The effects of solar parks on plants and pollinators: the case of Shell Moerdijk

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Large picture: Solar park Moerdijk (Photo: Laura Vriend)
Input left, middle and right: Local and sown plant species and bumblebee pollinators (Photo’s: Laura Vriend)

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Summary

In order to meet the energy transition and climate agreement goals, many areas in the Netherlands are being targeted or have already been converted into solar parks, including circa 39 hectares of the Moerdijk industrial estate. With 76.000 panels, the solar park has a peak capacity of 27 megawatts, equivalent to the energy consumption of 9.000 Dutch households. The generated solar energy will be used to help power operations at Shell Moerdijk. Realizing the contemporary urgency to investigate the impact of solar parks on (insect) biodiversity, in particular pollinators, Shell made a coalition with Smartland landscape architects and Naturalis Biodiversity Center. The main findings and conclusions are shown below:

- In this study, the suitability of solar parks on pollinator and plant diversity was studied by means of plant seed mixtures and vegetation and pollinator surveys during several monitoring rounds between April and August 2019.
- Five seed mixes were used and a control plot, which were duplicated over seven clusters. The seed mixtures included *Diverse Grasses*, *Green Manure*, *Eco Sun*, *Eco Shade* and *Industrial*, wherein each mixture contained six species.
- Pollinators were collected using pan traps in the sun (between the panels) and shadow (under the panels) and surveys, and plant species were identified in all plots by means of surveys.

- A high number of pollinators have been found, namely **17 hoverfly species** and **37 bee species** with a total of **54 pollinator species**. These include 5 threatened bee species: *Hoplitis tridentata*, *Lasioglossum brevicorne*, *Osmia aurulenta*, *Osmia caerulescens* and *Panurgus banksianus*. In total 431 individual pollinators were collected.
- **103 flowering plant species** were found, of which 22 out of 30 were seed mix species.
- In addition, many bird species frequent the solar park, including skylark (veldleeuwerik) and northern wheatear (tapuit).
- Significantly **more pollinators were found in the sun than in the shade**. As pollinators need solar energy to increase their body temperature, they seek a sunny environment to reduce energy loss.
- The **pollinators were significantly more attracted to the yellow pan traps**, then the blue and white ones, respectively. This trend was visible in both the sun and shade.
- The **seed mixtures did not have a significant effect on the pollinator abundance**. This may be due to the fact that the seed mixture plant species had a late start and in their first year made up only a small portion of the total vegetation.
- It was **not possible this year to determine which seed mixture was best in terms of pollinators and maintenance** due to the late sowing and low proportion of the seed mixture plants and consequent minimum maintenance. With the expected timely germination and competition of the mixture seeds next season, it is recommended to continue this research and include different mowing regimes to answer this question.
- The **seed mixtures did not have a significant effect on the average plant coverage**, **average plant height and number of plant species**.
- The **average plant coverage, average plant height and number of plant species did not differ significantly between the sun and shadow.**

- In conclusion, this research has shown that **solar parks can indeed be a suitable habitat for pollinators.** We found more species of bees than can be found normally in agricultural or industrial areas and good numbers of hoverfly species as well. **The design and maintenance of the Moerdijk solar park seems to fulfil several requirements that together provide beneficial conditions for pollinators, including:**

- Space in between the solar panels with sufficient solar radiation on the ground throughout the day.
- A diversity of flowering plants for foraging throughout the flying season of the pollinators (March – September).
- Extensive, periodic maintenance.
- Nesting opportunity (artificial structures, such as logs).
- Sufficient moisture for plants to grow.

Future outlook

Considering that this monitoring study has only been done one year and on one location, it is recommended to continue monitoring the following year(s) in order to investigate long-term effects of the solar park on pollinator and plant diversity. Furthermore, it would be interesting to include other solar parks in the study, which differ in terms of soil and background biodiversity (for instance agricultural areas) and/or design (orientation, angle). This will increase the knowledge on the effects of solar park design and background on biodiversity.

1. Introduction

1.2 Background to the project

Early 2019, Shell constructed a solar panel park of circa 39 hectares at its industrial estate in Moerdijk. With 76.000 panels, the solar park has a peak capacity of 27 megawatts, equivalent to the energy consumption of 9.000 Dutch households. The generated solar energy will be used to help power operations at Shell Moerdijk. The target location was an unused area for the last 20 years at the back of the Moerdijk industrial site and had turned into a biodiverse landscape, with even red-list species seeking refuge. At the same time, the energy transition goals are urging society towards alternative energy sources, with a focus on solar panels. Many areas in the Netherlands are being targeted for this purpose or have already been converted to solar parks, including part of the Moerdijk industrial estate. Taking into consideration the current biodiversity crisis with insect (pollinator) reduction in particular, it is imperative to investigate the effects of the solar panels on biodiversity.

Realizing this contemporary urgency to investigate the impact of the solar panel park on biodiversity, Shell made a coalition with Smartland landscape architects and Naturalis Biodiversity Center. As solar parks will be appearing more often to meet the energy transition goals, Naturalis was keen to join the team and investigate the impacts and measures to improve biodiversity.
In England and Germany, several studies have been conducted on the effects of solar parks on biodiversity (Ref. 1-8). These studies were devoted to reducing negative ecological impacts and improving biodiversity. Although not yet fully acknowledged, it appears that solar parks may even be an opportunity instead of a threat for biodiversity, including insects. Several examples and options have been provided in previous studies to improve biodiversity. In summary, the choice of location, measures such as bare strips and artificial structures, seed mixes and maintenance are all very location-dependent and need to be carefully considered based on ecology and landscape. This means that for each solar park design, the ecological situation and landscape need to be taken into account to develop a specific package of measures, one that is currently missing for the solar park at Moerdijk. Providing the knowledge needed to promote biodiversity for all land owners and land uses fits well within the goals of the 'Deltaplan Biodiversiteitsherstel' (Ref. 9), of which Naturalis is a strong representative. This study is also compatible with and may provide knowledge for implementation of the behavioural code 'Zon op Land', recently published by a broad coalition including the energy sector, nature and environmental organizations (Ref. 10).

Although the solar park at Moerdijk was developed prior to our study, the biodiversity, seed mixes and maintenance could still be investigated. Given the recent attention to pollinators and plants, this research will be especially focused on those groups of organisms.
The shadowy circumstances under the solar panels, in combination with the absence of fertilizers and chemical pesticides, a possibly higher groundwater level and extensive maintenance, may provide the right circumstances for some and a challenge for other biodiversity. Moreover, little is known about establishment and maintenance requirements. Similarly, the effects of adding environmental structures for living, foraging, nesting and hibernation for insects, such as rows of bare soil by means of dry ground walls or dead wood under the panels, is not well known. However, the latter is out of the scope of this study. The main goal is to improve the knowledge about the flower and insect communities (species, abundance, diversity) that can thrive in and around the solar panels on the solar park and to assess how installation and management of solar parks is linked to biodiversity.

2. Objective and aims

At the Moerdijk site a large solar park of circa 39 hectares has been realized with circa 75.000 panels, which provides the possibility to conduct biodiversity research based on the approach of the English and German studies (Ref. 1-8). This entails the use of a variety of seed mixes and to monitor the effects on pollinator biodiversity, in line with the technical setup of the panels in terms of height and row distances. The primary goal of this research is to investigate how the development of solar parks in the landscape using a variety of seed mixes and specific maintenance can contribute to the improvement of biodiversity in terms of pollinators.

This research will result in conclusions and recommendations for solar parks in general and for Shell Moerdijk specifically, and focuses on the following topics:

- Can solar parks be a suitable habitat for pollinators and plants? If so, what conditions are important to improve and sustain their communities?
- Are there differences in vegetation and pollinator abundance between sun and shade areas?
- What is the effect of flower colour on pollinator abundance?
- What type and periodicity of maintenance benefits pollinator diversity?
- Which type of seed mixtures benefits pollinator diversity and is best in terms of minimum maintenance labour and costs?
- What are the basic required conditions in terms of solar park design to benefit biodiversity?

Naturalis Biodiversity Center and Smartland landscape architects have collaborated in this solar park biodiversity research at Shell Moerdijk, the results of which will be used effectively in future solar park designs.

Smartland landscape architects focused on the following tasks:

- Determine plant species of the seed mixes (sun and shadow mixes).
- Planning maps.
- Visualization concept.
- Communication poster and brochure.
- Participation in realization and monitoring.

The majority of the research has been carried out by Naturalis Biodiversity Center, the details of which, in terms of methods, analysis, results, conclusions and recommendations, are discussed in this report.

3 Methods

3.1 Study area

The Shell Moerdijk site is located in the southwest of the Netherlands, in the province of North-Brabant (figure 3.1). The terrain is surrounded by industrial areas and bordered by the Hollands Diep canal in the north. The study area is situated at the northwest corner of the industrial site, where Shell realized a solar park within the red border in the beginning of 2019, covering about 390.000m^2.

Figure 3.1: Study area (red border) at industry site Shell Moerdijk. Source: Google Maps.

