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Measuring Biodiversity Improvements at Solar Plant in Blangslev (DK)

Case study for Better Energy's integration of biodiversity into a newly constructed solar plant site, using the Biological Diversity Protocol to assess the scale of impact

By Habitats (Cille Blak), December 2020

"We need to see the challenges before we can scale up the solutions – this holds true for all our efforts. Biodiversity data can be converted into decision making, but only if it is easy to understand and relevant to our business. The Biological Diversity Protocol creates a credible baseline and a context for discussion and further action. The metrics it provides are useful to us on three levels: management decision making, detailed ESG reporting and communication as a powerful tool for raising awareness and gaining support for our efforts.

Driving progress in biodiversity is a collaborative effort, and we need the right partners and tools for moving it forward. Our partnership with Habitats equips us with valuable information and knowledge, but to better incorporate biodiversity into our decision making and processes, we also need a system to assess our impacts. The Biological Diversity Protocol can help us evaluate and strengthen our efforts with biodiversity and frame it in a way that everyone can understand and use."

Rasmus Lildholdt Kjær, Better Energy CEO

Introduction

In Blangslev, Denmark, new methods for sustainability are being developed and explored. Better Energy, a company that builds and operates solar power plants, is on a journey to combine clean energy production with native species and habitat conservation. By including considerations for biodiversity in the construction of the new solar plant in Blangslev, Better Energy has made space to improve the quality of nature[1].

Biodiversity, underpinning the quantity, quality, and resilience of natural capital[2], is declining worldwide, and we are faced with possible consequences that jeopardise our societies. As with climate change, there is an increasing understanding that sustainable business is vital, but the complexity of biological systems makes it difficult to translate the losses and gains of biodiversity, into consistent and comparable data. However, directives, standards, and methodologies are currently being developed.

This case study tests the methodology described in the forthcoming Biological Diversity Protocol (BD Protocol)[3]. The BD Protocol is aligned with the Natural Capital Protocol and uses known principles from accounting to make a consistent, accurate, and transparent methodology to systematically record changes in biodiversity, thus measuring biodiversity impact.

The first part of the case study contains a summary of the project results, followed by an appendix applying the methodology.

Biological Diversity Protocol (BD Protocol): An accounting framework which enables any organisation to record systematically and consolidate net biodiversity impact data.

Biodiversity Footprint (BF): Surface area adjusted for condition. It is further broken down into a Positive Biodiversity Footprint (PBF) and a Negative Biodiversity Footprint (NBF), both expressed in surface area equivalents e.g. 250 ha eq of PBF and 750 ha eq of NBF for a total of 1000 ha.

1 Blangslev solar plant: https://www.betterenergy.com/about-us/biodiversity/

2 Natural capital: The stock of renewable and non-renewable natural resources (e.g. plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people (ecosystem services). Biodiversity underpins healthy natural capital stock and thus the goods and services that benefit people. https://naturalcapitalcoalition.org/biodiversity/

3 The BD Protocol: https://www.nbbnbdp.org/bp-protocol.html

A 61% increase in Positive Biodiversity Footprint (PBF) in 30 years

At the Blangslev solar plant, Better Energy, with the help of Habitats, has implemented eight distinct 'points of impact' within the plant site to improve conditions for biodiversity to develop: the fruit grove, the overlook, the lowland, the forest garden, the flower edge[4], the sandbank, the grassland, and the forest edge. In addition, the site includes the solar panel field, a windbreak surrounding the field and a small existing forest. For measuring the biodiversity impact, the different areas are grouped into their closest approximate type of ecosystem (or use). Figure 1 shows the changes in land use before and after construction of the solar plant.

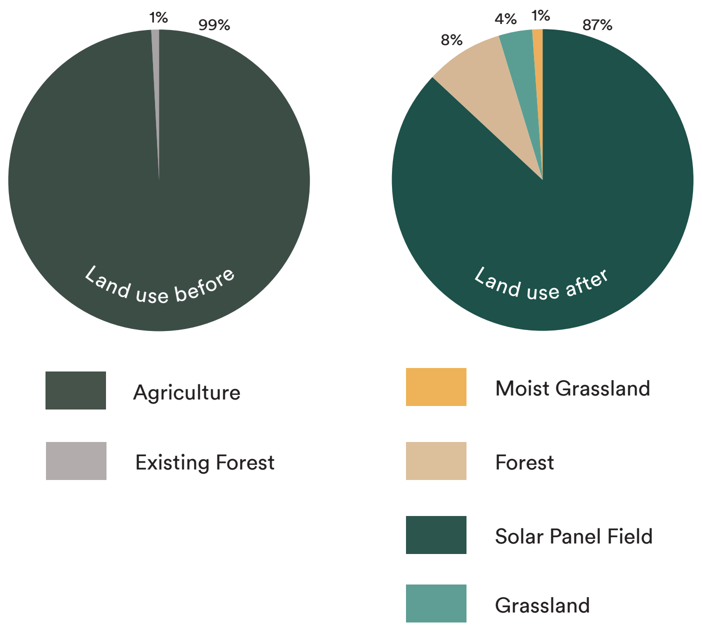

Figure 1. Land use before and after construction of the solar plant.

Ecological succession, the development of species composition in an area, takes time. To illustrate the biological impact of the changed land use the outcome of the biodiversity initiatives in Blangslev is estimated by projecting the results at different stages: right after construction, after 5 years and after 30 years. After conducting a biological assessment and applying the methodology from the BD Protocol, we have shown the results for the different stages are shown in Figure 2. Untouched nature is used as a reference state, according to the method.

