JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(11), 1–10
https://doi.org/10.12911/22998993/153456
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.07.26
Accepted: 2022.09.14
Published: 2022.10.01

Solar Park: Opportunity or Threat for Vegetation and Ecosystem

Dan Uldrijan[1], Martin Černý[1], Jan Winkler[1*]

[1] Department of Plant Biology, Faculty of Agri-Sciences, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

* Corresponding author's e-mail: winkler@mendelu.cz

ABSTRACT

Solar parks are currently considered a new source of energy generation and one of the methods for reducing the usage of fossil fuels. The studies related to the influence of solar parks on vegetation structure are not yet sufficient. The aim of this paper was to evaluate the structure of vegetation biodiversity within a solar park. The vegetation assessment took place in the solar park, located in the cadastral territory of Tišnov (Czech Republic). A total of 85 taxa of vascular plants were found. The vegetation of the solar park is species-rich and significantly fragmented. Perennial grasses and perennial dicots dominate between the panels, whereas annual grasses and annual dicots have more coverage under the photovoltaic (PV) panels. The influence of the solar park microclimate is seen in a higher representation of species with the indication of characteristics mid-continental, and species with the indication of characteristics mid-ocean are more represented among within the PV panels. The vegetation of the solar park is noteworthy from the perspective of biological importance in the agricultural landscape and has a substantial potential to perform ecosystem functions.

Keywords: solar parks, photovoltaic panels, synanthropic flora, technosphere.

INTRODUCTION

Photovoltaic (PV) panels are currently seen as one of the tools to limit the use of fossil fuels for energy production and are also seen as one of the tools to reduce emissions, including CO_2 (Brodziński et al., 2021; De Sousa, 2013; Doví a Battaglini, 2015). The development and expansion of electricity production from renewable sources, including solar energy, have been facilitated by the decline in the cost of PV modules and the simultaneous rise in the cost of energy produced by burning fossil fuels (Alsagri, 2020; Shahsavari et al., 2019; Millstein et al., 2017; Blazy et al. 2021). This has made renewable energy sources, such as wind and solar energy, viable options (MacDonald et al., 2016). The development of large-scale solar parks can be seen in some countries, especially in China and also in Europe, where it is Germany or the Czech Republic (Roos, 2021). In Europe, solar parks are most often located on arable land and pasture; which represents a significant change in land use (MacKay, 2013). Agricultural land, rural and urban settlements that surround solar projects represent a permanent threat to the existence of native flora and fauna as well as continuous anthropogenic disturbance. The area within the solar park can become a refuge for local species. The flora and fauna in solar parks escape disturbances or predation to which they would be exposed in surrounding areas (Sinha, et al., 2018).

The anthropogenic nature of disturbances affects the composition of species biodiversity and greatly influences biotic homogenization (Wang et al., 2021; Winkler et al., 2021). The plant species with specific characteristics that tolerate or require anthropogenic disturbance and various meteorological and soil conditions may be preferred over natural ecosystems (Kowalik et al. 2014; Williams et al., 2015). Habitat fragmentation caused by urbanization or agriculture leads to the loss of native species and has a negative impact on biodiversity (Nichol et al., 2010; Syphard et al., 2011; Dylewski et al., 2020). Therefore, the areas with natural and semi-natural vegetation are increasingly considered a haven for biodiversity (Byrne et al., 2015; Boulton et al., 2020).

However, the studies considering the influence of PV panels on vegetation characteristics are limited (Zisis et al., 2019; Jahanfar et al., 2019; Turney, Fthenakis, 2011). The lack of knowledge about the vegetation-solar park relationships limits the prediction of climate impacts of solar parks (Wang, Eltahir, 2000a; Wang, Eltahir, 2000b), as vegetation dynamics in solar parks play a key role in soil-climate interactions (Zeng, Yoon, 2009). Solar park vegetation can have implications for microclimate, biodiversity, soil erosion, air quality, and ecosystem energy balance (Armstrong et al., 2014, Hernandez et al., 2014). The physical presence of solar parks will affect the fluxes of solar radiation and thus the temperature, speed, wind turbulence, and distribution of precipitation in the solar park (Armstrong et al., 2014). These factors affect the vegetation, which can change the species composition and the intensity of occurrence of some plant species. The aim of the paper was (i) to evaluate the biodiversity structure of the vegetation of the solar park, (ii) to assess the representation of plant species indicating the specific conditions of the ecosystem (iii) to determine the influence of PV panels on the structure of the vegetation in the solar park.

