirski, 2019).

It is preferable for such a reservoir not to connect to watercourses, as this could lead to the introduction of large fish populations that limit amphibian numbers. However, it should be located near forests and/or wooded areas or wetlands. It is important to note that constructing a water reservoir must be tailored to specific amphibian species. For example:

Larger, deeper reservoirs are preferred by the Common Toad *Bufo bufo* and the Common Frog *Rana temporaria*.

Shallower reservoirs are suitable for most species of newts, Fire-bellied Toads *Bombina* spp., Green Toads *Bufo viridis*, and Spadefoot Toads *Pelobates* spp.

The presence or absence of riparian vegetation is also a significant factor for specific amphibian species. This highlights the importance of conducting a thorough inventory of local fauna and designing the reservoir appropriately to support the development of local species populations.

It is also advisable to preserve naturally occurring water reservoirs, even if they fall within the boundaries of the photovoltaic farm. In such cases, it is critical to adjust fencing to allow amphibians to migrate freely beyond the farm area. Additionally, if needed, guiding fences or fencing bases can be installed in selected locations to prevent amphibians from crossing roads or other anthropogenic areas directly.

## Birds

To minimise the impact of an already existing photovoltaic farm on local bird populations and to appropriately shape habitats that birds can utilise, the following measures can be implemented in farm management. These actions will compensate for any negative effects on birds during the construction and subsequent operation of the farm. Moreover, proper measures and management of the farm area will not only reduce negative impacts but may also allow the farm to have a positive effect on the bird populations present. Below are the key protective, mitigating, and compensatory actions for reducing the impact of photovoltaic farms on bird populations (based, among others, on the work of Pięta, 2020).

### Planting green vegetation on the farm

Such measures increase the abundance of invertebrates, including many insects that are a primary food source for most birds, particularly during the breeding season. Details regarding planting are included in the section of this guide on insects.

At the planning stage, as well as for established farms, it is recommended to plant low-growing native shrub species between panel sectors or along fences (where feasible). Forming compact groups or hedgerows significantly enhances habitat diversity. Such plantings are particularly valuable in degraded areas or within impoverished agrocenoses.

When selecting plant species, preference should be given to those beneficial to birds (providing nesting sites and food sources such as berries), e.g.: Dogwood *Cornus sanguinea*, Elderberry *Sambucus nigra*, Blackthorn *Prunus spinosa*, Hawthorn *Crataegus* spp., Buckthorn *Rhamnus cathartica*, Spindle *Euonymus* spp., Alder Buckthorn *Rhamnus frangula*. Natural vegetation strips, preferably consisting of shrubs, should also be planned along the farm's fencing.

## Land management

It is advisable to refrain from intensive land use. The use of chemical plant protection products e.g., pesticides, herbicides and artificial fertilisers should be avoided. Green areas should be managed extensively, with appropriate timings (e.g., delayed first mowing to consider bird nesting periods—first mowing should take place after 1 August), rotational mowing, and leaving some areas unmown. Grazing may also be applied depending on habitat conditions.

## Creating stone piles

Stone piles serve as development sites and shelters for many organisms. Birds, such as Wheatears *Oenanthe oenanthe*, have been observed nesting in these piles, as confirmed on the Sulechów Photovoltaic Farm Complex. Detailed guidelines for creating stone piles are provided in the section of this guide related to insects.

## Appropriate fence design

When installing fences on farms, consider leaving a gap of approximately 20 cm at the bottom. This allows free passage for many bird species (e.g., game birds such as Grey Partridge *Perdix perdix*, Common Quail *Coturnix coturnix*, and Common Pheasant *Phasianus colchicus*), as well as amphibians, reptiles, and mammals.

## Installing nesting boxes

To compensate for the loss of foraging areas (caused by covering ground surfaces with panels), it is advisable to install specialised nesting boxes and baskets for birds in the vicinity of photovoltaic farms. This includes installing nesting boxes for owls, such as Barn Owls *Tyto alba* on nearby buildings and baskets in nearby wooded areas or forests for Long-eared Owls *Asio otus*. Owls, which primarily feed on rodents, will also help maintain the balance of these mammal populations within the farm area. The installation of nesting boxes and baskets must be consulted with an ornithologist.