For the last 20 years, the study area has been an abandoned landscape with zero to low maintenance. Despite the modest size, the area has different soil types leading to a variety of environmental conditions (Table 3.1). This gave room for a large diversity of plant and animal species to inhabit the area, even red-listed orchids and skylarks.

Table 3.1: Soil types

Block	*Rectangle color*	*Soil type*	*Vegetation*
A	Green	Wet organic/sandy soil	Thick: grass and herbs
B + C	Pink	Moist to dry sandy soil	Intermediate: grass, herbs and small trees
D top + E top + H	Blue	Moist dense clayish soil	Open: grass, moss and herbs
D bottom + E bottom	Gray	Gravel and dry sandy soil	Bare: grass and herbs
F + G	Yellow	Dry sandy soil	Open: grass and herbs

The study was set-up as a randomized block design. The area was divided into five blocks based on soil type, in which the clusters (A - G) were organized in such a way that they randomly contained each of the five seed mixes including a control plot with a total of six plots per cluster (figure 3.2). Cluster H was additional and has not been used in this research, leading to 42 plots in total (7 clusters times 6 plots). Each field plot covered an area of 20 x 20 m, containing three rows of panels and three open rows in between (Figure 3.3).

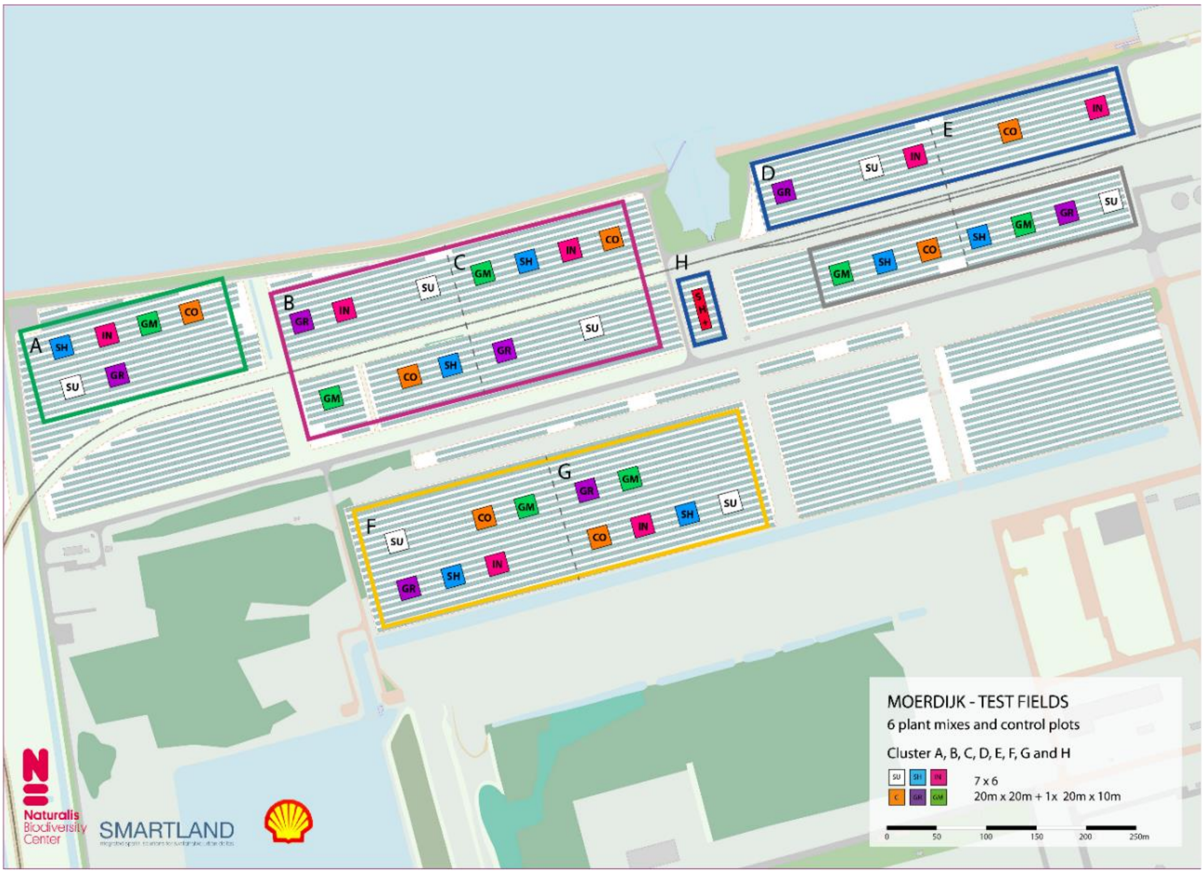


Figure 3.2: Schematic view of the solar park, including the segmentation based on soil type (coloured borders) and clusters A-H containing plots for the plant mixes (Source: Smartland landscape architects).

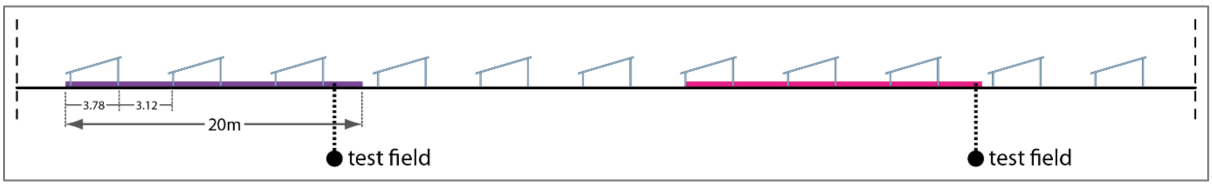


Figure 3.3: Schematic transection of the solar park, showing the plot sizes and placement in regard to the panels (Source: Smartland landscape architects).

3.2 Seed mixtures

In order to test suitable plant species for the special solar park environment that also benefit pollinators, six seed mixes were created and sown in March 2019. The mixtures were created using the online database of Dr. Arie Koster, an expert on Dutch wild bees and native plants, which indicates the attractiveness of plants for pollinators. In addition, the ‘Bijenplanten’ (bee plant) app of the NL Zoemt, which is based on this database, was used (Ref. 11). Further plant-bee interactions were investigated using websites for melliferous plants (Ref. 12) and wild bees (Ref. 13), complemented by wild bee observations in the surrounding area (Ref. 14) and a wild bee-plant interaction database of the European Invertebrate Survey (EIS) in the Netherlands.

Table 3.2: Seed mixtures and contents				
Mixture name	*Species (scientific)*	*Species (Dutch)*	*Sowing density (kg/ha)*	*Distribution in mixture (%)*
Diverse Grasses (GR)	*Agrostis capillaris*	Gewoon struisgras	75,0	15,6
	Cynosurus cristatus	Kamgras	35,0	8,5
	Festuca cinerea	Hardzwenkgras	75,0	15,6
	Festuca filiformis	Fijnbladig schapengras	40,0	7,5
	Festuca rubra	Roodzwenkgras	75,0	15,6
	Lolium perenne	Engels raaigras	25,0 – 40,0	37,2
				100
Green Manure (GM)	*Lotus corniculatus*	Gewone rolklaver	25,0	9,9
	Lupinus luteus	Gele lupine	100,0	59,6
	Ornithopus sativus	Seradelle	25,0	9,9
	Phacelia tanacetifolia	Phacelia	42,9	4,8
	Trifolium pratense	Rode klaver	25,0	9,9
	Trifolium repens	Witte klaver	15,0	5,9
				100
Eco Sun (SU)	*Achillea millefolium*	Gewoon duizendblad	18,2	27,6
	Campanula rotundifolia	Grasklokje	2,4	3,6
	Knautia arvensis	Beemdkroon	10,7	16,2
	Origanum vulgare	Wilde marjolein	5,9	9,0
	Reseda lutea	Wilde reseda	22,8	34,6
	Thymus pulegioides	Grote tijm	5,9	9,0
				100
Eco Shade (SH)	*Cynoglossum officinale*	Veldhondstong	31,5	47,8
	Geum urbanum	Geel nagelkruid	12,3	18,6
	Prunella vulgaris	Gewone brunel	8,6	13,1
	Silene dioica	Dagkoekoeksbloem	8,8	13,3
	Stachys sylvatica	Bosandoorn	4,1	6,2
	Veronica longifolia	Lange ereprijs	0,7	1,0
				100
Industrial (IN)	*Ammi majus*	Groot akkerscherm	5,7	4,8
	Borago officinalis	Bernagie	54,9	45,7
	Calendula arvensis	Akkergoudsbloem	18,5	15,4
	Carum carvi	Echte karwij	13,9	11,6
	Centaurea cyanus	Korenbloem	21,9	18,3
	Papaver rhoeas	Grote klaproos	5,1	4,2
				100
Eco Shade Plus	*Clinopodium vulgare*	Borstelkrans	1,5	1,2
	Cynoglossum officinale	Veldhondstong	55,4	42,1
	Geum urbanum	Geel nagelkruid	16,1	12,2
	Hieracium laevigatum	Stijf havikskruid	2,0	1,5
	Hieracium umbellatum	Schermhavikskruid	1,8	1,4
	Malva moschata	Muskuskaasjeskruid	9,5	7,0
	Prunella vulgaris	Gewone brunel	14,0	10,4
	Silene dioica	Dagkoekoeksbloem	17,0	12,8
	Stachys sylvatica	Bosandoorn	7,0	5,1
	Teucrium scorodonia	Valse salie	6,0	4,5
	Veronica longifolia	Lange ereprijs	1,5	1,2
	Veronica officinalis	Mannetjesereprijs	0,5	0,6
				100

The seed mixtures were selected based on the following requirements:
- Improve pollinator biodiversity (e.g. bees and hoverflies) in line with the functional requirements and maintenance of the park.
- Fit within a maximum height of 50-60 cm in order to reduce additional shade and enable air flow under the panels, thereby improving the yield efficiency of the panels.
- Minimize plant species with sticky pollen that can cover the panels and reduce yield efficiency.
- Usage of common seed mixes, but also develop seed mixes that fit shady as well as full sun environments.
- Maintenance focused on maximum biodiversity with the lowest possible costs and labour, for instance in terms of mowing frequency and flower periods.

