University of Groningen

Faculty of Science and Engineering

Bachelor Thesis

Promoting Biodiversity in Photovoltaic Solar Fields: a financial overview through systems thinking

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Abstract
This paper aims to investigate biodiversity opportunities in photovoltaic solar farms and determine the financial feasibility of measures proposed by academics to increase biodiversity in these facilities. Firstly, the photovoltaic solar farm system is described. The problem and objective are also defined. Then, the interrelationships between photovoltaic farms and biodiversity are explained and summarized in a system dynamics causal loop diagram. Following that, measures proposed by academics to improve biodiversity in solar fields are laid out. Finally, through a simulation on a hypothetical plot of land in the province of Groningen, the financial implications of these measures are explained.

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I-Photovoltaic panels and biodiversity: a brief introduction

Human activities are causing a decrease in biodiversity on a global scale, resulting in the extinction of many species. Some scientists are even sounding the alarm on what is categorized as the sixth mass extinction (Ceballos G. *et al.* 2015). These events are the result of decades of mismanagement and overexploitation of natural resources which also resulted in an increase in greenhouse gases in the atmosphere. Through initiatives such as the Paris Agreement (2016), governments worldwide have been attempting to limit their emissions of greenhouse gases and environmental impact through the promotion of alternative sources of energy.

Solar energy harvested through photovoltaic panels is a commonly used renewable energy alternative and is often presented as being part of the solution to the ecological problem (Turney, D., 2011). However, solar farms affect their direct environment and create new microclimates in their entourage (Liu, Y., 2019). The potential impact to wildlife and habitat is caused by the land occupation of photovoltaic solar farm . The power plant is typically enclosed by a fence, which limits the movement of animals. Some fences have openings to allow small animals to enter the facilities. This causes the land to change significantly. Indeed, for many species, hiding spots, preying strategy, as well as food availability are altered. Moreover, the soil is sometimes scraped to bare ground during construction and kept free of vegetation with herbicide. In other instances, the vegetation is allowed to grow but is mowed periodically to maintain it at a certain height. Additionally, the PV panels cast shadows and change the microclimate, causing an effect on vegetation (Fthenakis V. *et al.,* 2011).

It is therefore of essence to design , a catalog of measures to promote biodiversity in solar fields, while taking account of the financial repercussions entailed. Ensuring the financial viability of such measures is necessary to witness their implementation on an industrial scale. The reasoning behind this statement is that mismanaging solar fields could lead to a negative impact on surrounding flora and fauna which is antagonistic to the environmentally friendly purpose of harvesting solar energy. As a result of this potential risk, it is important to make sure solar farms do not harm their direct environment. However, monitoring and adopting a proactive approach to biodiversity in solar farms entails expenses which could potentially increase total energy production costs (Klaassen *et al*, 2019).

The two key concepts discussed in this document are solar fields and biodiversity. Hence, it is required to define these terms. A photovoltaic solar farm is a facility that commonly uses photovoltaic panels to harvest solar energy and transform it into electrical energy (Charfi W. *et al, 2018*). “Biodiversity” is often defined as the variety of all forms of life, from genes to species, through to the broad scale of ecosystems (Gaston, 1996). Practically, in the context of a solar farm, biodiversity can be expressed as numerical values such as, among others, the number of species and their population on a predefined plot of land.

The research is structured as follows: Firstly, the interrelations between biodiversity and PV solar farms are thoroughly investigated. A causal loop diagram is used to give a holistic view of the interrelations between the different variables of the PV farm-biodiversity system. Key performance indicators are also explained. Following that, methods and tools to design biodiversity friendly solar energy harvesting plants are laid out. The ecological and financial impacts of the implementation of these measures are also explained. Then, using the Dutch PV model 2.0 developed by TU Delft, two solar field plants are simulated, the first one being designed to maximize profits and the second one designed to take into consideration the promotion of biodiversity. The financial viability of both plants is then compared. Considering the available information regarding the biological impact of these measures, it is difficult to accurately quantify their impact. Moreover, depending on the chosen location for the facility, different biological systems are likely to react differently to these measures.

I.1 State of the art

A limited amount of literature is available regarding the subject, such as Klaassen *et al.* (2019) and Van der Zee *et al.* (2018), where the effects of photovoltaic farms on biodiversity in the north of the Netherlands are discussed and potential measures to increase biodiversity are laid out. Both of these papers point to an insufficient amount of knowledge about the effects of PV farms on biodiversity. Moreover, a knowledge gap is also identified as to the costs entailed by these measures. Considering the urgency of the biodiversity crisis (Ceballos G. *et al.* 2015), it is important to implement measures to preserve biodiversity in these industrial facilities. The main contributions of this paper are the system thinking approach applied to this specific problem and a better understanding of the financial impact of the measures proposed in academic works. Systems thinking can be useful to give a new perspective on this subject, which is most often discussed by biologists. Moreover, this approach also takes into consideration the financial inflow necessary for operations. This is done with the aim to facilitate the swift implementation of these measures promoting biodiversity. Currently, bifacial PV panels are investigated as a possible technique to increase biodiversity in solar farms by groups such as the SolarEcoPlus at TNO. However, to this date, the information available to investigate the financial feasibility of this approach is not available.

I.2 Photovoltaic panel farms and biodiversity: system definition

In order to better understand the problem setting, it is important to define the studied system and analyze its inflows and outflows. The system comprises of the land on which the facility is located (represented with a white rectangle), photovoltaic panel installations, vegetation growing on that plot of land and the wildlife (insects and animals) that resides in it. The interactions between these system components are investigated further in the document. This system is not isolated and interacts with its surrounding environment, which consists, in the case of the North of the Netherlands, mostly of farmlands and fields.