### Installing perching poles

Research discussed in this study indicates that photovoltaic farms are intensively used as foraging grounds by several species of birds of prey, including Kestrels *Falco tinnunculus*, Common Buzzards *Buteo buteo*, Marsh Harriers *Circus aeruginosus*, Red Kites *Milvus milvus*, and Black Kites *Milvus migrans*. These birds hunt rodents between the panels and often use the panels or fencing as resting and perching sites. To minimise potential issues arising from birds using the panels, it is advisable to install specialised tall perching poles (at least 4 metres high) on the farm. These poles would allow birds of prey to perch safely. Such poles can be installed in various sections of the photovoltaic farm (4–5 per sector) and should be placed away from structures where birds might risk collisions (e.g., power poles).

### Maintenance work

All maintenance work involving large sections of the installation and general upkeep should, as far as possible, be carried out outside the bird nesting period, from September to the end of February. If work must be conducted during the breeding season, it should be done under the supervision of an ornithologist.

## Mammals

Supporting local mammal populations is feasible in the context of building photovoltaic farms, although in some cases, it is crucial to first ensure proper site selection. For instance, areas with high foraging potential for bats—such as wetlands or meadows in river valleys—should be avoided when establishing farms. Ecological surveys are essential before making decisions about farm construction.

To support local mammal populations, farms should be managed to maintain a high diversity of plants that serve as a foraging base for small mammals, which in turn are prey for predators. Increasing habitat heterogeneity within a farm will benefit many species in landscapes dominated by intensive agricultural use.

To allow free movement of small mammals across the farm, the foundation of the fence should be avoided, and a gap of about 10–20 cm from the ground should be left. For large, multi-hectare investments, dividing the farm into sectors and ensuring migration corridors for larger mammals—such as along watercourses, local dirt roads, and tree lines—is a good idea.

Introducing green corridors is also beneficial for supporting local mammal populations. These corridors can simultaneously function as visual barriers to minimise the farm's impact on the landscape, serve as shelter and breeding sites for mammals, and enhance bat flight routes in open landscapes. They may also become part of an ecological corridor in the region.

Another effective measure is the installation of bat boxes under panels or near transformers for bats to use during their reproductive periods. Additionally, avoiding nocturnal lighting of the farm is recommended.

The construction and installation of various shelters are extensively described in the “Bat Protection Guide” (*Poradnik ochrony nietoperzy*, Bator et al., 2017).

## Actions to minimise the visual impact of photovoltaic farms on the landscape

The visual impact of photovoltaic farms on the surrounding landscape can be mitigated through appropriate measures, particularly during the project planning phase. These additional measures help avoid excessive disruption to the view caused by the installation. Recommendations for such actions are detailed in the publication *“Assessment of the Impact of Photovoltaic Farms on the Landscape: Methodological Guidelines”*, prepared for the General Directorate for Environmental Protection in 2022. The key suggestions are outlined below:

### Adjusting the layout, height, and colour of panels

The layout of photovoltaic panels should be designed to align with the natural topography of the land, taking into account height variations to maintain a harmonious appearance within the landscape. The height of the panels and other technical elements should be adapted to match the surrounding structures, ensuring they blend with the environment and do not introduce prominent, contrasting features into the landscape (landscape dominants).

### Engaging a landscape architect

When significant alterations to the terrain are anticipated, such as large-scale land levelling or the creation of terraces on sloped areas, it is recommended to involve a landscape architect in the design and implementation process. Their role will be to create a cohesive landscape that integrates seamlessly with the project’s surroundings.

### Minimising earthworks

In areas of high ecological or landscape value, all earthworks and changes to land cover should be kept to an absolute minimum to preserve their natural character.

### Preserving biologically active surfaces

If changes to land cover beneath the panels are planned, efforts should be made to retain as much biologically active surface as possible and introduce ground cover that enhances biodiversity and strengthens the ecological functions of the landscape.

## Avoiding vegetation removal

Avoid cutting down or destroying existing vegetation, which diversifies the local landscape and serves as visual barriers.

## Planting new vegetation

When planning the planting of protective vegetation and green belts that can serve as natural visual screens or enhance the landscape, it is advisable to consider areas near residential developments as well as zones along pedestrian and cycling routes. Additionally, the vegetation should be selected to match the character of the local landscape, and the planting project should be developed by a landscape architect.

