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Towards biodiverse solar parks

Integration of long-term biodiversity plan in cooperation with local stakeholders for Solar Park Revelhorst

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Dutch summary

Zonnepark Revelhorst in Zutphen is sinds 2020 operationeel. De aanleg hiervan hing af van de voorwaarde dat de biodiversiteit in het park wordt vergroot, met name die van vogels. De huidige stand van zaken moest echter nog worden onderzocht, te midden van enkele communicatieproblemen tussen belanghebbenden zoals Vogelwerkgroep Zutphen en Sunvest. In dit project zijn gegevens verzameld over omgevingsfactoren, waaronder temperatuur en bodemkwaliteit, en het huidige niveau van de diversiteit in vegetatie, insecten, vogels en zoogdieren, met behulp van een verscheidenheid aan ecologische onderzoeksmethoden. Belangrijker nog, het is ook bedoeld om advies te geven om de biodiversiteit in Zonnepark Revelhorst te verbeteren, zodat het biodiversiteitsniveau op de lange termijn kan lijken op dat van een typisch Nederlands, half natuurlijk graslandecosysteem. Het blijkt dat de huidige biodiversiteit, vooral die van planten, uniform en vrij laag is. Voor andere taxonomische categorieën is de status niet zo onwenselijk maar is er veel ruimte voor verbetering via bijvoorbeeld het aanpassen van bodemparameters door het verwijderen van nutriënten, het verbeteren van de vegetatiesamenstelling door het planten van gewenste soorten en het verwijderen van grassen, en het aanleggen van extra fysieke structuren voor dieren (bijvoorbeeld hagen of insectenhotels). Naast het ecologische aspect beveelt dit project constante, transparante communicatie aan met formele regels en een potentiële bemiddelaar tussen belanghebbenden om de verwachtingen op elkaar af te stemmen, de voortgang te controleren, een goed ingeregeld beheer toe te kunnen passen en het biodiversiteitsniveau in het park te blijven monitoren. Revelhorst kan een voorbeeld worden van hoe huidige soortenarme gebieden verbeterd kunnen worden door ecologisch beheer en hoe een zonnepark kan bijdragen aan de lokale biodiversiteit.

Summary

Solar Park Revelhorst located in Zutphen has been operational since 2020, whose initial construction depended on the prerequisite that biodiversity in the park will be increased, especially that of birds. However, the current state remained to be explored, amid poor communication problems among stakeholders such as Vogelwerkgroep Zutphen and Sunvest. Obtaining data on environmental factors including temperature and soil quality, this project sets out to assess the current level of vegetation, insect, bird, and mammal diversity using a variety of ecological survey methods. More importantly, it also aims at providing advice to improve biodiversity in Solar Park Revelhorst so that its biodiversity level, eventually, could resemble that of a typical Dutch, semi-natural grassland ecosystem. It is found that current biodiversity, especially that of plants, is homogenous and fairly low. For other taxonomic categories, the status is not as undesirable but there is much room for improvement via, for example, adjusting soil parameters by removing of nutrients, improving vegetation composition by planting of desirable species and removing grasses, and building additional physical structures for animals (e.g., hedges; insect hotels). In addition to the ecological aspect, this project recommends continuous, transparent communication with formal rules and a potential mediator among stakeholders to align expectations, check progress, to be able to apply well-planned management and continue to monitor biodiversity levels in the park. Revelhorst could become an example of how current species-poor areas can be improved through ecological management and how a solar park can contribute to local biodiversity.

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1. Introduction

Since 2015 there has been an exponential increase in the production of renewable energies across the world. Especially with solar power, there has been a drastic increase of over 700% in the period of 2015 to 2019 (Linders, Meurink, Muller, & Seger, 2019). The adoption of photovoltaic energy in the Dutch energy mix in the past decade has induced a considerable change in the landscape, as 229 solar parks were installed by 2020 in the Netherlands. As the industry competes with others over land use, this increase in the number of photovoltaic farms has attracted a lot of attention from the public and government. Furthermore, the number of ground-mounted photovoltaic farms is estimated to reach approximately 30.000 hectares in the Netherlands by 2050 (Schotman et al., 2021). Naturally, the focus of solar parks has been on energy production. However, especially since such an increasingly large portion of land is dedicated to photovoltaic farms, multi-land use would be desired, for example by increasing biodiversity in solar parks (Barros, Van Aken, Burgers, Slooff-Hoek, & Fonseca, 2022; Schotman et al., 2021).

The land is increasingly being dedicated to cities, grey infrastructure but also solar parks. These are not ecologically resilient and heterogeneous enough to host a variety of flora and fauna which isn't beneficial for the biodiversity. Specifically, the biodiversity in the Netherlands has been experiencing a considerable decrease in the past century and restoration has become a national priority (Veen, Brink, Braat, & Melman, 2008). A century ago, Dutch grasslands were rich in herb species, while still being used as farmland. With the intensification of agriculture and the 30-40-fold increase in nitrogen application, grassland herb species were eliminated (Bobbink et al., 2010; Soons et al., 2017). The area dedicated to semi-natural grasslands in the Netherlands has hereby plunged from 40% to only 3%. This decrease in vegetation diversity (among other causes) has resulted in a decrease in insect diversity as well (van Strien, van Swaay, van Strien-van Liempt, Poot, & WallisDeVries, 2019). For example, butterfly species have decreased by 80% in the last century, even more in terms of abundance. The same applies to bees, since of the 360 bee species that can be found in the Netherlands, more than half are now threatened (Rijksoverheid, 2022a).

Figure 1 Map of Revelhorst with the solar park in the orange circle

Therefore, creating solutions that address both biodiversity and land use issues is inevitable, especially for densely populated countries like the Netherlands. That is why this report looks at multi-land use for photovoltaic farms and more precisely the integration and enhancement of biodiversity in Revelhorst solar park. Solar Park Revelhorst was opened in October 2020 and is located on a former maize and grass field on the edge of the municipality of Zutphen, flanking an industrial area. The company Sunvest developed the park and co-manages it with Zutphen Energy, a local energy cooperative. The park is 8 hectares in size and consists of more than 20.000 south-faced solar panels. The lowest point of the panels is 50 cm above the ground and goes up to a height of 2 meters. Revelhorst was initiated on the prerequisite that biodiversity, especially that of birds, would be improved. Consequently, the decision was made not to mow the area during bird breeding season. Even though nest boxes are abundant in the park as a measure to meet the initial promise of increasing bird diversity, there has been less attention to other aspects of biodiversity, i.e., vegetation, insects, and mammals. By improving vegetation quality and ecological conditions for insects, birds, and other species, this project aims at making solar park Revelhorst a biodiverse, multifunctional area where both energy production and biodiversity thrive.

In many solar parks worldwide, attention is already shifting towards enhancing biodiversity (H. Blaydes, S. G. Potts, J. D. Whyatt, & A. Armstrong, 2021). However, in the Netherlands, not many photovoltaic farms have successfully improved their biodiversity. 'De Kwekerij' is an example of a photovoltaic farm that was able to successfully combine green energy production with biodiversity as well as recreational purposes (Schotman et al., 2021). By reverting agricultural lands to species-rich grasslands, biodiversity around the photovoltaic cells can be increased significantly (H. Blaydes, S. G. Potts, J. Whyatt, & A. Armstrong, 2021). Increased biodiversity comes with many benefits such creating bird feed, pollination, recreation, and water cycling (Y. Zhao, Liu, & Wu, 2020).

Various groups are now involved in the operation and management of Solar Park Revelhorst. The most important stakeholders are Zutphen Energy, Sunvest, a volunteer group, a local bird group, a local bee group, and our ACT commissioner Friso van der Zee from Wageningen Environmental Research (more information on stakeholders in appendix A). The volunteer group is important as they help with measurements, and maintenance of the park. The local groups help setting up the measurements and assist the volunteers on how to proceed in the park.

Based on the stakeholders' wishes, this report aims to increase the value of nature where it is often neglected while not interfering with energy production and not excessively reduce the financial profits of Sunvest and Zutphen Energy.

1.1. Research questions

Based on the information mentioned above and the ones received from the stakeholders, the following questions will be answered in this report. The most important part is determining the long-term management plan. For that we need to know what the current situation is and what is desired by the stakeholders.

Main research question

What management is required to increase the long-term biodiversity in Revelhorst solar park in cooperation with the local stakeholders?

SQ1: What is the current biodiversity, soil quality, and maintenance regime at Revelhorst solar park?

SQ2: What are the possible toxic effects of the construction material and panels leaching into the soil?

SQ3: What are the species desired by the different stakeholders and which management options for the selected species improve the overall biodiversity?

SQ4: What is a desirable approach to monitor biodiversity in the future? Who would be responsible for managing the different monitoring practices performed by the volunteers?

SQ5: How can the municipality, local nature workgroups, and residents be involved in the solar park?

1.2. Report layout

The layout of this report has been created by trying to make it easy to access various information quickly. So, it's easier to find information about the birds when looking on how to improve the habitat for birds. Thereby, the order of the chapters was discussed based on the food chain. So that's the reason why this report starts with explaining the abiotic conditions, which affect the mowing management, which has an effect on vegetation etc. The second to last chapter, management plan, provides a summary of all the important aspects, combined with a year-overview to create an easy-to-follow plan. The final chapter, conclusion, answers the research question, and concludes this report.

2. Materials & Methods

This chapter demonstrates how we collected the information, on which the advice is based. The methods are described in a way that will allow volunteers to reproduce the procedures. Coordinates of the locations where measurements were taken can be found in the Appendix B or online in the interactive map.

2.1. Map

On this map of solar park Revelhorst, all measurement locations are shown (Figure 2). These include the camera traps (blue), vegetation plots (green), insect pan traps (dark blue), insect pitfall traps (yellow), soil samples (red), temperature data loggers (purple) and bird boxes (brown).

Figure 2: The map overview of locations in and around Solar Park Revelhorst where measurements were obtained. Camera traps (blue), vegetation plots (green), insect pan traps (dark blue), insect pitfall traps (yellow), soil samples (red), temperature data loggers (purple) and bird boxes (brown).

2.2. Camera traps

The presence and abundance of mammals were detected and measured using camera traps. Kays et al. (2020) used one camera for every 0.2 km in a small-scale temperate zone, and therefore approximately four cameras are needed in an area of 8 ha. Instead, because a low mammal abundance was expected in the solar park, this project put in place more cameras to capture a higher percentage of mammals present (Kays et al., 2020). Ten cameras made available by the Wildlife Ecology & Conservation Group were set up. The park was divided in a grid with four quarters, one of the four measured at a time every week. Towards the end of the project, due to time constraints, only 3 out of 4 areas were completed. The camera digital storage (32 GB per camera) was checked weekly and emptied when necessary.

2.3. Vegetation

Analysis of randomised vegetation plots throughout the field allowed for the approximation of current plant biodiversity in Solar Park Revelhorst. New plant species found outside the plots were also recorded to create an overview as complete as possible. The plots were chosen based on four different types of locations: between the rows of PV panels, underneath the panels, and in the vicinity of the inside and outside of the fence bordering the park. Six plots were set up in each location (a total of 24). Plots of 9 m^2 were used, as the biodiversity is low, and we aimed at finding as many plant species as possible. However, the narrow strips of space between the panels necessitated rectangular plots of 1.5m by 6m. For consistency these were used for plots everywhere.

Regarding the randomisation of the location for data collection points between and under the solar panels, this project used the following technique: first randomly generating the panel row number (between 1 and 20) and then the number of individual panels to walk past (1-100) (the upper limit is approximate and may change given specific locations in the park). Furthermore, for locations inside and outside the fence, the following method was used: first randomly selecting the side of the border (north, east, south, or west) and then the number of steps (1-500) to take from it.

The plots examined were marked with 4 bamboo sticks, one at each vertex, and a rope of 15 meters around it. Then, species which were easily observed looking into the plot while standing at the edge were noted, and coverage classes were assigned to each species. Lastly, observers stepped inside the plot to identify smaller plants inconspicuous outside the plot. The order is important to avoid trampling and overlooking small plants and cover classes are estimated more accurately.

The cover classes used were developed by Braun-Blanquet (Westhoff & Van Der Maarel, 1978), a widely applied method for classification of vegetation (Van der Maarel & Franklin, 2012), putting plant species into categories based on the percentage of ground covered by the plants when looking from above. This method is determined by two parameters, cover percentage and number of individuals estimated by eye. The method distinguishes 9 classes, four below 5%, in which case, individual plants are counted, and five classes between 5 – 100% (Table 1). Classes are indicated per species and the total percentage can be higher than one hundred since plants overlap each other to compete for sunlight.

Table 1: The Braun-Blanquet cover-abundance scale

Symbol (cover class)	Cover percentage	Number of individuals
r	≤1%	1
+	≤1%	2-5
1	≤5%	6-50
2m	≤5%	>50
2a	5% - 15%	-
2b	16% - 25%	-
3	26% - 50%	-
4	51% - 75%	-
5	76% - 100%	-

Other vegetation assessment methods, such as the following, were explored but rejected. For one, the Daubenmire cover scale method only takes into consideration 6 classes of vegetation cover and does not record the number of individuals, therefore reducing the precision of the analysis (Ellenberg & Mueller-Dombois, 1974). For another, the Levy Bridge method developed by Levy and Madde sets the size of sampling plots at 0.1 $m^{2,}$ therefore requires greater precision of observers. This method does not align with our sampling size of 9 m^2 and time restrictions (Everson & Clarke, 1987).

2.4. Insects

This report uses various methods to sample arthropod diversity at the Revelhorst site. These methods include pan traps, pollinator transects, and pitfall traps. Pollinator transects and pan traps provide a good measure of pollinating flying insects such as bees, bumblebees, hoverflies, butterflies, and certain beetles. The pitfall traps allow us to sample a larger diversity in taxonomic groups (Montgomery, Belitz, Guralnick, & Tingley, 2021). Including both pan traps and transects should allow us to better assess species diversity and abundance of wild pollinators (O'Connor et al., 2019). The insects from the pan- and pitfall traps were collected and analysed weekly.

2.4.1. Pan traps

Three traps, with white, blue, and yellow fluorescent paint on the inside, were placed at each sampling point in line with the vegetation height (Figure 3). These colours attract the highest number of species, and in terms of species sample, the blue trap is expected to show a high degree of dissimilarity to white and yellow (Vrdoljak & Samways, 2011), resulting in a good variety of species sampled. For insect identification this project used ‘ObsIdentify,’ an image recognition application that correlates information with nature database.