MATERIAL AND METHODS

Territorial characteristics

The solar park (Figure 1) is located in the cadastral territory of the municipality of Tišnov (South Moravian Region, Czech Republic; 49.3358417N, 16.4452700E; Figure 1). The land is located 265 meters above sea level. The long-term average annual temperature is 6–7 °C, and the long-term annual precipitation is 650–750 mm. Geographically, the area of interest falls into the Boskovická brázda. The object of the solar power plant is on a plot of land with a total area of 17,224 m^2. The land had been used as a waste dump until 2008. Construction and inert waste were mainly dumped here. In 2009, the landfill was reclaimed, the soil was transported to the land, and the surface of the land was leveled. In 2010, PV panels were installed, and the solar power plant operation began. Extensive grazing provided by sheep regulates the vegetation in the solar park, and unsaved vegetation is occasionally mulched.

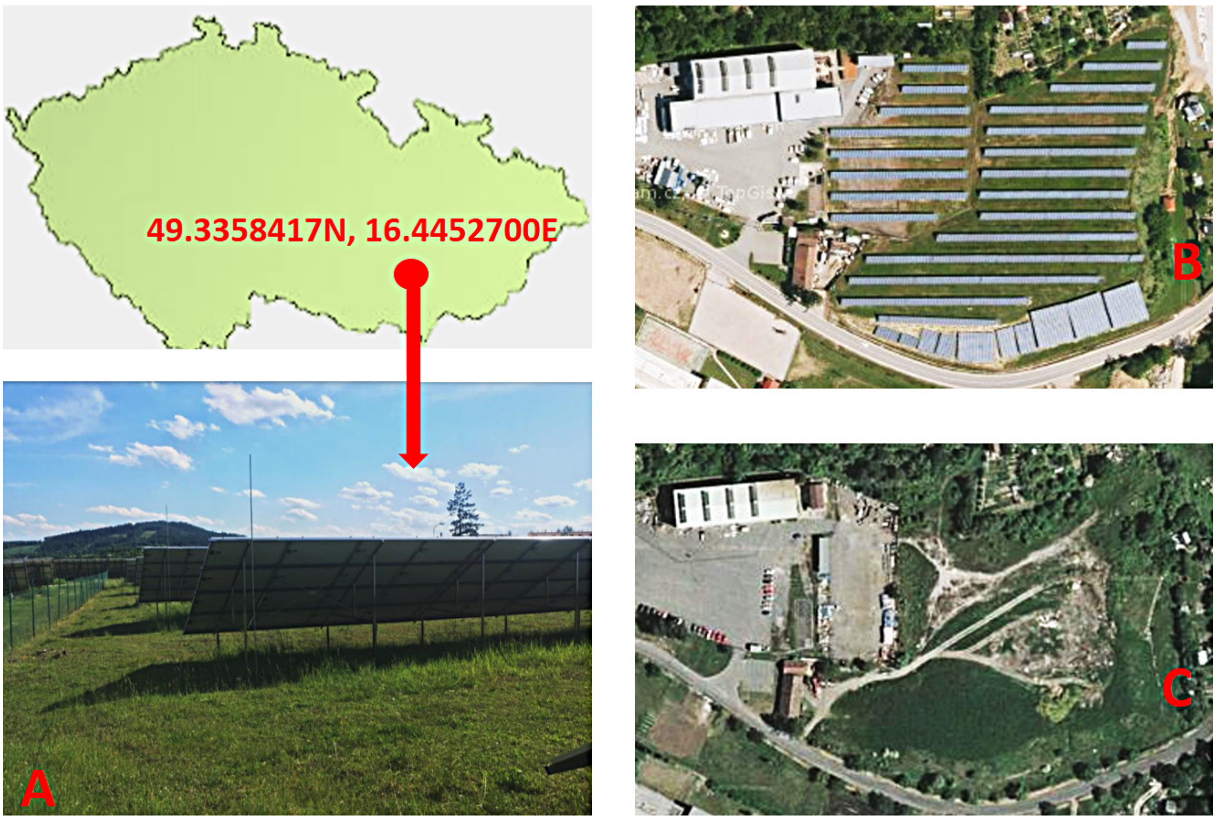

Figure 1. Site with the solar park (A - PV panels; B – current state of the land; C – land before reclamation)