The created seed mixtures were named *Diverse Grasses* (GR, purple), *Green Manure* (GM, green), *Eco Sun* (SU, white), *Eco Shade* (SH, blue) and *Industrial* (IN, pink). Their distribution in the study area is shown in Figure 3.2. Each mixture contained seeds of six different flowering melliferous plant species, except for Diverse Grasses, which contained seeds of six different grass species (Table 3.2).

The *Diverse Grasses* mix was created as many solar parks seem to have only grasses as undercover.
The *Green Manure* mix is abundantly applied in agricultural practice. It was created with species that enrich the soil and, therefore, make it more suitable as arable land after the solar panels are removed.
The *Eco Sun* and *Eco Shade* mixes are created with native plant species, which grow around the area of Moerdijk, which prefer sunlight (*Eco Sun*) or shade (*Eco Shade)*, are attractive for bees and grow well on sandy soil.
The *Industrial* mix reflects a standard mix with species known to be attractive for pollinators. Similar mixes are often applied in green infrastructure management.
Additionally, a sixth seed mixture, Eco Shade Plus, was created for a different purpose and was applied in sector H only. This mix is out of the scope of this research.

3.3 Monitoring

3.3.1 Scope

By pollinators we refer to flower-visiting insects, with a focus on bees and hoverflies, independent of them being involved in pollination. In terms of plants, we have registered all plants (angiosperms, i.e. flowering plants, thus excluding mosses and ferns) that were encountered during the monitoring rounds.

3.3.2 Frequency

In order to monitor spring as well as summer pollinators, monitoring was carried out at three intervals, namely at the end of April - beginning of May, in June, and at the end of July - beginning of August.

3.3.3 Pan traps

During the monitoring periods, pan traps were used to collect pollinators (Ref. 15-16). These traps were small pots painted with UV-reflecting blue, yellow and white colours, which represent common flower colours. Placed on the ground, they were filled with several centimetres of water with a drop of neutral soap to break the water surface tension in order to quickly engulf the pollinators when they are drawn to the trap (Figure 3.4).
Using every colour twice, six traps were placed in the sun, six in the half-shade and six in the shade underneath the solar panels in every plot with a total of 18 pan traps per plot (Figure 3.5). During the first and second monitoring periods, one type of seed mix per cluster was monitored, resulting in 18

pan traps per plot five times, resulting in 90 pan traps per visit. During the last monitoring period, only the sun and shade areas were monitored but in all six plots in all seven clusters, with 12 pan traps per plot times 42 plots resulting in a total of 504 pan traps.
The pan traps were collected circa 24 hours after placement. Bees and hoverflies were picked out and placed in a plastic tube, which was labelled with the date, time, pan trap colour, cluster, mixture, weather conditions and temperature. The insects were preserved in 70% alcohol. Prior to their identification at Naturalis, the insects were put into a tea strainer and blow dried, pinned and placed inside an insect collector box.

Figure 3.4: Pan trap with insects

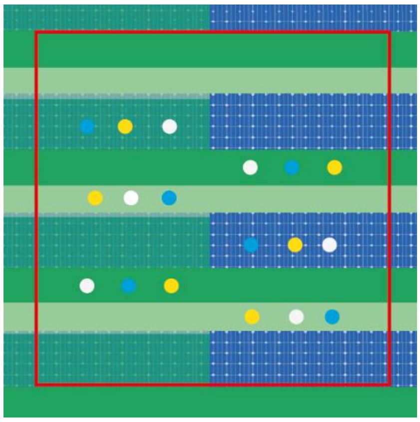


Figure 3.5: Placement of pan traps in plot

3.3.4 Pollinator survey

In addition to the pan traps, 15-minute visual surveys were done in each plot following the method of the British Butterfly Monitoring Scheme (Ref. 17). Below 13 °C and above 30 °C conditions were expected to be too extreme for the pollinators and the monitoring was postponed. Between 13 and 17 °C, there should be at least 60% sun for a survey to be carried out, and between 17 and 30 °C surveys were carried out in any weather condition as long as there was no (heavy) rainfall. In each plot, three transects of 20 meters were surveyed for five minutes using a butterfly net. Within the boundaries of the plot and within five meters, all flying, resting or foraging bee and hoverfly species were noted down as well as the (flowering) plant it visited if applicable, as well as the date, time, section, mixture, weather conditions and temperature. If the species could not be identified, it was collected in plastic tubes with a cotton ball treated with ethyl acetate. In case no ethyl acetate was available, collected insects were put in the freezer overnight and treated with ethyl acetate the next day. All bees and hoverflies were pinned in the same box as the individuals caught with pan traps.

3.3.5 Pollinator identification

The insects were identified in a process room at Naturalis in Leiden using a Zeiss zoom light microscope and book literature on Dutch and Belgian Bees and hoverflies (refs. 18-20). All bee and hoverfly species have been double-checked by experts from European Invertebrate Survey (EIS). Identified species were noted in a database with information on their genus, sex, date, sector, mixture, treatment, colour, pan trap number, location (coordinates), weather and temperature.

Figure 3.6: Pollinator identification process.

3.3.6 Botany survey

In addition to the pollinator survey, the plant species in both the sun and shadow sites of each plot were surveyed in a randomly chosen 1x1 meter area. Within this 1 m^2, the mixture, cluster, coverage, average height, plant species, maximum height per plant species and number of flowers per plant species were measured and registered.

3.3.7 Data analysis

Pollinator and plant species were identified during all three monitoring rounds and have been used to assemble the total species lists for the solar park biodiversity.
The data analyses for the pollinator and plant correlations were carried out based on the monitoring data of August, as that monitoring round covered all six seed mix plots in six clusters, namely B-G. At the time of the monitoring, the vegetation was too high in cluster A to be able to use the pan trap method and was therefore excluded. However, cluster A was included in the number of plant species, plant height and plant coverage analysis. The intensive sampling in August was used to infer linkage between plants, flowers and pollinators.
The plant and pollinator data have been analysed for correlations using a generalized linear mixed model (GLMM), wherein the clusters were identified as a random factor. In the model, the parameters of the seed mix, position, pan trap colour, average plant height, average plant coverage, number of plant species and number of pollinators were analysed, using a 95% confidence interval.

4 Results and discussion

4.1 Species assemblages

4.1.1 Pollinator species

During the three monitoring periods, ranging from April to August, a total of 431 individual solitary bees, bumblebees and hoverflies have been captured, covering 54 species of which 5 red-list bee species (Table 4.1). The red-list bee species include *Hoplitis tridentata*, *Lasioglossum brevicorne, Osmia aurulenta, Osmia caerulescens and Panurgus banksianus* (Figure 4.1a and 4.1c). In appendix 1 the full species name, quantity per species and red list status are listed (Ref. 21-22).

Table 4.1: Pollinator types and (species) quantities

Type	*Number of species*	*Of which red-list species*	*Quantity*
Solitary bee	32	5	294
Bumblebee	5	0	39
Hoverfly	17	0	98
Total	**54**	**5**	**431**

Whereas agricultural grasslands are dubbed ‘gr-asphalt’ to indicate the low biodiversity in terms of pollinators, the Moerdijk solar park shows a different picture with high number of bee and hoverfly species. This is presumably due to the high number of different habitats found on and nearby the solar park as well as plant species. Indeed, Billeter et al. (Ref. 23) have found that (agricultural) landscapes with a large number of diverse habitats have more diverse pollinator communities, leading to higher bee species richness (Ref. 24). In addition, extensive management, as is the case at the Moerdijk solar park, maintains plant diversity that can support pollinator species (Ref. 25).

a. Hoplitis tridentata (red-list)
(Photo: Tim Faasen)

c. Panurgus banksianus (red-list)
(Photo: Dick Belgers)

d. Eristalis tenax
(Photo: Jannie Bosma)

b. Andrena barbilabris
(Photo: Roy Kleukers)

e. Sphaerophoria rueppelli
(Photo: Peter Koblens)

Figure 4.1: Red-list and common bee and hoverfly species (Source photos: www.nederlandsesoorten.nl)

4.1.2 Plant species

During the three monitoring periods, ranging from April to August, a total of 103 plant species have been identified. The number of plant species was independent of the seed mixture, with 41 to 57 plant species in total in all plots per seed mixture. In other words, the 103 plant species were randomly distributed among the five seed mixes and control plots (Table 4.1). In appendix 2 the 103 plant species are listed along with their average coverage per seed mixture plot.

