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Bee-Friendly Native Seed Mixtures for the Greening of Solar Parks

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Abstract: Photovoltaics is one of the key technologies for reducing greenhouse gas emissions and achieving climate neutrality for Europe by 2050, which has led to the promotion of solar parks. These parks can span up to several hundred hectares, and grassland vegetation is usually created between and under the panels. Establishing species-rich grasslands using native seed mixtures can enhance a variety of ecosystem services, including pollination. We present an overall concept for designing native seed mixtures to promote pollinators, especially wild bees, in solar parks. It takes into account the specific site conditions, the small-scale modified conditions caused by the solar panels, and the requirement to avoid panel shading. We highlight the challenges and constraints resulting from the availability of species on the seed market. Furthermore, we provide an easy-to-use index for determining the value of native seed mixtures for wild bee enhancement and apply it as an example to several mixtures specifically designed for solar parks. The increased availability of regional seed would allow a more thorough consideration of pollinator-relevant traits when composing native seed mixtures, thereby enhancing ecosystem services associated with pollinators such as wild bees.

Keywords: grassland; native seeds; seed-mixture pollinator-feeding index; regulating services; solar energy; ground-mounted photovoltaic power plant

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1. Introduction

Two of the biggest challenges of our time are tackling the climate and biodiversity crises [1]. In addressing the climate crisis, photovoltaics are considered one of the key technologies for reducing greenhouse gas emissions [2], which has led to the expansion of solar parks across Europe [3,4]. To address the biodiversity crisis, in particular the qualitative and quantitative decline of insects [5–7], solar farms offer great potential [8–10].

Ecological assessments of existing ground-mounted photovoltaic systems show diverse impacts, ranging from markedly negative effects on the landscape and biodiversity [11–14] to potentially positive effects on ecosystem services [15,16] and several animal species groups [13,17,18]. In addition to siting [19,20], a key aspect of the ecological assessment of solar parks involves the design of the respective installation [15]. These parks can be up to several hundred hectares in size, with a continuous increase in their numbers [21,22], and grassland is usually included between and under the panels [23]. In addition to spontaneous succession, sowing is a widespread method of revegetation [24]. Until now, species-poor standard seed mixtures have often been used for this purpose, resulting in species- and structure-poor vegetation stands [25–27] with a low value for pollinator insects [28,29]. Initial studies indicate that the use of species-rich seed mixtures in the greening of solar parks can increase local pollinator services, which, in turn, have positive effects on biodiversity and agricultural production [8,9,15,30].

Grassland restoration using native seed mixtures has already been tested and put into practice for many vegetation types such as dry grassland [31,32], mesophile meadows [26,33–36], and wildflower strips [37]. Solar parks have been built on land that was previously used in different ways, e.g., arable land, brownfield sites, military ammunition depots, slag heaps, and waste disposal sites [38–40]. However, the site conditions in solar parks differ significantly from those of typical grassland communities. Inside the solar parks, the microclimate, light conditions, and soil–water balance are modified on a small scale due to changes caused by the solar panels [41–46]. In addition, there are plant-related requirements for the target vegetation, such as a low-growth height, to prevent shading of the panels. These specific site conditions and requirements call for seed mixtures that are specifically designed for solar parks. Thus, solar park seed mixtures must take into account a variety of parameters in addition to those that must be considered for grassland restoration such as soil properties and large-scale climatic conditions. In addition, the suitability of seed mixtures for the promotion of pollinators such as wild bees in solar parks should be systematically evaluated. Although the Pollinator Feeding Index (PFI) developed by Schmidt et al. [47] can be used to assess the supply of feeding resources of already-established vegetation stands with regard to provided pollen and nectar resources, there is currently no index that can be used to easily assess the suitability of native seed mixtures in providing feeding resources for wild bees. Therefore, we aim to (i) establish criteria for the composition of bee-friendly site-adapted seed mixtures for solar parks, (ii) develop an index for determining the value of native seed mixtures in promoting pollinators, especially wild bees, and (iii) apply this index using mixtures that are specifically designed for solar parks as an example.

2. Derivation of Criteria for the Composition of Bee-Friendly Site-Adapted Seed Mixtures for Solar Parks

We used a multi-step approach to compose bee-friendly seed mixtures for the greening of solar parks (Figure 1). Beginning with a basic species pool, each step applies specific criteria to filter the species selection from the previous step.