The projected achievement of the Blangslev site – 61.1% increase of PBF in 30 years - is a significant improvement for nature, all areas of the site contributed to this increase.

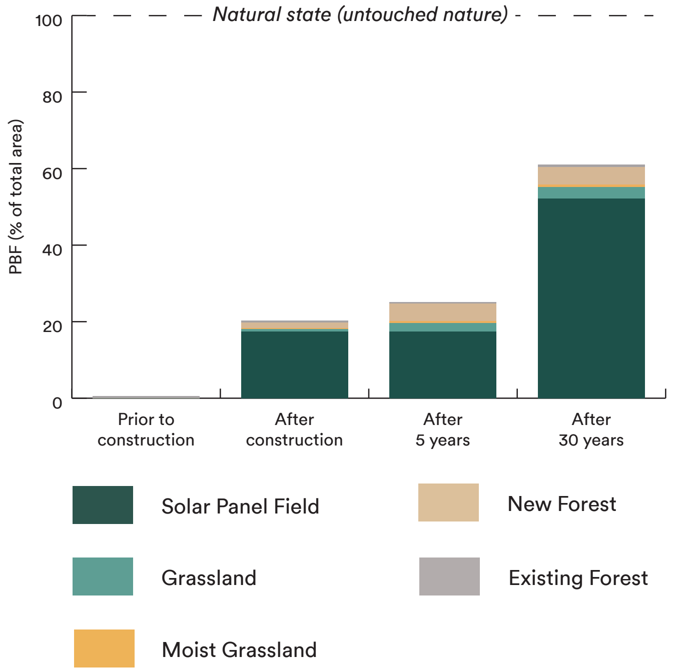

Figure 2. The projected changes in Positive Biodiversity Footprint (PBF) at different stages after construction (% of total area).

The majority of the site is dedicated to the production of solar power (87% of the total area of 67.14 ha). However managing the solar panel field with consideration for biodiversity, causes a profound increase in natural value. The natural areas outside the solar panel field (13%) have a greater biodiversity potential, but this will take time to develop. In the text below, the considerations for each projection are outlined.

Before construction

The land had been used for conventional agriculture and has been managed with drainage, tilling, fertilisation and use of biocides. The small existing forest on the site (0.49 ha) is the reason that the initial score for the site is not completely lacking biodiversity.

After construction

At this point, the solar panel field and the points-of-impact have been established. New trees and bushes have been planted and native seeds have been sown, but no natural succession or habitat establishment have had time to develop.

After 5 years

A variety of native plants are expected to flourish. Trees and bushes have been established, and the microorganisms in the soil have begun to regenerate.

4 More information about the points of impact can be found at Better Energy's homepage: https://www.betterenergy.com/media/1641/be-biodiversity-print.pdf

After 30 years
A variety of plants, bushes, and trees are expected to have developed mature root networks, fungi have been reestablished and soil organisms are thriving. Thus, basic functions of the ecosystems have been restored, providing shelter and food for insects, birds, and animals in the higher levels of the food web. Some of the higher functions, such as a variety of large, grazing animals, predators or natural decomposing of dead animals, are not currently possible in Denmark for various reasons, setting a limit for the total restoration of the ecosystems. Long-lived organisms, like trees, have not yet had time to live a full lifecycle from seed to old tree.

Development of each area / ecosystem

To analyse the biodiversity footprint in further detail, we calculated the footprint for each of the ecosystem types and the solar panel field. Figure 3 shows the expected development during the projected time frames. The appendix provides more information about the assessment of the expected biological development (given as the condition score (CS) for each area), general criteria, and the calculation of the footprint.

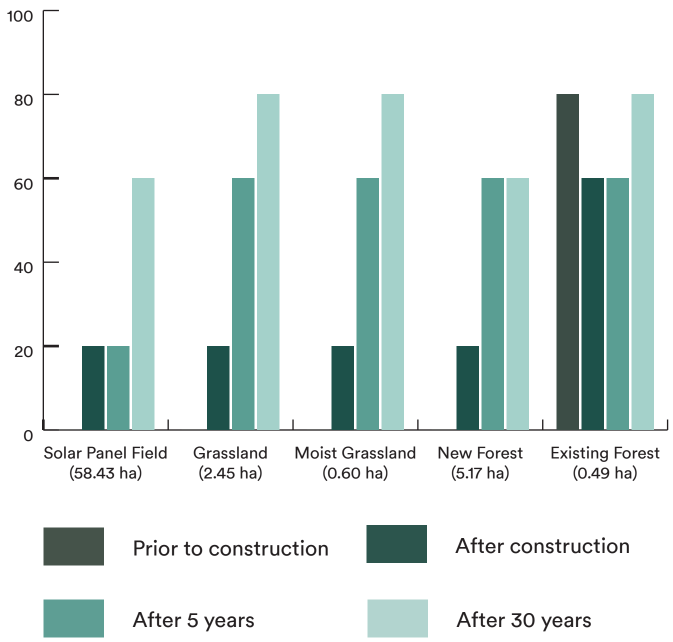

Figure 3. Projected development of Positive Biodiversity Footprint (PBF) for each area/ ecosystem.