## Location beyond visibility range

Photovoltaic farms should be located in areas where they do not disrupt views of valuable regional tourist landmarks or important vantage points. Furthermore, they should be situated at an appropriate distance from culturally or historically significant sites.

## Avoiding impact on panoramic views

Projects should be sited away from areas that form part of panoramic views encompassing heritage objects to ensure their presence does not detract from the visual value of these landscapes.

## Diversifying landscape functions

Plans for new photovoltaic farms should incorporate multiple functions, such as combining solar energy production with agricultural activities (agrivoltaics), establishing wildflower meadows and apiaries, grazing sheep, and making the farms available for research or educational purposes (as detailed in the section on insects).

## Best practices from previous projects

The authors' experience with similar projects shows that the most commonly employed methods include avoiding excessive deforestation and introducing protective vegetation, as well as creating new green belts around the project site. These measures effectively conceal farm elements, forming natural visual barriers.

## Considering landscape during the design phase

Incorporating landscape considerations into photovoltaic farm design should be one of the key factors influencing site selection. Investment projects should address landscape issues as early as possible to avoid excessive mitigation efforts later. It is also crucial to inform the local community about the benefits of photovoltaic farms and involve them in the planning process. This approach helps preserve the most landscape-valuable areas for the local community (both naturally and culturally significant) and can significantly reduce the negative perception of photovoltaic farms within the landscape, contributing to a more sustainable and acceptable implementation of renewable energy technologies.

# 10. Renewable energy sources and forms of nature protection

With the development of ground-based photovoltaic farms in Poland, easily accessible areas with suitable grid connection infrastructure are becoming increasingly scarce for investors. Questions are arising more frequently regarding the possibility of utilising areas under various forms of nature protection for constructing photovoltaic farms.

In national parks and nature reserves, this is not permissible due to the purpose of these forms of nature protection and the direct prohibition of constructing buildings in such areas, as outlined in Article 15 of the Nature Conservation Act. These highest forms of nature protection in Poland are established to preserve areas of outstanding natural, scientific, social, cultural, and/or educational value. They protect not only the entire natural environment but also the landscape qualities. Structures and technical equipment can only be built in national parks and nature reserves as infrastructure serving the purposes of the park or reserve.

Landscape parks are established due to the natural, historical, and cultural values of a given area, as well as its landscape qualities, to preserve and promote these values under conditions of sustainable development. In theory, locating photovoltaic farms in landscape parks is possible. However, due to the existing provision prohibiting projects that may have a significant environmental impact under the Act of 3 October 2008 on Access to Environmental Information, Public Participation in Environmental Protection, and Environmental Impact Assessments, such development is unlikely. Therefore, a photovoltaic farm location that does not negatively impact the environment is feasible, provided that other prohibitions adopted by regional councils for a given landscape park are also adhered to.

Additionally, it is essential to consider other conditions within the boundaries of landscape parks (and beyond) arising from the landscape audits conducted for individual provinces.

Similarly, the situation applies to protected landscape areas, where the location of a photovoltaic farm is possible upon obtaining an environmental decision indicating no negative impact of the installation on the environment. Protected landscape areas are designated due to their distinctive landscapes with diverse ecosystems, tourist and recreational appeal, or their role as crucial ecological corridors.

A landscape audit identifies, characterises, evaluates, and specifies methods for shaping and protecting landscapes (including cultural landscapes) in specific landscape segments. As part of the audit, so-called priority landscapes are designated. These are areas particularly valuable to society due to their natural, historical, architectural, cultural, urban, rural, or aesthetic-scenic values. The audit includes a list of guidelines related to the shaping and protection of these landscapes, which are implemented in municipal spatial planning acts and regional spatial development plans.

For both of the aforementioned forms of protection, a construction ban may be introduced within 100 meters of water bodies. Additionally, in priority landscapes covered by local spatial development plans, there may be a further prohibition on locating new buildings that deviate from the local architectural style or exceed a height of two storeys or 7 meters.

The Natura 2000 network consists of areas designated to preserve valuable or endangered components of biodiversity, such as bird species and their habitats, other valuable animal species and their habitats, and valuable plant communities. These areas are distinguished by their natural value and form a network that sustains biodiversity at a high level. They also facilitate genetic exchange among the organisms living there, ensuring their long-term existence in the environment.