Table 4.1: Number of (mixture) species, average overall coverage and average overall height

Seed mixture	*Number of total species*	*Number of mixture species*	*Average overall coverage (%)*	*Average overall height (cm)*
Control (CO)	41	N.A.	55,5 ±28,0	21,1 ±13,0
Diverse Grasses (GR)	52	5	42,4 ±29,3	11,0 ±8,2
Green Manure (GM)	43	6	39,6 ±32,7	15,9 ±21,7
Industrial (IN)	55	6	52,7 ±28,7	16,7 ±12,1
Eco Shade (SH)	57	3	54,2 ±20,9	21,5 ±11,9
Eco Sun (SU)	53	2	55,5 ±28,6	13,9 ±11,6
Total diversity	103	22/30	50,0 ±28,0	16,7 ±13,1

Table 4.2: Coverage of plants of seed mix species

Seed mixture	*Average coverage* (%)*	*Seed mixture*	*Average coverage* (%)*
Diverse Grasses (GR)		**Eco Shade (SH)**	
Agrostis capillaris	1,0	*Cynoglossum officinale*	0,8
Cynosurus cristatus	1,7	*Geum urbanum*	-
Festuca cinerea	9,1	*Prunella vulgaris*	0,1
Festuca filiformis	-	*Silene dioica*	0,1
Festuca rubra	4,2	*Stachys sylvatica*	-
Lolium perenne	0,8	*Veronica longifolia*	-
Green Manure (GM)		**Industrial (IN)**	
Lotus corniculatus	1,2	*Ammi majus*	0,1
Lupinus luteus	0,1	*Borago officinalis*	0,3
Ornithopus sativus	0,5	*Calendula arvensis*	0,2
Phacelia tanacetifolia	0,7	*Carum carvi*	0,1
Trifolium pratense	2,0	*Centaurea cyanus*	0,2
Trifolium repens	1,8	*Papaver rhoeas*	0,7
Eco Sun (SU)			
Achillea millefolium	7,4		
Campanula rotundifolia	-		
Knautia arvensis	-		
Origanum vulgare	-		
Reseda lutea	10,5		
Thymus pulegioides	-		

* In respective seed mix plots

All six plant species of the seed mixtures Green Manure and Industrial germinated, whereas five species of the Diverse Grasses germinated, and only three and two of the Eco Shade and Eco Sun, respectively. In table 4.2, the species of the seed mixtures and their average coverage in the seed plots are listed. Overall, the coverage of the sown mixtures is extremely low with a coverage of <2%. This may be explained by the late sowing in March, as some species need a cool period in order to germinate successfully and background species already had a head start. In addition, some species in the mixes are perennials and thus expected to proliferate from next year. Possibly, these other mixture species will germinate, grow and flower more during the next season and will be able to compete better with background species. Exceptions are *Festuca cinerea* (9,1%, GR), *Festuca rubra*

(4,2%, GR), *Achillea millefolium* (7,4%, GM) and *Reseda lutea* (10,5%, GM). However, the higher presence of *Achillea millefolium* (found in four types of plots), *Reseda lutea* (found in three types of plots) and *Festuca rubra* (found in all types of plots) can be explained by the fact that these species were already present before the mixtures were sown. The grass *Festuca cinerea* was only found in the Diverse Grasses mixture. Its high coverage indicates that it is a relatively strong species and successful at competing with the background species.

Overall, there were 14 plant species that were very common and that contributed each more than 2% of all records. The other 89 plant species were seen less often. A record indicates that the species was seen in a plot and registered. The reason for choosing to show records in addition to coverage is to indicate the distribution of the species, regardless of its size. In Table 4.3 these 14 most abundant plant species, in terms of records, have been listed, along with their average coverage in the study area. The green highlights indicate that it concerns a plant species from a seed mixture.

Table 4.3: Most abundant plant species (>2% of total sightings)

Species (dutch)	*Species (scientific)*	*% of total sightings*	*% of average total coverage**
Bezemkruiskruid	*Senecio inaequidens*	9,3	8,0 ±2,5
Canadese fijnstraal	*Conyza canadensis*	7,7	3,9 ±1,5
Middelste teunisbloem	*Oenothera biennis*	5,8	6,6 ±4,0
Gewone zandmuur	*Arenaria serpyllifolia*	5,2	2,6±1,2
Muurpeper	*Sedum acre*	4,8	1,8 ±1,0
Roodzwenkgras	*Festuca rubra (GR)*	3,9	2,7 ±2,0
Schapenzuring	*Rumex acetosella*	3,7	3,4 ±2,6
Ruige leeuwentand	*Leontodon hispidus*	3,7	1,2 ±0,4
Duinriet	*Calamagrostis epigejos*	3,1	10,1 ±8,1
Smalle weegbree	*Plantago lanceolata*	2,9	3,9 ±1,5
Reigersbek	*Erodium cicutarium*	2,9	0,8 ±0,8
Grijze mosterd	*Hirschfeldia incana*	2,8	8,3 ±13,0
Gewone rolklaver	*Lotus corniculatus (GM)*	2,8	5,9 ±8,4
Fioringras	*Agrostis stolonifera*	2,3	5,2 ±5,8

* Total average coverage in all plots, regardless of cluster, seed mixture and position (shade/sun).

4.2 Data analysis

The data analysis of the GLMM takes into account the average plant height and coverage, and the number of plant species and pollinators per seed mixture, position (sun/shade) and pan trap colour. The results are shown in separate paragraphs for plants and pollinators. Please note that the plot averages may differ from those shown in the tables. This is due to the graphs reflecting the results of the GLMM, which takes into account a random effect, and the actual averages and standard deviation shown in the tables.

4.2.2 Pollinator individuals

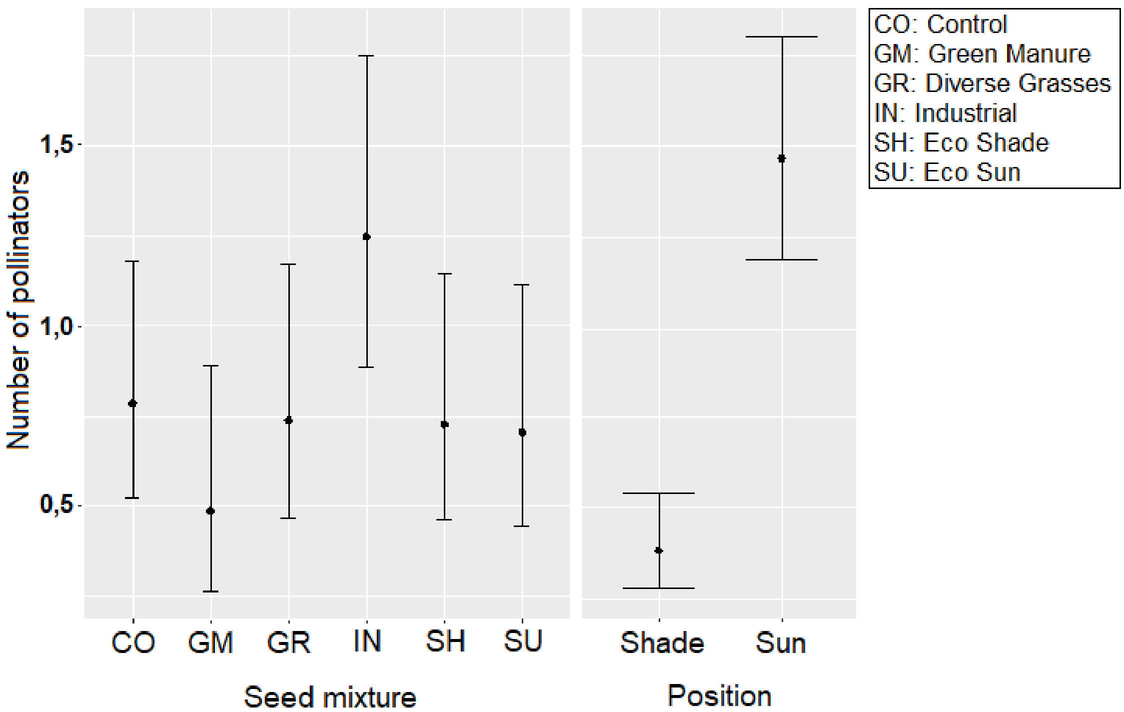
The GLMM results show that the seed mix plots do not have a significant effect on the number of pollinators. The *Industrial* mix plot appears to attract more pollinators, but it not significantly different from the other seed mix plots (Table 4.4, Figure 4.2a). This may be due to the fact that the seed mixture plant species made up only a small portion of the total vegetation. In terms of position, pollinators prefer the sun, with more individuals found in the sun than in the shade (Table 4.5 and Figure 4.2b). As pollinators need solar energy to increase their body temperature, it is not surprising that they seek a sunny environment to reduce energy loss.