Methodology for assessing vegetation

Vegetation was assessed using the method of phytocenological images. The size of the images was 20 m^2 (2 × 10 m). Within the solar park, images were recorded at two different locations, between the PV panels and below the PV panels. Five permanent areas were marked at each site, on which images were recorded. Vegetation was evaluated according to a standard procedure. First, all taxa of plants appearing on the image were identified, and then the above-ground biomass coverage of individual taxa was estimated. The images were recorded in the same areas in 2016, 2017, and 2018, always in spring and summer. The scientific names of the plant species were taken from the Pladias flora and vegetation database (Chytrý et al., 2021).

On the basi of the information from the database of Tyler et al. (2021), plant species were divided into several groups according to 3 criteria. The first criterion was the significance for biological relevance (Biodiversity relevance). The importance of biodiversity relevance is defined for each species as the number of other organisms that depend on this species or use it as a food source, substrate, shelter, or condition for survival and reproduction. The importance of the relevance of the biodiversity of plant species is given on an eight-point logarithmic scale:

- BR1 = <6 associated species
- BR2 = 6–12
- BR3 = 13–24
- BR4 = 25–50
- BR5 = 51–100
- BR6 = 101–200
- BR7 = 201–400
- BR8 = >400

The second criterion was the continentality. In addition to temperature extremes and temperature sums, the distribution of temperatures and precipitation over time is important for the occurrence of plant species, which is commonly summarized as continentality. A nine-point scale was used to express the continentality:

- Co1 = hyperoceanic (limited to the Atlantic coast)
- Co2 = strongly oceanic (absent in most continental areas)
- Co3 = mid-oceanic (dominant occurrence in the oceanic region, but with some occurrences in continental areas)
- Co4 = weakly oceanic (dominant occurrence in oceanic conditions but showing no climatic constraints)
- Co5 = indifferent (shows end of oceanic influence)
- Co6 = continental (showing no climatic limitations)
- Co7 = mid-continental (predominance of occurrence in areas with continental conditions)
- Co8 = strongly continental (absent in most oceanic regions)
- Co9 = hyper continental (limited to the most continental part)

Light was the third parameter expressing the optimal light/shade conditions for the given species. This criterion is expressed on a seven-point scale:

- Li1 = strong shade
- Li2 = medium-deep shade
- Li3 = partial shade to shade
- Li4 = half-shadow
- Li5 = sun to partial shade
- Li6 = sun, but also permanent moderate shading
- Li7 = constant full sun

The coverage values of the plant taxa found at the monitored sites were processed using a multivariate analysis of ecological data. The selection of the optimal analysis was guided by the gradient lengths determined by segmental Detrended Correspondence Analysis (DCA). Canonical Correspondence Analysis (CCA) was also used. Statistical significance was determined using a Monte-Carlo test in which 999 permutations were calculated. The computer program Canoco 4.0 was used to process the data (Ter Braak a Šmilauer, 2012).

RESULTS

On the basis of the vegetation evaluation, 85 taxa of vascular plants were found. The average coverage of groups of plant species is shown in Figure 3. The representation differs significantly between the observed habitats. Perennial grasses and perennial dicot species dominate between the panels. The average vegetation cover is significantly lower on the site under the panels. The lower coverage is especially noticeable in perennial grasses. On the contrary, annual grasses and annual dicot species have a higher coverage under the panels. The relationship between the species found and the monitored habitats were assessed using CCA analysis. The graphical result of the analysis is presented in Figure 2. The division of species into groups according to the analysis is shown in Table 1. The first group of species (Between) had a predominant occurrence and higher coverage in the habitat between the PV panels. These are mainly perennial grass species and perennial dicotyledons. The second group (indifferent) consists of species without a significant preference for a specific location recorded at both habitats. The third group of species (Under) was more often found in the habitats under PV panels. The fourth group of species (Under – nitrophilic) was also more often recorded in the habitat under the panels, but they formed a separate group.