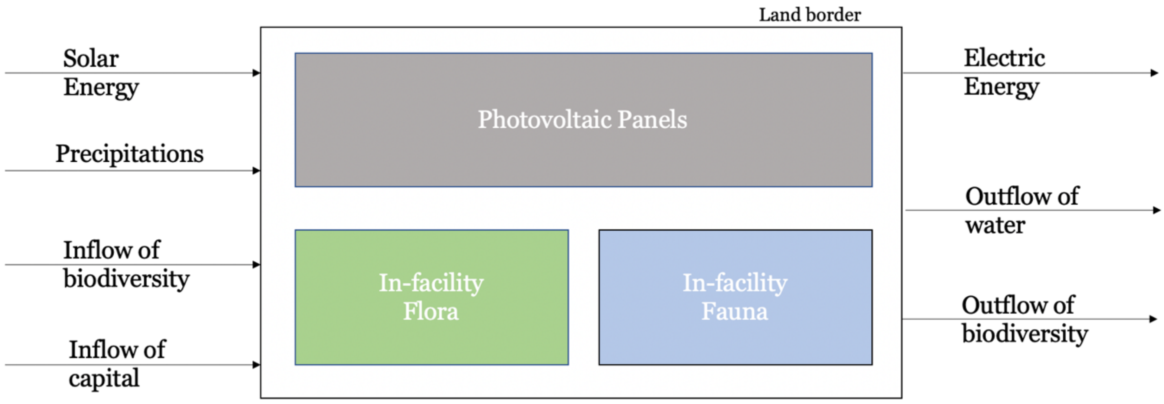

Figure 1: The photovoltaic solar farm system (PSFS)

Description of Inflows

- **Solar energy**: The radiations of the sun are an inflow in the system. They are transformed into electric energy by the photovoltaic panels and into biomass through photosynthesis by the plants. The rest is dissipated in the form of heat loss, which increases the temperature within the system. A graph of the daily horizontal irradiation during an average year for the province of Groningen, provided by the TU Delft Dutch PV model 2.0, is available in the appendix.

- **Precipitations:** It is the flow of water caused by the rainfall. The water is absorbed by the soil, which increases in-soil moisture and promotes the growth of vegetation. A graph of the Daily sum of rainfall during an average year for the province of Groningen, provided by the TU Delft Dutch PV model 2.0, is available in the appendix.

- **Inflow of biodiversity:** As it is illustrated in figure 1, the photovoltaic solar farm facility is not an isolated system. It heavily interacts with its surroundings. The inflow of biodiversity is related, in one part, to colonizing herbs that come from the surroundings and in a second part to an inflow of wildlife which interacts with the in-facility flora and in-facility fauna.

- **Inflow of capital:** It comprises the initial investment made to create the facility and install the photovoltaic panels (fixed costs) and the money necessary to fund maintenance and daily operations (variable costs).

Description of Outflows

- **Electric Energy:** Electric energy is produced by the photovoltaic panels when they are exposed to sunlight. The sale of electric energy is the main source of revenue of the photovoltaic solar farm industrial facility.

- **Outflow of Water:** The excess water permeates out of the system in the form of evaporation and water that goes into nearby ponds and canals as well as groundwater in the soil's pore spaces.

- **Outflow of biodiversity:** Through the same pathways In-facility flora and In-facility fauna interacts with the surrounding of the solar field, colonizing herbs and seeds as well as insects and animals can move from the facility into the surrounding environment.

I.3 Problem and Objective definition through a systems perspective

Now that the system is defined, it is possible to clearly and explicitly formulate the problem and desired objective. Preserving biodiversity in solar fields requires a less intensive utilization of the land, as well as a proactive management (Fthenakis, 2011). This entails additional costs. Thus, the problem is that measures increasing In-facility flora and In-facility fauna are likely to increase the necessary inflow of capital and decrease the production of electric energy, which is the main source of revenue for a PV solar farm.

The objective resides in providing a catalog of measures that would help operators to maximize In-facility flora and In-facility fauna, while minimizing the necessary inflow of capital and mitigating the negative impact these measures can have on electric energy outflow.

I.4 Research Questions

The objective defined in the previous paragraph can be satisfied by answering these three project steering research questions:

1- What are the interrelations between Photovoltaic solar fields and biodiversity?
2- What measures can be implemented to increase biodiversity in solar fields?
3- What is the financial impact of these measures on the Photovoltaic solar field operators?

II-The interrelations between PV Solar farms and biodiversity

In order to better understand how the photovoltaic panels, affect biodiversity within the photovoltaic solar fields, it is important to look into the dynamic mechanisms intrinsic to the system.

II.1-Key Performance Indicators

The Key Performance Indicators for biodiversity in a PV solar panel farm are identified as the In-soil Moisture, In-soil Temperature and the In-facility Flora (Liu, 2019). Additionally, In-facility fauna is an important indicator of the health of an ecosystem (Van der Zee, 2019). The way these key variables are affected by PV panel installations is further discussed in detail in the following paragraphs.

II.1.1-In-soil Temperature:

In-soil Temperature is affected by the installation of PV panels due to shading (Marrou, H., *et al.*, 2013). It appears that in a Mediterranean climate, during the day, In-soil temperature under PV Panels is lower than in non-shaded zones with a variation observed between -0.5 and -2.3 degrees Celsius (Marrou, H., *et al.*, 2013). However, another study made in arid lands concludes that In-soil temperature decreases more significantly in shaded zones. As it can be seen in *figure 2* the temperature of the land under the PV panels is 3.2 degrees Celsius lower than the temperature of lands 30m away from the solar panel installations (Liu, 2019). It is possible to conjecture that in territories with more sun exposure, the effects of shading on in-soil temperature are more important. This can be explained by the fact that, in lands with a higher exposure to sunlight, the sun's radiations have a higher influence on the micro-climate, therefore, the effects of shading, which stops the inflow of sunlight are therefore more perceivable. As a result, when applying this knowledge to the North of the Netherlands, which is less exposed to sunlight compared to the plots studied in the researches mentioned above, it is possible to estimate that variations in In-soil temperature due to the installation of PV panels will be smaller.