Solar Panel Field
The Solar Panel Field will be sown with a mix of grass and clover and grazed by sheep. This change from agriculture is significant. Stopping the use of tilling, fertilisers and biocides, will allow for the soil organisms, such as bacteria, fungi, insects and worms, to develop and provide food for other plants and animals. The use of sheep for maintenance is beneficial to the site in some ways, for example by their movement patterns and droppings. However, overgrazing needs to be avoided by adapting managed grazing or similar systems. The primary purpose of the field is power production which places limits on the extent of natural development due to factors such as growth height, access for panel maintenance and shade. Also, site characteristics, such as the lack of natural hydrology and a variety of larger animals (upper functions of the ecosystem), also limit development. The next major step to reach a positive footprint of 60% (CS 3) in 30 years would be to promote a more species-rich ground cover of local plants and herbs.

Grassland and Moist Grassland
The Grassland, Moist Grassland, and sandy area are points of impact, which should be able to reach a positive footprint of 80% (CS 4) within 30 years. Nutritious topsoil has already been removed and a mix of local plants has been sown, which should provide slow-growing perennial plants with an advantage and enable them to develop naturally over several seasons. Due to the absence of large animals some ecosystem functions like grazing, will have to be mimicked by maintenance for example by removing hay. The main factor preventing a higher rating is the lack of natural hydrology.

New Forest
The New Forest ecosystem consists of the windbreak and the remaining points of impact. Since these areas are newly planted, no old living trees are present, and it will take 150-1000 years for these newly planted trees to complete a single or a few lifetimes. Some of the ecosystem functions of old trees may be mimicked, for example by the placement of dead wood and perhaps by the veteranisation[5] of selected trees as they grow older. As for the rest of the site, there is no natural hydrology, which prevents reaching a positive footprint that is higher than 60% (CS 3) in 30 years.

Existing Forest
After construction, the Existing Forest is located within the fence, limiting access for larger wild animals, such as deer, which reduces the positive footprint. The small size of the forest limits the deep forest variety, and there is a lack of natural hydrology, also limiting the final rating. However, the Existing Forest already has mature forest vegetation and older trees, which should allow the area to reach a positive footprint of 80% (CS 4) in 30 years. This score is dependent on mimicry through maintenance of natural disruption from a variety of larger animals.

5 Veteranisation: Simulating natural disruption of trees to enhance the development of e.g. hollows and broken branches for birds, bats, fungi, and insects.

Improving biodiversity conditions

Improving the conditions for biodiversity is a continues effort and not all biological solutions are applicable everywhere. Legislation, resources or concerns from stakeholders may significantly influence final solutions. However, the questions raised, the discussions held and the obstacles encountered in the process are important to creating biodiversity awareness and finding best practices.

Monitoring of ecosystem and species development

Preferably, the monitoring of the biological development of the site should be done annually and during different seasons to map the development of the ecosystems and include species, selected according to method, as they inhabit the site. To make this monitoring manageable, we recommend selecting a few KPI's to measure annually and then performing a more thorough biological screening at longer intervals, e.g. every five years.

We especially recommend a basic ongoing monitoring of plant composition, as this composition most accurately indicates if the ecosystems are developing as desired. Some amphibians, bats and birds already live on site and with the improved conditions and designated habitats more can be expected to migrate as the landscape develops. Periodic screenings for animals, enables the monitoring of animal composition and red-listed species development.

Contribution to Denmark's national biodiversity targets

At the Blangslev site, Better Energy has created an area with improved conditions for wildlife habitats to develop. A large area has been taken out of farming, and soil organisms will benefit from undisturbed soil without fertilisers and biocides. The site is located in a farmed landscape with several small biotopes throughout the area. Adjacent to the area is Snesere Å, a stream that connects the site to the nearby wet meadows and related nature types.

Denmark is home to about 30,000 species of plants, fungi and animals[6].

6 https://www.cbd.int/countries/profile/?country=dk#facts

Danish biodiversity is nowadays in net decline. Currently, 10,662 species in 28 major species groups have been assessed according to IUCN Red List criteria, and 4,439 or 41.6% of these have been red-listed[7]. In agricultural ecosystems, trends are negative for several species of farmland birds, brown hare, vascular plants of small biotopes, butterflies, bumblebees and beetles. The area occupied by open habitat types, such as commons, heaths, bogs and dunes are also decreasing.

After construction of the solar plant, the vegetation at the Blangslev site will develop over time, without regular farming-related disturbances. This will increase the area of suitable habitat for the local flora and fauna, and thus functionally closes the gaps between the small biotopes and the larger landscape context. Small biotopes rank among the most culturally influenced and impoverished nature in Denmark. The issues caused by farming, in the form of eutrophication, pesticides, drainage and overgrowth, have multiplied in the small habitats due to the direct contact to the cultivated areas[8]. The points of impact in Blangslev support a more natural species composition from the start. This will contribute to Denmark's current biodiversity goals, notably Measure 3 "Nature conservation plans will create a better and more connected countryside" and Measure 7 "New habitats for the benefit of biodiversity and climate"[9] [10].

About the case study

This case study has been prepared in collaboration between Habitats Aps[11] and Joël Houdet from the Biological Disclosure Project of the Endangered Wildlife Trust[12].

This study has been performed for a specific site, but it can be extended to provide data for a complete biodiversity business strategy, including red-listed species, targets and annual reporting, across all directly controlled business activities.