Plant species were divided into groups according to biological relevance (Biodiversity relevance). The share of coverage of individual groups is shown in Figure 4. The habitats between the panels were mainly represented by species that create mutual relationships with 51–200 other species (BR5, BR6). The species linked to 6–24 other species of living organisms (BR2, BR3) had a higher representation in the habitat under the PV panels.

Representation of continentality using plant species is shown in Figure 5. Both habitats are dominated by indifferent species (Co5). In the habitat between the PV-panels, mid-oceanic species (Co3) have a higher share of the coverage. Under the PV panels habitat, there is a higher share of mid-continental species (Co7). Another evaluation criterion corresponded to the lighting conditions. The share of the coverage of the individual groups is shown in Figure 6. The sites between the panels were mainly represented by groups with a value of Li5 (sun – partial shade) and Li6 (sun, but also permanent moderate shading). On the site under the PV panels, species Li7 (constant full sun) had a higher representation, and species Li3 (partial shade to shade) and Li4 (half-shadow) had only slightly higher coverage.

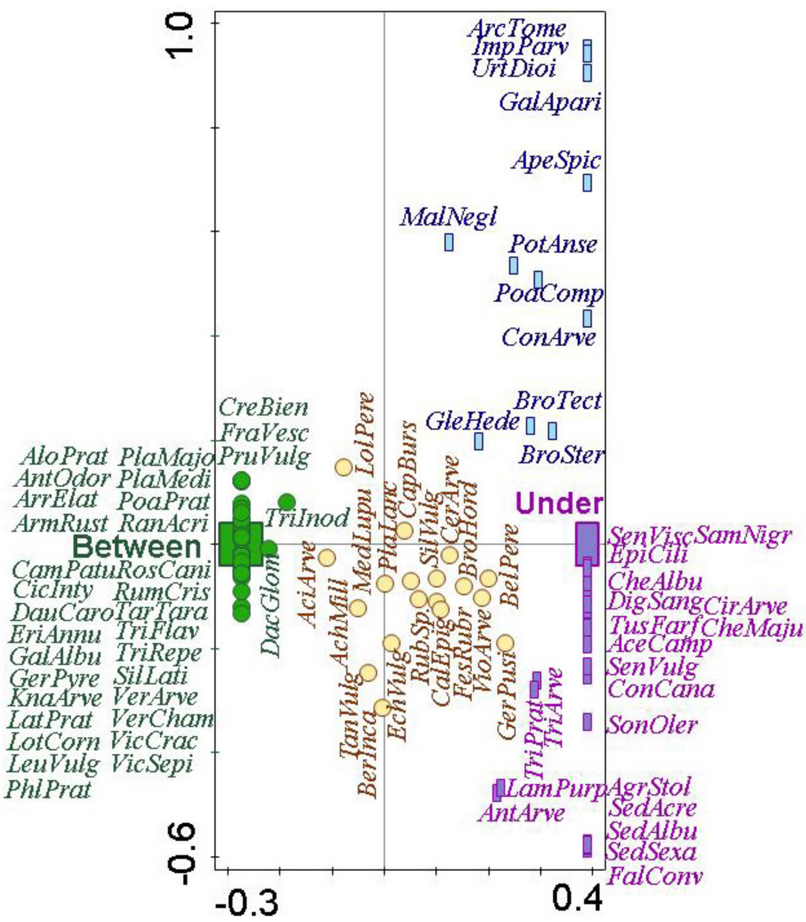

Figure 2. Ordinal diagram expressing the relationship between the occurrence of plant species and the location in the solar park (A - PV panels, B – current state of the land, C – land before reclamation)