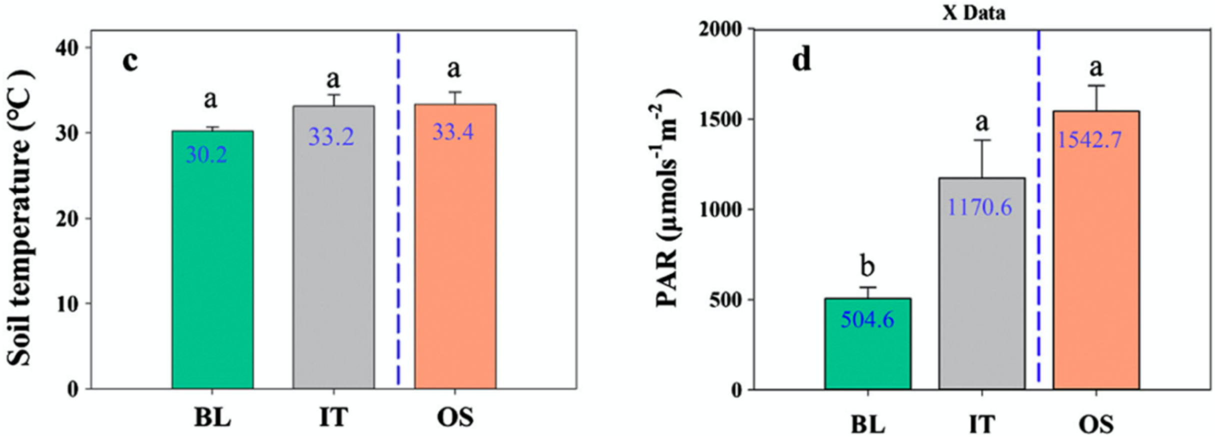

Figure 2: Variance of soil temperature (in Celsius degrees) and Photosynthetically Active Radiation in three different zones in an arid climate with different shading. BL, IT and OS being respectively the land below the PV panels, the land in between the panels and OS being a zone 30m away from the PV panel installations (Liu, 2019).

II.1.2- In-soil Moisture

The spatial modifications caused by the installation of PV panels have two effects on In-soil moisture. On one hand, they change the way precipitation is received by the soil, but on the other hand, through a shading effect, they reduce the solar energy received by the soil, which as a result, limits evaporation. Through these mechanisms, the overall impact of PV panels on in-soil moisture is to increase the soil water content at a depth between 0 and 100cm, as it can be seen in *figure 3* (Liu, 2019). The evaporation also decreases by 2.9 mm between completely shaded and non-shaded zones. However, considering that the effects of shading are much stronger in lands with high sunlight exposure, it is expected that, in the north of the Netherlands the variance in soil moisture content and evaporation measured in shaded and non-shaded zones should be lower.

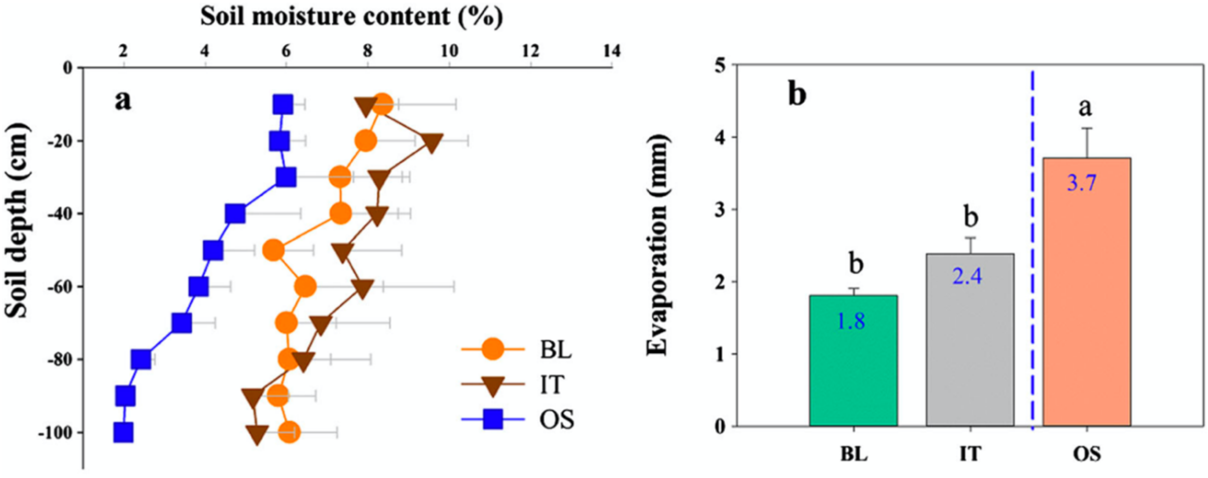

Figure 3: Variance of moisture content (%) and Evaporation (mm) in three different zones in an arid climate with different shading. BL, IT and OS being respectively the land below the PV panels, the land in between the panels and OS being a zone 30m away from the PV panel installations (Liu, 2019).

II.1.3-In-facility Fauna

In-facility fauna is affected by the installation of solar panels as it causes a drastic change in habitat for many animals (Fthenakis, 2011). The effects of the installation of PV panels on fauna in the North of the Netherlands are extensively described in "Solar parks, nature and land use" (Van der Zee, 2019), where the fauna is divided in five categories: mammals, birds, insects, amphibians and reptiles, and aquatic organisms. Based on this paper, the effects of PV solar panels on these animals are summarized in the following paragraphs.

Mammals

Mammals can select PV farms as a habitat. If the grassland between and among the panels is rich in herbs, the facility can potentially be a more attractive habitat than intensely farmed lands. In order to ensure exchanges with the environment, the frame around the facility should not act as a barrier. For this purpose, it is recommended that the lower edge of the frame should be 10cm off the ground. In order to allow the circulation of deer (which is necessary), hedges are also recommended (Van der Zee, 2019).

It appears that bats avoid solar parks which do not attract them. Bat activity seems to be lower in PV solar farms (Montag et al. 2016). This might be because bats perceive panels as water surfaces. This is however unlikely as there is no evidence of a collision risk. Further research is needed. (Harrison et al. ,2017). Hares, rabbits and deers were also observed in PV solar fields (Van der Zee, 2019). This may be partly caused by an attractive and varied vegetation due to the sowing of flowered clover mixtures in the PV farms. Mammals that can be observed in solar parks also include foxes and badgers (Harrison et al. ,2017). Dears and squirrels were also observed (Herden et al., 2009).