7 Red-List 2019: https://bios.au.dk/forskningraadgivning/temasider/redlistframe/roedliste-2019/roedlistestatus/fordeling-paa-artsgrupper/

8 https://dce.au.dk/udgivelser/vr/nr-101-150/abstracts/nr-143-smaabiotoper-2007-og-2013-novana/

9 A total of 25,000 ha of new nature areas should be established by 2020 and the value of nature should be improved at 125,000 hectares inter alia through prohibiting the use of pesticides and fertilisers on 35,000 hectares of meadows, heaths and other protected areas. https://biodiversity.europa.eu/countries/denmark

10 Danish Nature Policy: https://www.cbd.int/doc/world/dk/dk-nbsap-v2-en.pdf

11 Habitats: https://www.habitats.dk/

12 Biological Disclosure Project: https://www.nbbnbdp.org/

Figure 4. The fruit grove is one of the eight points of impact at Blangslev Solar Plant. Native species of fruit bearing trees and bushes ensure flowers for nectar seeking insects as well as fruits and berries for both people and animals. The yellowhammers will use the dense bushes as hiding places for their nests, and male yellowhammers will perch and sing in the tree tops.

Appendix - Methodology

The Biological Diversity Protocol (BD Protocol)[13]

The BD Protocol has been developed to provide companies with an accounting and reporting framework which helps consolidate biodiversity impact data in a standardised, comparable, credible and unbiased manner. The BD Protocol further aims to enable any organisation to identify, measure, account for and manage its impacts on biodiversity for various business applications, e.g. modeling of future scenarios, monitoring, and setting targets.

The BD Protocol provides accounting foundations[14] to systematically record and consolidate net biodiversity impact by adapting double-entry bookkeeping, which originates in financial accounting. It is based on seven accounting and reporting principles: relevance, equivalency (compare like-to-like), completeness, consistency, transparency, accuracy and time period assumption. The outcome of the protocol is the Statements of Biodiversity Position and Performance, which quantify the state and changes in ecological systems and result in the Biological Footprint.

In this analysis, the following tasks were undertaken:

- Identifying the different ecosystem types on the property and assessing their surface areas (Table 2).
- Assessing their condition according to the scoring system (Table 2).
- Recording accounting journal entries for biodiversity gains and losses (Table 3).
- Producing Statements of Biodiversity Position and Performance to show consolidated impact data for the whole project (Table 4 and 5).

The metrics used to express the results of the protocol are given as surface area (ha) and surface area equivalent (ha eq). Because of the complexity of ecosystems, there is no one single metric (like a financial value in accounting). The surface area (ha) measures the actual total area of the measured ecosystem. The surface area equivalent (ha eq) is a condition-adjusted value in which the quality of the ecosystem is taken into account. Please see “Recording journal entries for biodiversity gains and losses” below for further details.

Validity and triggers for re-assessment

The assessment of the Biological Footprint has time-limited validity and will change, for example, as habitats develop or use of the site is changed. Therefore, situations of a reasonable significance should trigger a re-assessment of biological impacts, including changes at the site, organisational changes in biodiversity strategy or changes in the used assessment methodologies. An annual update is also recommended as part of consistent reporting of biodiversity.

BD Protocol applied to Blangslev Solar Plant

Scope

This analysis is limited to the directly controlled, geographical location of the Blangslev solar plant, not including the value chain of the solar panels. It provides a momentary status of the existing biodiversity conditions and future impacts that can reasonably be expected to occur since the project is already under construction.

At this point, specific species have not been included as a category in the report, primarily due to the starting conditions of the site. However, as the ecosystems develop, a diverse biota, including red-listed species, is expected to inhabit the areas, which increases the relevance of including them in a follow-up assessment of the natural capital. A framework for assessment of species is included in the BD Protocol.

Blangslev solar plant and the eight points of impact

The landscaping of Blangslev, developed with the aim of supporting greater biodiversity, was carefully researched and planned in the context of the surroundings. After a thorough local environmental study, Habitats suggested eight distinct biodiversity ’points of impact’ to be incorporated in and around the solar plant site, to improve local conditions for flora and fauna to thrive and spread over the coming years. In addition to the eight points of impact, the area accommodates the solar panel fields and a five-meter-wide windbreak to shelter the area. Figure 5 shows the site and the points of impact[15].

Over time, the composition of species in an area will develop, a process called ecological succession. Species will immigrate, establish populations, and complete several lifecycles while serving an increasingly interconnected function in the ever-changing ecosystems. Some organisms, like trees, have lives spanning hundreds of years, and the intricate soil networks of their roots, fungi, bacteria, and invertebrates develop and change over time. At Blangslev, the aim is to conduct business while supporting local

13 https://www.nbbnbdp.org/bp-protocol.html

14 https://www.sciencedirect.com/science/article/abs/pii/S2212041620300462

15 More information about the points of impact can be found at Better Energy’s homepage: https://www.betterenergy.com/media/1641/be-biodiversity-print.pdf

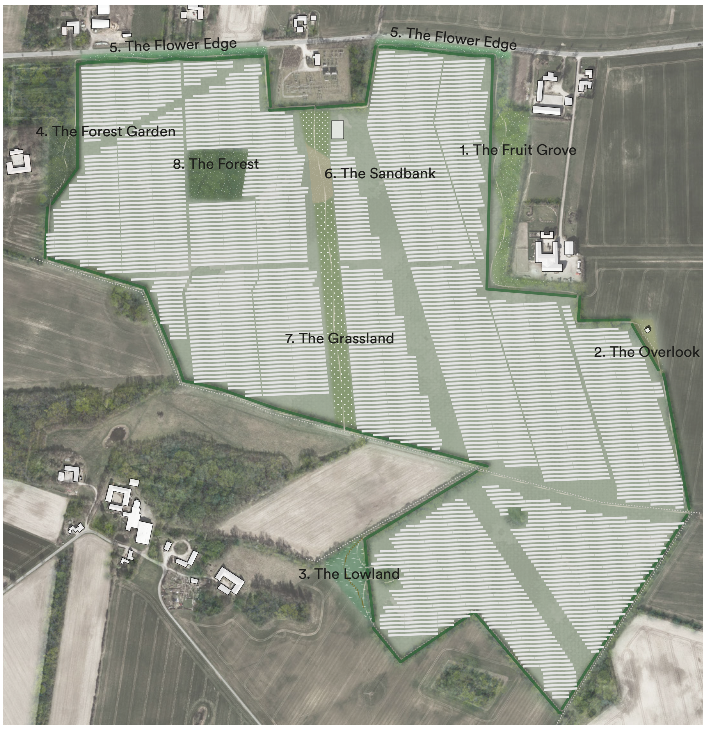

Figure 5. Outline of the solar panel field surrounded by windbreak and the eight points of impact.