The traps were not chemically baited but only relied on colour as an attractant. They were filled with a solvent of water, mixed with a drop of dish soap and 3% salt as a preservative (Leather, 2008). The top of the traps was covered with a lid to prevent overflowing during rain. One trap per square kilometre is generally sufficient to sample pollinators (Montgomery et al., 2021). For this report, three were used to account for error and location influences.

Figure 3: Pan traps

2.4.2. Pitfall traps

The pitfall traps consisted of plastic cups, filled with the same solvent as the pan traps (Laub, Youngman, Love, & Mize, 2009). They were covered with a lid placed a few centimetres above the ground to prevent them from filling with rainwater. Four pitfall traps were placed at random spots throughout the solar park. Two were placed underneath the panels, one next to a junction box and one in the middle of a solar panel row.

2.4.3. Butterfly transects

This method focused on the presence of butterflies along the 100 m transects. Observers made use of Pollard walks, where observers focussed on a 5-by-5-meter area ahead of them in which they made observations as they walked along the transect at a slow pace of six to eight minutes per trip (Pollard & Yates, 1994). Individuals were counted and identified, and when an adequate identification cannot be made, they are netted and identified or photographed (Montgomery et al., 2021).

Pollard walks were done for a total distance of 1500 metres, split up into 100 metre transects. These transects were placed solely along the edge of the park, as performing them between the panels proved too difficult due to the vegetation height. Observers walked along the transects between 10.00 and 17.00 only when temperature exceeded 17 ˚C during overcast weather or 13˚C in sunny weather, as outlined by Pollard and Yates (1994). Due to unfortunate weather conditions the transects were walked only once (27-06-2022), instead of weekly as originally planned.

2.5. Soil

To investigate soil quality, two samples were taken from the solar park for analysis. One of the samples was taken from the former agricultural grassland, and the other from the former maize field. Eurofins tested organic (organic compounds, etc.), inorganic (metals, nitrate, phosphate, etc.) and physical parameters (friability, compactness, etc.). The results from Eurofins were interpreted by looking at relevant parameters for our research and how these soil parameters affect plant growth and possible management options. These parameters are nitrogen, phosphorus, sulphur, pH, calcium and magnesium, heavy metals, and physical, and microbiological properties.

2.6. Temperature

Temperature data were taken by HOBO data loggers from six different points throughout the photovoltaic system, as shown in Figure 4. One data logger (6) was positioned mid-height on the fence bordering the solar park to provide a reference point. Ideally, these temperature data are to be used to identify the area where certain plant and insect species could be integrated appropriately. However, regarding temperature we limited this report to data collection (between 30-05-2022 and 07-06-2022) and we did no intensive processing.

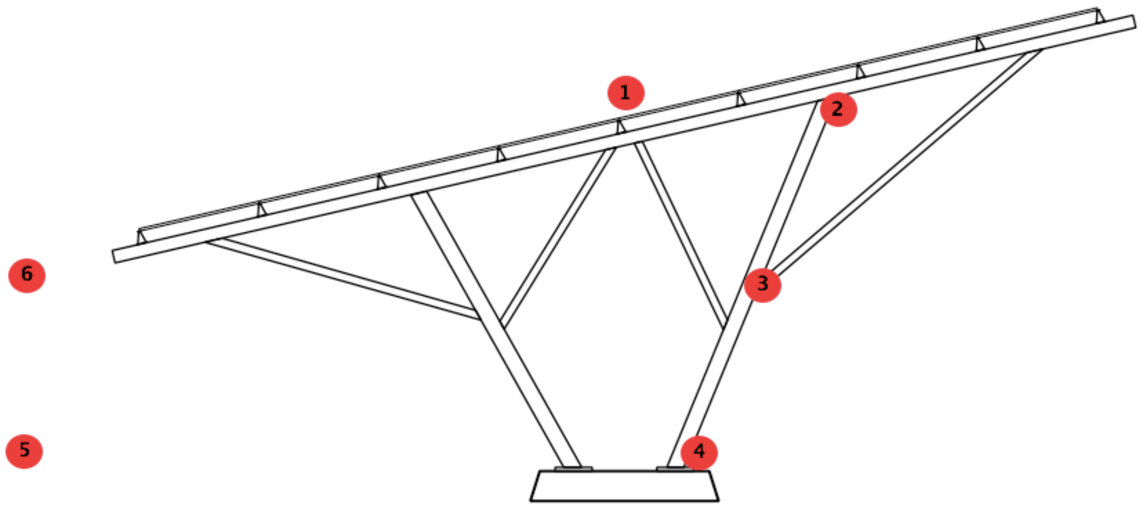

Figure 4: Overview of placements data loggers for temperature measurements in a solar park. 1: On top of PV panel, 2: under panel, 3: Mid-height under panel, 4: ground level under panels, 5: ground level between panels, 6: mid-height on fence.

2.7. Birds

The nest box analysis was done according to the steps mentioned below. The boxes were accessed following the numbers mentioned in the map. The bird boxes were observed by firstly giving a gentle tap on the box to allow the adult bird to leave when present, and then the box was slowly opened to access the content. The categorisation of the observation followed with the absence of birds, the traces (straw, moss, faeces, feathers), or their presence (nest, bird) (see appendix D).

2.8. Literature

In addition to data obtained from field experiments, literature research forms the backbone of this project and contributes to most chapters. Chapters 3.2 (Soil quality & toxicity) and 4 (Grazing vs mowing) were particularly informed by literature on the topic.

3. Abiotic conditions

Abiotic conditions of the solar park are important for determining the possible interventions to improve vegetation and the broader biodiversity. Temperature and soil conditions among other environmental factors affect vegetation, which consequently affects insects, mammals, and birds. Solar Park Revelhorst might differ from natural areas in the Netherlands, as the PV panels might affect the temperature and there is a possibility of PV components changing soil characteristics. Also, the fact that the land had former agricultural purposes prior to the construction of the solar park is expected to have left an impact on, for example, soil chemistry.

3.1. Temperature

To test whether the panels influence the temperature in the solar park, data loggers were used to determine the temperature on different locations in the park. The temperature by the fence, under PV panels, above PV panels and between PV panels were compared in Figure 5.

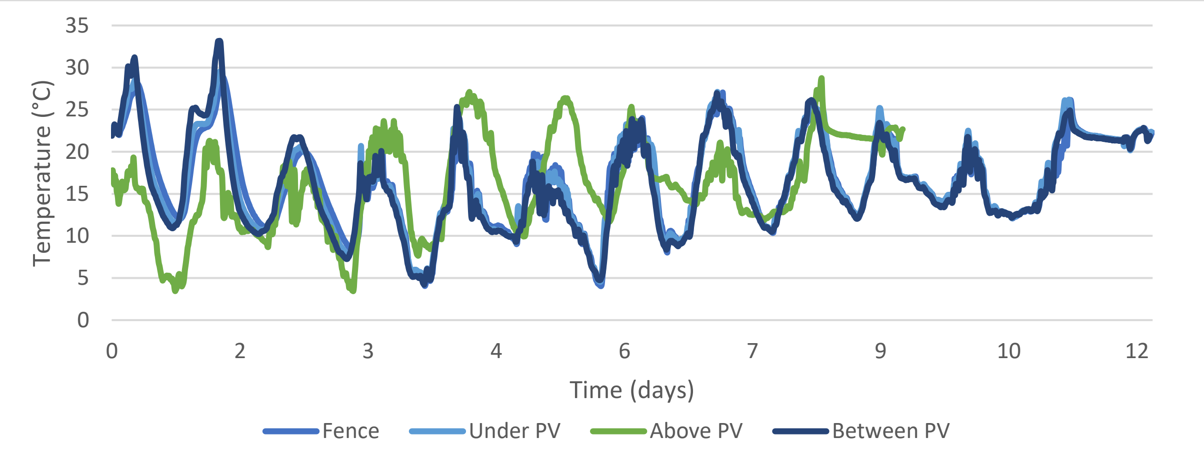

Figure 5: Temperature in different locations of Solar Park Revelhorst: Fence, Under PV panels, Above PV panels and Between PV panels. The data was collected between 27-05-2022 and 08-06-2022.

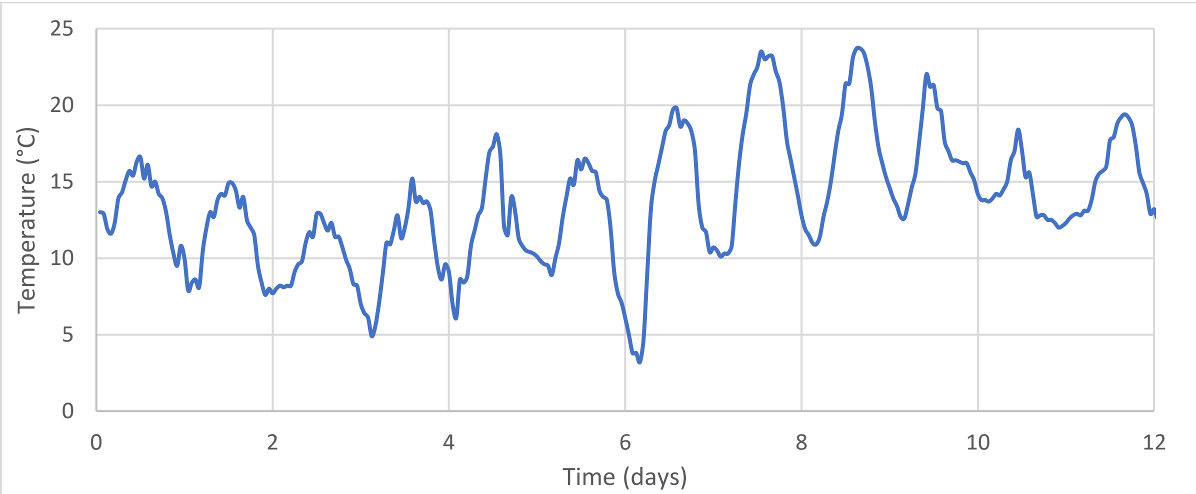

Figure 6: Temperature obtained from a nearby weather station in Deelen. The data was collected between 27-05-2022 and 08-06-2022.

Overall, temperature data obtained at the fence, under the PV panels and between PV panels are similar (Figure 55). All locations returned temperatures within a range of 4.5°C and 31.5°C, which expectably does not have significant, negative impacts on plant growth (Yamori, Hikosaka, & Way, 2014).However, the pattern of the temperature above the PV panels deviates from other locations. In comparison, temperature data from local weather station Deelen (KNMI, 2022) matched those above the PV cells the best (Figure 66).

It is an unexpected pattern that the project can neither adequately address nor draw a conclusion from because other weather conditions (e.g., sunny and rainy days) were not collected and because it is beyond the initial scope of this section to analyse temperature data; it remains a knowledge gap to be explored in future research.

3.2. Soil quality & toxicity (literature review)

Typically speaking, PV systems consist of modules, racking structures and inverters (Huang et al., 2022). Half of the materials, by weight, in this system are made from glass and aluminium, while steel, copper, plastics, silicon, and other chemicals make the rest. Different types of PV panels and manufacturing techniques lead to different material composition, and in theory hazardous chemicals can be released into the environment at the end of the PV life cycle. The biggest chemical hazards in PV systems could potentially include lead in the module, cadmium-telluride and selenium in thin-film cells and other heavy metals (Curtis et al., 2021).

Normally, these hazardous materials are well encapsulated in the toughened glass and film. They should be stable in normal environmental conditions in the recommended performance period, which is usually 25 years. However, an acidic environment of, for example, soil and landfill can liberate the compounds and expose the environment and the ecosystem to substantial chemical risks (Curtis et al., 2021). Su, Ruan, Ballantine, Lee, and Cai (2019) treated exposed and crushed panel material with nitric acid to simulate corrosion and buried the pieces in different types of soil to explore if metal leaching took place. They discovered that in all scenarios heavy metals were detected in the soil and their concentration was proportional to the contact time of panels with acid, the amount of panel material, and the acid concentration (Su et al., 2019). Researchers found mostly nickel (Ni), zinc (Zn), and copper (Cu) as they were consistently released at the highest concentration in soil, acting as potential sources of toxic effects in plants. The research concluded with support for the theory that once the protective layers of PV panels deteriorate and/or are damaged, heavy metals and other toxins are released into the environment and have the potential to affect plant growth and nutrient uptake.

Nevertheless, it is critical to note the limited relevance of this piece of research in our context of solar parks: first, Su et al. (2019) crushed solar panels into fragments and buried them in soil, therefore increasing the exposure of panel material to acid solutions per cm^2 surface area; In reality, panels standing in solar parks are intact and functional before they are replaced and disposed of. Second, researchers used strong acids of H_2SO_4 and HNO_3 mixture in the experiment, while rain (weak acid H_2CO_3) and soil acidity in nature do not reach the same level of acidity, therefore less capable of breaking down panel material and inducing leaching.

Considering the limited applicability of examining the effect of acids on degraded PV panels in our project, there have only been few studies directly studying the effect of solar parks on soil quality. Lambert, Bischoff, Cueff, Cluchier, and Gros (2021) hypothesized that solar park construction degrades soil quality and they comprehensively measured physical, chemical, and microbiological properties of the soil collected in sampling plots below PV panels. Research findings supported their overall hypothesis that soil quality indexes were generally lower in solar parks than in semi-natural land cover types (Lambert et al., 2021). For *physical* properties of soil in solar parks, the aggregate mean weight diameter was significantly lower than that in semi-natural areas, suggesting a low stability of soil, therefore increased susceptibility to erosion, and a degraded vegetation. Researchers pointed out the studied solar parks further reduced the soil physical quality beyond the baseline. For *chemical* properties of soil in solar parks, particularly in the study of Lambert et al. (2021), solar park construction had no effect on reducing C and N content or other chemical quality indicators. However, there is contrasting evidence that total C and N are usually lost during the land use change from natural to anthropogenic and other researchers found decreased C and N in soil from solar parks than from a reference grassland site (Choi et al., 2020). The effect of solar parks on soil chemical properties remains unclear, but theories tend to suggest the likelihood of deterioration. For soil *microbiological* properties, enzyme activity and soil basal respiration were both lower than those in semi-natural lands, which reflect reduced microbial activities and limited ecosystem functioning (Lambert et al., 2021).