Birds

In studies in which the incidence of birds was compared between solar parks and control areas, negative effects were found regarding the diversity of bird species as well as the population densities (Montag et al. 2016). Effects of PV solar parks on birds are often negative when the facility is built in zones with high ecological value. However, bird population density and species diversity are positively affected by the installation of PV panels in lands formerly used for intensive agriculture (Montag et al. 2016; Herden et al., 2009). The attractivity of solar parks for birds increases when there is more space between the panels: indeed, more bird nests are found in solar parks with wider spatial gaps between the PV panels (Tröltzsch & Neuling, 2013). A proactive management approach, such as building herb rich grasslands also increases the health of bird populations (Montag et al. 2016; Herden et al., 2009). Grazing, which diminishes the herb coverage, mostly has negative effects (Van der Zee, 2019).

In general, the construction of a solar park causes a shift in the ecological composition of the concerned area. This is because different species react differently to the construction of a PV solar park. Farmland birds breeding in PV solar farms include the following species: Skylarks, Meadow Pipits, Yellow Wagtails, Eurasian Tree Sparrows, Yellowhammers, Red-backed Shrikes, Whinchats and Partridges (Raab, 2015). It appears that raptors such as Buzzards, Red Kites and Kestrels do not breed in Photovoltaic solar farms but regularly forage on the land occupied by these industrial facilities (Raab, 2015; Montag et al. 2016). There are indications that large birds, and especially birds living in groups avoid solar parks (Herden et al., 2009). Birds nesting on the fixed panel construction itself include Linnets, White Wagtails, Black Redstarts, Red-backed Shrikse and Fieldfares (Tröltzsch & Neuling, 2013; Herden et al., 2009).

Insects

PV panel installations do not affect species richness of butterflies and bumblebees. However, the density of butterflies and bumblebees was significantly higher in solar parks compared to lands dedicated to intensive farming, mainly due to the sown flowery vegetation (Montag et al. 2016; Raab, 2015). In general, one can say that if the organization and management of solar parks provides for the conservation of a flower and herb-rich vegetation, the land of the facility can turn into an important habitat contributing to ecological connections and an increased biodiversity.

Grasshoppers and crickets are dependent on direct sunlight. For this reason, soil and vegetation which is wholly or partly shaded are not adequate habitats for these species. This applies to both dry and moisture-loving species (Herden et al., 2009). Thus, these organisms do not thrive in the shaded areas of the PV solar farm. On the other hand, there are strips between the rows where there is sun and the microclimate in solar parks is attractive to this species group (Armstrong *et al*, 2016). In these areas, researchers in Germany have found up to fourteen species of grasshoppers and crickets, including four endangered ones (Herden et al., 2009).

Amphibians and reptiles

In pools situated inside PV solar farms, in addition to common frogs and toads, Great crested newts can be found (BRE., 2014). Contrary to agricultural lands, puddles in solar parks can easily be surrounded by an herb-rich grassland due to the secondary nature of farming crops among these premises. As a result, the water quality can be high, as opposed to pools in farmlands which are rich with nutrients coming from agricultural crops. These pools can offer a cooler and moister habitat, which can act as a shelter from warmer climate. However, a good ecological pool would also need sufficient zones exposed to direct sunlight (Van der Zee, 2019).

Similarly, to crickets and grasshoppers, reptiles rely on direct sun exposure, they can therefore thrive in the zones between the PV panels. Furthermore, it is common to see viviparous lizards on solar panels (Van der Zee, 2019).

Aquatic organisms

Solar panels reflect polarized light. For that reason, they are mistaken for stretches of water by some insects. It appears that water insects are strongly attracted by solar panels, for instance for egg laying :panels are even preferred over stretches of water (Herden et al., 2009). Panels work this way as a trap, but so far there are no studies on the effects on the population level. However, it is important to take this phenomenon's impact on aquatic insects into consideration, as solar energy usage is expanding (Száz et al. 2016). The attraction of panels on water insects can be reduced by applying white stripes on the panels. Small lines (1.8% of surface) appear sufficient (Horváth et al. 2010). In addition, it is recommended solar farms to place not too close to stretches of water (Száz et al. 2016). Unfortunately, there is no information regarding a recommended minimum distance between panels and water that prevents this phenomenon (Van der Zee, 2019). This is an important gap in knowledge.

Soil organisms

A healthy soil hosts an abundant in-soil life, that consists of animals, such as worms, slugs, beetles (in-fauna), algae and smaller life forms such as bacteria, fungae and viruses (Klaassen, 2018). The latter three are crucial for the mineralisation of dead plants and animals which is necessary to form essential nutrients. The nutrients facilitate (above the ground) the absorption of sunlight necessary to photosynthesise. As of this date, there seems to be an informational gap regarding the effect of PV panels on bacteria, fungae and viruses. During construction of the PV solar farm, soil compaction through the use of heavy machinery can be a danger to soil organisms (Peschel,2010).

II.1.4--In-facility flora

The main limitation of the vegetation is the obstruction of direct sunlight during daytime. Sun-loving plants will therefore not thrive. For shade-loving plants, especially forest plants, solar parks are a good opportunity, provided the rainwater under the panels on the bottom can drip (Van der Zee, 2019). From a system view, In-facility flora is a very interesting variable to monitor due to its high interdependence with multiple elements of the system. Indeed, plants are highly dependent on In-soil moisture, In-soil temperature and sunlight exposure (PAR), as an inflow of water, an appropriate temperature and an inflow of photosynthetically active radiations are necessary conditions to perform photosynthesis. Moreover, flora is highly affected by fauna, as many animals rely on plants for nutrition. Through a systems perspective, it is possible to analyze these interdependencies and determine an emerging system behavior.

II.2-A System Dynamics approach

Developed by J.W Forrester, system dynamics is a methodology and mathematical modeling technique to frame, understand, and discuss complex issues and problems (Forrester, 2009). In the context of complex non-linear systems, such as biodiversity in PV solar farms, this approach can be useful in offering a better understanding of the key dynamics influencing the system's behavior. A positive link between two variables means that if one increases, the other one increases too. For example, according to the law of conservation of energy, when the Solar energy received by the soil increases, the in-soil temperature increases. A negative arrow means the opposite: for example, if the spatial modification of the environment increases, in this case it would be an increase in land utilization by PV panels, the solar energy received by the soil decreases due to shading. As explained in the previous section, solar photovoltaic panels cause specific modifications in the environment. These changes affect precipitation irrigating the soil, as panels can affect the distribution of water on the ground. These installations also limit the solar energy received by the soil through shading, which results in a reduction in evaporation and as well as a decrease of In-soil temperature, which leads to an increase of In-soil moisture.