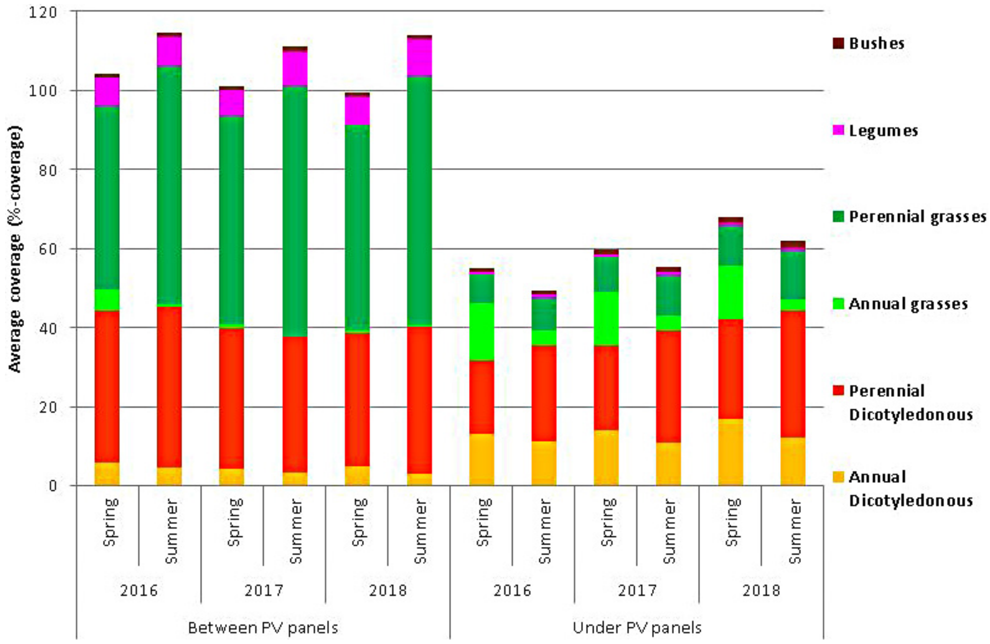

Figure 3. Average coverage of plant species groups in the solar park

Tabel 1. Distribution of the found species into groups according to their relationship to habitats in the solar park based on CCA analysis

Groups	Species plants (Abbreviations)
The first group of species with the occurrence of between	*Alopecurus pratensis (AloPrat), Anthoxanthum odoratum (AntOdor), Armoracia rusticana (ArmRust), Arrhenatherum elatius (ArrElat), Campanula patula (CamPatu), Cichorium intybus (CicInty), Crepis biennis (CreBien), Dactylis glomerata (DacGlom), Daucus carota (DauCaro), Erigeron annuus (EriAnnu), Fragaria vesca (FraVesc), Galium album (GalAlbu), Geranium pyrenaicum (GerPyre), Knautia arvensis (KnaArve), Lathyrus pratensis (LatPrat), Leucanthemum vulgare (LeuVulg), Lotus corniculatus (LotCorn), Phleum pratense (PhlPrat), Plantago major (PlaMajo), Plantago media (PlaMedi), Poa pratensis (PoaPrat), Prunella vulgaris (PruVulg), Ranunculus acris (RanAcri), Rosa canina (RosCani), Rumex crispus (RumCris), Silene latifolia (SilLati), Taraxacum* sect. *Taraxacum (TarTara), Trisetum flavescens (TriFlav), Tripleurospermum inodorum (TriInod), Trifolium repens (TriRepe), Veronica arvensis (VerArve), Veronica chamaedrys (VerCham), Vicia cracca (VicCrac), Vicia sepium (VicSepi)*
The second group of indifferent species	*Acinos arvensis (AciArve), Achillea millefolium (AchMill), Bellis perennis (BelPere), Berteroa incana (BerInca), Bromus hordeaceus (BroHord), Calamagrostis epigejos (CalEpig), Capsella bursa-pastoris (CapBurs), Cerastium arvense (CerArve), Echium vulgare (EchVulg), Festuca rubra (FesRubr), Geranium pusillum (GerPusi), Lolium perenne (LolPere), Medicago lupulina (MedLupu), Plantago lanceolata (PlaLanc), Rubus* sp. *(RubSp.), Silene vulgaris (SilVulg), Tanacetum vulgare (TanVulg), Viola arvensis (VioArve)*
The third group of species occurring under the panels (Under)	*Acer campestre (AceCamp), Agrostis stolonifera (AgrStol), Anthemis arvensis (AntArve), Cirsium arvense (CirArve), Conyza canadensis (ConCana), Digitaria sanguinalis (DigSang), Epilobium ciliatum (EpiCili), Fallopia convolvulus (FalConv), Chelidonium majus (CheMaju), Chenopodium album (CheAlbu), Lamium purpureum (LamPurp), Sambucus nigra (SamNigr), Sedum acre (SedAcre), Sedum album (SedAlbu), Sedum sexangulare (SedSexa), Senecio viscosus (SenVisc), Senecio vulgaris (SenVulg), Sonchus oleraceus (SonOler), Trifolium arvense (TriArve), Trifolium pratense (TriPrat), Tussilago farfara (TusFarf)*
The fourth group of species with the occurrence of Under - nitrophilic	*Apera spica-venti (ApeSpic), Arctium tomentosum (ArcTome), Bromus sterilis (BroSter), Bromus tectorum (BroTect), Convolvulus arvensis (ConArve), Galium aparine (GalApari), Glechoma hederacea (GleHede), Impatiens parviflora (ImpParv), Malva neglecta (MalNegl), Poa compressa (PoaComp), Potentilla anserina (PotAnse), Urtica dioica (UrtDioi)*