In conclusion, researchers recommended ecological restoration and/or compensation measures and long-term monitoring for solar parks and the conclusion inspired measures taken in this project as well. While Lambert et al. (2021) developed a correlation between the establishment and management of the studied solar park and degraded soil quality, whether we can extend the applicability of their findings to solar parks in general remains debated.

For one, none of the studies clearly laid out the mechanisms of which solar parks affect soil quality, be it light conditions, moisture, leaching, construction disturbance, length of operation, etc., and therefore various confounders need to be controlled. Among the above-mentioned determinants, light conditions, we hypothesise, are one of the most important causal factors that affect soil quality via vegetation abundance and health. However, since studying the link of solar parks (its layout and operation) and environmental and ecological conditions is a field only emerging in very recent years, how strong the causal effect from light levels to soil quality (e.g., within the same park but in different locations around the panels; differential light conditions across the world) remains a critical knowledge gap. For another, Lambert et al. (2021) recognized that the previous land use of the solar park as vineyards may have affected the ecosystem and the soil profile via intensive tillage, to which statistical differences in soil properties of the current solar park and of semi-natural land cover types can be (partly) attributed. As a result, if a plot of grassland did not undergo such practices and disturbances, building solar parks on top of might result in a less pronounced change in soil properties.

Despite that this section attempts to explore the effect of PV panels and potential leaching on the composition of receiving soil as the environmental medium, this project in addition recognizes the urge to call to attention an under-studied aspect of how leaching affects rainwater quality and causes environmental impact via water streams. Researchers aimed at investigating the environmental impact of thin-film solar cell technology and they cut thin-film copper indium gallium selenide cells (CIGS) into small pieces, submerging them in acid rainwater at pH 5 (Zimmermann, Schäffer, Corvini, & Lenz, 2013). They found "[r]oof-top acidic rain runoff from CIGS … the prominent emission source for metals and metalloids" and especially the concentration of leached cadmium was so exceedingly high beyond drinking water guidelines as to cause acute toxicity in aquatic organisms like water flea (Zimmermann et al., 2013). The concentration of other heavy metal elements did not reach such alarming levels, but researchers nevertheless raised teratogenicity (fetus malformation) and nanotoxicity (toxicity related to the exposure to nanomaterials) concerns. The research is limited in applicability in the context of solar parks because researchers exposed broken PV panels to acidic solutions for over 100 days, while in reality the contact time between rainwater and solar panels is minimal. Additionally, the paper focused on CIGS at the end of their life cycle, but all PV panels in Solar Park Revelhorst are composed of crystalline silicon solar cells, a different technology from CIGS with different composition and therefore behaviour. Nevertheless, these limitations should not obscure the fact that resource streams including water are also threatened by the contamination potential.

3.3. Soil parameters (analysis)

Table 2: Soil parameters at two locations in the solar park compared to normal values found in Dutch agricultural fields (greater details can be found in the Eurofins report). Numbers in red are either too low or too high and therefore concerning.

	Units	Observed values, former agricultural grassland	Observed values, former maize field	Normal values
pH	/	5.3	5.1	5-5.7
Bioavailable N	kg/ha	1920	2280	1480-2160
Bioavailable P	kg/ha	5.3	10.7	2.9-4.3
Bioavailable S	kg/ha	<2	<2	20-30
Bioavailable Ca	kg/ha	10	130	95-225
Bioavailable Mg	kg/ha	95	155	120-180
Bioavailable Zn	g/ha	2330	1730	670-1000
Microbial activity	mg N/kg	65	66	125-175

Type of soil: loamy sand soil because of its significant sand content at approximately 75%-80% with a smaller share of silt.

Site overview: Solar Park Revelhorst used to be divided into two areas, the first on the southern side being an agricultural grassland and the second a maize field in the north. When this report lists numbers of soil properties below, the order of the numbers corresponds to the first and the second section of the solar park as mentioned above.

Important soil parameters for our research:

pH: pH is a critical soil characteristic that affects physical, chemical, and biological properties of the soil as well as plant growth, since different plant species prefer different acidity levels (Neina, 2019). As it is challenging to change the pH over a short time, the current pH must be considered when deciding on the desired vegetation. In general, a higher pH of 6-7 is better for plant species diversity (Critchley et al., 2002). Another effect of the pH is that, when it drops too low, aluminium toxicity can take place, which has a negative effect on plants (S. Silva, 2012). We hypothesise that the pH of soil in Solar Park Revelhorst is relatively low because a high nutrient level leads to acidification (Neina, 2019). In acidic soil environment, it is noted that Zn and Cu have increased leaching ability and therefore are more likely to affect plant health at higher, undesirable concentrations (Su et al., 2019).

The pH levels in Solar Park Revelhorst are characteristics of agricultural fields (5-5.7), 5.3 and 5.1 respectively, but they are on the lower end. As mentioned above, low soil pH affects nutrient availability and plant health, and therefore is an important indicator to be continuously monitored.

Nitrogen (N): Nitrogen content is an important parameter, because it generally supports plant growth (Andrews, Raven, & Lea, 2013). The main form of nitrogen that is taken up by plants is nitrate (NO_3^-). However, too much nitrogen will lead to eutrophication, which results in dominant plants outcompeting other plants. Therefore, a nitrogen surplus will lead to a low plant diversity (Van Landuyt, Vanhecke, Hoste, Hendrickx, & Bauwens, 2008). Furthermore, since nitrogen fertilizers are widely applied for agricultural purposes, the nitrogen level in the solar park is expected to be high. The same applies for other nutrients that are used as fertilizer on agricultural lands and are used for plant growth and development, like phosphorus and sulphur.

The current nitrogen levels are 1920 kg/ha for the first location and 2280 kg/ha for the second location, excessively high for semi-natural grasslands and also too high for agricultural fields (Table 2). Due to a build-up of nitrates, molybdenum (Mo) deficiency has also been found in the soil from Solar Park

Revelhorst (Kaiser, Gridley, Ngaire Brady, Phillips, & Tyerman, 2005). The current concentration is less than 10 g/ha while the ideal range is above 140 g/ha.

Phosphorus (P): It has been noted that the loss of plant species, especially the endangered ones, can be partly attributed to P-enrichment in some terrestrial ecosystems, such as temperate grasslands and freshwater wetlands (Wassen, Venterink, Lapshina, & Tanneberger, 2005). Phosphorus abundance increases the productivity of the site and allows fast-growing, dominant plant species to dominate the grassland, outcompeting smaller and/or endangered species. Therefore, to restore biodiverse semi-natural grassland plant communities, researchers recommend a reduction of P levels in soil, particularly on former agricultural land (Critchley et al., 2002).

According to the soil analysis, P-overabundance consistently occurs in both sections of the solar park, significantly surpassing the recommended levels even for agricultural fields (5.3 and 10.7 kg/ha vs the recommended upper limit of 4.3 kg/ha). This excessive concentration also affects the iron level in the soil (< 2770 g/ha in the first sample), as it is significantly below the acceptable level of 3430 g/ha. It is critical that no more fertilizer or manure is applied to the field and nitrogen-fixing plants are recommended, so that they can correct the N:P ratio. However, what complicates the situation is that there is no feasible (technical or ecological) intervention that singlehandedly reduces P concentration, and that excess N is also an emerging issue (although to a smaller degree compared to excess P). Admittedly, it is possible that N or P is depleted by the plants and becomes limited, leading to a drop in the biomass production and a potential of more species invading the ecosystem. However, this project does not view it as a concern at least in the foreseeable future due to exceedingly high concentrations.

Sulphur (S): Sulphur is one of the most important nutrients for plant growth and functioning (F.-J. Zhao, Tausz, & Kok, 2008). While the overall sulphur level (storage) is quite high in both locations, S in the bioavailable form is at both locations lower than 2 kg/ha. According to standards of Eurofins for agricultural crops, this is significantly too low. This sulphur deficit can be explained by a nutrient imbalance, mainly caused by the suboptimal use of fertilizers (F.-J. Zhao et al., 2008).

Calcium (Ca) and Magnesium (Mg): Calcium and magnesium are essential for plant growth and health. Due to the use of fertilizers, in theory, calcium deficit may occur when no extra calcium is added. With dry conditions or a low soil pH, magnesium deficit can occur, since plants cannot take up enough magnesium under these conditions (Pilbeam & Morley, 2016).

In the first location, calcium availability for plants is exceptionally low, with 10 kg/ha, while the favourable level should be between 100 and 230 kg/ha according to Eurofins. The overall level of Ca is, however, quite high, with a total amount of 1015 kg/ha. The reason for this might be the use of fertilizers (Pilbeam & Morley, 2016). Surprisingly, the calcium availability as well as the total amount are satisfactory at the former maize section. This difference may be caused by the differential use of calcium-containing fertilizers. For the bioavailable magnesium, both locations are at the required level (between 120 and 180). However, as mentioned above, in times of droughts, magnesium deficit can still occur due to the inefficient plant uptake (Pilbeam & Morley, 2016).

Heavy metal: In this category, only Zn will be discussed due to its undesirably high concentration in the soil tested (2230 and 1730 g/ha vs the recommended upper limit of 1030 g/ha. Excess Zn is known to inhibit microbial growth and activity, the undesirable phenomenon of which are also present in our soil samples (see below) (Wyszkowska et al., 2016). At even higher concentrations, Zn reduces plant development and can be lethal. The origin of such Zn overabundance is unclear and monitoring the chemical release into the environment during the construction process of the solar park should be emphasised going forward.

Microbiological properties: Microbial activity, 65 and 66 mg N/kg, in both samples was low and beyond desirable levels, indicating a degradation of soil and ecosystem functions even when microbial biomass is within normal range for agricultural fields (more can be found in Table 2) (Lambert et al., 2021).

3.4. Summary and advice on soil improvement

Recalling the overall aim of restoring the ecosystem in Solar Park Revelhorst to a state that resembles semi-natural grasslands, several points should be noted.

- Soil conditions including high pH and low nutrient levels are conducive to alleviating heavy metal leaching potential and reducing dominant grass species. Grounded limestone can be applied to the soil occasionally to increase soil pH (Critchley et al., 2002).
- It is an ongoing problem that nitrogen surplus leads to the dominance of grass species and certain species being outcompeted, and therefore a suboptimal vegetation diversity. It is critical that no more fertilizer or manure is applied to the field and nitrogen-fixing plants are recommended, so that they can correct the N:P ratio.
- Low soil phosphorous is a good indicator for suitable soil conditions for (neutral acidity) grassland communities as well as beneficial for biodiversity in general (Critchley et al., 2002).
- More research is critically needed on the potential of heavy metal leaching during functional years of PV panels in a solar park setting, with soil and/or water streams as the media.
- There is no denying the effect of soil properties on ecosystem health, but this section might have the potential of overstating the correlation. There is evidence that for grassland biodiversity, land use history and site location hold greater importance over and can even override effects of soil characteristics (Cousins, Lindborg, & Mattsson, 2009; Kaiser et al., 2005). It implies that if solar park managers want a biodiverse solar park, the land use history also has to be taken into consideration when choosing the site (merely prioritising power generation will fall short).

4. Comparison grazing and mowing

Currently, Solar Park Revelhorst is mowed two times a year, before autumn and after winter. Previously, cuttings have been removed from the site after mowing, but not anymore. Moreover, sheep are going to be placed in the Solar Park, which is of financial interest. It is argued by stakeholders, that with sheep present in the park, mowing would not be necessary as frequently as it is needed now. It is planned, that the sheep will be present in the park all year around.

Managing semi-natural grasslands to influence resource use and ecological succession is critical to biodiversity conservation in this habitat (Tälle, Fogelfors, Westerberg, & Milberg, 2015). While characteristics of most solar parks and semi-natural grasslands differ in terms of nutrient level, species composition, etc., management options are especially worth examining with our goal of restoring Solar Park Revelhorst to a state of semi-natural grasslands in mind. Mowing and grazing are widely used management options, also the ones put forth by stakeholders in this project, by Sunvest in particular. However, each has its own benefits and pitfalls, so a further investigation is done below to eventually reach a relevant advice on this.

4.1. Characteristics

Mowing and grazing both help maintain grassland landscape and biodiversity through the mechanism of reducing vegetation cover as well as competition via physical disturbance so that new grassland species have a higher chance of establishment (Kapás, Plue, Kimberley, & Cousins, 2020). However, they also differ significantly in the following aspects. One of the main differences between grazing and mowing is the fact that grazing is a continuous process, even when done for a short period, while mowing is mostly done at one certain time. Another difference is that with mowing all plants are cut evenly, while sheep have different preferences in plants to graze. For the location of our project, however, this may not be beneficial since sheep may prefer flowering plants, like clover over grasses (Rutter, 2010).

Each method is associated with unique benefits and limitations. Generally speaking, grazing contributes to increasing vegetation diversity in restored grasslands because of the mobility and connectivity brought about by grazing animals and thus the improved spatial and temporal seed dispersal (Kapás et al., 2020). Besides, grazing also provides environmental and social advantages. Researchers noted that carbon sequestration potential and soil health indicators in all plots across the grazed site were consistently higher than land that was not grazed. In theory, grazing can also diversify and increase income of farmers or site owners, since subsidies can be obtained for grazing (Kochendoerfer & Thonney, 2021).

The effect of mowing depends on the frequency and the timing, but also on whether the grass is removed after the operation (Tälle et al., 2018). Regarding this subject, an interview was conducted with the municipality Bronckhorst because of their exemplary work in promoting biodiversity in solar parks, by being involved in creating solar parks where biodiversity is a priority. According to them, for Solar Park Revelhorst and any solar park built on former agricultural land, mowing is the best method for the first 5 years. By removing the grass, a reduction in the soil nutrient levels help decrease the dominant grasses, which allows fewer dominant species to grow as well, hereby increasing biodiversity. Another advantage of mowing is that plants that will not be eaten by sheep are also mowed, which prevents the dominance of these plant species. Since grass removal is not implemented in Solar Park Revelhorst due to financial considerations, the benefits of mowing will be suboptimal. It is important to remove the cuttings after mowing, since nitrogen levels in the soil are already high and sheep grazing would not decrease that as effectively as mowing does. One round of mowing at the beginning of the year causes only small disturbance to birds, flowering plants, and insects. It would be before the nesting season of birds, so they would be able to nest later without disturbance from mowers. Moreover, plants that are utilised by birds during the winter and by insects during late spring and summer would have time to grow after the mowing in early spring. In comparison, when mowing is done later in the year or for several times a year, negative effects on biodiversity will be bigger, such as decreased nesting chances of birds, destroying flowering plants and consequently limiting food supply for pollinators.