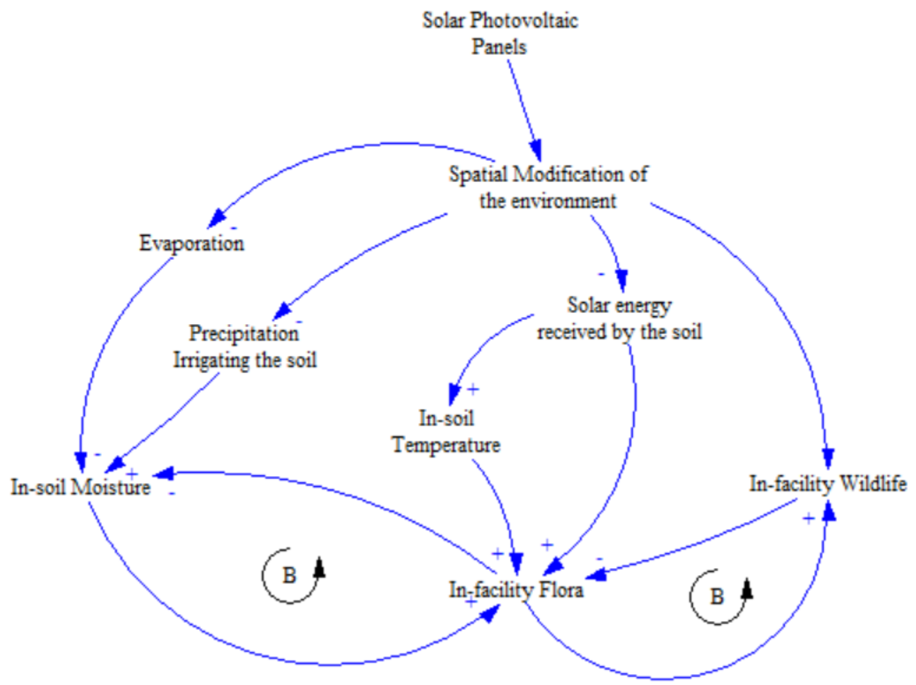

Figure 4: A causal loop diagram describing the effects of PV panels on biodiversity

Furthermore, these spatial modifications of habitats affect the livelihoods of the diverse organisms constituting the fauna. As discussed in the previous section, these effects can be either positive or negative, which is why the arrow linking the two variables is without a sign. The following causal loop diagram is used to represent the interactions between the key variables within the system and is not interested in how external factors such as the surrounding environment affect it. It is only concerned with variables that can be affected by the actions of the plant operator. Like all models, it is neither complete and all inclusive, nor is it perfectly correct, but it is a useful tool to give an overview of the internal functioning of the system. For this diagram, the plot of land is assumed to be free of construction and non-artificialized.

The feedback concept is a central element of the system dynamics approach. Diagrams of loops and circular causality are tools for modelling the structure of a complex system. “If the tendency in the loop is to reinforce the initial action, the loop is called a *positive* or *reinforc- ing* feedback loop; if the tendency is to oppose the initial action, the loop is called a *negative, counteracting*, or *bal- ancing* feedback loop”. (Richardson, 2009).

In the system represented above, two balancing feedback loops are identified. The first one is between In-soil moisture and in-facility Flora. An increase in vegetation leads to a decrease in moisture: the plants absorb the water in the soil in order to produce organic matter, as described by the basic equation of photosynthesis. As a result, an increase in soil moisture leads to an increase in vegetation. However, a decrease in moisture leads, over time, to a decrease of In-facility Flora due to a lack in water hampering the mechanism of photosynthesis. The resulting dynamic of this balancing feedback loop is a stabilizing effect. The second balancing feedback loop is between vegetation and animal life. An increase in vegetation leads to an increase in animal life as it creates a nutrient abundant environment for animals. However, as a result, an increase in animal life causes a decrease in vegetation because of grazing by herbivores for example. The resulting dynamic of this balancing feedback loop is also a stabilizing effect. In-facility flora is hence at the center of two balancing feedback loops, stabilizing in-soil moisture and in-facility fauna. It is therefore a variable that heavily impacts the stability of the system. This means that measures to improve biodiversity should have an important focus on the health of the in-facility flora.

III- Methods and tools to improve biodiversity in Solar farms

Scientific literature on the subject is scarce, however, three phases in which biodiversity in PV farms can be protected are identified: The Planning phase, the Building Phase and the Operating phase. These three different steps are illustrated in the figure below.