Table 4.4: Effects of the seed mixtures on the number of pollinators in August.				
Seed mixture	*Total number of pollinators in seed mixture*	*Average number of pollinators in seed mixture per cluster*	*Average number of pollinators in seed mixture per cluster, position and colour**	*GLMM significance group*
Control (CO)	36	6,00 ±3,42	0,9 ±1,4	A
Green Manure (GM)	42	7,00 ±3,00	0,8 ±1,2	A
Diverse Grasses (GR)	32	5,33 ±2,87	1,2 ±1,6	A
Industrial (IN)	55	9,17 ±2,67	1,4 ±1,9	A
Eco Shade (SH)	36	6,00 ±3,56	1,0 ±1,2	A
Eco Sun (SU)	30	5,00 ±2,58	1,0 ±1,5	A

*Used to calculate the significance of the correlations in GLMM. Note that the plot averages may differ, as the GLMM calculation takes into account the random effect of the clusters.

Table 4.5: Effects of sun or shade on the number of pollinators in August.				
Position	*Total number of pollinators in sun or shade*	*Average number of pollinators in sun or shade per cluster*	*Average number of pollinators in sun or shade per cluster, seed mixture and colour**	*GLMM significance group*
Shade	50	8,3 ±3,6	0,4 ±0,8	A
Sun	181	30,2 ±8,1	1,6 ±1,7	B

*Used to calculate the significance of the correlations in GLMM. Note that the plot averages may differ, as the GLMM calculation takes into account the random effect of the clusters.



a. b.

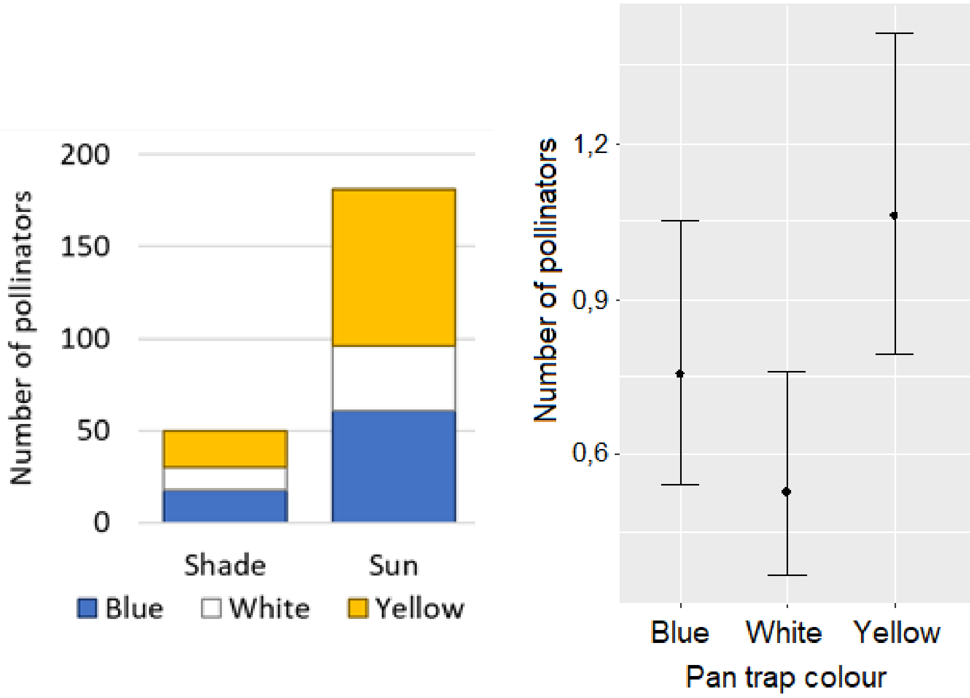
Figure 4.2: The effect of the seed mixture plots (a) and position (b) on the average number of pollinator individuals in the seed mixture plots per cluster, position and colour.

The colour of the pan traps, being yellow, white and blue, had a significant effect on the number of pollinators that were attracted to them. Indeed, most pollinators have a preference for yellow, followed by blue. White appears to attract the least number of pollinators (Table 4.6). Figure 4.3a reflects this preference in colour by showing the number of pollinators per colour and also gives insight into the distribution of the colour visitation in the shade and sun locations. This indicates that this preference is independent of sun or shade locations as this pattern is evident in each situation. Figure 4.3b shows the significant results of the GLMM of the colour effect on pollinator abundance.

Table 4.6: Pan trap colour preference of pollinators.

Colour	*Total number of pollinators in pan trap colour*	*Average number of pollinators in pan trap colour per cluster*	*Average number of pollinators in pan trap colour per cluster, seed mixture and position**	*GLMM significance group*
Blue	47	7,8 ±2,9	1,0 ±1,6	AB
White	79	13,2 ±5,1	0,7 ±1,0	A
Yellow	105	17,5 ±3,3	1,4 ±1,7	B

*Used to calculate the significance of the correlations in GLMM. Note that the plot averages may differ, as the GLMM calculation takes into account the random effect of the clusters.



a. b.

Figure 4.3: a) The number of pollinators in the pan trap colours in the shade and sun in August. b) The effect of the pan trap colour on the number of pollinators in August.

4.2.2 Plant coverage, height and number of species

GLMM results show that there is no significant difference in the average plot coverage, average plant height and number of plant species in terms of seed mixture and sun or shade (Table 4.8, Table 4.9 and Figure 4.4).

Table 4.8: Effects of location on the average plant height and coverage

Location	*Average plant height (cm) + GLMM significance group*	*Average plot coverage (%) + GLMM significance group*	*Number of plant species + GLMM significance group*
Shade	13,5 ±12,8 (A)	51,9 ±30,3 (A)	9,5 ±3,7 (A)
Sun	19,6 ±14,7 (A)	47,9 ±27,0 (A)	10,4 ±3,9 (A)

*Used to calculate the significance of the correlations in GLMM. Note that the plot averages may differ, as the GLMM calculation takes into account the random effect of the clusters.

Table 4.7: Effects of the seed mixtures on the average plant height and coverage			
Mix	*Average plant height (cm)* + GLMM significance group*	*Average plot coverage (%)* + GLMM significance group*	*Average number of plant species* + GLMM significance group*
Control (CO)	21,1 ±13,0 (A)	55,5 ±28,0 (A)	8,6 ±4,4 (A)
Green Manure (GM)	11,0 ±8,2 (A)	42,4 ±29,3 (A)	10,6 ±3,5 (A)
Diverse Grasses (GR)	15,9 ±21,7 (A)	39,6 ±32,7 (A)	9,4 ±3,3 (A)
Industrial (IN)	16,7 ±12,1 (A)	52,7 ±28,7 (A)	12,0 ±4,3 (A)
Eco Shade (SH)	21,5 ±11,9 (A)	54,2 ±20,9 (A)	8,5 ±3,2 (A)
Eco Sun (SU)	13,9 ±11,6 (A)	55,5 ±28,6 (A)	10,8 ±3,2 (A)

*Used to calculate the significance of the correlations in GLMM. Note that the plot averages may differ, as the GLMM calculation takes into account the random effect of the clusters.