DISCUSSION

The vegetation of solar parks has its own distinct dynamics; the type and characteristics of the vegetation do not respond to the changing microclimate caused by solar parks (Wang, Eltahir, 2000a; Wang, Eltahir, 2000b). The obtained results show that solar park vegetation is relatively stable over the growing season and time, but there are large differences between solar park habitats. The vegetation under the PV panels is significantly different, there are fewer perennial grass

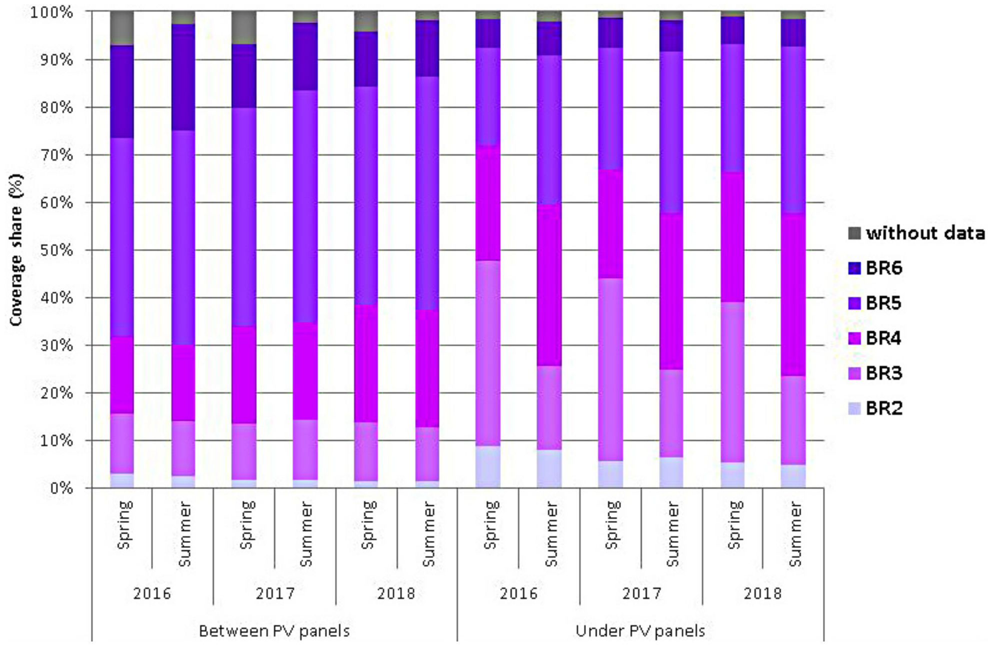

Figure 4. Share of the coverage of species groups according to indicator values for biological relevance