Step 1: General criteria for solar parks

The general criteria for solar parks are applied to a pool of native grasses and forbs. In this step, two criteria are used to filter out a selection of species that are generally suitable for grasslands in solar parks. In general, species covering a wide range of grassland communities can be used. Due to the extensive vegetation management usually implemented in solar parks [23], as well as the partially lower light availability [48,49], species of fringe communities should also be used. In order to ensure year-round maintenance of the technical systems and avoid shading the panels, which could reduce the energy yield, the growth height of the species used must not be higher than the lower edge of the panels [50]. As the lower edge is usually about 80 cm high, only low- to medium-growth-height species should be included in mixtures for solar parks.

Step 2: Site-specific requirements

When applying seed mixtures in grassland restoration practices, the use of regional species of certified provenance is recommended and usually applied [32,51–55]. The same should generally apply to the greening of solar farms if it is not already regulated by laws or requirements. Regional species are grassland and fringe species that are typical for the region. In Germany, for example, these would be the natural units, according to Ssymank [56], in which the solar park is being built or were once typical.

The exclusive use of seeds of regional provenance maintains the integrity of the local gene pool and ensures the development of vegetation stands with typical regional characteristics [36,57–59]. In this way, genetically diverse plant populations can be established at the natural level of genetic differentiation [57]. Furthermore, it has been proven that provenance selection does affect pollinator abundance and diversity in the sown vegetation stands [53,60]. Due to the comparatively large area of solar parks and the corresponding high demand for available regional seed, the use of seed directly harvested from natural stands is usually not possible [61], and certified seed produced for restoration should be used. Certification schemes for seeds of regional provenance already exist in many

European countries, including Germany, Austria, Italy, and France [62]. In addition to the ecological benefits of using regional seed, in some countries, it is even legally obligatory to do so. For example, in Germany, the use of regional seed has been mandatory for the restoration of grassland in the open landscape since 2020 [54].