Despite the theoretical benefits and drawbacks of mowing and grazing respectively discussed above, it is unclear which one of the two management plans is the desirable approach to grassland maintenance under various conditions. Since much research on, for example, the benefits of grazing studied the effects in isolation without comparing them to the mowing regime, the result only indicates how grazing compares to the no-management baseline scenario and the conclusion that it is the preferrable solution cannot be drawn. Moreover, applications of the management in Solar Park Revelhorst are further complicated by the limited research in the setting of the solar park itself and technical constraints of the site.

4.2. Advice

To mow or to graze, that is the question. The evidence supporting one over the other is mixed and sometimes contradicting, but this project recommends mowing based on the following reasons. A meta-analysis on the effects of the two methods on biodiversity conservation in grassland management, shows that grazing, with species like horses, cattle or a mix of them, compared to mowing generally is marginally better than mowing in terms of overall biodiversity effects but the correlation is only weak to moderate (Tälle et al., 2016). However, with sheep as the grazer, mowing is the preferrable option considering biodiversity. Also, for metrics such as seed counts, organisms such as earthworms and grasshoppers, mowing has a slight advantage. In other words, statements about preferring one over the other are context-dependent and one must specify the goal of improving (what kind of) biodiversity before choosing either grazing or mowing. Last but not the least, in historically agricultural fields, mowing is shown to be significantly better for biodiversity than grazing (Tälle et al., 2016). To summarize, the discussion is to present the uncertainty and the complexity in choosing which management plan to adopt and the choice must be made based on the characteristics and goals unique to the site. But concerning Solar Park Revelhorst as a former agricultural land with sheep potentially considered as the grazer, mowing, which scores higher on more relevant metrics, is the preferred method.

Table 3 Pros and Cons of mowing and grazing

Mowing		Grazing	
Pro	Con	Pro	Con
Reduces height of vegetation cover	Disturbs birds, insects, and vegetation (more negative effects later in growing season)	Reduces height of vegetation cover	Sheep prefer flowers over grass
Prevents dominance of not eaten plant species by sheep	Not effective in lowering nutrients if clippings are not removed	Contributes to seed dispersal	Disturbs birds, insects, and vegetation (more negative effects if sheep are whole year round in the park)

If only mowed once at the beginning of spring, disturbance is as low as possible		Creates heterogenous vegetation (only if sheep are placed in divided sections over the park)	Creates homogenous vegetation (only if sheep are not placed in divided sections over the park)
In former agricultural land, mowing is significantly better in terms of biodiversity		Not as effective in lowering nutrients	

In terms of the debate on grazing versus mowing in Solar Park Revelhorst, this project concludes the following: mowing is preferred over grazing (Table 33), but it is dependent on the way it is implemented. To keep the height of the vegetation below the solar panels and to make sure birds can nest without disturbance by mowers, it is recommended to mow once at the beginning of the spring. When mowing will be implemented between 15 March and 15 April, the negative effect on birds, flowering plants and insects will be kept as low as possible (Natuurpunt, 2019). Moreover, to improve management efficiency and decrease nitrogen content of the soil, the high level of which is found in the current soil profile of Solar Park Revelhorst, mowing with the removal of clippings is preferred (Natuurpunt, 2019; Tälle et al., 2015). This project acknowledges that additional grazing can be part of the management to acquire subsidies however, it is advised to keep the sheep grazing short. Mowing under the panels can pose financial burden to the management of the park, which is why a combination of mowing and grazing can be a more cost-effective option. First, the park should be mowed between the panels and on the edges and then sheep should be placed in the park for grazing for a short period. However, it is not recommended to have the whole area grazed by sheep at once, since this can result in a homogenous vegetation. To make sure that there will be flowering plants all growing season round, the sheep grazing needs to be in different areas of the solar park over time. The solar park needs to be divided in sections in where the sheep are placed. After a while, the vegetation will be eaten short by the sheep and at that moment the sheep can be transferred to another section to let the vegetation recover at the current section. Depending on the number of sheep and amount of time spend in the field needed to receive the subsidies, the advice is to keep both at a minimum. It is better for the vegetation to keep the grazing pressure relatively low.

5. Vegetation

Vegetation forms the foundation of biodiversity, subsequently affecting insects, birds and mammals in the food web (Austin, 1999). In Appendix D there is a full list of vegetation which can be used to improve the conditions for birds and/or bees, but this chapter will show the most applicable ones with reasoning.

5.1. Vegetation current situation and improvement

In total 69 species were found in the vegetation plots observed during the monitoring exercise and 14 more were noted outside of the focused plots. Therefore, we have registered 83 species spread over the 8 hectares of the park. For comparison, a very rich temperate grassland can have a species richness up to 80 different species in a mere 0.1 hectare, suggesting that vegetation diversity is low and can significantly be improved throughout Solar Park Revelhorst (Faber-Langendoen, 2010). Figure 7 displays the total number of species per plot measurement.

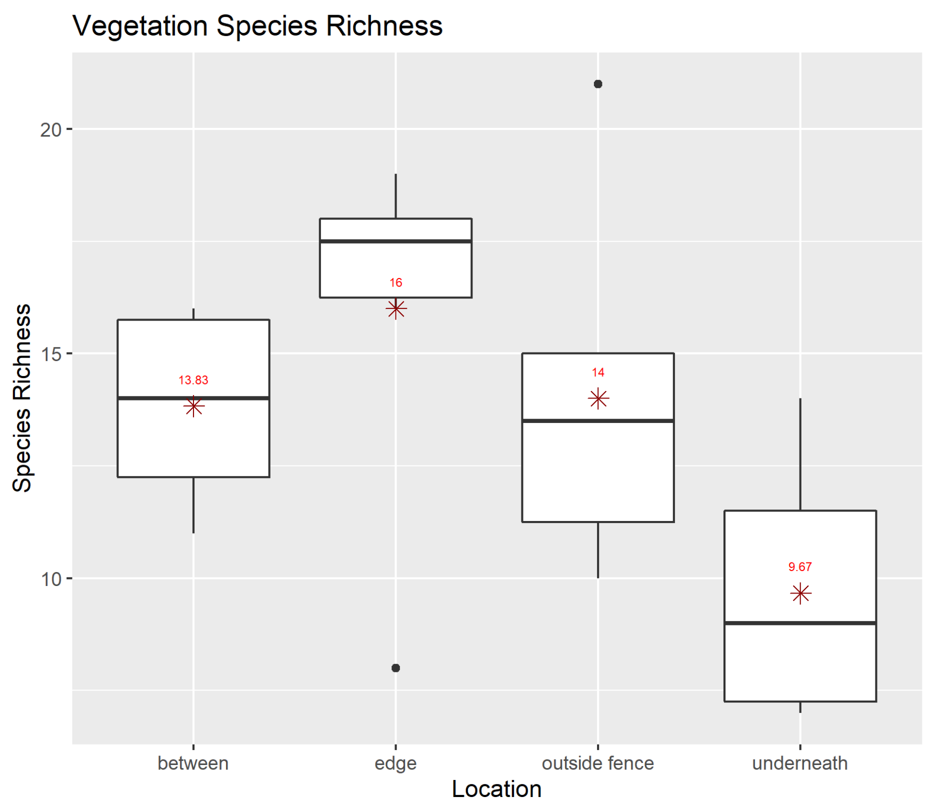

Figure 7: Boxplot of the number of species per location. Red dot shows the mean per location

As can be seen in Figure 7, overall, the lowest number of species was underneath the panels. On Average per plot, there were less than 10 different species (9.7) underneath the panel. This can probably be explained by the low light availability underneath the panels (Wang, Sun, Lin, & Gao, 2017). In between the panels and outside the fence, the average number of species per plot was higher with 13.8 and 14 different species respectively, as is shown in Figure 7. At the edge of the park, but still inside the fence, the number of species was the highest, with an average of 16 different species per plot. Also, the total number of species was highest at the inside of the fence on the edge with a total of 43 different species. Outside the fence it was a bit lower with 41 different species found, while in between the panels 28 different species were found. The place that can be improved the most on number of species is the location underneath the panels, since the total number of unique species found there was 27. An improvement on these locations can be accomplished by introducing new shade tolerant plant species, such as ferns.

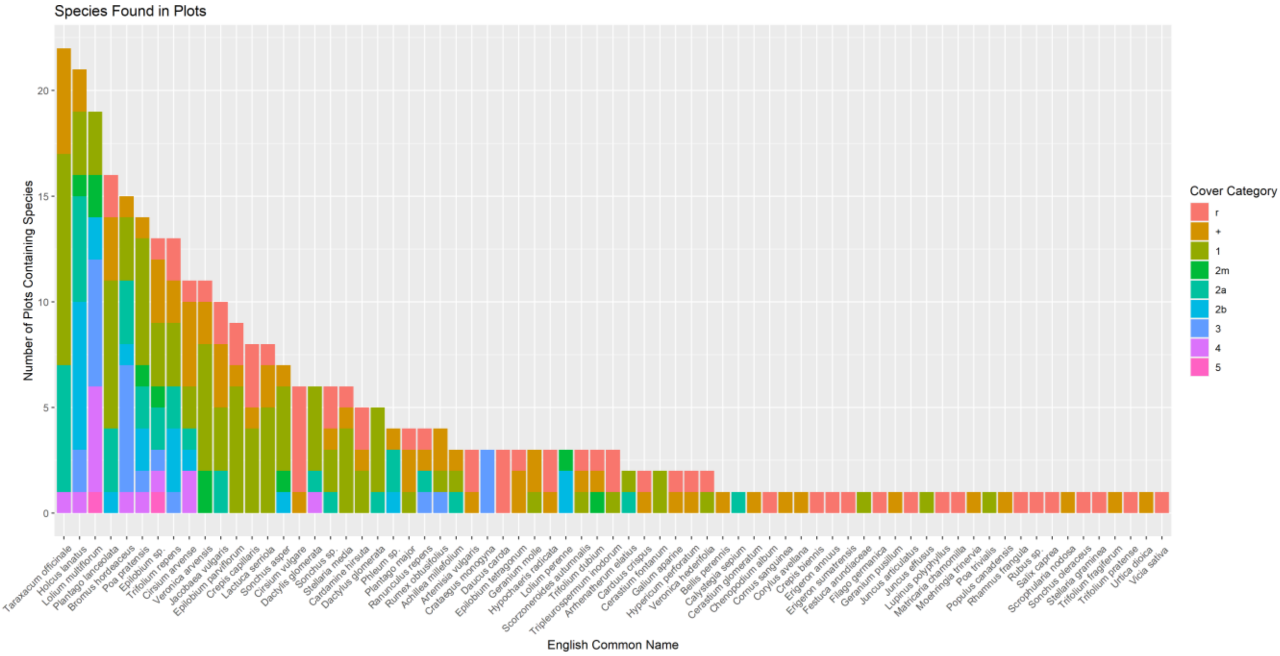

Figure 8: Number of plots in which species were found, colored by cover category

Although the number of species was lowest underneath the panels, the species were more evenly distributed than in the plots between the panels. Between the panels, there was a strong dominance of grass species, which caused that other plant species were present only in small amounts. This dominance of grasses (Figure 8) could also be observed in the plots at the edge of the panels and outside the fence, but to a lesser extent. For these locations, mainly in between the panels, it may be beneficial for overall biodiversity to decrease the quantity of grasses and increase the number of herbaceous flowering plants as this improves the pollinator population (Le Provost et al., 2021). This can be done via the removal of cuttings and the spread of flower seeds. Furthermore, in some plots there was a strong dominance of other species like willow herb, thistle, and common dandelion. For these plots it will also be beneficial to reduce the dominance of these species, since a more evenly distributed species richness is an indicator of a high biodiversity (Rousseau & Van Hecke, 1999). A lower species dominance will also lead to chances for other species to establish on these spots, so it may also lead to a higher plant species richness. At the basis of this uneven distribution in species lies the high nutrient level of the soil, which was discussed in Chapter 3.

Once the soil nutrient level has been lowered, vegetation interventions can be made to improve biodiversity even more. In this consult, vegetation should be functional in the sense that they can be used by insects, birds, and mammals for feed or as nesting/host plants. The following sections will discuss some examples of improvements that can be made.

5.2. Fence advice

Hedges are a great way of improving the outside part of the solar park. Hedges also offer privacy and less noise disturbances for the birds. Luckily, there has already been some initiative in planting hawthorn hedges around the park. On the sides where these hedges are still missing, there is a possibility of planting other types of hedges to increase plant variety. The species recommended for the hedge is *Ligustrum vulgare*, in Dutch 'Wilde liguster.' The hedge blooms in summer and is immensely popular with bees. After the summer they produce black berries which the birds can eat. The *Ligustrum vulgare* can also grow on clay and sandy soil which is the mixture present at the solar park. Moreover, this species is native to the Netherlands (Boomkwekerijen, 2022a). Another option is the *Prunus spinosa*, in Dutch 'Sleedoorn.' This species yields berries for birds and flowers for butterflies and bees (Boomkwekerijen, 2022b).

On some places, especially when you want to let people walk past the park to look inside, it might not be the best idea to have a hedge. Then it is recommended to use climbing plants on the fence. There are a couple of recommendations for this. The first species is *Lonicera periclymenum*, in Dutch 'Wilde kamperfoelie.' It blooms from June till August, creating flowers which bees and butterflies like. Thereby, birds can hide and nest in the branches (Boomkwekerijen, 2022a; van Ham, 2019; Vogelbescherming, 2022). It is important to note that the climbing plants should grow on the outside of the fence, as to not interfere with the infrared fence on the inside.

5.3. Field advice

After balancing, nitrogen and phosphorus levels of the field through the removal of cutting, it is thereafter recommended to sow native flowers as those have a higher chance of being attractive to pollinators, such as bees and butterflies (Balasubramanian, 2021). It is thereby recommended not using one year/ two-year plants as these plants can easily be outcompeted by grasses, so therefore it is recommended to use perennials (Natuurpunt, 2019). At the same time, once the soil nutrient level is decreased, grasses will be less competitive, allowing annual flowers to flourish as well. For instance, seed mixes of native flowers can be bought to spread around the field.