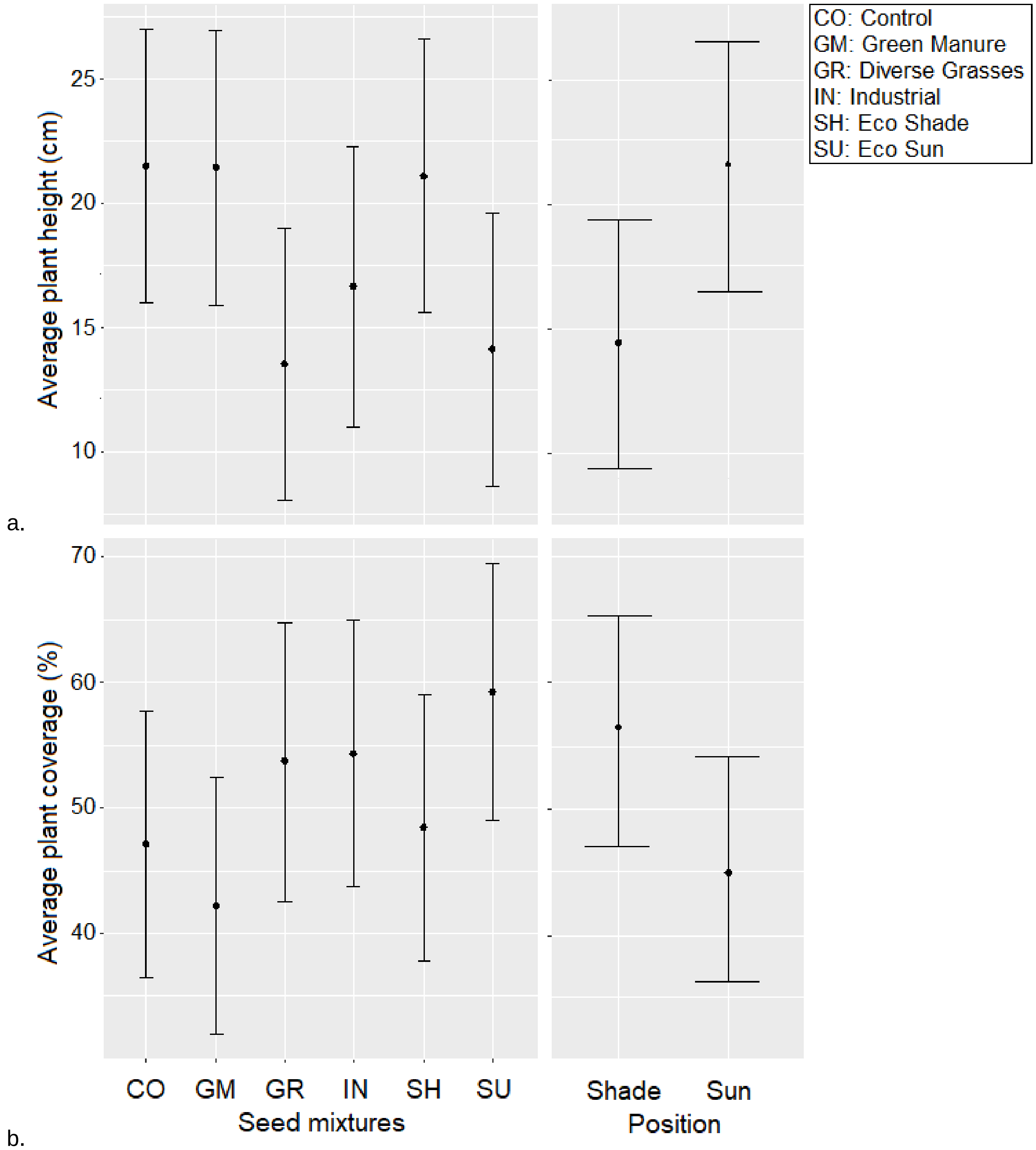


Figure 4.4: The effect of seed mixtures and location on average plant height (a) and coverage (b).

It appears that despite the shadows cast by the solar panels, the (background) vegetation is able to grow just as well under the panels as in the full sun. Bearing in mind the hot summer this year, this may even be especially due to the solar panels, which reduced evapotranspiration from the plant leaves and evaporation from the soil, maintaining soil moisture and a relatively stable atmosphere for the vegetation in the shade.

5 Conclusions and recommendations

In this section the findings are discussed based on the research questions presented in chapter 2, followed by conclusions and recommendations.

Can solar parks be a suitable habitat for pollinators? If so, what conditions are important to sustain this suitability?
This research has shown that solar parks can indeed be a suitable habitat for pollinators. We found more species of bees than can be found normally in agricultural or industrial areas and good numbers of hoverfly species as well. The solar park is even a good habitat for five threatened bee species, namely *Hoplitis tridentata, Lasioglossum brevicorne, Osmia aurulenta, Osmia caerulescens* and *Panurgus banksianus.*
However, the vegetative conditions are important, as well as the presence of sunny patches. There need to be attractive flowering plants from spring throughout late summer to provide foraging and nesting opportunity for the flower visitors. In the study location (being exceptional in its floral and faunal richness for an industrial estate) this can be established through an extensive maintenance with periodical mowing. In addition, sunny locations are required to ensure the establishment and flowering of a large variety of plant species and proper flying conditions for the pollinators. The Shell Moerdijk solar park fulfils these conditions having extensive space around and between the solar panels.

Are there differences between sun and shade in terms of vegetation and pollinator abundance?
Significantly more pollinators are found in the sun than the shade. As pollinators need solar energy to increase their body temperature, it is not surprising that they seek a sunny environment to reduce energy loss. In other solar parks, the panels cover the whole area. These are likely to harbour much lower biodiversity both in abundance and species richness.
In terms of number of plant species, plant height and plant coverage, no significant difference were found between the sun and the shade, indicating that plants can grow just as well under the solar panels. Bearing in mind the hot summer this year, this may even be especially due to the solar panels, which reduced evapotranspiration from the plant leaves and evaporation from the soil, maintaining soil moisture and a relatively stable atmosphere for the vegetation in the shade.

Recommendation:
Pollinators occur more in a sunny than a shady environment, so it is important to leave sufficient space in between the solar panels to enable sun rays to hit the ground throughout the day. At the Moerdijk solar panel park the space between panels is 3 to 4 meters, which is considered sufficient for vegetation and therefore pollinators to flourish.

What is the effect of pan trap colour on pollinator abundance?
Pollinators showed a distinct preference for yellow, followed by blue. White was the least favourite colour. This trend was visible in both the sun and shade.

What type and periodicity of maintenance benefits pollinator diversity?
Pollinators need nectar and pollen for food (flowers) and nesting area. In order to maintain a steady and high biodiversity of pollinators throughout their flying seasons in (early) spring and (late) summer, it is important to facilitate these resources. This is common knowledge and not a result from our study. We have decided in this first year to keep mowing regimes to a minimum (all mowing occurred after our study). In the following year it would be of interest to compare different (extensive) mowing regimes, in order to see which would be best suitable for Moerdijk.

Recommendation:
Maintenance in terms of mowing should be kept to an absolute minimum to facilitate the required resources throughout the pollinator flying seasons. In case maintenance is required, it is

recommended to tailor the frequency and type of mowing according to the landscape and vegetation needs.
Frequency: Poor soils, such as Moerdijk, only require a mowing frequency of 1-2 times a year, whereby the last mowing time should be done as late as October to spare pollinators (Ref. 26).
Type: Maintenance should be aimed at partial, phased mowing (sinus), with the goal of leaving some flowering vegetation present to host pollinators.
Equipment: Rigorous machines that completely destroy the vegetation are not recommended, due to the killing of pollinators in the process. The working speed of the machine should be such that insects have enough time to vacate the vegetation. Furthermore, it is best to have light-weight machines with a large range to reduce destruction of nesting areas (soil) (Ref. 26).
Cuttings: The cuttings should be exported from the terrain in order to keep the soil nutrient poor to avoid competitive species to proliferate (for instance nettles in case of high nitrogen deposition). However, it is best to leave the cuttings on the ground for 2-3 days in order for seeds to fall out and for pollinators and other insects to escape the cuttings (Ref. 26).

Which type of seed mixtures benefits pollinator diversity and is best in terms of minimum maintenance labour and costs?
Despite the use of different seed mixtures, there is no significant difference among the seed mixtures and the control plots and their effect on the number of pollinators in this first year. The main reasons being (1) the abundant background vegetation that was established partly before the sowing of the seed mixes; (2) the fact that not all seed mixture species have germinated this year, and if they did, their overall coverage was smaller than 2%. This low germination rate and coverage may be due to the late sowing in March, as opposed to the recommended sowing in late autumn (November/December). With some seeds still in the soil, including new seeds formed this summer, the seed mixture species will have a timely germination and be in a better competitive position against the background species next year (2020). The late sowing and low germination rates of the mixture seeds were also the reasons to keep the maintenance at a minimum, due to which it is still uncertain which type of maintenance is most suitable for which seed mixture.
Therefore, it was not possible this year to determine which seed mixture was best to facilitate pollinators and boost their diversity, as well as which maintenance type is best suited for that particular seed mixture.

Recommendation:
Next year the obstacles for establishment of the seed mixture species will presumably be no longer effective, as the old and new seeds will have an even start with the background plant species. It is therefore recommended to continue this research next year to be able to assess differences in seed mixture preference of pollinators as well as the longer term persistence of the background species. With the expected proper growth of seed mixture species, it would then be possible to apply different mowing regimes in order to answer the question which seed mixture is best in terms of pollinator diversity and maintenance labour and costs.

What are the required conditions in terms of solar park design and maintenance to benefit pollinator biodiversity?
In order to provide beneficial conditions for pollinators, the design needs to include:
- Space in between the solar panels with sufficient solar radiation on the ground throughout the day (circa 3-4 m).
- A diversity of flowering plants for foraging throughout the flying season of the pollinators (March – September).
- Extensive, periodic maintenance.
- Nesting opportunity (artificial structures, such as logs).
- Sufficient moisture for plants to grow

The Shell Moerdijk solar park seems to fulfil all of the above conditions. In that respect it seems a positive exception to the rule. Many solar parks in our landscapes seem to be established in areas of much lower background biodiversity or have established the cover under the panels by simply using a grass layer. Others have used a general floral mix, which will do fine in year one, but may deteriorate in the next years. Although we have only studied the solar park for one year, the conditions (high background biodiversity, low maintenance, addition of annual/perennial seed mixes) seem optimal for long-term development of biodiverse plant and insect populations.