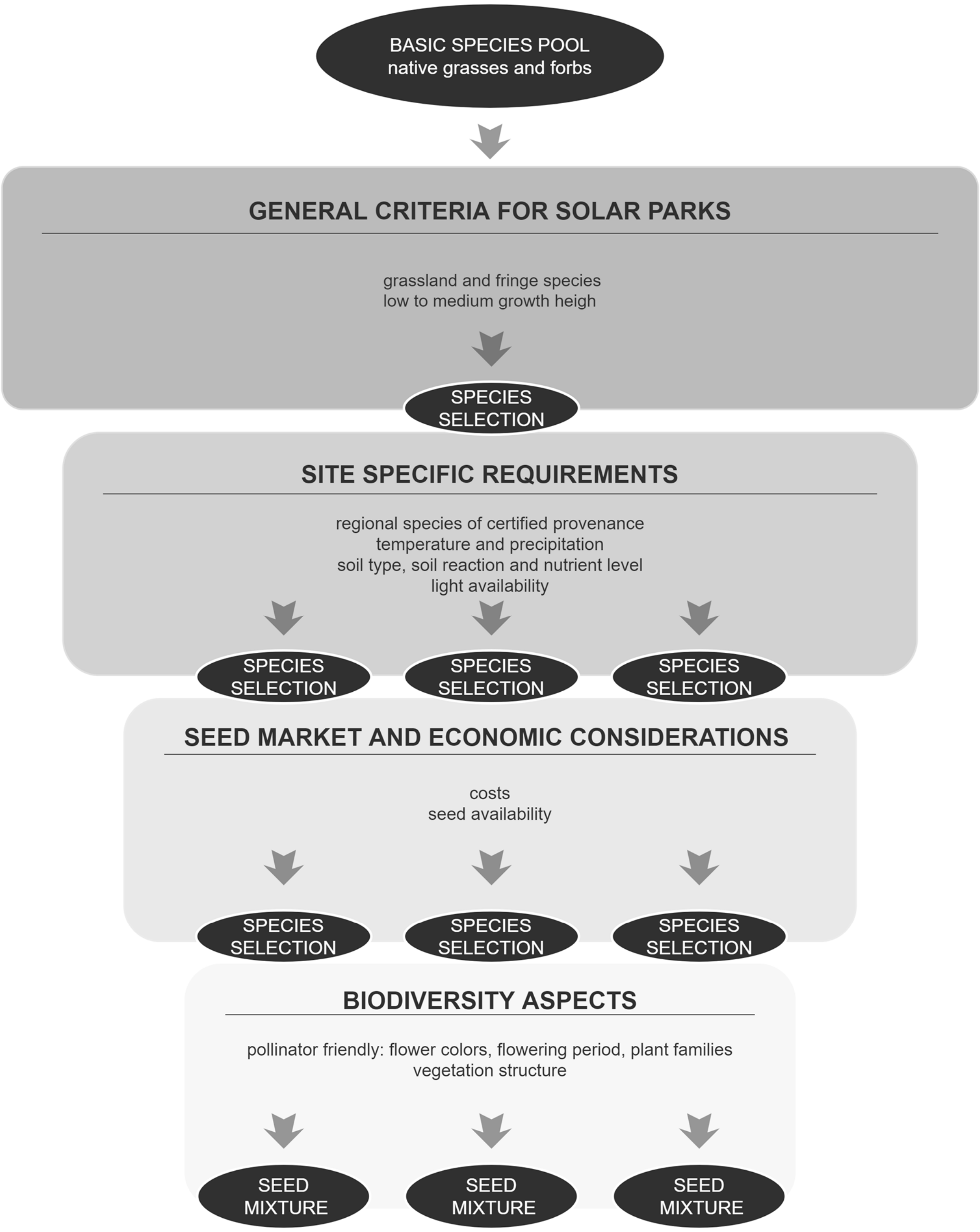

Figure 1. Multi-step concept for the design of bee-friendly native seed mixtures for solar parks.

Specific climatic conditions are essential for the occurrence of plant species [63]. Therefore, the local conditions with regard to temperature and precipitation must be taken into account when selecting species. It should also be considered that the distribution of precipitation can vary over small areas due to the modification with solar panels [43]. As a result, certain parts of the area to be sown may benefit less from precipitation than regionally expected, even in areas with high precipitation. On the other hand, season-dependent lower evapotranspiration under the panels has an effect on the soil–water balance [45,64], but it does not fully compensate for the differences in precipitation [65].

Soil properties also influence the occurrence of species [63,66], but their variation is on a much smaller scale compared to climatic conditions. Therefore, soil properties should be analyzed for each solar park individually. These include the soil type, soil reaction, and nutrient content. When solar parks are built on sites with high nutrient content, soil properties can present a specific challenge. This can cause species to grow taller than predicted [67,68], potentially leading to shading of panels or the dominance of a few fast-growing species that outcompete the majority of sown species. Another factor that influences soil parameters and consequently species selection is the previous land use. In addition to previously intensive arable land, solar parks are also built on de-sealed soil and contaminated sites, e.g., covered ash heaps or waste disposal sites [38–40].

Compared to typical grassland communities, the small-scale changes in light intensity caused by the solar panels create challenges. In particular, the row spacing of the module arrays, depending on the installation, has a significant impact on light availability. The reduced light availability in certain parts of the installation affects the species composition [45,69,70]. Therefore, native seed mixtures for solar parks should contain not only light-demanding species but also species with a preference for semi-shaded conditions.

Step 3: Seed market and economic considerations

The costs for regional seed of certified provenances are significantly higher compared to conventional seed due to high production costs and increased demand in some countries [71,72]. The prices of regional seed mixtures vary significantly according to the reference region, number of species included, species composition, and quantity of diaspores or weight percentage [71–73]. Species that are more complex to propagate and harvest are significantly more expensive compared to those that can be propagated easily on large fields [72,74].

The availability of native seeds from regional provenances varies both between countries and regions [71,75]. In Germany, the legal prohibition on sowing non-native seeds in the open landscape [76] has further complicated the market situation. The number of seed producers and the quantity of seed available only increases gradually, and commissioning the production of larger quantities of desired species needs to commence several years in advance [77,78].

Therefore, not all species suitable for the respective solar park are available from the region of provenance and cannot be used [79]. The challenge of seed availability is exacerbated by the large quantities of seed required for the greening of solar parks due to the large area to be covered [3,4]. Even easily reproducible species may only be available in smaller quantities than required.

Step 4: Biodiversity aspects

Grasslands with a diverse vertical vegetation structure can be attractive to pollinators due to architectural complementarity [80,81]. In order to build such a diverse vertical vegetation structure, species with varying growth heights should be used according to the previous species selection. As specifically composed mixtures can significantly improve the availability of feeding resources for pollinators, especially wild bees in solar parks [8], special consideration should be given to pollinator-relevant species characteristics. In order to provide feeding resources for a wide range of wild bee species, it is important to select forbs with a wide variety of flower colours and plant families that are adapted to the needs of the local insect communities [82,83]. The selection of plant families should take into account the current state of research and include key plant families known to be important for wild bees such as Asteraceae, Fabaceae, Lamiaceae, and Campanulaceae [82]. In particular, oligolectic wild bees depend on certain plant families or species [82]. Furthermore, it is important to consider not only the nutritional needs of adult species but also those of juvenile stages when composing seed mixtures [84,85]. Seed mixtures should be designed to include species with a long flowering period, which flower at different times throughout the season to ensure continuous resource availability, especially when feeding resources in adjacent habitats become limited [8,83,86,87].