Knautia arvensis, in Dutch 'Beemdkroon,' is a flowering plant which is on the red list, and attracts a lot of insects, of which the 'knautiabij' which is a mining bee. The plant dies in winter, grows again in spring and blooms in June. (Appeltern, 2022b).

Achillea millefolium, in Dutch 'Duizendblad,' is a flowering plant which creates a lot of seeds and is often seen as a weedy plant. Its weedy characteristics are good for the solar park as it needs to outcompete a lot of grass at this moment. Thereby, it creates nice white flowers which are attractive to bees. This plant is not as attractive for pollinators as the *Knautia arvensis*, but it can help decrease the grass levels in the solar park. This plant is already present outside the fence, and a small number was found inside the fence on the southwest side. So, this plant can be introduced without risking the natural habitat already present. As per the last species, it is recommended to mow or graze around May to help with the resprouting. (Appeltern, 2022a; Extension gardener, 2021).

We further recommend enriching the vegetation diversity by green-hay transfer, sourced from species-rich road verges in the vicinity of the solar park. Hay spreading in combination with topsoil removal often leads to the establishment of a large proportion of the species present in the hay (Hedberg & Kotowski, 2010). Further hay spreading tend result in higher species establishment than seeding with commercial seed mixtures, often contain rare species, and may be cheaper than a site-specific seed mixture (Kiehl, Kirmer, Donath, Rasran, & Hölzel, 2010). We recommend waiting with hay transfer until abiotic conditions improve, as topsoil removal is not an option in the Revelhorst solar park.

Furthermore, it is recommended to increase shade-tolerant flowering species between the panels to stimulate the pollinator numbers. Examples of such species are *Galium mollugo* (hedge bedstraw), *Polygonatum multiflorum* (Solomon's seal), *Allium ursinum* (Wild garlic), *Convallaria majalis* (Lily of the valley) or *Lamium* (deadnettles), although soil conditions also need to be accounted for when selecting appropriate species. Adding to that, the use of any herbicides is clearly not recommended in any situation.

Lastly, the area around the pond, that is located on the north-western corner of the solar park shows a poor water-holding capacity, based on the cracks in the ground. Fortunately, this can be improved with increasing vegetation. By planting or sowing of the plants above or other native flowering plant species. This will not only make the pond look more lively, but also the roots of the plants can modify the water holding capacity (Doussan et al., 2015) and the soil will be less exposed to sunlight. This will lead to a better water-holding capacity, and it will give chances to other plant species to establish on the shore. Moreover, a more vegetated shore will be beneficial for water loving insects (Andersson, 2014).

5.4. Overall vegetation advice

The prevalent recommendation is to decrease the dominant grasses by decreasing soil nutrient levels via mowing, as mentioned in the previous chapters. Thereafter, new species can be introduced that will increase overall biodiversity. Thereby, it is important to keep in mind that the plants need to provide enough food for birds in the winter, and enough flowers in the summer for the bees. Especially the areas below the solar panels provide room for shadow tolerant flowering plants to be seeded, to increase the number of flowering species drastically. Moreover, the edges of the park provide excellent places for hedges or climbing plants, and these should be implemented. Hedges help a lot with providing shelter and food for various birds, insects and mammals (Wolton, Morris, Pollard, & Dover, 2013) and is an easy improvement to the existing solar park. Solar Park Revelhorst can best help in achieving their goal of restoring natural biodiversity by mimicking a typical Dutch landscape as much as possible in regards of flora and fauna. Refer to the Chapter 10 for more information on the management.

6. Insects

Insects are crucial in any ecosystem and are essential for human survival. Nevertheless, insects are decreasing drastically (Hallmann et al., 2017). Now, both habitat fragmentation and intensified agricultural practices threaten most insect species. Semi-natural grasslands act as population sinks for several species, such as some butterfly species and bumblebees. Therefore, preserving semi-natural grasslands or recreating flower-rich grasslands is a good method for sustaining the diversity and abundance of insects (Öckinger & Smith, 2007).

6.1. Current insect diversity

The insect diversity and abundance were assessed with pan traps, pitfall traps, and walking transects. The pan traps and pitfall traps were successful, capturing a total of 516 and 458 insects respectively. However, especially for the pan traps, it was often not possible to identify a species to a genus level. Two large groups consisted of flies and spiders, but these can be hard to distinguish, so that some identifications were only specified on the order level. Nevertheless, this project managed to identify 90 different species in the pan traps and 86 in the pitfall traps. This results in a Shannon biodiversity index of 3.17 and 3.67 respectively (Table 4), which are high. However, all species together were considered, so when looking at individual groups (e.g., butterflies) in the category of, for example, order, the diversity index might be lower within this order (a smaller numbers of individuals).

Table 4: Summary table of the insect traps

	Pitfall traps	Pan traps
Number of insects & others	516	468
Number of species identified	86	90
Shannon index (H')	3.17	3.67

Of the species that could be determined up to the genus level, the sweat bee (*Lasioglossum*) genus was found the most in the pan traps (Figure 9). Also, the bumblebee (*Bombus*) genus was found more than ten times in the pan traps. It is unsure whether these species were found more because they were easier to determine, or because their occurrence was high. However, the fact that their occurrence at this level is good since both are wild bee species, which are essential species to conserve biodiversity and ecosystem services.

For the pitfall traps, the species that were determined most until at least genus level were the species of the *Harpalus* genus (Figure 10), which is a genus in the ground beetle family. Other species that were determined more are the *Pterostichus, Poecilus* and *Nebra* genus, which are also all ground beetles. This could also be explained by the fact that these species are easier to determine than smaller species, but it stands out that these species were there also in high numbers.

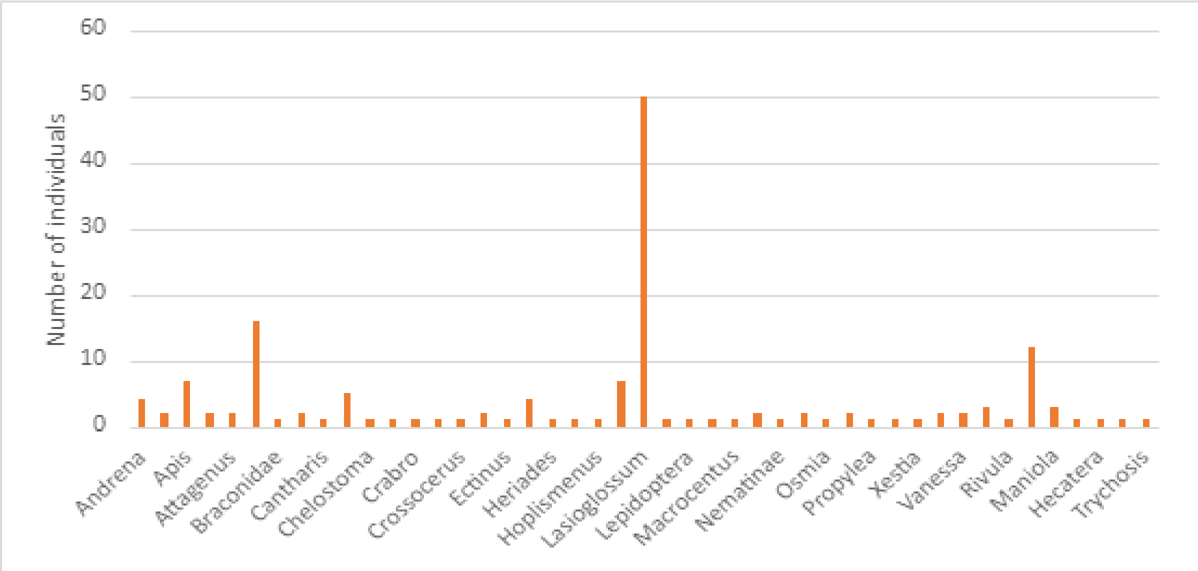

Figure 9: Number of individuals sorted by genus types found in pan traps.

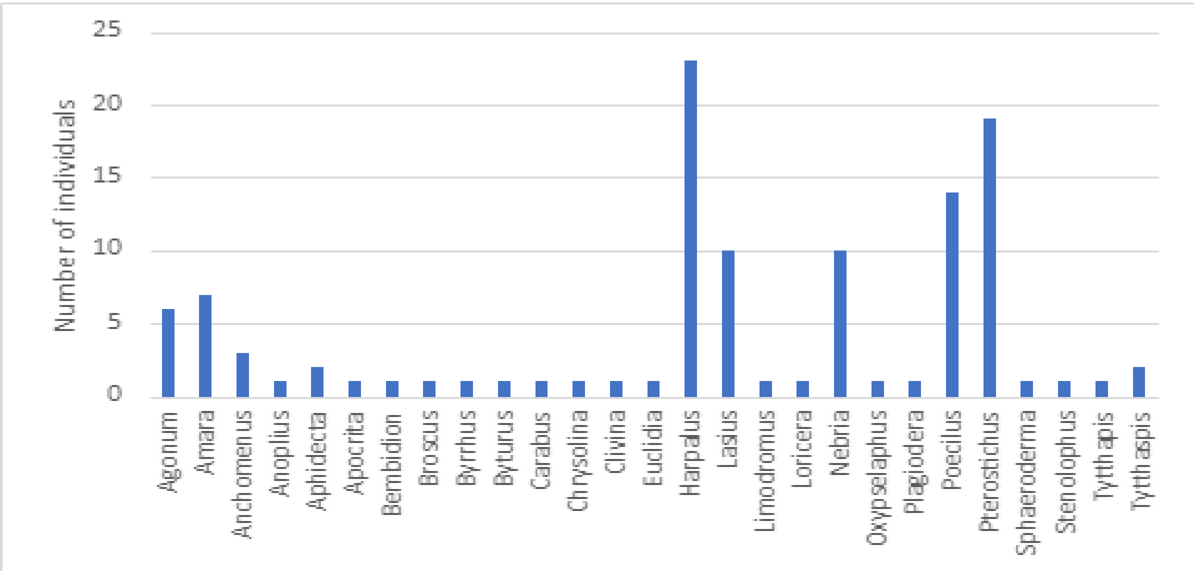

Figure 10: The number of individuals per genus found in the pitfall traps.

6.2. Target species & Vegetation

According to the wishes of the stakeholders, the focus of the interventions will be on attracting wild bees and butterflies. Hoverflies and beetles are also prioritized because of their value as pollinators. For the target species, the presence of flowers as a food source is an important goal. The vegetation is currently dominated by grasses in all areas. To increase the target species, the density of flowers must be increased (Scriven, Sweet, & Port, 2013). How to increase the flower diversity is discussed in Chapter 5 (Vegetation). When the grasses are reduced, there is more space for flowering plant species, which will be beneficial for pollinators.

Furthermore, the proximity of more flower-rich grasslands in the surrounding area increases the number of insects found in the solar park, since they serve as a source area. Insects will also prefer sunny areas. A study in a solar park in Oregon found that shading by solar panels changed the microclimate by decreasing the irradiance (Graham et al., 2021). This resulted in differences in soil moistures and temperature, leading to changes in floral abundance and timing, decreasing the pollinator abundance, richness, and diversity. However, flower visits by pollinators do not change in the shade, so as mentioned in chapter 5.2, it is recommended to increase shade-tolerant flowering species between the panels to stimulate the pollinator numbers.

For attracting more insect species, it is also necessary to have enough nesting places. These places are generally bare sand and no vegetation cover on it and dead wood or plant stems (Graham et al., 2021). Lastly, insect hotels can also serve as nesting places for different kinds of insects.

6.3. Advice

As mentioned in the vegetation advice, the focus for insects also lies in decreasing the grass species and increasing the number of flowering plants in the solar park (see chapter 5.2 on how to achieve this). In this way, there are more food resources in the area and more pollinator species will be attracted to it.

Access to pollen and nectar-producing plants are not the only thing needed for an increase in the target species. The nearby area must also provide water, barren soil, and dead wood. The latter two serve as nesting places for a variety of insects (Graham et al., 2021). Since a pond is already present, the main improvement on this is to create some places at the edge of the park where no vegetation is present. These places are recommended to create on a place where there is direct sunlight, so a possibility for this is on the west or south side of the park near the fence. It is also possible to create a sandhill by mixing yellow street sand with loam sand. Furthermore, dead old wood can be placed to create a place where they can nest. The wood must be placed in the sun as bees love sitting in the sunshine, around the pond for example.

Lastly, multiple insect hotels can be placed at the fence of the park, since they also are a particularly good option for nesting places for flying insects. These insect hotels need to be placed in the sun and the vicinity of flowering plants. A good location for these insect hotels might be on the fence of the northern side, so facing south. The insect hotels can be placed at the same height as the bird nest boxes as well as higher or lower than that if they are in a sunny place and higher than the vegetation.

7. Mammals

Mammals on Dutch agricultural lands are limited. Badgers, hamsters, mustelids, hares, and mice are species that can be found in agricultural areas. However, most of these species are either threatened or decreasing (Rijksoverheid, 2022b). Still, mammals are a big part of biodiversity and play an important role in seed dispersal, food chains and nutrient cycling (Churchfield, Hollier, & Brown, 1991; Kollmann & Schill, 1996). The following section will describe present mammals in Solar Park Revelhorst and suggest interventions with the goal of increasing mammal numbers.

7.1. Current mammal diversity

Altogether, camera traps captured 12 different species. Of these, domesticated animals, such as cats (*Felis catus*) and dogs (*Canis lupus familiaris*) were captured 11 and 6 times, respectively. Birds make up a large proportion of the captured species as can be seen in Figure 11; however, we do not take them into consideration here, since they do not belong to the class Mammalia.

Based on camera traps data, hares (*Lepus europaea)* are the most common wild mammalian species in the park. Moreover, European hedgehogs *(Erinaceus europaeus*), Martens (Family *Mustelidae*) and a House mouse (*Mus musculus*) appeared on the photos taken by the camera traps (Figure 11). Droppings of rodents, possibly hares' (*Lepus europaea*), have been found in the park along with several carcasses and skeletal remains.

The most animals appeared on photos captured by camera traps located between panels, followed by camera traps located on the western fence of the area (Figure 12).