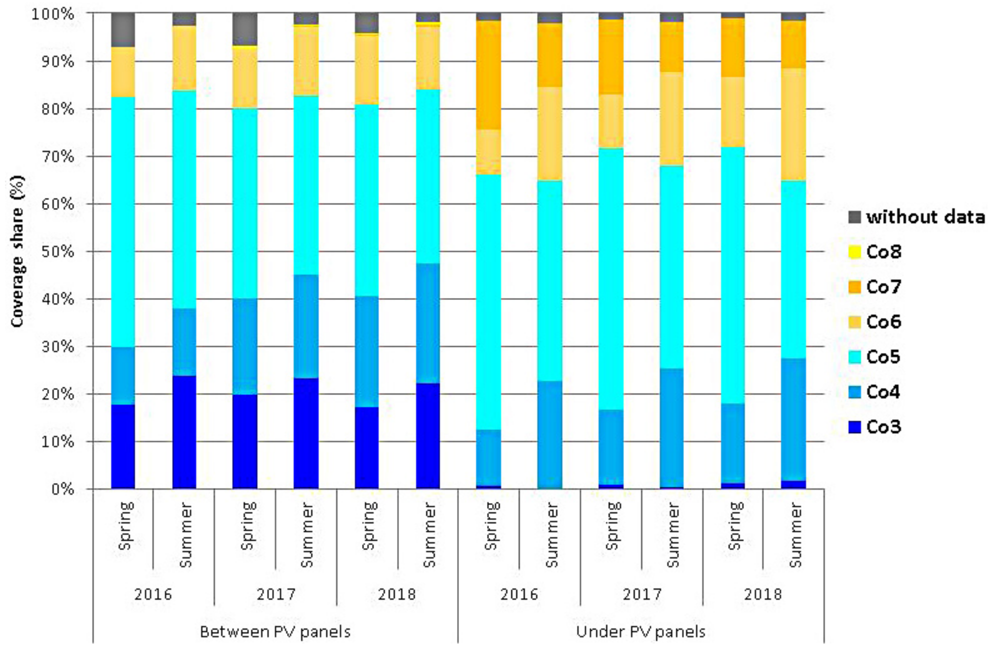

Figure 5. Share of the coverage of species groups according to indicative values for continentality

species, and the share of annual plant species is increasing. The marked fragmentation of habitats and the strip arrangement of PV panels are very typical for solar parks. The nature of the layout of the ecosystem of solar parks is similar to vineyards in the Czech Republic (Ragasová et al., 2021).

Solar projects can help preserve and promote biodiversity by providing a haven for plants. Botanical biodiversity can lead to a greater abundance of invertebrates and higher diversity of bird species (Montag et al., 2016; Gazdag a Parker 2019). However, even here, there are significant differences in the habitats within the solar park. The vegetation under panels is less attractive for establishing ecosystem relationships and providing ecosystem functions. The inter-row vegetation will compensate this deficiency, which has high biological relevance. The vegetation of solar parks has a number of ecosystem functions; it can serve as a source of food for animals, contributes to the

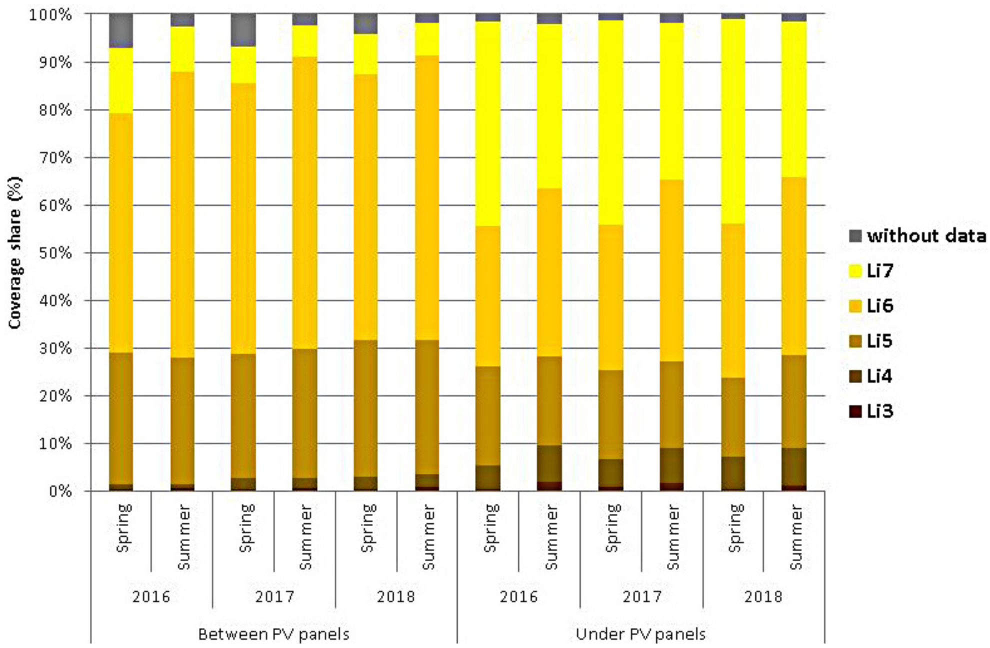

Figure 6. Share of the coverage of groups of species according to indicative values for light conditions