Future outlook

Considering that this monitoring study has only been done one year and on one location, it is recommended to continue monitoring the following year(s) in order to investigate long-term effects of the solar park on pollinator and plant diversity. Furthermore, it would be interesting to include other solar parks in the study, which differ in terms of soil and background biodiversity (for instance agricultural areas) and/or design (orientation, angle). This will increase the knowledge on the effects of solar park design and background on biodiversity.

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APPENDIX 1: List of pollinator species

Red list abbreviations

NB	Not considered species
TNB	Species currently not threatened: species that are stable or have increased and are general to rare, and species that have moderately decreased and are general.
GE	Sensitive species: species that are stable or increased but are very rare, and species that have severely decreased but are still general.
KW	Vulnerable species: species that have moderately decreased and are currently quite to very rare, and species that have severely decreased and are currently quite rare.
o/+	Stable or increased: Decrease in distribution of number of procreating individuals since 1950 less than 25%.
t	Moderately decreased: Decrease in distribution of number of procreating individuals since 1950 25 to almost 50%.
a	Common: Actual distribution at least 12,5% of the atlas blocks, or at least 25.000 procreating individuals.
z	Quite rare: Actual distribution 5 to almost 12,5% of the atlas blocks, or 2.500 to 24.999 procreating individuals.
zz	Rare: Actual distribution 1 to almost 5% of the atlas blocks, or 250 to 2.499 procreating individuals.
zzz	Very rare: Actual distribution almost 0 to almost 1% of the atlas blocks, or 1 to 249 procreating individuals.

Table S1: List of pollinator species			
Species	***Type***	***Quantity***	***Red list status***
Andrena barbilabris	Bee	23	(TNB) a,o/+
Andrena flavipes	Bee	12	(TNB) a,o/+
Andrena nigroaenea	Bee	1	(TNB) z,o/+
Andrena ventralis	Bee	1	(TNB) z,o/+
Anthidium strigatum	Bee	1	(TNB) z,o/+
Apis mellifera	Bee	7	(TNB)
Colletes cunicularius	Bee	1	(TNB) a,o/+
Colletes daviesanus	Bee	1	(TNB) a,o/+
Colletes fodiens	Bee	4	(TNB) z,o/+
Dasypoda hirtipes	Bee	7	(TNB) a,o/+
Epeolus variegatus	Bee	1	(TNB) z,o/+
Halictus tumulorum	Bee	5	(TNB) a,o/+
Hoplitis tridentata	Bee	1	GE zzz,o/+
Hylaeus communis	Bee	1	(TNB) a,o/+
Lasioglossum brevicorne	Bee	19	KW zz,t
Lasioglossum calceatum	Bee	19	(TNB) a,o/+
Lasioglossum leucozonium	Bee	9	(TNB) a,o/+
Lasioglossum lucidulum	Bee	31	(TNB) zz,o/+
Lasioglossum minutissimum	Bee	114	(TNB) z,o/+
Lasioglossum morio	Bee	1	(TNB) a,o/+
Lasioglossum pauxillum	Bee	2	(TNB) z,o/+
Lasioglossum punctatissimum	Bee	7	(TNB) z,o/+
Lasioglossum sexstrigatum	Bee	6	(TNB) a,o/+
Lasioglossum spec.	Bee	5	NB
Lasioglossum villosulum	Bee	1	(TNB) a,o/+
Lasioglossum zonulum	Bee	5	(TNB) z,o/+
Megachile centuncularis	Bee	2	(TNB) a,o/+
Osmia aurulenta	Bee	1	KW zz,t
Osmia caerulescens	Bee	1	KW z,t
Panurgus banksianus	Bee	2	KW z,t
Sphecodes albilabris	Bee	2	(TNB) a,o/+
Sphecodes puncticeps	Bee	1	(TNB) z,o/+
Bombus hortorum	Bumblebee	1	(TNB) a,o/+
Bombus lapidarius	Bumblebee	4	(TNB) a,o/+
Bombus pascuorum	Bumblebee	21	(TNB) a,o/+
Bombus pratorum	Bumblebee	1	(TNB) a,o/+
Bombus terrestris	Bumblebee	12	(TNB) a,o/+
Chloromyia formosa	Hoverfly	1	NB
Episyrphus balteatus	Hoverfly	3	(TNB) a,o/+
Eristalinus sepulchralis	Hoverfly	1	(TNB) a,o/+
Eristalis spec.	Hoverfly	1	NB
Eristalis tenax	Hoverfly	11	(TNB) a,o/+
Eupeodes corollae	Hoverfly	15	NB
Eupeodes luniger	Hoverfly	10	NB
Helophilus trivittatus	Hoverfly	3	NB
Paragus haemorrhous	Hoverfly	1	(TNB) a,o/+
Platycheirus clypeatus	Hoverfly	1	(TNB) a,o/+
Platycheirus scutatus-complex	Hoverfly	1	(TNB) a,o/+
Scaeva pyrastri	Hoverfly	3	(TNB) a,o/+
Sphaerophoria rueppellii	Hoverfly	16	NB
Sphaerophoria scripta	Hoverfly	26	(TNB) a,o/+
Sphaerophoria spec.	Hoverfly	3	NB
Syrphidae spec.	Hoverfly	1	NB
Syrphus ribesii	Hoverfly	1	(TNB) a,o/+

APPENDIX 2: List of plant species

Green highlighted plant species are part of a seed mixture, which is highlighted at the specific mixture column.

Table S2: Plant species and their average coverage per seed mixture and total average coverage.