On Natura 2000 sites, actions are prohibited that, individually or in combination with others, could negatively affect the conservation objectives. Such actions include investments that could deteriorate the conservation status of natural habitats or species habitats, or the populations of specific species for which the area was designated, as well as the integrity of the Natura 2000 area or its connections with other areas.

Natural monuments, documentation sites, ecological sites, and nature-landscape complexes are forms of nature protection established to preserve outstanding examples of living and non-living nature that possess particular natural, scientific, cultural, historical, educational, or aesthetic value. These are typically small-scale forms of nature protection, the loss of which could cause significant ecological damage. Therefore, they are a priori excluded from hosting photovoltaic farms. Resolutions establishing or abolishing these forms of protection, along with detailed lists of prohibitions, are included in municipal council resolutions designating the specific form of nature protection.

The conflict arising from the overlap of energy production potential with the protection of biodiversity, landscape, and historical-cultural values is inevitable in the era of renewable energy development, including photovoltaic farms. The overlap of existing solar, wind, hydroenergy installations, and protected areas of key biodiversity and wilderness is significantly highest in Western Europe (Rehbein et al., 2020).

On the other hand, using solar and wind energy is far less harmful to the environment than fossil fuels and the emission of harmful gases, including carbon dioxide, into the atmosphere. Certainly, the location of photovoltaic farms must be thoroughly analysed in terms of existing biodiversity, particularly regarding existing forms of nature protection. It is essential to ensure that areas outside these protected zones are exhausted, that the energy yield will be economically and environmentally viable, and that the farm itself will not interfere with the conservation objectives of the given protected area. On the contrary, it should support biodiversity, as well as the aesthetic, landscape, cultural, or educational values of the area.

Building a solid evidence base, understanding local natural conditions, and identifying major environmental issues will help reduce compromises between the expansion of renewable energy and biodiversity. A good practice is also the development of biodiversity management plans for individual photovoltaic farms, aimed at ensuring proper farm placement, minimising impacts during project implementation, and supporting and enhancing biodiversity during the operation of the project over several decades.

# Summary

The publication discusses the results of a two-year study on the impact of the Sulechów Photovoltaic Farm Complex on the biodiversity of local ecosystems. The authors analyze how land management practices at photovoltaic farms, particularly the planting of nectar-producing plants, contribute to ecosystem restoration and support plant and animal diversity. The study encompassed various organism groups, including plants, insects, amphibians, reptiles, birds, and mammals (including bats).

A total of 104 plant species were identified within the farm area, most of which are ruderal and forage species commonly found in pastures, fallow lands, hedgerows, and agricultural areas. Notably, parts of the farm were sown with flowering plant mixes to create a suitable food base for pollinators. The most frequently observed species included Alfalfa *Medicago sativa*, Viper's Bugloss *Echium vulgare*, White Clover *Trifolium repens*, Red Clover *T. pratense*, Crimson Clover *T. incarnatum*, Bird's-foot Trefoil *Lotus corniculatus*, Sainfoin *Onobrychis viciifolia*, and Cornflower *Centaurea cyanus*.

During the study, 42 species of wild bees from all six bee families found in Poland were recorded on the farm, with polylectic species dominating. Thirteen legally protected species, including rare ones such as the Brown-banded Carder Bee *Bombus humilis*, the Large Garden Bumblebee *Bombus ruderatus*, and the Violet Carpenter Bee *Xylocopa violacea*, were observed. The study indicated significantly higher insect numbers in areas sown with nectar-producing plants compared to areas where vegetation developed spontaneously. Additionally, nesting sites were confirmed for several bee species in exposed soil patches, abandoned rodent burrows, and an "insect hotel", highlighting the favorable habitat conditions created on the farm.

A total of 32 butterfly species were observed on the farm, representing approximately 19% of Poland's butterfly fauna. Protected species, such as the Large Copper *Lycaena dispar* and the Scarce Swallowtail *Iphiclides podalirius*, both listed in the Polish Red Data Book of Animals, were identified. Most observed species were mesophilic butterflies preferring open and transitional habitats.

Bird monitoring indicated that the farm area is utilized by numerous bird species. During year-round field observations from April 2023 to May 2024, 106 bird species were recorded in the Photovoltaic Farm Complex in Sulechów and its immediate vicinity, with 58 of them identified as breeding species. Fourteen species nested on the farm, and an additional 44 species nested in its proximity. The Skylark *Alauda arvensis* was the most numerous breeding species on the farm. The farm infrastructure provided resting, perching, and singing spots for 32 bird species. The richness of plants and insects attracted species typical of open, agricultural, and transitional areas.