biodiversity: species and habitats. Careful researching and planning the of landscaping at Blangslev promotes the reversal of certain man-made changes, thus providing an improved platform for ecological succession to reach a local variety of species and habitats.

Project stages

To show the net biodiversity impacts over time, the BD Protocol recommends compiling a biodiversity statement of position for each stage of the project: before construction, after construction, 5 years after construction, and 30 years after construction, since natural habitats take time to develop. In addition to the project stages, a reference state is included in the assessment, describing the area untouched or the natural condition of the area.

Identifying ecosystem types

To assess the Biodiversity Footprint, we consider the development of the land by examining the two main approximated types of ecosystems at the site: Forest and Grassland (including Wet Grassland and the Solar Panel Field).

The *forest ecosystem* is the nearest approximated nature type of the existing forest and some of the points of impact: the newly planted forest edge, the fruit grove, the forest garden, and the windbreak. All the newly established forest areas will be planted with a variety of native trees and bushes, providing habitat and food for a range of insects, birds, bats and other animals. This ecosystem type is increasingly important in the Danish agricultural landscape due to a general loss of windbreaks, trees, and bushes.

The *grassland and wet grassland ecosystems* are the nearest approximated nature types of the solar panel fields and the remaining points of impact: the overview, the grassland, the lowland, and the sandy areas. These ecosystem types are defined as nutrient-poor grass-dominated vegetation types and are often important habitats for many species of plants and insects, some endangered by the effects of recent land-use changes of former pastures on the vegetation structure. Management of grasslands includes periodical grazing and haymaking to maintain the light conditions and improve vegetation heterogeneity as an effect of animal manure and grazing patterns. The dry grassland sites at Blangslev are, however, all nutrient-rich at the moment, due to the former agricultural land-use, and will need to be managed to remove nutrients from the soil, to encourage more biodiverse vegetation. The lowland includes the lowest elevation points of the managed site, where water accumulates periodically, creating soil-conditions that are similar to wet grassland. Marl pit west is located in conjunction with the lowland, some of the growth around it will be removed to allow for more sunlight exposure for the water, to improve conditions for the amphibians.

The selected ecosystem types are used to produce the reference state for the BD Protocol (see below).

Figure 6. Construction of the lowland in september 2020. The nutrient-rich top soil is removed to expose the underlying nutrient-poor sandy soil which will encourage biodiverse vegetation.

Assessing surface area and condition score for each ecosystem

Since the biological quality of ecosystems can vary significantly, a condition score (CS), based on a biological assessment, is assigned to each ecosystem at different stages in the project. The biological assessment of the ecosystem condition is based on the landscaping research done by Habitats, including several on-site visits by a biologist. A number of factors have been considered for the assessment, including the variety and composition of biota, ecosystem functions and disruptions, ecosystem diversity, soil and hydrology, and the size and surroundings of the site.

Rating		Description
5	Natural	No change in natural habitat, biota, and ecosystem processes have occurred (e.g. full trophic cascades and predator/ prey dynamics). No ongoing human impact. Natural hydrology.
4	Largely Natural	Small changes in natural habitat and biota may have taken place, but the ecosystem function is essentially unchanged. Variety and natural composition of species. A few natural dynamics may be mimicked as part of restoration.
3	Moderately Modified	Losses and changes of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged. Some natural dynamics may be mimicked as part of restoration.
2	Largely Modified	Losses and changes of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged.
1	Seriously Modified	Large losses of natural habitat, biota and basic ecosystem functions have occurred. Stands of alien species. Some effort to contain or rehabilitate the area has been made.
0	Transformed	Complete losses of natural habitat, biota and basic ecosystem functions.

Table 1. The rating system criteria used to assign condition scores to the ecosystems.

To quantify the biological assessment, a basic condition/ integrity-rating method from the BD Protocol has been chosen and adapted to Natura 2000 ecosystem types and Danish conditions. The rating system, with scores from 0 to 5, is shown in Table 1. In the rating system, 5 corresponds to the reference state of natural ecosystems and 0 is the complete loss of ecosystem functions.

For the application of the rating system to Blangslev, each ecosystem type is evaluated at the different stages of the project and given a score comparing it to the reference state. Table 2 summarises the surface area and the condition score for the identified ecosystems at each stage of the project. The scoring is explained in the following paragraphs.

Condition of the ecosystems before construction

Agriculture

Before construction, the land was used for agriculture which is a completely transformed land use with a condition score of 0. Due to the periodical tilling, fertilising, and use of biocides, there is a complete loss of natural habitat, biota, and basic ecosystem functions.