3. Development of a Seed Mixture-Pollinator Feeding Index (SM-PFI)

Based on the already-validated Pollinator Feeding Index (PFI) of Schmidt et al. [47], which assesses the value of already established vegetation stands as a food supply for pollinators, we develop a Seed Mixture-Pollinator Feeding Index (SM-PFI). The SM-PFI is used to assess the potential suitability of native seed mixtures for establishing vegetation stands with high feeding values for wild bees [82].

$$SM - PFI = \sum_{i=1}^{N}(P_i + N_{i)} * flowering\ period * forbs\ \%.$$

Referring to the PFI of Schmidt et al. [47], the SM-PFI is based on the quantification of pollen (P) and nectar values (N). These values represent the pollen and nectar production of the flowering species according to Pritsch [88]. Grass species are excluded from the index, as their pollen seems to have only minor importance for pollinating insects [47]. Nectar is the main food source for adult bees, whereas pollen is the main food source for bee larvae [85]. The pollen and nectar values are calculated by summing the contributions of the species included in the seed mixture.

Considering that a long flowering period and a high percentage of forbs have a positive effect on the abundance of pollinators such as wild bees [82,89], the sum of the quantified pollen and nectar production is multiplied by the flowering period and the percentage of forbs. To assess the duration of feeding resource provision by the seed mixture, the number of months in which at least two forbs from the seed mixture are flowering (number of flowering months per species according to Jäger [90]) is used as the flowering period. The forbs % refers to the weight proportion of all species, excluding species from the plant families Poaceae, Cyperaceae, and Juncaceae in the total mixture.

4. Application of SM-PFI to Seed Mixtures Specifically Designed for Solar Parks

The SM-PFI was tested on 12 native seed mixtures (Tables A1 and 1) with varying species richness and a percentage of forbs ranging from 30 to 100% in solar parks with different conditions (Table A2). The test mixtures were designed according to the presented criteria for the composition of bee-friendly seed mixtures for solar parks. The mixtures included native forbs from several key plant families for wild bees, such as Asteraceae, Fabaceae, and Campanulaceae, and also incorporated a variety of proven attractive native forbs for both polylectic and oligolectic wild bees, as suggested by Kuppler et al. [91].

Table 1. Characteristics of test seed mixtures for three solar parks in Saxony-Anhalt (Germany). The compositions are shown in Table A1. Detailed information on the three solar parks is shown in Table A2.

	Areas with Solar Panels									Marginal Areas without Solar Panels		
Solar Park Number	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Species richness	Species-poor (19–20 species)			Species-poor (19–20 species)			Species-rich (34–37 species)			Species-rich (35–36 species)		
Forbs %	30%			70%			70%			100%		
SM-PFI	120	118	111	279	274	260	515	500	485	762	762	744

As a result, the SM-PFI of the test mixtures clearly differed according to the species richness and forb percentage. Species selection, which differed between the three solar parks due to their very diverse site conditions, had only a minor influence on the index values.

5. Discussion

5.1. Criteria for the Composition of Pollinator-Friendly Site-Adapted Seed Mixtures for Solar Parks

As shown, seed mixtures for the greening of solar parks have to fulfil criteria that are in addition to those of the usual grassland restoration practice. One of the most important criteria for large-scale areas canopied with panels is the maximum growth height of the target vegetation. Since the majority of solar parks that also take biodiversity aspects into account are currently projected with a height of 80 cm from the lower edge of the panels, this value was used as an orientation for the seed mixture concept. However, solar parks with a lower panel under-edge of 60 cm or less will also still be realised. For these parks, a lower target vegetation must be selected and the species selection must be more closely specified in Step 1. In addition, abiotic factors can also influence the growth height of the sown species. Particularly on formerly intensive arable land and contaminated sites (e.g., covered slag heaps or waste disposal sites) on which solar parks are sometimes constructed [38–40,92,93], there may be a high soil nutrient surplus, which can lead to above-average plant growth. This problem can be addressed by adapted, more intensive management, which usually results in higher costs and negative effects on biodiversity, especially due to lower attractiveness for pollinators [94].

Species-rich regional seed mixtures with a high percentage of forbs are usually expensive [71,72,95]. If the budget is limited, one solution may be to reduce the seed rate of expensive species or replace them with less expensive ones. Alternatively, different mixtures can be developed for a solar park, of which only one may contain particularly costly species in the hope that these species will spread throughout the solar park, as described by Török et al. [95], for dry grassland.