A well-managed photovoltaic farm, where favorable habitats for various animal groups are created, is essential for the development of complex ecological interdependencies. This is particularly relevant to bat populations. Studies confirmed

bat activity on the farm, a result of favorable foraging conditions provided by the high diversity of insects attracted by the flowering plants. With appropriate management, photovoltaic farm areas can support these crucial species that play key roles in ecosystems.

The Sulechów photovoltaic farm, covering over 60 hectares, exemplifies modern land use on previously intensively farmed agricultural land. Despite the scale of the investment, the authors emphasize that, with appropriate measures like seeding areas with plant mixtures and building infrastructure for wildlife, photovoltaic farms can be integrated into the local landscape. These areas have become attractive habitats for many plant and animal species while minimizing visual impacts on the landscape. Biodiversity restoration at photovoltaic farms enhances aesthetic values, reduces soil erosion, and improves water retention, positively influencing ecosystem functionality.

The publication outlines best practices for designing and managing photovoltaic farms to minimize their impact on biodiversity. It highlights the need for careful planning of photovoltaic farm locations, recommending investments on degraded or agriculturally low-value land. Building photovoltaic farms in ecologically valuable areas, such as Natura 2000 sites or landscape parks, should be avoided due to their unique ecological importance. Best practices also include appropriate vegetation management to protect soil from erosion and increase plant diversity. Introducing nectar-producing plants and native flora attracts pollinators, which positively impacts ecosystem stability.

Agrotechnical measures such as mowing and reseeding should be implemented on photovoltaic farms to support biodiversity and prevent the spread of invasive species. Additionally, integrating photovoltaic farms with organic farming, for example, by cultivating shade-tolerant plants such as certain vegetables or herbs, allows for efficient use of spatially limited areas. The publication also emphasizes the importance of creating "green corridors" between farms, facilitating animal migration. Collaboration with local farmers and programs promoting organic food further support biodiversity and enhance social acceptance of photovoltaic farms. Regular monitoring of environmental impact and educating local communities about conservation and renewable energy benefits are also critical.

The study results suggest that photovoltaic farms can play a significant role in restoring local ecosystems, especially in agricultural areas. Proper vegetation management on photovoltaic farms, such as planting nectar-producing plants, increases biodiversity and supports numerous species that might otherwise be displaced from agricultural landscapes. The Sulechów study demonstrates how renewable energy technology can support nature conservation, bringing benefits to the environment and local communities alike.

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"... it is worth emphasizing that the presented book is not only a valuable source of information for naturalists but also a material with significant application potential, encouraging a more serious interest in the impact of photovoltaic farms on the environment. The clear and professional elaboration of the collected material provides a solid foundation for comparative analyses with results obtained in other areas, allowing for a better understanding of these phenomena in diverse ecosystems. Given its accessible language and the reliability of the presented data, this publication is a valuable resource not only for specialists but also for local government officials and administrators who make decisions regarding the location of such investments. Thanks to this book, they can gain knowledge about the potential benefits and challenges that photovoltaic farms pose to nature, which facilitates more informed and sustainable decision-making."

Prof. Dr. Hab. Piotr Tryjanowski
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"The development of new technologies and the necessity of seeking renewable, low-emission energy sources, including those utilizing solar power, seem to be an imperative today in the face of the progressing climate crisis. However, the rapid development of infrastructure based on ‚green energy' should not come at the expense of nature and, in turn, exacerbate the biodiversity loss crisis, as both crises are evidently interconnected in this regard.

Therefore, a multi-criteria process for selecting suitable locations for such projects, as well as the development and implementation of appropriate measures to minimize the potential impact of large-scale solar systems, should be considered crucial for reducing environmental and social costs. By applying these fundamental principles, it is certainly possible to seek a compromise between the necessity of renewable energy development and the protection of biodiversity, space, and the landscape values of the environment in which we live.

However, the question arises—how can this be done in practice? And this publication, presenting an intriguing scientific analysis of a photovoltaic farm, is an attempt by the authors to provide answers in this regard."

MSc Eng. Michał Bielewicz
Regional Directorate for Environmental Protection
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