Existing Forest

The 0.49 ha of Existing Forest reached a condition score of 4 before construction. The assigned score is due to the presence of old trees and veteran trees, that may serve as shelter for birds, bats, other animals, including insects. Dead wood in the forest can provide food for fungi, insects, and decomposers at the low levels of the food web. Because of the limited size, this forest ecosystem is, however, dependent on the surroundings for large primary consumers (e.g. deer, boar, beaver, and large predators). Because of the developed status of almost all of Denmark, large wildlife is only found inspecific locations, and

Ecosystem type	Area (ha)	Condition score				
		Ref. state (neutral)	Before construction	After construction	5 years after construction	30 years after construction
Forest (new)	5.17	5	0	1	3	3
Forest (existing)	0.49	5	4	3	3	4
Grassland	2.45	5	0	1	3	4
Moist Grassland	0.60	5	0	1	3	4
Solar panels	58.43	5	0	1	1	3
Total area	**67.14**					

Table 2. Summary of the identified ecosystems of Blangslev. For each ecosystem the corresponding surface area and condition scores (CS) are noted. The assigned condition scores are explained in the text.

a small forest, surrounded by agriculture, cannot sustain the upper levels of the natural food web.

Condition of the ecosystems after construction

Solar Panel Field

After construction, the Solar Panel Field will reach a CS 1. The change from agriculture is significant. Stopping the use of tilling, fertilising and biocides, will allow for the soil organisms, like bacteria, fungi, insects, worms, to develop and provide food for other plants and animals. The most important constraint for a higher condition score is the grass/cover monoculture. The grass/clover seed mix will effectively outcompete several grassland species, which calls for a different conservation-based approach to ground cover reestablishment. Restoration could be achieved by stripping the soil of excess nutrients so a more species-rich ground cover could establish itself or speed up the process by introducing locally sourced seed mixes, where natural immigration is inhibited by landscape barriers. Other actions that could help reestablishment are avoidance of overgrazing by sheep, making the surrounding fence as permeable as possible for smaller wild animals, mimicking disruptions, and introducing microhabitats in unused corners of the field, e.g. dead wood or piles of stones. A CS 3 is expected to be the maximum rating for this area because of the limitations given by production (e.g. growth height, panel maintenance and shade), the lack of natural hydrology and absence of larger animal variety.

Grassland

The remaining grasslands have been sown with a mixture of many native plants and the conditions will mimic those of a natural grassland e.g., with nutrient-poor conditions and periodically flooding. Therefore, these areas are expected to develop from an initial condition score of 1, right after the construction, into a condition score of 3 after 5 years. In 30 years, local species will have had time to migrate to the site, find niches, and develop the food networks, thus a CS of 4 can be expected. The main factor preventing a higher condition score is the lack of natural hydrology, that is characteristic for all of the site.

New Forest

The New Forest areas will be planted with young trees and bushes, and it will be many years before old trees and veteran trees can fill their natural role in the ecosystem. Right after construction, the areas will be seriously changed from the natural reference state, but within 5 years it can be expected that plants and animals will settle in the provided spaces and basic ecosystem functions will develop. After 30 years, the basic functions of the ecosystem will have developed further and the biological composition can be expected to have great variety. However, trees with a lifespan of more than 100 years will not yet have grown old and died from aging, which limits the rating to a CS 3, even after 30 years.

Existing Forest

After construction, the Existing Forest is located within the fence, limiting access for animals such as deer, thus the condition score is 3. However, the Existing Forest already has a mature forest vegetation and older trees. This should allow the area to reach a CS 4 in 30 years, dependent on mimicry of natural disruption from a variety of larger animals. The small size of the forest limits the deep forest variety, and because of the lack of natural hydrology, the maximum condition score for the area is projected to a CS 4.

Calculation of condition-adjusted surface area

To express the changing conditions of an ecosystem, the BD Protocol uses a condition-adjusted value called "surface area equivalent" (ha eq). Applying the data from Table 2 – the surface area (ha) for each ecosystem, the current condition score (CS_{cur}), and the condition score for the reference state (CS_{ref}) – it is possible to calculate the "surface area equivalent" (ha eq):

$$ha\ eq = ha \times \frac{CS_{cur}}{CS_{max}}$$

For example, the Existing Forest before construction of the solar plant: the surface area is 0.49 ha with CS 4. So the total surface area is comprised of the positive impact (B = 0.49 · 4/5 = 0.39 ha eq) and the negative impact (C = 0.49 · (5-4)/5 = 0.1 ha eq). Values B and C, referring to the positive and negative impact respectively, will be explained in further details in the section "Statement of Biodiversity Position and the Biodiversity Footprint" below.

Recording journal entries for biodiversity gains and losses

Using the accounting framework of the BD Protocol, we can prepare two statements, adapting the principles and methodology from double-entry bookkeeping:

- Statement of Biodiversity Position: (A) total impacts on biodiversity features = (B) accumulated positive impacts + (C) accumulated negative impacts
- Statement of Biodiversity Performance: (X) net biodiversity impacts on biodiversity features over the accounting period = (Y) periodic biodiversity gains – (Z) periodic biodiversity losses