Due to the large area of a solar park, which can be up to several hundred hectares in size, seed availability plays a crucial role in the composition of native seed mixtures [79]. Seed availability can vary significantly at the national and regional levels [61,71,75]. Alternative, well-developed techniques, such as revegetation by hay transfer or on-site threshing [34,96], are often not feasible on the required scales and are only viable options for smaller solar farms or sub-areas. The agricultural production of seeds from regional provenances currently appears to be the only option for providing high-quality material for large-scale ecological restoration [78], as required for biodiversity-enhancing solar parks. Although much has been achieved in the field of native seed production in recent years, further research and economic promotion efforts are imperative to develop a market that is adapted to the demand. Currently, a relatively small number of wild plant species are successfully propagated for commercial use, while there are still significant knowledge deficits for many others [97,98]. Especially in solar parks, with their small-scale and differentiated site conditions, species could be established that are not currently used in seed mixtures but have high value for wild bees. By incorporating these species, the attractiveness for oligolectic species, in particular, could be increased through more diversified feeding resources [83,91,99]. Improved availability of seeds from regional provenances would also facilitate better consideration of pollinator-relevant traits, especially the nutrient needs of wild bees, in the design of native seed mixtures. Early-flowering species, in particular, which make an important contribution to extending the flowering period that is important for wild bees [82,89,99–101], are often excluded from native seed mixtures or included in very small quantities due to their limited availability [79]. It is essential to provide spontaneously established species, which often provide important feeding resources for wild bees, especially in spring and winter [47,91,99]. These can be promoted within solar parks through small-scale non-sown sub-areas where the spontaneous succession of, e.g., early flowering perennials, is possible.

The current limited availability of regional seeds can be addressed by developing different mixtures for solar parks. In this approach, small quantities of available species are only sown in sub-areas, whereas other small-scale restoration methods such as spontaneous succession and hay transfer are used to complement the planting process [95,102]. Depending on the size of the area, this approach offers the possibility to establish various vegetation stands, which can lead to a significant increase in plant species numbers and feeding resources for wild bees within a confined spatial context [103]. In German-speaking countries, native seed mixtures have recently become available for solar parks [104,105]. These are characterised by a high number of species, which is beneficial for pollinators, and a species selection adapted to the local insect community [88]. They usually contain a relatively lower percentage of forbs and a higher percentage of grasses (measured by weight). Although the high percentage of grasses reduces the cost of the mixtures, a more grass-dominated target vegetation is expected. According to Schubert et al. [82], this may have a potentially negative impact on the abundance of wild bees. Furthermore, the mixtures offered contain species such as Verbascum spp., which are unsuitable for the inter-row areas of most solar parks due to their tall growth. Even though ready-made seed mixtures are a starting point, these mixtures should certainly be further refined and optimally adapted to the conditions of each individual solar park.

Wild bee-friendly seed mixtures are also important in agrivoltaics (e.g., on fruit crops), where their performance directly on-site is desired [106]. However, due to different technical requirements, the criteria for these plants need to be adjusted. For example, in conventional stilt-mounted systems installed over fruit crops, the height of plant species does not need to be considered for the potential shading of the panels.

Feeding resources for wild bees are just one measure to promote pollinator insects. Numerous other aspects must be considered for a pollinator-friendly design of solar parks. In addition to adapted management, the requirements of the different roles and life stages of various non-bee pollinators [84,85,89,107,108] must also be taken into account. Besides wild bees, many other pollinator insects such as Diptera and Lepidoptera make important contributions to the regulating ecosystem service of "pollination" [89,109,110]. These species groups have very different requirements [84,108,109], which can often only be met with a complex and diverse target species concept.

If there are target species concepts for local pollinator species specific to solar parks, these should, of course, also be taken into account in the composition of seed mixtures according to the current state of research with regard to the special nutritional needs (including the quality of the feeding resources and all related factors) of the corresponding target species. When formulating target species concepts for pollinator species, the deficiencies in the food provided by the surrounding landscape should also be taken into account [111].