support of biodiversity, and protects against water and wind erosion (Uldrijan et al., 2016; Uldrijan et al., 2021; Schindler et al., 2018; Blaydes et al., 2021; Tang et al., 2018). Vegetation is a source of nectar and pollen for pollinators (Blaydes et al., 2021, Walston et al., 2021), provides shelter for fauna, and contributes to nutrient cycling (Ren et al. 2020). The consequence of solar panels is also a specific microclimate, mainly the change in wind speed, lighting conditions, and the deflection of rainfall (Hassanpour et al. 2018; Guoqing et al. 2021). In the monitored conditions of the solar park, the habitat between the panels is more suitable for the occurrence of the species indicating oceanic climatic conditions. On the contrary, the places under panels are more suitable for the species indicating a continental climate. This may be a consequence of the different rainfall distribution. Under the PV panels, the vegetation is protected from rain, and the water enters here by running off from the inter rows or by soil capillarity. These microclimatic conditions are probably more similar to the course of the continental climate. Owing to this, the PV panels create living space for species that the surrounding vegetation would otherwise displace.

Light conditions are also part of the specific microclimate of solar parks (Montag et al., 2016). In shaded conditions under the panels, light-demanding plant species have a higher share of coverage. This paradox may be a result of limited vegetation competition (lower average cover) under the panels. The limited solar radiation is probably better compensated by a sufficient amount of other life factors and less competition from other species. Sunstroke plant species seem to better compensate for the lack of direct sunlight and give way to the competition of other species in the intermediate row. The response of vegetation in solar parks can also affect the climate change (Kucharski et al., 2012; Zeng, Yoon, 2009). Here, the carbon cycle and the carbon storage in the plant biomass of the solar park will be crucial (Heimann, Reichstein, 2008). The microclimatic conditions of solar parks can change the species composition of vegetation, biotic interactions, and, consequently, ecosystem functions such as soil carbon storage (Melguizo-Ruiz et al., 2020). The vegetation of solar parks can also represent the surrounding agricultural land as a source of weed spread and the introduction of pests. Some species are already able to spread during the construction of solar parks, using the technology and equipment used to build these parks. Therefore, weed control is essential (Guerin, 2017). Since solar farms are built on land with optimal solar radiation, this vegetation also increases the risk of hazards such as fires (Dias et al., 2021; Chiabrando et al., 2009).

The massive occurrence of various human artifacts in ecosystems and geological layers that are products of human technological creativity leads to the use of the term "technosphere" (Haff, 2012; Herrmann-Pillath, 2013; Herrmann-Pillath, 2018). The ecosystem of a solar park is a connection between biological and technical components; therefore, solar parks can be described as an example of the technosphere.

CONCLUSIONS

The solar park creates very diverse habitats for vegetation. This makes the vegetation of the solar park very diverse. Between the PV panels, there are species dominated by perennial grasses and perennial dicotyledons, and under the PV panels, there is a higher coverage of annual grasses and annual dicotyledons. The presence of PV panels changes the conditions for the plants and thus enriches the landscape of the place. The influence of the microclimate is shown in a higher representation of species with the indication of mid-continental, and species with the indication of mid-ocean traits/characteristics are more represented within the PV panels. Plant species also respond to different light conditions. The species requiring constant full sun had a higher representation under PV panels. The species that require full sun, but also tolerate permanent moderate shading are mainly represented between panels.

The vegetation of the solar park has a significant potential to fulfill ecosystem services and is important from the perspective of biological relevance in the agricultural landscape. The habitats between the panels were mainly represented by species that create mutual relationships with 51–200 other species. The habitat under the PV-panels had a higher representation of species with lower values of biological relevance (6–24 species). The human civilization changes and transforms ecosystems but also geological layers. The results of human technological creativity are referred to as the technosphere. Its example also includes solar parks, showing the connection and mutual influence of human civilization and the biosphere.

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