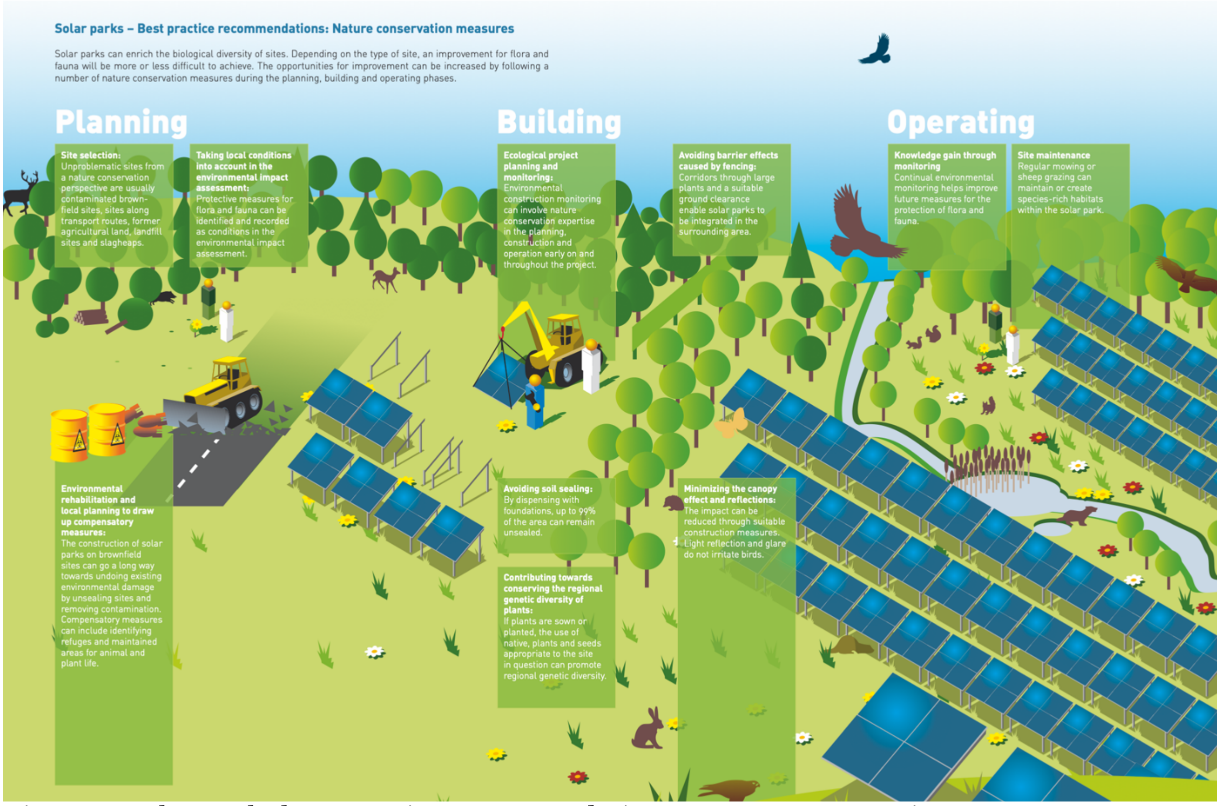

Figure 5: Solar parks best practice recommendations: Nature conservation measures (Wade A., 2011)

The planning phase is concerned with the site selection, assessment of the local biodiversity and the creation of an environment management plan, which would mitigate the effects of construction and operations. The building phase involves further ecological planning, fine-tuning and monitoring, preventing barrier effects caused by fencing, minimizing polarized radiations coming from the PV panels, preventing the artificialization of soils, as well as contributing to the local biodiversity by ensuring the resilience of the local biological diversity. Finally, the operating phase is concerned with knowledge gain through monitoring and maintenance of the site. The following tables build on the work presented in (Klaassen, 2018), which is as of this date, the only document extensively discussing measures to increase biodiversity in photovoltaic solar plant in the north of the Netherlands. This is done by providing additional literature sources and as well as a financial aspect to measures increasing biodiversity in solar farms, which is an informational gap.

III.1-Preliminary actions: before building a photovoltaic solar farm

These are the actions that must be taken before making the solar field plant.

Measure ID	Planning Measures	Impact on biodiversity	Impact on finances
1-a	Solar parks should not be built in parks and areas with a high ecological value. They should be built adjacently to nature only when carefully fitted. (Klaassen, 2018)	This prevents the loss of habitats with high ecological value. An example where building a solar could be beneficial to biodiversity is near a meadow, as it would provide optimal conditions for a successful breeding of meadow birds. (Klaassen, 2018)	None
1-b	Initial Environmental Examination must be carried out, as well as additional environmental assessments (IFC, 2015).	Identifying the species on a plot of land and determining the ecological construction allows to prevent or minimize risks of conflicts. (Fthenakis, V., et al. 2011)	Additional fixed cost required before making the solar field. It is highly dependent on the plot of land on which the facility is going to be built. Factors that affect the pricing include the land surface, the surrounding environment and the complexity of the local biodiversity. (increase in capital Inflow)
1-c	With the help of an ecologist, a biodiversity management plan must be created (Klaassen, 2018).	Environmental planning and management must be tailored to the local biodiversity to yield satisfactory results (Klaassen, 2018).	Additional fixed cost required before making the solar field. It is highly dependent on the plot of land on which the facility is going to be built. Factors that affect the pricing include the land surface, the surrounding environment and the complexity of the local biodiversity. (increase in capital Inflow)
1-d	Biodiversity should be monitored the first five years according to a fixed monitoring protocol. Then the solar park should be monitored every five years. (Klaassen, 2018). A measurement protocol is described in detail in	Monitoring the park in the first few years allows to have a better overview of the situation. The information collected would allow for proactive management measures to promote biodiversity when needed.	Additional maintenance (variable) costs. Factors that affect the pricing include the land surface, the surrounding environment and the complexity of the local biodiversity. (increase in capital Inflow)

	Zon in landschap (2020) "Meetprotocol biodiversiteit zonneveleden".		
1-f	The planned solar park should contribute to solving a research problem (knowledge). For example, spacing between rows of panels is varied, this way, the effect of PV panel spacing on the behavior of farmland birds can be investigated (Klaassen, 2018).	More research should be carried out about the effects of PV solar farms on biodiversity. This would allow for a more scientific and efficient management of biodiversity in solar fields.	None. Costs can be prevented by cooperating with universities and offering thesis opportunities to students.

III.2- Construction measures: while building a photovoltaic solar farm

These are measures affecting the structural design of the plant and the construction phase. The construction phase has the potential to perturb the biodiversity. Some aspects therefore also need to be monitored.

Measure ID	Measures to implement during construction	Impact on biodiversity	Impact on finances
2-I-a	Vehicles that do not put too much pressure on the soil should be used. Building activities should also be halted during long spells of wet weather (Peschel,2010).	This results in preventing soil compaction which changes the site conditions and has undesirable effects on habitat conditions, to the detriment of soil organisms. (Peschel,2010)	This might delay construction, which might cause an increase in construction costs. (possible increase in capital Inflow)
2-I-b	The use of extensive lighting should be minimalized. The time lights are switched on should be reduced. (Peschel,2010).	This measure prevents endangering valuable insects (Peschel,2010).	None.
2-I-c	Building activities should not occur during breeding season (Klaassen, 2018).	This measure prevents perturbing the fauna during a critical time of the year for the reproduction of animals.	This might delay construction for big projects, which in turn can cause an increase in construction costs. (possible increase in capital Inflow)
2-I-d	The environmental impacts of the building work should be reduced through sustainable	This results in a better conservation of habitats and a	None. Only additional planning required.

	planning of access roads and limiting the size of the construction site (Peschel,2010).	minimization of the negative impacts on species. (Peschel,2010).	