5.2. Seed Mixture-Pollinator Feeding Index (SM-PFI)

In order to harness the potential of solar parks for promoting pollinators, one measure is to consider the provision of feeding resources, which are essential for the presence of pollinators such as wild bees [91], when planning the solar park and the seed mixtures to be applied therein. The developed Seed Mixture-Pollinator Feeding Index (SM-PFI) allows for the assessment of native seed mixtures in terms of their potential suitability as feeding resources for wild bees. It serves as a useful extension of the Pollinator Feeding Index (PFI) developed by Schmidt et al. [47]. The PFI by Schmidt et al. [47] has been validated for assessing the species richness and abundance of wild bees [82]. It can be assumed that the application of seed mixtures with a high SM-PFI would result in the establishment of vegetation stands with a high PFI, as suggested by Schmidt et al. [47]. Therefore, this would contribute to promoting the species richness and abundance of wild bees. A requirement for the valid application of the SM-PFI is that all species must be included in the mixture in proportions that allow for long-term establishment. Additionally, the sowing process should be carried out using approved methods. The main difference between the two indices is that the PFI uses the cover of forbs established in the vegetation stand to determine the pollen and nectar values of individual species, whereas the SM-PFI treats all species included in the mixture equally. Weighting based on seed number percentage or weight percentage was not used to prevent individual species from having a disproportionate effect on the index. If weighted based on weight fraction, species with heavy seeds, such as *Agrimonia* spp. and *Lathyrus* spp., would be overemphasised, even though they do not represent the target vegetation more than other species. In contrast, when weighted based on seed number proportion, small-seeded species such as *Campanula* spp., which are included in the mixture with a high seed number, would strongly influence the SM-PFI, although small-seeded species are less likely to establish successfully compared to large ones [112]. In addition, mixtures are often calculated using weight percentages, and the percentage of diaspores is not always known. The absence of weighting for individual species also results in a greater emphasis on the number of forbs when summing the pollen and nectar values. The number of forbs is considered an important parameter for bee attractiveness, as it positively affects the number of species and can specifically enhance the number of oligolectic wild bee species [87,91,99]. The flowering period and percentage of forbs were included as factors in the formula because they are instrumental in the temporally staggered provision of food [8,82,83,86,87,103]. In order to develop an easy-to-understand and easy-to-use index, the focus was on the most important parameters for the enhancement of wild bees, whereas other influencing factors, such as the flower colour, diversity of plant families, and nutrient quality, were excluded. If target species concepts for local pollinator species exist for specific solar parks, the index can complement these concepts but it should not be relied on as the sole tool. In such cases, additional tools and approaches are required to address factors such as nutrient quality, which are not included in the index but are also of major importance [107,109,111]. The SM-PFI is only designed to assess the potential of seed mixtures in creating a vegetation stand that is attractive to pollinators such as wild bees but it cannot assess the actual value of the resulting vegetation. For example, in addition to the sown species, the resulting vegetation stand may contain spontaneously established species that can also contribute significantly to wild bee enhancement [87,113] but are not considered by the SM-PFI. Consequently, the values of the SM-PFI should not be directly compared with those of the PFI according to Schmidt et al. [47]. Furthermore, in addition to the introduction of a high-quality seed mixture with an appropriate sowing rate, the success of establishing a pollinator-attractive vegetation stand depends on many other factors such as proper seedbed preparation [114] and adapted management (cutting frequency, timing, technique) [115–117]. Challenges in applying the SM-PFI may arise due to an insufficient database. Unless pollen and nectar values [88] are available for those species in the mixture in the aggregated data, the calculation of the SM-PFI may become laborious, or if values are missing, it may provide an incomplete picture of the potential of the mixture. Therefore, all forb species that are successfully propagated should be evaluated with regard to their nectar and pollen supply. As shown by the test mixtures for solar parks, the index is suitable for evaluating seed mixtures for a wide range of sites. Its transferability to other potentially bee-friendly vegetation stands, such as field margins or urban wildflower meadows, can be assumed. The index proves particularly valuable for evaluating seed mixtures for wild plant structures in the agricultural landscape, e.g., field margins and wildflower strips in agrivoltaics, where pollinator services directly on-site are desired. However, the index should not be applied to seed mixtures containing cultivars and non-native species. The index is based on the assumption that regional wild plant species, to which local wild bee communities are adapted, are utilized.

6. Conclusions

When designing bee-friendly seed mixtures for solar parks, a variety of criteria must be taken into account beyond the usual practice of restoring typical grassland plant communities. Due to the often-large spatial dimensions of solar parks, seed availability is currently a decisive factor for determining the compositions of seed mixtures. With better availability of regional seeds, biodiversity-promoting aspects can be given greater consideration, leading to increased ecosystem services. As long as regional seeds remain scarce, more flexibility is needed in terms of combining different seed mixtures and revegetation practices to promote bee-friendly solar parks. In order to exploit the potential of solar parks in promoting pollinator-linked ecosystem services in the long term, additional plant species that are particularly suitable for pollinator promotion must be identified and regionally propagated.