Journal entries	Accounting events	Account	Account category	Condition score	DR	CR
			(a) Reference state			
1	Accounting for reference state of ecosystem assets, which underpins their subsequent condition scoring	Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 5	67.14	
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Forest 5		67.14
			(b) Prior to project construction			
2	Stock taking of ecosystem assets, according to their condition scores	Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 0	66.65	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 4	0.49	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 5		67.14
3	Recording condition-adjusted losses and gains associated with existing ecosystem asset condition scores	Periodic losses (ha eq)	Z (Statement of Biodiversity Performance)	Forest 5	67.14	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Forest 0		66.65
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Forest 4		0.10
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Forest 4		0.39
			(c) After project construction & initial rehabilitation measures			
4	Recording changes in ecosystem assets and / or according to changes in their condition scores	Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 1	5.17	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 3	0.49	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Grassland 1	60.88	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Moist Grassland 1	0.60	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 0		66.65
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 4		0.49
5	Recording condition-adjusted losses and gains associated to new ecosystem assets	Periodic losses (ha eq)	Z (Statement of Biodiversity Performance)	Forest 4	0.39	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Forest 0	66.65	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Forest 4	0.10	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Forest 1		4.14
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Forest 3		0.20
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Grassland 1		48.70
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Moist Grassland 1		0.48
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Forest 1		1.03
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Forest 3		0.29
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Grassland 1		12.18
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Moist Grassland 1		0.12
			(d) After 5 years of rehabilitation measures			
6	Recording ecosystem assets according to changes in their condition scores	Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 3	5.17	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Grassland 3	2.45	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Moist Grassland 3	0.60	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 1		5.17
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Grassland 1		2.45
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Moist Grassland 1		0.60
7	Recording condition-adjusted losses and gains associated to new ecosystem asset condition scores	Periodic losses (ha eq)	Z (Statement of Biodiversity Performance)	Forest 1	1.03	
		Periodic losses (ha eq)	Z (Statement of Biodiversity Performance)	Grassland 1	0.49	
		Periodic losses (ha eq)	Z (Statement of Biodiversity Performance)	Moist Grassland 1	0.12	
		Acc. neg. Impacts (Ha eq.)	C (Statement of Biodiversity Position)	Forest 1	4.14	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Grassland 1	1.96	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Moist Grassland 1	0.48	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Forest 3		2.07
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Grassland 3		0.98
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Moist Grassland 3		0.24
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Forest 3		3.10
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Grassland 3		1.47
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Moist Grassland 3		0.36
			(e) After 30 years of rehabilitation measures			
8	Recording ecosystem assets according to changes in their condition scores	Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 4	0.49	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Grassland 1	55.98	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Grassland 4	2.45	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Moist Grassland 4	0.60	
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Forest 3		0.49
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Grassland 1		58.43
		Ecosystem asset (ha)	A (Statement of Biodiversity Position)	Moist Grassland 3		0.60
9	Recording condition-adjusted losses and gains associated to new ecosystem asset condition scores	Periodic losses (ha eq)	Z (Statement of Biodiversity Performance)	Forest 3	0.29	
		Periodic losses (ha eq)	Z (Statement of Biodiversity Performance)	Grassland 1	11.69	
		Periodic losses (ha eq)	Z (Statement of Biodiversity Performance)	Moist Grassland 3	0.36	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Forest 3	0.20	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Grassland 1	46.74	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Moist Grassland 3	0.24	
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Forest 4		0.10
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Grassland 3		22.39
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Grassland 4		0.49
		Acc. neg. Impacts (ha eq)	C (Statement of Biodiversity Position)	Moist Grassland 3		0.12
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Forest 4		0.39
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Grassland 3		33.59
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Grassland 4		1.96
		Periodic gains (ha eq)	Y (Statement of Biodiversity Performance)	Moist Grassland 4		0.48
10	Closing the Statement of Biodiversity Performance	Net periodic gains (ha eq)	X (Statement of Biodiversity Performance)	Net impacts	40.99	
		Acc. pos. Impacts (ha eq)	B (Statement of Biodiversity Position)	Forest 3		3.10
		Acc. pos. Impacts (ha eq)	B (Statement of Biodiversity Position)	Forest 4		0.39
		Acc. pos. Impacts (ha eq)	B (Statement of Biodiversity Position)	Grassland 3		35.06
		Acc. pos. Impacts (ha eq)	B (Statement of Biodiversity Position)	Grassland 4		1.96
		Acc. pos. Impacts (ha eq)	B (Statement of Biodiversity Position)	Moist Grassland 4		0.48

Table 3. Journal entries according to double-entry bookkeeping practice.

First, the reference state (the natural, untouched ecosystem with CS 5) is established. For each stage and for each ecosystem with a given CS, the surface area is then determined and the corresponding positive and negative impacts are calculated. Next the changes since the last stage (gains and losses) are calculated. Each of these values are written as a journal entry (either debit or credit) according to the accounting conventions listed in the BD Protocol, section 3.3.3.

Using Blangslev as an example: When an ecosystem reestablishes functions (increase in the condition score), this is recorded in the journal with a positive entry that increases the total positive impact (accumulated positive impact) and likewise a negative entry which decreases the total negative impact (accumulated negative impact). Table 3 shows journal entries for each stage of the Blangslev project.

Thus, the adaptation of the double-entry bookkeeping system in the BD Protocol allows for accurate accounting of biodiversity-related events and impact (Houdet et al., 2020). The bookkeeping principles ensure that journal entries (Table 3) can be verified by comparing changes recorded as positive or negative: For each stage, the sum of debits (DR) must be equal to the sum of credits (CR).