The following measures are related to the configuration of the solar panels. The configuration highly affects the environment of the solar field facility. It is therefore crucial that the PV panel structure is conceived in a way that protects biodiversity.

Measure ID	Measures affecting configuration	Impact on biodiversity	Impact on finances
2-II-a	Solar Panels should not be put directly on the ground (Klaassen, 2018).	The solar panels should be held at a minimum distance from the land in order to prevent perturbing the activities of animals.	The minimum distance recommended is 0.8m (Klaassen, 2018). This means that fixed cost will increase because of the need for an elevated structure. (increase in required capital Inflow)
2-II-b	There should be sufficient space between the rows of panels (Klaassen, 2018).	The distance between the rows of panels should be sufficient for farmland birds to utilize the space between them. The exact distance is still a knowledge gap, but a rough guideline is that 10% of the area within the facility should be free of panels (Klaassen, 2018). Some companies have chosen to create corridors to increase the mobility of the animals (Wade. 2011)	This causes a decrease in land utilization for economic purposes. Therefore, more land is needed to produce the same energy output. This increase in fixed costs is highly dependent on the price of the land. Overall this translates in a 10% increase in land acquisition costs, because 10% more land is needed. (increase in required capital Inflow)
2-II-c	Technical structures should be included in the ecological design (Klaassen, 2018).	These structures include bird nests or Kit fox dens (Fthenakis, 2011). (increase of in-facility fauna)	The costs entailed are dependent on the technical structures needed, there is therefore a high variability. (increase in required capital Inflow)
2-II-d	Special habitats should be created if they are expected to have a positive impact	Special habitats include open land, natural vegetation, sand and stone heaps,	Limited fixed costs. (increase in required capital Inflow)

	on specific target species. (Klaassen, 2018).	piles of wood and branches as well as ponds and ditches. They should be chosen according to the target species. (Klaassen, 2018). (increase of in-facility fauna)	
2-II-e	Insect-friendly panels are recommended in the case of construction near water (lakes and ponds) (Horváth et al. 2010).	Panels act as trap for aquatic insects, but problems can be solved by using special panels with white strips (Száz et al. 2016). (increase of in-facility fauna)	The white stripes covering the PV panels reduce their overall sun exposure. This leads to a decrease in production efficiency with regards to electric energy of 1.8%. (Horváth et al. 2010). The financial consequences of this loss in efficiency can be further investigated in part IV. (decrease in electrical energy outflow)

III.3-Proactive measures: managing a photovoltaic farm

These are measures that do not involve structural modifications to the plant but need to be implemented on a periodic basis.

Measure ID	Measures during operations	Impact on biodiversity	Impact on finances
3-a	The solar park should not be lit at night (Klaassen, 2018).	This measure insures the preservation of the natural luminosity levels of the ecological habitats.	None.
3-b	Extensive vegetation should cover the park. The plants and seeds sown should be chosen according to the ecological management plan made in the preliminary phase by an ecologist (Klaassen, 2018).	It has been shown in the causal loop diagram presented in part I that in-facility flora is a factor of stability in the PV-biodiversity system. (increase of in-facility flora and indirectly of in-facility fauna)	Purchasing and sowing seeds entails additional albeit limited costs. The seeds needed should be determined in 1-c. (increase in inflow of required capital)
3-c	Pesticides and chemical fertilizers cannot be used (Klaassen, 2018).	Pesticides and fertilizer can pejoratively affect the biodiversity in the facility Only solid fertilizer is allowed. (Klaassen, 2018)	None.

		(increase of in-facility flora and fauna)	
3-d	Mowing and Grazing should be minimal (Klaassen, 2018).	Grazing can disturb some ecological habitats. (Klaassen, 2018)	Grazing is a potential way of reducing the necessary inflow of capital as grazing can be a source of revenue.
3-e	The solar park should not be protected by dogs (Klaassen, 2018).	This measure ensures that dogs do not scare off animal life. (increase biodiversity inflow)	None.
3-f	The land borders should be marked with shrubs and bushes rather than fences (Klaassen, 2018).	Shrubs are used instead of fences to introduce native species and increase biodiversity in the facility. (increase of in-facility flora and fauna)	None or very limited. Hedges and fences are priced similarly.
3-g	The vegetal fencing should allow for the circulation of larger mammals (Fthenakis, 2011). This can be done by installing some barriers or leaving spaces big enough for their circulation.	This allows for the movement of animals between the facility and the surrounding environment. (Increase inflows and outflows of biodiversity)	None.
3-h	There should be a wide buffer between the vegetal fence and the solar panels, this would be in compliance with the landscaping (Klaassen, 2018).	This buffer should become a grassland which in herbs or fallow vegetation. This should be determined in the ecological planning. (increase of in-facility flora)	No additional costs as the extra land needed is already accounted for in 2-II-b and the seeds are accounted for in 3-b.

IV- A financial feasibility study

In order to implement the measures proposed in the previous section in a real-life scenario, it is necessary to investigate their financial impact. Indeed, if these measures are prohibitively expensive, they cannot be applied in industry. The knowledge compounded is applied to a theoretical solar field project in the north of the Netherlands. A mathematical model developed by TU Delft is used to predict the energy output and financial income of a solar field in the North of the Netherlands. Methods for preserving biodiversity in that specific region are used and their costs are compared to the plant that is conceived only to maximize profits.