The Seed Mixture-Pollinator Feeding Index (SM-PFI) provides an easy-to-use tool for assessing the potential suitability of seed mixtures for establishing vegetation stands in solar parks as a food source for wild bees. The SM-PFI can also be applied to the assessment of native seed mixtures for wildflower stands in agrivoltaics and various other vegetation stands.

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Appendix A

Table A1. Compositions of test seed mixtures for three solar parks in Saxony-Anhalt (Germany), specifying all parameters required for the Seed Mixture Pollinator Feeding Index (SM-PFI). Values of nectar (N) and pollen (P) indices range from 0 = no productivity (or not relevant for wild bees) to 3 = high productivity [88,118,119]. Grasses (G), forbs (F), and flowering months are presented according to Jäger [90]. Flowering period means the number of months in which a minimum of two forbs are flowering.

																			Areas with Solar Panels							Marginal Areas without Solar Panels *		
															Solar Park Number	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
															Species Richness	**Species-Poor (19–20)**			**Species-Poor (19–20)**			**Species-Rich (34–37)**			**Species-Rich (35–36)**		
															Forbs (Weight %)	**30%**			**70%**			**70%**			**100%**		
															Flowering Period	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**6**	**6**	**6**
G/F	**N**	**P**	**Flowering Month**												**SM-PFI**	**120**	**118**	**111**	**279**	**274**	**260**	**515**	**500**	**485**	**762**	**762**	**744**
			J	F	M	A	M	J	J	A	S	O	N	D	Species												
G															*Briza media*		x			x		x	x				
G															*Festuca rubra*	x	x	x	x	x	x	x	x	x			
G															*Festuca rupicola*	x	x		x	x		x	x	x			
G															*Phleum phleoides*	x			x			x	x				
G															*Poa angustifolia*			x			x			x			
G															*Trisetum flavescens*			x			x			x			
F	1	2						x	x	x	x	x			*Achillea millefolium*	x	x	x	x	x	x	x	x	x	x	x	x
F	2	2						x	x	x	x				*Agrimonia eupatoria*	x	x	x	x	x	x	x	x	x	x	x	x
F	2	1					x	x	x	x					*Ajuga reptans*							x	x				

Table A1. *Cont.*

												Areas with Solar Panels									**Marginal Areas without Solar Panels ***		
											Solar Park Number	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
											Species Richness	**Species-Poor (19–20)**			**Species-Poor (19–20)**			**Species-Rich (34–37)**			**Species-Rich (35–36)**		
											Forbs (Weight %)	**30%**			**70%**			**70%**			**100%**		
											Flowering Period	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**6**	**6**	**6**
G/F	**N**	**P**	**Flowering Month**								**SM-PFI**	**120**	**118**	**111**	**279**	**274**	**260**	**515**	**500**	**485**	**762**	**762**	**744**
F	2	2			x	x	x	x			*Anthyllis vulneraria*											x	
F	2	1			x	x	x				*Barbarea vulgaris*									x	x	x	x
F	3	1					x	x			*Betonica officinalis*							x	x	x	x	x	x
F	2	2				x	x	x	x		*Campanula rapunculoides*							x	x	x			
F	1	1	x	x	x	x					*Cerastium holosteoides*	x	x	x	x	x	x	x	x	x			
F	3	3					x	x	x	x	*Cichorium intybus*									x	x	x	x
F	2	1					x	x	x		*Clinopodium vulgare*							x	x	x	x	x	x
F	2	2			x	x	x	x			*Crepis biennis*										x	x	x
F	2	2				x	x	x	x		*Daucus carota*	x	x	x	x	x	x	x	x	x	x	x	x
F	1	2				x	x	x	x		*Dianthus carthusianorum*		x			x		x	x		x	x	x
F	3	2					x	x			*Dipsacus fullonum*										x	x	x
F	3	2			x	x	x				*Echium vulgare*										x	x	x
F	2	1					x	x	x		*Falcaria vulgaris*										x	x	x
F	0	3				x	x				*Filipendula vulgaris*							x	x		x	x	x
F	1	1				x	x	x	x		*Galium album*			x			x	x	x	x	x	x	
F	1	1				x	x	x	x		*Galium verum*	x	x		x	x		x	x				
F	1	1			x	x					*Galium wirtgenii*									x			x
F	1	2				x	x	x	x	x	*Helianthemum nummularium*								x				
F	0	3					x	x			*Hypericum perforatum*	x	x	x	x	x	x	x	x	x	x	x	x
F	2	2				x	x	x	x		*Hypochaeris radicata*							x	x	x			
F	1	1					x	x			*Knautia arvensis*							x	x	x	x	x	x
F	2	1				x	x	x			*Lathyrus pratensis*												x
F	2	1				x	x	x			*Lathyrus tuberosus*										x	x	
F	2	1				x	x	x	x		*Leonurus cardiaca*										x	x	x
F	2	1				x	x	x	x	x	*Leucanthemum vulgare*	x	x	x	x	x	x	x	x	x	x	x	x
F	2	1				x	x	x	x	x	*Linaria vulgaris*	x	x	x	x	x	x	x	x	x	x	x	x
F	3	1				x	x	x			*Lotus corniculatus*	x	x	x	x	x	x	x	x	x	x	x	x
F	2	2			x	x	x				*Lychnis viscaria*	x			x			x			x		
F	2	1				x	x	x	x	x	*Malva moschata*										x	x	x
F	2	1				x	x	x	x	x	*Malva sylvestris*										x	x	x
F	3	2					x	x	x		*Origanum vulgare*	x	x	x	x	x	x	x	x	x	x	x	x
F	0	3			x	x	x	x	x		*Plantago media*							x	x	x			
F	1	2				x	x	x	x	x	*Potentilla argentea*							x	x	x	x	x	x
F	1	2		x	x	x					*Potentilla neumanniana*	x	x	x	x	x	x	x	x	x			
F	1	2				x	x	x			*Potentilla reptans*							x	x	x			
F	2	1				x	x	x	x		*Prunella vulgaris*	x	x	x	x	x	x	x	x	x	x	x	x
F	1	1			x	x	x				*Ranunculus bulbosus*							x	x				
F	1	1			x	x	x				*Ranunculus lanuginosus*	x		x	x		x	x		x			
F	2	3			x	x	x	x	x		*Reseda lutea*											x	