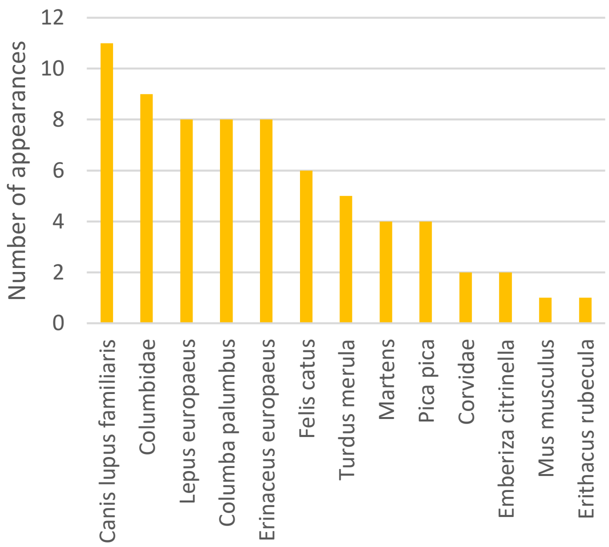

Figure 11: Species appearances on camera traps at Solar Park Revelhorst

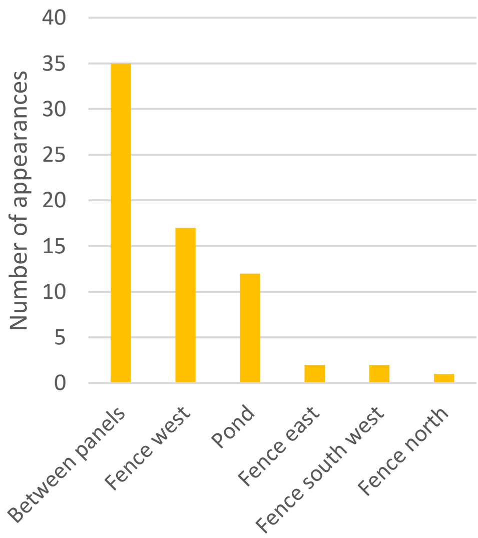

Figure 12: Appearances based on camera trap location

7.2. Optimal habitat for mammal species

Different habitat features attract different species of small mammals. For instance, woody debris provide protection, nesting cover and food in the form of insects that feed on the rotting wood. A management practice is therefore to manually integrate dead trees and branches in the solar park (Jacques, 2017). Like woody debris, snags (standing dead trees) offer equal benefits in providing protection and nesting cover. Jacques et al. (2017) also suggests retaining dense forest patches.

However, these forest patches should not limit light interception by the panels. Tree lanes and bushes can function as habitats and as forage for small mammals alongside insects and birds (van Ginkel, n.d.). There is currently a tree lane on the north outside of the park.

Ground cover types are also of importance. To attract a wide range of species, the ground cover types in the area should be as diverse as possible, ranging from litter-covered to grassland to rocky outcrops (Jacques, 2017).

Vertical vegetation structures can also contribute to an increase of species. Introducing different plant heights by alternating shrubs and grasses could be a solution (Jacques, 2017).

Other predators that can utilize the park are weasels provided there are enough food sources, mainly mice, in the area. It is not known how large the mouse population park is in the park currently, but since one mouse was found in one of the traps and caught on camera traps, it can be assumed that there are at least a few. The other habitat requirements are at this moment quite good for weasels, since they can live in dry grasslands with an alternation of bushes and hedges (Geurts & BV, n.d.).

7.3. Advice

From the paragraph above the following advice was concluded to potentially increase the mammal counts of the solar park.

The addition of trees on the premise would be of real benefit for mammal count. The northern side of the park is recommended for the integration of trees as it would not allow any direct shading on the PV panels. Following the idea of vegetation gradient, the integration of shrubs and bushes is an additional option. The inner borders of the field are recommended as a location for such vegetation as it would not affect the function of the PV panels.

In line with the other advice regarding vegetation given in this report, it is recommended to have a species diverse vegetation for an increase in mammal species. The more diverse the vegetation is, the more different food sources are available for small herbivorous mammal species (Jacques, 2017).

Moreover, the implementation of varied ground cover types is suggested. Several small rock piles were noted next to the pond but adding more rocks to those or other part of the field is recommended. Furthermore, the presence of dead trees next to the pond was also recorded, although adding more of them with dead branches across the PV farm is suggested.

Following the idea of seed dispersal and accessibility, it is suggested to ease animal access to the park (Figure 13). To do so and not jeopardize the park security, the following feature could be placed in the fence uniformly. 15 to 20 centimetres is enough for a lot of animals to pass through.

Figure 13 Fence entrance for bigger mammals, picture taken at Texel.

With sufficiently high insect numbers, bats can utilize the Solar Park as feeding grounds. To increase bat numbers, bat boxes could be added to the field, although they need to be placed at least 4m above ground to prevent predation from cats. This can be done with so-called 'bat-towers' (*vleermuis paalkast*) which can be placed anywhere in or outside the field, but preferably in proximity of a tree line, since bats use these to navigate.

Finally, the presence of the different mammals can be monitored using camera traps (see Chapter 2 for method) or tracking methods. Operating the camera traps does however take some practice and analysing the results can be quite time intensive. Therefore, active search for direct and indirect traces of animals (trails, faeces, burrows, carcasses) is recommended to assess changes in the biodiversity. This assessment should be done yearly between late spring and early summer (Hoffmann et al., 2010).

8. Birds

Several bird species can utilise solar parks, for different purposes. These include foraging, nesting or utilizing the structures for cover (Montag, Parker, Clarkson, & Montag, 2016). Solar parks, especially under management with biodiversity focus can support great diversity of plants and insects, such as butterflies and bumblebees. This can lead to increased bird diversity, due to more opportunities in invertebrate prey and seed availability (H. Montag, 2016).

Most cavity-nesting bird species have some preferences regarding nest height above ground, entry hole diameter and cavity size (Svensson, 1991). However, in many cases bird boxes that are put out look the same and are placed at the same height above ground. In this case, birds do not have a range of options to choose from, and rather they have to make do with what is presented to them. Therefore, it is important to present different options for birds, especially in areas of low utilisation, such as solar parks.

8.1. Data analysis

There are 25 bird boxes deployed in Solar Park Revelhorst. 20 of those are along the fence and 5 are attached to inverters at the end of the rows of the panels. There are two types of nest boxes in Solar Park Revelhorst, differentiated by the entry hole size. Small nest boxes, with entry hole size of 30 mm are suitable for smaller birds, such as Tits, while bigger nest boxes, with entry hole size of 40 mm are deployed to attract larger birds, such as Starlings.

When we conducted an analysis about their occupancy status, it was revealed that 48% (12/25) of nest boxes are empty, with no sign of bird presence, most of which are located on the western fence or attached to inverters. 44% (11/25) of nest boxes, show traces of bird activity but no active nesting takes place there now, and 8% (2/25) of nest boxes have birds nesting in them currently (See Figure 14 for visual representation. When comparing the occupancy of the two different types of nest boxes, it is revealed that 50% of large nest boxes and 67% of small nest boxes show traces of bird activity. The nest boxes that contain nest/bird currently are close to each other and trees and are of the small size.

Furthermore, the camera traps showed the sightings of the following birds: 8 common Wood pigeons (*Columba palumbus)*, 5 Blackbirds (*Turdus merula),* 4 common magpies (*Pica pica)*, 2 unidentified Corvids (*Corvidae)*, 2 Yellowhammers (*Emberiza citronella)* and 1 European robin (*Erithacus rubecula).*

8.2. Advice

Considering the agreement between Vogelwerkgroep Zutphen and Sunvest, this section advises on how to increase bird numbers as well as bird diversity in the park. The main aim will be to improve the habitat for shelter and food availability. In addition, some changes could be made to the already present next boxes to use them more efficiently. Our advice focuses on Tits, Starlings, Kestrels and Robins, but we believe that with appropriate management, more species can be attracted to Solar Park Revelhorst. Brief advice on vegetation management is given so that bird species can better utilize the Solar Park for feeding purposes.

8.2.1. Bird shelter and nesting

Shelter is crucial for bird wellbeing, by providing escape from predators and weather conditions. Native trees, shrubs, tall grasses and tree cavities are examples of natural shelters for birds (Bowser, 2020). The trees on the north side of the park already provide a good starting point in regards of allowing birds to seek refuge near the park. Moreover, hedges are already planted around the fence, which will eventually also offer shelter once the hedges have grown. As mentioned in chapter 5: vegetation, additional hedges could be planted to increase the diversity as well as their number. These hedges do not only offer shelter, but increase food availability as well, therefore being great actors in improving the area for birds. In addition to improving the habitat naturally, some alterations could be made to the bird boxes, allowing them to be used more efficiently by the desired birds.

Tits nest in the park already, in two of the nest boxes. According to Löhrl (1986), Great tits (*Parus major*) prefer deeper nest boxes (19 cm) with an entrance hole of 28-32 mm in diameter and at a height of 4-6 meters, probably because there is a smaller chance that predators can access it. Blue tits (*Cyanistes caeruleus*) prefer nest boxes with smaller entrance holes (25-26 mm in diameter) and at a height of 2-4 meters (Löhrl, 1986).

Figure 14: Map of solar park Revelhorst. Green dots: bird boxes containing a nest; Orange dots: bird boxes containing traces of nests; Red dots: bird boxes containing nothing; Blue boxes: the advice for adding/moving bird boxes.

European starlings (*Sturnus vulgaris*) need large nest boxes, with an at least 45mm diameter entrance hole. Starling nests can be found anywhere between 3 and 18 meters above ground (The Cornell Lab, 2019). According to a study by Svensson (2019), which was looking at nest preferences at different heights (1.5m, 3.0m and 4.5m above ground), Starlings showed a preference towards the highest nests. However, there was no significant difference in utilization between the boxes, it cannot be stated that there is a preferred height, or Starlings just choose the highest available nest (Svensson, 1991). In the solar park Revelhorst, the fence around the area is 2.0 m height and the nest boxes are placed at 1.5 m above ground. Just like for tits, this is not high enough for Starlings to make nests in them, which is why we advise putting the nest boxes on poles, to reach the height mentioned above. Moreover, it is advised that nesting boxes should face north or east to avoid getting too wet (The Royal Society for the Protection of Birds, n.d.). It can be seen in Figure 14, that almost all boxes face west or southeast in Solar Park Revelhorst. This can be the reason why almost none of the boxes are utilized, and the ones that have some traces of bird activities are on the southwest fence, facing north.

Kestrels could very well utilize nesting boxes if placed in the solar park (RSPB, 2000a). However, at the time of the advice, the specific nest boxes have not been placed. It is advised to place the nest boxes on open fields or along fences. The nest box should be between 3 m and 30 m above ground, facing south or east. Since in Solar Park Revelhorst the fence is about 2 m high, we advise putting the Kestrel nest boxes on poles, so they reach the desired height. Nest boxes should be maintained periodically, and nesting material should be provided as well, since Kestrels bring no nesting material. Best nesting materials include sawdust, wood shavings, leaves or straw (Service, 1998). The expectation is that one Kestrel box should suffice, since Kestrels defend their territory directly around their nest (RSPB, 2000b). In contrast to Kestrels, European robins (*Erithacus rubecula*) nest close to the ground in open nest boxes. Therefore, nest boxes should be placed about a meter high with a completely open front. It is important to place it in a location, that is rich in undergrowth, and which is not easily accessible to predators (Wildlife, 2013). European robin has a diet that comprises of seeds and invertebrates among others, therefore by creating a habitat that is rich in those can increase the chance of getting robins in the solar park. Providing them nesting places would also encourage them to stay and breed in the solar park.

We advise the relocation of the bird boxes from the western fence of the Solar Park, and the ones attached to the inverters. None of them contain any trace of bird activity, which might be because of anthropogenic induced noise from the road located on the other side of the fence or the inverters they are attached to, additionally they are exposed to sunlight all day long (Blickley & Patricelli, 2010). Road proximity can increase stress in birds, and it can play a role in masking/distorting calls of mates, which can lead to avoidance of roads, in this case nesting further away from them (Foppen, 1994).

Since there are no nest boxes on the northern section of the southeast fence (Figure 14) we advise considering deploying some of them. The area shows potential, due to the distance from the road, the bushes alongside the fence and the proximity of trees. The tree line alongside the northern fence can provide shelter and food source for birds and can be utilized as a stepping stone, when moving across the landscape (C. M. Silva et al., 2020). Moreover, it is argued that trees can reduce negative effects of urbanization on birds (Pena et al., 2017). Unfortunately, when the bird boxes are place on the north side, the entrances will be south-faced, possibly increasing the chances of overheating as well as being more susceptible to wind (University, 2018). To tackle this risk, climbing plants could be planted near the nest boxes to offer shadow and protection against weather. Another option could be to place the bird boxes on the outer side of the fence instead of the inner side.

Moreover, it is advised to carry out yearly maintenance regarding the nests. Each year, during autumn nest boxes should be opened, cleaned from feathers and nest remains and finally wood shavings should be placed in the Kestrel nest boxes (Services, n.d.). Nonetheless, the focus should shift towards creating natural shelters throughout the park, rather than focusing too much on improving and adding bird boxes.

8.2.2. Food supply

Increasing and diversifying vegetation will increase bird food supply in the park. The birds will be able to feed on the seeds and fruits of the plants, but also on the insects that are attracted by flowers. However, the food supply should be year-round. Vogelwerkgroep Zutphen and Sunvest agreed that the area of Solar Park Revelhorst should be mowed once a year after winter, preferably early March, as mentioned above. Hereby, the grasses are kept long in the winter, supplying the birds with a hard-needed source of seeds. In addition, it is important to restrict mowing after the wintering period and before and in the breeding season, because this can ensure the least amount of disturbance to birds. Also, if sheep are incorporated into the management plan, they should only graze the park for a limited period only to limit the disturbance on bird shelters and food supply. It is beneficial for birds that seedy plants (e.g., Thistles) remain abundant in the Solar Park, which then can provide continuous food source for granivorous birds. Finches, such as the Goldfinch (*Carduelis carduelis*) feed on seeds and buds, mainly thistles and teasels. Therefore, they could potentially utilize seedy plants in the Solar Park, alongside with House sparrows (*Passer domesticus*) (Derhé, 2022). Moreover, Sparrows feed their chicks with insects, which means that the Solar Park could also provide them with resources during the spring months (Trust, 2022).