Statement of Biodiversity Position and the Biodiversity Footprint

The Statement of Biodiversity Position, one of the primary outcomes of the BD Protocol, is prepared from the accounting journal entries. The biodiversity assets accounts (A) is the total surface area and expresses the sum of the accumulated positive (B) and negative (C) biodiversity impact.

$$A = B + C$$

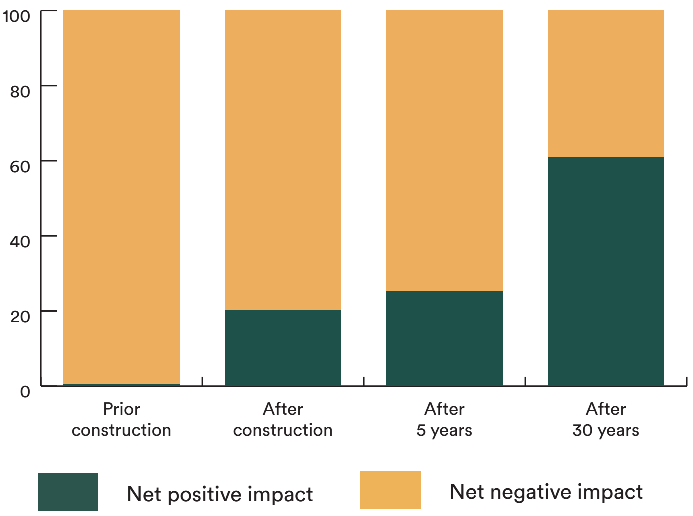

Figure 7. Net biodiversity impact divided into positive and negative impact.

In other words: A is the total surface area, B is a value combining size and quality of the existing ecosystems, and C is the gap to the natural stage of the entire area.

The net biodiversity impact is divided into two parts: the net positive impacts and the net negative impact. The total impact, or total Biodiversity Footprint, stays the same, as seen in Figure 7 and Table 4.

Table 4 shows the Statement of Position for the Blangslev project and summarises all changes during the projected

Assets (A)					
Project stage		Before construction	After construction	After 5 years	After 30 years
Ecosystem accounts		**Hectares (ha)**			
Ecosystem type	**Condition score**				
Forest	0	66.65			
Forest	1		5.17		
Forest	3		0.49	5.66	5.17
Forest	4	0.49			0.49
Grassland	1		60.88	58.43	
Grassland	3			2.45	58.43
Grassland	4				2.45
Moist Grassland	1		0.60		
Moist Grassland	3			0.60	
Moist Grassland	4				0.60
Total (A)		**67.4**	**67.14**	**67.14**	**67.14**

Accumulated positive impacts (B)					
Project stage		Before construction	After construction	After 5 years	After 30 years
Ecosystem accounts		**Hectares (ha eq)**			
Ecosystem type	**Condition score**				
Forest	0	0.00			
Forest	1		1.03		
Forest	3		0.29	3.40	3.10
Forest	4	0.39			0,39
Grassland	1		12.18	11.69	
Grassland	3			1.47	35.06
Grassland	4				1.96
Moist Grassland	1		0.12		
Moist Grassland	3			0.36	
Moist Grassland	4				0.48
Sub-total (B)		**0.39**	**13.62**	**16.91**	**40.99**

Table 4. Statement of Position for each stage of the Blangslev project. The table summarize the assets accounts (A), the accumulated positive biodiversity impact (B), and the accumulated negative biodiversity impact (C).

Accumulated negative impacts (C)					
	Project stage	Before construction	After construction	After 5 years	After 30 years
Ecosystem accounts		Hectares (ha eq)			
Ecosystem type	Condition score				
Forest	0	66.65			
Forest	1		4.14		
Forest	3		0.20	2.26	2.07
Forest	4	0.10			0.10
Grassland	1		48.70	46.74	
Grassland	3			0.98	23.37
Grassland	4				0.49
Moist Grassland	1		0.48		
Moist Grassland	3			0.24	
Moist Grassland	4				0.12
Sub-total (C)		**66.75**	**53.52**	**50.23**	**26.15**

Table 4 (continued). Statement of Position for each stage of the Blangslev project. The table summarises the assets accounts (A), the accumulated positive biodiversity impact (B), and the accumulated negative biodiversity impact (C).

stages of the project (excluding the reference state). The (B) accounts show the change in accumulated positive impact (from 0.39 ha eq to 40.99 ha eq) and the (C) accounts is the gap to the reference state (natural state of the ecosystem).

Each sub-total for A, B, and C in Table 4 is summarized in Table 5 to show the Biodiversity Footprint (BD Footprint). The total surface area of the property is 67.14 ha. Before construction, the Footprint consisted of 0.39 ha eq positive impact from the forest and 66.75 ha eq negative impact from agriculture. Looking at the changes in the positive BD Footprint we can see that after construction the positive BD Footprint will increase to 13.62 ha eq. After 5 years it can reasonably be expected that the ecosystems will flourish and further increase to 16.91 ha eq and after 30 years, a positive BD Footprint of 40.99 ha eq can be expected.

For reporting purposes, the positive BD footprint is calculated as a percentage of the total surface (Table 5 bottom row). The projected increase in positive impact, from 0.6% before construction, 20.3% after construction, 25.2% within 5 years, and 61.1% within 30 years, shows a significant positive development in the conditions for biodiversity at the Blangslev Solar Plant.

Biodiversity Footprint				
Project stage	**Before construction**	**After construction**	**After 5 years**	**After 30 years**
Total area (A)	67.14 ha	67.14 ha	67.14 ha	67.14 ha
Positive BD Footprint (B)	0.39 ha eq	13.62 ha eq	16.91 ha eq	40.99 ha eq
Negativ BD Footprint (C)	66.75 ha eq	53.52 ha eq	50.23 ha eq	26.15 a eq
% positive BD Footprint (B/A)	**0.6 %**	**20.3 %**	**25.2 %**	**61.1 %**

Table 5. The Biodiversity Footprint for each stage of the Blangslev project.