Table A1. *Cont.*

G/F	N	P	Flowering Month								Areas with Solar Panels									Marginal Areas without Solar Panels *		
										Solar Park Number	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
										Species Richness	**Species-Poor (19–20)**			**Species-Poor (19–20)**			**Species-Rich (34–37)**			**Species-Rich (35–36)**		
										Forbs (Weight %)	**30%**			**70%**			**70%**			**100%**		
										Flowering Period	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**6**	**6**	**6**
										SM-PFI	**120**	**118**	**111**	**279**	**274**	**260**	**515**	**500**	**485**	**762**	**762**	**744**
F	2	3			x	x	x	x		*Reseda luteola*										x		x
F	3	1		x	x	x	x			*Salvia pratensis*	x	x	x	x	x	x	x	x	x	x	x	x
F	1	1			x	x	x	x		*Saponaria officinalis*										x	x	x
F	2	1				x	x	x	x	*Scabiosa ochroleuca*							x	x	x	x	x	
F	1	1	x	x	x	x	x	x		*Silene dioica*		x			x		x	x	x	x	x	x
F	1	1			x	x	x	x		*Silene latifolia* subsp. *alba*										x	x	x
F	1	1		x	x	x	x	x		*Silene vulgaris*	x	x	x	x	x	x	x	x	x			
F	3	1			x	x	x	x	x	*Stachys recta*							x	x		x	x	x
F	3	3			x	x	x	x		*Trifolium pratense*	x	x	x	x	x	x	x	x	x	x	x	x
F	1	3				x	x	x		*Verbascum densiflorum*										x	x	x
F	1	3			x	x	x	x		*Verbascum nigrum*										x	x	x
F	2	2			x	x	x			*Veronica maritima*									x			x

* Seed mixtures for marginal areas also contain high-growing species.

Table A2. Test solar parks in Saxony-Anhalt.

Solar Park Number	**1**	**2**	**3**
County	Mansfeld-Südharz	Salzlandkreis	Halle (Saale)/Saalekreis
Size (ha)	2.2	1	13.3
Size covered with panels (ha)	1.3	0.4	6.3
Type of solar panels	Monofacial, south facing	Monofacial, south facing	Monofacial, south facing
Under-edge of the panels (cm)	80	80	80
Inclination of the panels	17°	20°	15°
Distance between module rows (m)	3.1	4	2.4
Previous use	De-sealed soil of former farm buildings	Abandoned area	Ash dump covered with soil substrate
Preparation for seeding	No tillage	Rotary tilling	Rotary tilling
Surrounding land use	Biogas plant, residential and production buildings, non-irrigated arable land	Residential buildings, industrial complexes, abandoned extraction sites (limestone)	Non-irrigated arable land, covered ash dump, industrial complexes

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