Plant species	CO	GM	GR	IN	SH	SU	Total
Achillea millefolium		3,5 ±1,5		2,0 ±0,0	1,0 ±0,0	7,4 ±6,9	3,5 ±2,4
Agrostis capillaris	11 ±7,8	37,5 ±32,5	1,0 ±0,7	13,5 ±18,2	5,0 ±0,0	13,0 ±25,6	13,5 ±11,6
Agrostis stolonifera	5,0 ±2,1	0,5 ±0,0	0,1 ±0,0	0,5 ±0,6	8,8 ±2,4	16,1 ±13,1	5,2 ±5,8
Ammi majus				0,1 ±0,0			0,1 ±0,0
Anagallis arvensis						0,1 ±0,0	0,1 ±0,0
Angelica archangelica				2,0 ±0,0		0,0 ±1,0	2,0 ±0,0
Arenaria leptoclados						10,0 ±0,0	10,0 ±0,0
Arenaria serpyllifolia	4,8 ±6,8	1,3 ±1,0	1,4 ±1,9	3,2 ±2,7	2,3 ±2,5	2,8 ±3,0	2,6 ±1,2
Arrhenatherum elatius				2,0 ±0,0	5,0 ±0,0		3,5 ±1,5
Artemisia vulgaris	0,1 ±0,0	10,0 ±0,0			0,1 ±0,0	10,0 ±0,0	5,1 ±5,0
Asteraceae sp.	0,2 ±0,2						0,2 ±0,0
Atriplex patula						0,1 ±0,0	0,1 ±0,0
Borago officinalis				0,3 ±0,3			0,3 ±0,0
Bryophyta	15,0 ±0,0	3,8 ±4,4	16,5 ±11,5	0,1 ±0,1			8,9 ±7,0
Calamagrostis epigejos	17,7 ±26,2	2,9 ±3,6	10,8 ±9,3	5,4 ±2,1	23,2 ±27,2	0,7 ±0,4	10,1 ±8,1
Calendula arvensis				0,3 ±0,2			0,3 ±0,0
Carduus nutans				1,0 ±0,0			1,0 ±0,0
Carduus sp.			3,0 ±0,0				3,0 ±0,0
Carex hirta						15,0 ±5,0	15,0 ±0,0
Carex sp.	2,6 ±2,5	2,6 ±1,6	0,6 ±0,5	8 ±7	2,4 ±1,8		3,2 ±2,5
Carum carvi				0,1 ±0,0			0,1 ±0,0
Centaurea cyanus				0,3 ±0,2			0,3 ±0,0
Cerastium fontanum	1,0 ±0,0		0,7 ±0,9			15,0 ±0,0	5,6 ±6,7
Cerastium glomeratum					0,8 ±0,3		0,8 ±0,0
Cerastium semidecandrum	6,5 ±0,5	1,5 ±1,8	5,0 ±0,0	0,2 ±0,0	4,0 ±1,0	2,0 ±0,7	3,2 ±2,2
Cerastium sp.	0,1 ±0,0		0,6 ±0,5				0,4 ±0,3
Cirsium arvense	2,0 ±0,0		0,5 ±0,0	1,9 ±2,2	3,5 ±1,5	0,1 ±0,0	1,6 ±1,2
Cirsium vulgare		2,0 ±0,0	1,0 ±0,0				1,5 ±0,5
Conyza canadensis	1,4 ±1,6	4,7 ±6,6	3,8 ±5,6	5,6 ±5,1	5,5 ±6,5	2,5 ±2,5	3,9 ±1,5
Corispermum intermedium	15 ±0,0	2,1 ±2,4	0,1 ±0,0	4,4 ±3,3	1,4 ±1,8	2,5 ±1,5	4,3 ±5,0
Crataegus monogyna			0,5 ±0,0	0,1 ±0,0			0,3 ±0,2
Crepis capillaris	1,0 ±0,0			2,0 ±2,1		1,6 ±1,5	1,5 ±0,4
Cynoglossum officinale					1,2 ±1,1		1,2 ±0,0
Cynosurus cristatus			2,2 ±1,7				2,2 ±0,0
Cyperus sp.	3,0 ±0,0		1,0 ±0,0	2,5 ±0,5		15 ±0,0	5,4 ±5,6
Daucus carota		3,0 ±0,0					3,0 ±0,0
Diplodaxis tenuifolia		1,0 ±0,0	2,0 ±0,0				1,5 ±0,5
Equisetum arvense	15,0 ±0,0	0,6 ±1,0	7,0 ±0,0	0,2 ±0,0	0,6 ±0,5	0,7 ±0,4	4,0 ±5,5
Erodium cicutarium	2,5 ±1,8	1,1 ±1,0	0,4 ±0,4	0,2 ±0,3	0,2 ±0,2	0,6 ±0,6	0,8 ±0,8
Euphorbia helioscopia		0,6 ±0,5					0,6 ±0,0
Fallopia convolvulus	0,1 ±0,0			0,1 ±0,0		5,0 ±0,0	1,7 ±2,3
Festuca cinerea			15,0 ±17,8				15,0 ±0,0
Festuca rubra	3,1 ±3,0	0,8 ±0,7	4,2 ±6,4	1,9 ±1,6	0,1 ±0,0	5,8 ±6,6	2,7 ±2,0
Filago minima			0,1 ±0,0	0,1 ±0,0			0,1 ±0,0
Fragaria vesca		1,0 ±0,0					1,0 ±0,0
Gnaphalium luteo-album	2,0 ±0,0				0,6 ±0,5		1,3 ±0,7
Hirschfeldia incana	0,6 ±0,5	37,0 ±33,0	6,5 ±5,3	2,6 ±1,7	1,7 ±1,2	1,4 ±1,5	8,3 ±13,0
Hypericum perforatum	10,0 ±0,0	0,6 ±0,5	11,6 ±19,3	4,8 ±6,0	2,6 ±2,5	4,0 ±4,3	5,6 ±3,9
Jacobaea vulgaris	1,4 ±1,2	3,7 ±2,5	0,4 ±0,4	8,0 ±8,5	0,5 ±0,7	8,5 ±6,0	3,8 ±3,4
Lactuca serriola					2,0 ±0,8	3,0 ±0,0	2,5 ±0,5
Leontodon autumnalis	0,1 ±0,0	0,1 ±1,0	2,0 ±0,0			0,2 ±0,2	0,6 ±0,8
Leontodon hispidus	0,5 ±0,4	0,8 ±0,7	1,5 ±0,8	1,6 ±1,7	1,1 ±1,0	1,5 ±1,3	1,2 ±0,4
Leontodon saxatilis			1,0 ±0,0			0,1 ±0,0	0,6 ±0,5
Lolium perenne	0,1 ±0,0		0,8 ±0,7			3,0 ±0,0	1,3 ±1,2
Lotus corniculatus	3,7 ±3,1	1,2 ±3,1	22,5 ±17,5	1,4 ±1,2		0,8 ±0,3	5,9 ±8,4

Table S2 (continuation): Plant species and their average coverage per seed mixture and total average coverage.							
Plant species	CO	GM	GR	IN	SH	SU	Total
Lupinus luteus		0,3 ±0,2					0,3 ±0,0
Luzula campestris					0,1 ±0,0		0,1 ±0,0
Luzula sylvatica		0,5 ±0,0					0,5 ±0,0
Myosotis arvensis		0,3 ±0,0		0,3 ±0,2			0,3 ±0,0
Nardus stricta			0,5 ±0	4 ±4,9			2,3 ±1,8
Oenothera biennis	12,3 ±7,0	4 ±4	2,9 ±5,5	9,2 ±8,7	1,4 ±1,7	9,5 ±10,9	6,6 ±4,0
Ornithopus sativus		0,8 ±0,8					0,8 ±0,0
Papaver rhoeas			0,1 ±0,0	0,7 ±0,9	0,6 ±0,5	1,6 ±1,5	0,8 ±0,5
Pastinaca sativa	30,0 ±0,0						30,0 ±0,0
Persicaria maculosa				0,1 ±0,0	0,3 ±0,2	0,4 ±0,4	0,27 ±0,1
Phacelia tanacetifolia		0,9 ±0,7					0,9 ±0,0
Plantago lanceolata	5,2 ±8,4	3,4 ±3,7	5,7 ±3,3	3,8 ±3,7	1,0 ±0,0	4,5 ±5,3	3,9 ±1,5
Poa annua						0,5 ±0,0	0,5 ±0,0
Poa bulbosa			0,1 ±0,0	0,2 ±0,0			0,2 ±0,1
Poaceae sp.			1,0 ±1,2		1,0 ±0,0		1,0 ±0,0
Polygonum aviculare		0,1 ±0,0	0,3 ±0,2	0,1 ±0,0	0,3 ±0,2	0,8 ±0,4	0,3 ±0,3
Populus nigra		18,8 ±10,9	25,0 ±11,2	5,5 ±4,5	25,0 ±0,0		18,6 ±8,0
Potentilla reptans				10,0 ±0,0		0,1 ±0,0	5,1 ±5,0
Prunella vulgaris					0,1 ±0,0		0,1 ±0,0
Reseda lutea				20,0 ±0,0	55,0 ±0,0	10,5 ±9,5	28,5 ±19,1
Rubus caesius				17,5 ±7,5			17,5 ±0,0
Rubus fruticosus	1,0 ±0,0	1,0 ±0,0	70,0 ±0,0	30,0 ±0,0	35,0 ±5,0		27,4 ±25,6
Rumex acetosa						2,5 ±1,8	2,5 ±0,0
Rumex acetosella	1,5 ±2,0	7,0 ±7,4	1,6 ±1,9	1,8 ±1,6	1,1 ±1,4	7,2 ±9,6	3,4 ±2,7
Rumex palustris					2,0 ±0,0		2,0 ±0,0
Sedum acre	1,9 ±1,0	0,7 ±0,6	0,1 ±0,1	2,7 ±3,7	2,7 ±4,4	2,5 ±3,2	1,8 ±1,0
Senecio inaequidens	8,4 ±10,3	8,8 ±14,0	2,6 ±3,5	9,8 ±13,4	7,9 ±10,0	10,2 ±12,4	8,0 ±2,5
Setaria viridis	0,1 ±0,0					0,1 ±0,0	0,1 ±0,0
Silene dioica					0,1 ±0,0		0,1 ±0,0
Sinapis arvensis	2,8 ±1,3		1,0 ±0,0	0,1 ±0,0	0,7 ±0,9	0,4 ±0,4	1,0 ±0,9
Sonchus sp.					0,5 ±0,4		0,5 ±0,0
Spergula arvensis	1,0 ±0,0	3,5 ±1,5			0,1 ±0,0		1,5 ±1,4
Stachys palustris				7,0 ±0,0	1,0 ±0,0	7,0 ±0,0	5,0 ±2,8
Symphytum officinale				5,0 ±0,0			5,0 ±0,0
Taraxacum officinale	0,1 ±0,0			0,3 ±0,0			0,2 ±0,1
Trifolium arvense	2,3 ±1,8	0,1 ±0,0	3,3 ±5,8	0,8 ±0,2		0,6 ±0,4	1,4 ±1,2
Trifolium dubium		0,1 ±0,0					0,1 ±0,0
Trifolium pratense		2,0 ±3,1				1,5 ±0,5	1,8 ±0,3
Trifolium repens		1,8 ±2,4	0,1 ±0,0				1,0 ±0,9
Trifolium sp.		1,4 ±1,8				0,1 ±0,0	0,8 ±0,7
Tripleurospermum maritimum						1,0 ±0,8	1,0 ±0,0
Urtica dioica						8,0 ±5,0	8,0 ±0,0
Veronica arvensis	1,0 ±0,0		1,0 ±0,8				1,0 ±0,0
Veronica sp.						0,1 ±0,0	0,1 ±0,0
Vicia sativa						0,5 ±0,0	0,5 ±0,0
Vicia sp.		5,0 ±0,0		1,0 ±0,0	20,0 ±0,0		8,7 ±8,2
Vicia tetrasperma						1,0 ±0,0	1,0 ±0,0
Vulpia myuros					2,0 ±0,0		2,0 ±0,0