8.3. Conclusion birds

Most importantly, the area in and around the park should be changed to fit a habitat suited for birds. Trees, hedges, shrubs, and tall grasses offer shelter against predators and extreme weather conditions, while also increasing the food availability by increasing seeds, fruits and insects present. Once shelter options and food resources are increased, the area will become more attractive to birds, thereby increasing the chance of birds willing to nest in the park. Then, some adjustments can be made to the bird boxes, namely using different bird boxes specific for each bird species and keeping the desired nesting height into account.

9. Communication

9.1. Current concerns

One concern the stakeholders of the Vogelwerkgroep and the bumblebee Werkgroep have mentioned is the lack of communication between the management of Solar Park Revelhorst and them as conservation groups. According to them, there has been little to no initiative for meetings and information sharing. They both showed interest in helping with measurements and improvements on biodiversity in the solar park, however, Zutphen Energy and Sunvest were unresponsive to this.

Both Zutphen Energy and the Vogelwerkgroep Zutphen have mentioned tension between them. Therefore, we suggest a mediator, should the situation not improve after the publication of this report and the following meetings. They would intervene and help with communication to achieve a better understanding of the signed agreement for both parties. This should make the intentions of both parties clearer and allow them to discuss the way forward.

9.2. Recommended meetings

Each stakeholder has mentioned that they would appreciate more consistent communication with not only Zutphen Energy but also each other. As all werkgroepen expressed the intent of increasing biodiversity in Solar Park Revelhorst, it makes sense for them to negotiate and collaborate. Therefore, this project suggests that the stakeholders have at least one stakeholder meeting annually. These meetings could take place in February, just before spring, to talk about the plans for the area. These plans should entail introducing new species, measurement days, building new structures, etc. Doing this collaboratively would be a sign of good faith for all parties involved and clarify what the plans are and ways to improve the communication.

It would also be interesting for the different parties involved to share the monitoring results at the end of the nesting and flowering season around September. Thus, this project recommends another meeting to check the results and allow parties to decide on goals and possibilities for the following year. In this way, there is a better understanding of what is happening and what can be done next.

9.3. Rules

Besides the agreement already made between Sunvest and the Vogelwerkgroep Zutphen, it is also beneficial to place ground rules for the other volunteers on, such as:

- how they can work.
- when they can work.
- what they can expect from Sunvest and Zutphen Energy.
- what Sunvest and Zutphen Energy can expect from them.
- what the long-term goal is.

In case of an unproductive meeting or stakeholder preferences decidedly irreconcilable, it is recommended to include a mediator to ensure that all parties express themselves as equals and are all satisfied with the result.

10. Management plan

10.1. Abiotic conditions

To lower the nutrient level, clippings should be removed when the solar park is mowed, which costs on average about 1300 euros per hectare. Additionally, long-term monitoring (e.g., biyearly) of soil conditions (pH and phosphorous concentration are among the most important indicators) is needed for an insight into soil health and potential metal leaching from PV panels.

10.2. Grazing vs mowing

10.2.1. Mowing

It is recommended that mowing should happen once a year before the breeding season at the beginning of the spring and between the 15th of March and 15th of April. It is not recommended to mow after the growing season, since it will destroy flowering plants which will cause that there will be no food for insects and birds. The removal of clippings is also essential for the first few years.

10.2.2. Grazing

Understanding that sheep grazing generates a small income in the form of subsidies, this project advises on how to incorporate it into the solar park maintenance plan. However, mowing and removing is still the preferred option for the coming years.

It is not recommended to have the whole area grazed at once, and it is preferred that sheep grazing be in different areas of the solar park over time. The solar park needs to be partitioned into sections, where sheep are moved from one to the next. After some time (depending on the number of sheep and surface area), the vegetation will be eaten short by sheep, and then they can be transported to another section to allow the grazed vegetation to recover. The grazing pressure should not be too high. The recommended time for introducing sheep into the park is (after the mowing) in March.

10.3. Vegetation

10.3.1. Fence improvement

We suggest the introduction of the following plant species: *Ligustrum vulgare*, in Dutch 'Wilde liguster,' or the *Prunus spinosa*, in Dutch 'Sleedoorn' for the area along the fence, and climbing plants such as *Lonicera periclymenum*, in Dutch 'Wilde kamperfoelie,' or also the *Prunus spinosa*, in Dutch 'Sleedoorn.' It is important to note that climbing plants should mainly grow on the outer face of the fence as to not interfere with the infrared fence on the inside. The liguster can be planted during the entire year as long as the ground isn't frozen, and the recommended time is between October and April (Hans, 2018). The 'Wilde kamperfoelie' can also be planted year-round if the ground isn't frozen (Evergreen, 2015). The 'Sleedoorn' needs to be planted in spring (Ecopedia, 2022).

10.3.2. Clipping

Clipping is an important part of the plant growth, but it is recommended to not clip the hedges during the first year of placement for their development (Altrad Fort, 2020).

The liguster can grow fast and should be clipped twice a year. The recommended time is from May to September (Marechal, 2022). However, when combined with the bird nesting season, it is preferrable to do clipping during early may and late September to decrease the disturbance. The 'Wilde kamperfoelie' can be clipped in March (Evergreen, 2015). The 'Sleedoorn' does not require much clipping, but occasionally it should be clipped for a healthy hedge. When it does require clipping, it's also recommended between April and September (Pari-daeza, 2013).

10.3.3. Field improvement

For the field it is suggested to use native flowers as those have a higher chance of attracting wild bees and other pollinators. It is thereby recommended not to use one year / two-year plants as these plants can easily be outcompeted by grasses, so therefore it is recommended to use perennials.

Knautia arvensis, in Dutch 'Beemdkroon,' is a native flowering plant which is on the red list, and attracts a lot of insects, mainly the 'knautiabij' which is a mining bee. The plant dies in winter but grows again in spring. In June the plant blooms, but it is recommended to remove the old plant in spring. So, either mow or graze around May.

Additionally, Achillea millefolium, in Dutch 'Duizendblad,' is a flowering plant which creates a lot of seeds and is often seen as a weedy plant. As per the last species, it is recommended to mow or graze around may to help with the resprouting.

Furthermore, it is recommended to enrich the vegetation diversity using green-hay transfer. It is also recommended to increase the number of flowering plants underneath the panels.

10.3.4. Vegetation improvement

It is advisable to decrease the quantity of grasses present in the solar park by mowing, as mentioned in the previous chapters, and by introducing new species, which grow at the same rate as, or faster than, the grass. The area underneath the panels can be an important place to increase flowering plants that like the shade.

10.4. Insects

To increase the target (wild bees and butterfly) species, the density of flowers must be increased (Scriven et al., 2013). The method is discussed in the section above (Vegetation).

Furthermore, it is recommended to increase shade-tolerant flowering species underneath the panels to stimulate the pollinator numbers.

To provide bees with a nesting place, it is suggested to have bare ground where there is no vegetation to give them space to live underground. It is also possible to create a sandhill by mixing yellow street sand with loam sand. One can also place dead old wood in the sun, as bees love sitting in the sunshine, to create a place where they can nest.

Lastly, insect hotels, another potential nesting place for different insect species, can be placed on the fence. It needs to be placed in sunny places in the vicinity of flowering plants.

10.5. Mammals

The addition of trees on the premises would be of real benefit for mammal count. The northern side of the park is recommended for the integration of trees. Following the idea of vegetation gradient, the integration of shrubs and bushes is an additional option (Jacques, 2017). The inner borders of the field are recommended as location for such vegetation.

Moreover, the implementation of varied ground cover types is suggested. Several small rock piles were noted next to the pound, adding more rocks to those or other part of the field is recommended. Furthermore, the presence of dead trees next to the pond was also annotated, although adding more of them with dead branches across the PV farm is suggested.

Following the idea of seed dispersal and accessibility, it is suggested to ease animal access to the park. To do so and not jeopardise the park security, the following feature should be added to the fence. The idea is to spread them uniformly across the fence and in a maximum number.

Additionally, bat boxes could be added to the field, although they need to be placed at least 4m above ground to prevent predation from cats.

Finally, the active search for direct and indirect traces of animals (trails, faeces, burrows, carcasses) is needed to assess change in the biodiverse. The presence of the different mammals can be monitored using camera traps (see Chapter 2 for method) or tracking methods. This assessment should be done yearly between late spring and early summer following Hoffmann et al. (2010).

10.6. Bird

10.6.1. Food and habitat

As it is mentioned in the agreement between Vogelwerkgroep Zutphen and Sunvest, the area of Solar Park Revelhorst should be mowed once a year after winter, preferably in March, as mentioned above in the mowing part. It is important to restrict mowing after the wintering period and before breeding season as well as in the rest of growing season since the food for insects and birds should be secured. Furthermore, by adding hedges for their berries, promoting plants with seeds, and creating optimal conditions for insects, the food supply for birds will be secured. The hedges will also contribute to providing shelter for birds.

10.6.2. Nest boxes

European starlings (*Sturnus vulgaris*) need large nest boxes, with an entrance hole of at least 45mm diameter. The bird box can be placed anywhere between 3 and 18 meters above ground and facing north to avoid overheating or getting too wet (The Cornell Lab, 2019).

For kestrels, it is advised to place the nest boxes in open fields or along fences. The nest box should be between 3m and 30m above ground, facing south or east. Since in Solar Park Revelhorst the fence is about 2m high, we advise putting the kestrel nest boxes on poles, so they reach the necessary height.

Nest boxes should be maintained periodically, and nesting materials provided as well, since kestrels bring no nesting material. Good nesting materials include sawdust, wood shavings, leaves or straw.

It is important that starlings can outcompete kestrels by occupying the nest boxes installed for them, so checking signs of starling activity and the removal of brought-in material should be done to encourage kestrel nesting and discourage starling occupancy (Service, 1998).

Placing different types of nest boxes can be a way of attracting other types of birds to the solar park. For instance, European robins (*Erithacus rubecula*) nest boxes should be placed about a meter high with a completely open front. It is important to place it in a location, that is rich in undergrowth, and which is not easily accessible to predators (Wildlife, 2013).

Since there are no nest boxes on the northern section of the eastern fence (Figure 14), we advise considering deploying some of them along the area. Also, the area under the PV panels could be explored for the integration of bird box, as they provide shelter.

Furthermore, it is advised to maintain the nests yearly. During autumn nest boxes should be opened, nest remains cleaned and wood shavings placed in them.

10.7. Communication

This project suggests that the stakeholders have at least one stakeholder meeting annually. These meetings could take place in February, just before spring, to talk about the plans for the area. These plans should entail introducing new species, measurement days, building new structures, etc.

It would also be interesting for the different parties involved to share the monitoring results at the end of the nesting and blooming season around September. Thus, this project recommends another meeting to check the results and allow parties to decide on goals and possibilities for the following year. In this way, there is a better understanding of what is happening and what can be done next.

Besides the agreement already made between Sunvest and the Vogelwerkgroep Zutphen, it is also beneficial to place ground rules for the other volunteers on, such as:

- how they can work.
- when they can work.
- what they can expect from Sunvest and Zutphen Energy.
- what Sunvest and Zutphen Energy can expect from them.
- what the long-term goal is.

In case of an unproductive meeting or stakeholder preferences decidedly irreconcilable, it is recommended to include a mediator to ensure that all parties express themselves as equals and are all satisfied with the result.

10.8. Gradients

Not only a diverse vegetation, but also a gradient in the vegetation can be beneficial for biodiversity. This gradient can be achieved by sowing different plants at different places in the park or by sheep grazing in different areas over time. With this, the vegetation height will differ along the park, attracting different insect and bird species and therefore increasing overall biodiversity.

Another gradient that can be implemented to create a biodiverse solar park is to have some gradients in the height of the soil. This can be achieved my making some small hills in the park, for example near the pond. These hills do not have to be large, since just a small elevation already creates some gradients in environmental gradients, like slop, soil moisture and ground water depth. By doing this, a higher plant species richness can be obtained, since environmental gradients in a semi-natural grassland have a positive effect on the plant species richness (Raduła, Szymura, Szymura, Swacha, & Kącki, 2020). An environmental gradient that is already present in the solar park is the pond. With the creating and maintaining of vegetation on the shores of the pond, a diverse vegetation can be achieved since different plants can settle on this place.

10.9. Visual summary

11. Conclusion

This report attempts to present a comprehensive overview of the current biodiversity status of vegetation, insects, birds, and mammals in Solar Park Revelhorst and to provide advice on soil quality, maintenance, and future management actions to improve biodiversity where it is oftentimes neglected.

11.1. Main findings

Formerly, the area where the solar park stands now was used for agricultural purposes (growing grass and maize in two separate areas of the land), leading to a nutrient-rich soil profile. If our goal is for the ecosystem of Solar Park Revelhorst to resemble that of a semi-natural grassland, then the current soil properties, such as a relatively low pH and an exceedingly high phosphorous (and nitrogen but to a smaller degree) concentration, are unfavourable for the transition and biodiversity purposes. It is no coincidence that plant diversity in the park is limited: with a count of 83 species over the 8 hectares of the park, instead of 80 species per 0.1 hectare for as mentioned in (Faber-Langendoen, 2010). The current vegetation not only lacks in abundance, but also is troubled by an uneven distribution in species caused by soil enrichment and therefore dominance of selective plants, mostly grasses. Based on those conditions, recommendations on vegetation choices, the use of hedges, etc. are provided to attempt to recreate a typical Dutch plant landscape in Solar Park Revelhorst and increase plant diversity. While there remains much to be desired with plants, the current insect diversity in fact is quite satisfactory following Shannon index, totalling 77 and 97 species of insects caught in pitfall traps and pan traps respectively and a Shannon index between 3-4 for both. By improving the vegetation composition and creating resources and habitats (e.g., flowering plants) for insects, this project aims at attracting more wild bees and butterflies in the solar park. As for mammals, the current suboptimal richness can be improved by increasing vegetation and physical structures, passages, etc. favourable to mammals. Lastly, given practical constraints of seasons, only an observation regarding the occupancy of already set up bird boxes was done. A visual/video survey of bird biodiversity was not conducted in this project. Although, suggestions on how to optimise the conditions for birds in the park has been provided in chapter 8, the focus was made on supplying habitat and food. In summary, the biodiversity is far from what a natural grassland has to offer and therefore there is great room for improvement (Faber-Langendoen, 2010).

In addition, improving biodiversity in the solar park is also a social problem, as it involves a multitude of local stakeholders with different goals and values. One of the most noteworthy divides among stakeholders is that nature conservation groups and the managers of the park continue to be troubled by their history of unmet expectations and poor communication. Recommending ongoing, transparent communication with formal rules and a potential mediator, we have addressed the stakeholder issues and offered transdisciplinary recommendations on how to enhance biodiversity in the solar park and generally in the built environment.

11.2. Limitations

Like any scientific research, this project has its own limitations. For one, studying the setting of the solar park is only emerging in recent years and literature particular to this environment is limited, so that sound judgement is needed before deciding on which interventions to apply from literature research on, for example, soil toxicity and grazing versus mowing. Additionally, the methodology of biodiversity surveys also has flaws. First, in some locations, camera traps might have been installed at a position too high from the ground to avoid the disturbance from tall grasses in front, but that introduces a bias of overlooking smaller, shorter mammals. Second, data loss is another source of reduced validity. Some insects collected were blown away by the wind once, and some camera traps had long reached their storage capacity by the time we replaced their SD cards, meaning that some meaningful photo captures might have been missed. Further, biodiversity surveys were done over the course of a few weeks, and thus might not fully represent the biodiversity over the whole season, particularly for insects. Nevertheless, these flaws should not impact the overall quality of the advice.

After all, while the advice is largely site-specific, this project is general enough for the insights to be applicable to other solar parks in the Netherlands and those in a similar, temperate climate. As an increasing number of solar parks start to harvest solar power and take over the space for greenery and agriculture, it is urgent and inevitable that we consider multi-functional land use and sustainable transitions in an age of diminishing land availabilities. Perhaps one day, Solar Park Revelhorst will truly become an exemplary site where all of community engagement, energy generation, and biodiversity can flourish in a semi-natural grassland landscape as we envisioned. Under the sun hopes and opportunities abound.

11.3. Revisiting research questions

SQ1: What is the current biodiversity, soil quality, and maintenance regime at Revelhorst solar park?

The biodiversity of vegetation is very low compared to the recommended species richness. It is desired to have 80 different species per 0.1 hectare. In the solar park there were 83 species spread across 8 hectares (Faber-Langendoen, 2010).

To measure biodiversity for insects, the Shannon biodiversity index was used. The results were 3.17 for pitfall traps and 3.67 for pan traps (Table 4). However, all the species were considered together, so when looking per category the index might be lower within this order.

For the soil quality, the nutrient levels are too high to have a healthy soil.

Lastly, the maintenance regime currently is focused on mowing and bird boxes. The mowing is currently done twice a year, but using sheep is desired by the management and are planned to be placed in the park soon. The bird boxes should be cleaned out and monitored once a year by the Zutphen Vogelwerkgroep.

SQ2: What are the possible toxic effects of the construction material and panels leaching into the soil?

Literature found mostly nickel (Ni), zinc (Zn), and copper (Cu) as they were consistently released at the highest concentration in soil, acting as potential sources of toxic effects in plants. The soil analysis revealed that mainly zinc was in the soil in large amounts.

The report took a different approach to answering this question as more emphasis was devoted to the effect of solar park on soil quality and toxicity in Chapter 3 and Chapter 11.1. Little time was spent on this question describing toxic effects as they turned out to be less relevant for our goals.

SQ3: What are the species desired by the different stakeholders and which management options for the selected species improve the overall biodiversity?

The stakeholders currently don’t have a desired species. Both the Vogelwerkgroep and the bee group wanted to see a better condition in general for both the insects and the birds. The bee group did mention they would prefer to see more wild bees, which are attracted by flowering plants, hedges, and nesting places. The birds will be more attracted to the area if there are more high seed plants in winter and nesting places. The nesting places include birdboxes but mostly hedges, trees etc.

SQ4: What is a desirable approach to monitor biodiversity in the future? Who would be responsible for managing the different monitoring practices performed by the volunteers?

The most desired approach is volunteers helping to monitor the biodiversity in cooperation with the various groups. For this to work there is a need for consistent meetings during the year. During a meeting in February the volunteers will discuss what they plan to do during this spring and summer. This meeting could be about which plants to introduce, building nest boxes, maintaining the solar park overall, which measurements to take, and more.

The second meeting should be in September at the end of the summer. As then it's easier to recollect what was done, what needs to be done next year and how to improve. This makes it easier to plan for the nextE biodiversity. This would also mean that the 'heads' of the various groups need to stay in touch with each other and increase the communication between the groups.

SQ5: How can the municipality, local nature workgroups, and residents be involved in the solar park?

The involvement of the municipality is not completely discussed in this report. However, Municipality Zutphen can follow the example of Municipality Bronckhorst, since they have been involved in creating a biodiverse solar park, the Kwekerij. Local nature work groups can be involved by yearly monitoring processes of the park and by communicating actively and openly with Sunvest and Zutphen Energy. It is important that the municipality and stakeholders work together in creating solutions of how to involve residents regarding Solar Park Revelhorst.

Main research question

What management is required to increase the long-term biodiversity in Revelhorst solar park in cooperation with the local stakeholders?

See the management plan (Chapter 10) for a complete overview of the management that is required for long-term biodiversity in Revelhorst solar park.

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13. Appendix

Appendix A: Stakeholder analysis

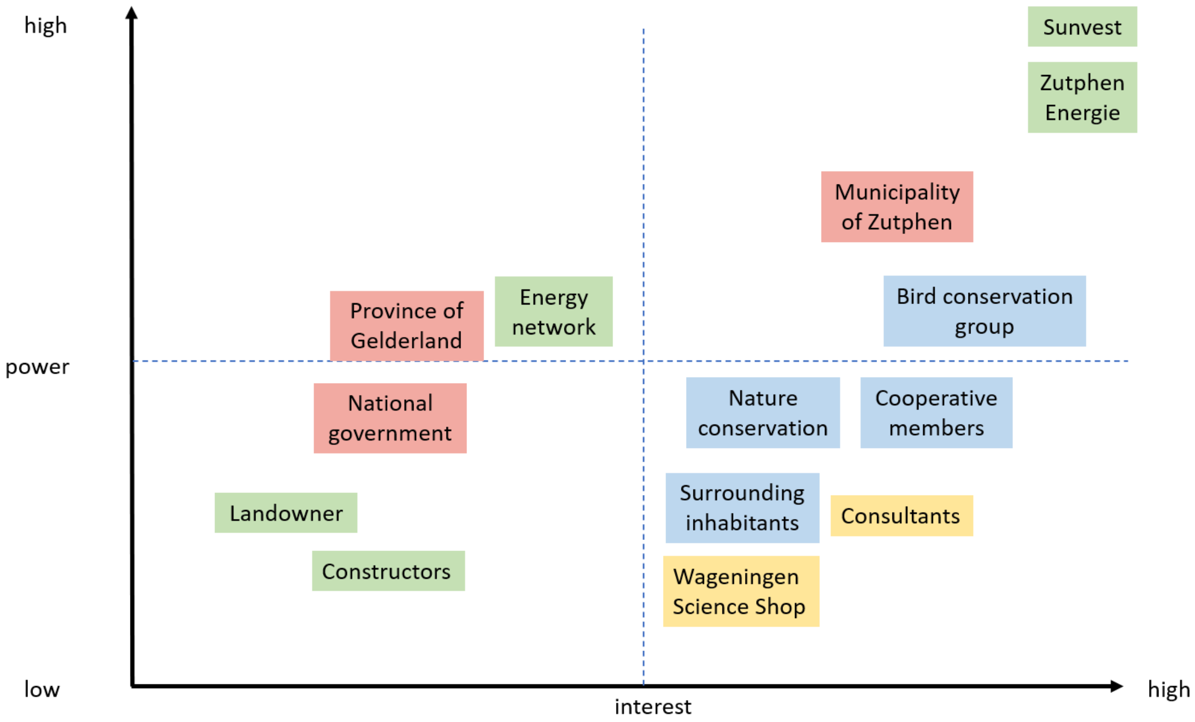

Figure 15 Power-interest matrix for stakeholders involved in solar park Revelhorst, Zutphen (Colours indicate stakeholder categories. Red: public actors; Green: private actors; yellow: academia; blue: civil society).

Zutphen Energy, the local energy cooperative in Zutphen, is devoted to energy transition and providing renewable electricity to consumers in Zutphen. It receives financial assistance in the form of loans from the Municipality of Zutphen, as their goals in regional energy strategy, locating favourable hotspots suitable for renewables, and developing clean energy are closely aligned (Van der Zee, 2022). Thanks to this partnership, it now has the capacity to co-manage the solar park with Sunvest with a smaller share of 20% of the total surface area and 4.000 out of the total 20.500 PV panels.

Because of the current lack of biodiversity in the park, Zutphen Energy aims to conduct a baseline assessment in the park so that the cooperative can implement monitoring and improvement strategies in the future. As a citizens' initiative, it lacked resources to fund its own research and therefore contacted Wageningen Science Shop for this research project, which later was delegated to consultants.

A significant part of the project as well as the other 80% of the land surface of solar park Revelhorst are managed by Sunvest, a solar park developer and operator with an ideal of social engagement and greening solar parks. Sunvest has been working closely with Zutphen Energy and the municipality since the construction of the park in 2020 and the park has been generating electricity to thousands of households by the end of that year.

In summary, WUR consultants worked closely with these two private stakeholders, which are among the most important ones given their interest (involvement) in the solar park Revelhorst since its initiation, both in the sense of the park being their property and social and environmental benefits it can generate. Zutphen Energy and Sunvest are also stakeholders with the most power over this area and this project, as they commissioned Wageningen Science shop to carry out research in the way that is mutually beneficial but also furthers their interests (Figure 15).

While, as mentioned above, public (e.g., government at all administrative levels) and private stakeholders share the common goal of providing clean energy generation at a low cost to consumers through solar parks, some other conservation-oriented stakeholders might not be as pleased with the development of solar park Revelhorst. The Vogelwerkgroep Zutphen initially protested against it and remains critical of its management, for example, on the mowing frequency (Van der Zee, 2022) as it disturbs nesting meadow birds. It also is a strong proponent for the conservation of geese in the area. Therefore, this project recognizes the importance of holding stakeholder co-creation meetings to manage expectations and goals and to avoid potential clashing conflicts. Following the same logic, the group is assigned high interest and medium power in this assessment.

Appendix B: Coordinates measurements

Table 5 camera trap locations & key numbers

name	latitude	longitude	latitude/longitude combined
Chris	52.12263	6.230382	52.122634, 6.230382
Alicia	52.12262	6.229677	52.122624, 6.229677
Karen	52.12246	6.228903	52.122458, 6.228903
Matt	52.12194	6.228751	52.121942, 6.228751
Bob	52.12145	6.228742	52.121446, 6.228742
Greta	52.12158	6.230849	52.12158, 6.230849
Hector	52.12149	6.229742	52.121487, 6.229742
Loic	52.12206	6.230789	52.122056, 6.230789
Jeroen	52.12236	6.230198	52.122363, 6.230198
Ian	52.1218	6.229493	52.121795, 6.229493

Table 6 corner points

Corner point	Decimal Degrees
A	52.122639, 6.230611
B	52.121389, 6.22875
C	52.121444, 6.229806
D	52.121556, 6.230889
E	52.121639, 6.232194
F	52.120444, 6.230056

Table 7 pan traps locations

Trap nr.	Latitude	Longitude	Latitude / longitude combined
1	52.12033	6.22888	52.12033, 6.22888
2	52.12072	6.23051	52.12072, 6.23051
3	52.12252	6.22931	52.12252, 6.22931

Table 8 pitfall traps locations

Trap nr.	Latitude	Longitude	Latitude / longitude combined
1	52.12040	6.22795	52.12040, 6.22795
2	52.12086	6.22862	52.12086, 6.22862
3	52.12070	6.22814	52.12070, 6.22814
4	52.12263	6.23086	52.12263, 6.23086

Appendix C: Bird box data table

Table 9 overview of bird boxes in Solar Park Revelhorst

Birdbox number	latitude	longitude	Size	Location	Information
1	52,120101	6,227788	small	Fence southwest	Some green moss
2	52,119993	6,228061	small	Fence southwest	Some green moss
3	52,119909	6,228277	small	Fence southwest	Some green moss
4	52,119834	6,228436	small	Fence southwest	More green moss
5	52,119742	6,228648	small	Fence southwest	More green moss
6	52,119849	6,22901	small	Fence southeast	Bird poo + feathers
7	52,120011	6,229329	big	Fence southeast	Nothing
8	52,120175	6,229661	small	Fence southeast	Bird poo + feathers
9	52,120365	6,23008	big	Fence southeast	Nothing
10	52,120555	6,230459	small	Fence southeast	Feathers + straw
11	52,120761	6,230806	big	Fence southeast	Nothing
12	52,120945	6,231173	small	Fence southeast	Bird nesting (Eurasian Blue tit)
13	52,121127	6,231551	big	Fence southeast	Bird poo + feathers
14	52,121315	6,231876	small	Fence southeast	Bird poo + feathers
15	52,121502	6,232178	big	Fence southeast	Bird nesting (Eurasian Blue tit)
16	52,122099	6,228888	small	Inverter west row 8	Nothing
17	52,12192	6,228715	big	Fence west	Some straw
18	52,121722	6,228861	small	Inverter west row 15	Nothing
19	52,121508	6,228751	big	Fence west	Nothing
20	52,121287	6,228708	small	Inverter west row 23	Nothing
21	52,121182	6,228493	big	Fence west	Nothing
22	52,121004	6,228422	small	Inverter west row 28	Nothing
23	52,120802	6,228081	big	Fence west	Nothing
24	52,1206	6,227969	small	Inverter west row 35	Nothing
25	52,120452	6,227687	big	Fence west	Nothing

Appendix D: Full vegetation & insect lists

The entire list of plant species found in and around solar park Revelhorst can be found as an attached Excel file. For extra overview, the column 'overall commonness' was added, which is based on species occurrence in plots. A commonness of '1' means the species was only found in 1 plot, a '2' means the species occurred in 2-5 plots, '3' in 6-10 plots, '4' in 11-15, '5' in 16-20, and '6' in 21 to all plots.

The full insect list of both the pan traps and pitfall traps can also be found as an attached Excel file.