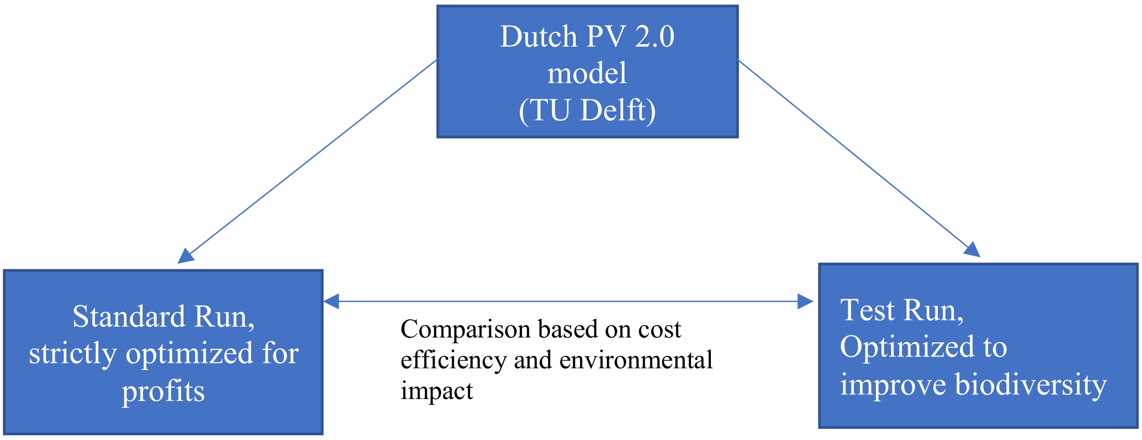

Figure 6: Framework of the financial comparison between two PV farm facilities: the first one being strictly run for profits and the second one taking into consideration the prosperity of biodiversity.

At present no actual project is in a phase allowing for such a financial comparison has emerged. The simulation is therefore focused on a hypothetical plot situated in the Groningen province

The Standard Run: Strictly optimized for profits

Very limited space between panels to maximize land use efficiency. Inclination of panels is of 37 degrees, oriented south, as it is the most efficient in the Netherlands according to the TU Delft Dutch PV Model 2.0.

System characteristics	
The selected system location:	Random location within the province of Groningen.
The weather data location:	Eelde
The number of modules installed:	2,822 modules.
Module technology:	Cadmium Telluride.
Module power capacity:	122 W_p

Module efficiency at Standard Test Conditions (STC):	16.98%
System type:	free-standing
Design choice:	Field area design
Installed power:	345 kW_p
Module tilt:.	37°
Module azimuth (relative to North):	180°
Active area:	2,032 m^2
Ground area:.	1,623 m^2
Field area (total):	10,000 m^2
Ground coverage ratio:	0.162

The Test Run: Operational efficiency and environmental mitigation

Changes required in initial investment:	**Cost**	**Explanation**	**Source**
1- Initial ecological study and management plant	35 000 euros	It includes determining the optimal seeds to sow and the technical structures to install.	A biology professor at the University of Groningen (personal communication)
2- Monitoring biodiversity in the first 5 years	35 000 euros x 4 Or 6000 euros x 4	The difference in pricing can be explained by different priorities for academics and businesspeople.	A biology professor at the University of Groningen (personal communication) Ecological consultancy operating in Groningen

3- 10% more land needed	7000 euros. It is assumed that 10% more land is purchased. This gives an overall surface of 11 000 sqm.	Land prices fluctuate with the market forces. A good estimate is 70 000 euros for 1 ha in the province of Groningen.	A biology professor at the University of Groningen (personal communication) Boerderij.nl
4- Elevating Solar panels by 0.8m	Information not available. We assume it is between1.5% and 5% of the initial investment. This amounts to a cost between 5,476 and 18,254 euros. (Estimate)	Elevating the PV panels by 0.8m can be done in many different ways.	According to a professor working on an ecofriendly solar park project at TNO, this additional cost should not be a big cost factor in the overall initial investment required (personal communication).
5- Installing technical structures (5000)	3000-5000 euros (Estimate)	This includes all the technical structures such as bird houses.	According to a biology professor at the University of Groningen this budget should be more than satisfactory. (personal communication).
6- Sowing seeds	The total cost of sowing seeds can be calculated to be approximately 4 300 euros.	Seeds for flowery grassland in sunny environment cost 0.32 euros per sqm. Seeds for flowery grassland in a shadowy environment cost 0.35 euros per sqm. The cost of manually sowing is 452 euros per ha. It is assumed that 10 000 sqm are in a shadowy environment and	Ecological consultancy operating in Groningen (Further information is available in the appendix)

	An estimation can be 200-400 euros per ha.	1000 sqm are in a sunny environment.	A biology professor at the University of Groningen
Total extra initial investment	**From 78,776 to 209,554 euros**		

NB: The cost of sowing seeds is calculated according to the following method. The ground coverage ratio is of 0.162. For a field of 10 000 sqm where PV panels are installed, this amounts to 1620 sqm which are a shadowy environment. Hence, the remaining 8380 sqm, as well as the extra 1000 sqm dedicated to biodiversity, are categorized as sunny. The estimation given by the biology professor is not used in the calculations as it is less precise than the more extensive information given by the ecological consultancy (available in the appendix).

Changes required in Operations and maintenance

The main change in operations and maintenance is related to mowing. In general mowing costs 323 euros per hectare according to the ecological consultancy based in Groningen. The ground below the panels should be mowed three times per year. The ground of the paths between the panels should be mowed and drained once per year. The first zone is the ground area and consists of 1623 sqm. The rest of the active zone is 409 sqm which is assumed to be dedicated to paths between the panels. Over the lifetime of the facility the mowing costs can hence be estimated to be of 767 euros. Considering that many assumptions are made to obtain this number, it can only be a vague estimate. However, this gives a clear picture that mowing costs are negligible compared to the total operating costs.

Changes in total revenue:

It is assumed panels friendly to aquatic insects are installed everywhere on the facility. These panels have an efficiency of 99.2% compared to the ones modeled by the TU delft algorithm. This amounts to a loss of 21 342 euros in revenue over the lifetime of the project, which is 25 years.

Financial overview

Financial Metrics	Standard Run	Test Run (worst case scenario)	Test Run (best case scenario)
Required initial investment	€365,076	€574,630	€443,852
Required operation and maintenance (O&M) cost	€172,474	€173,241	€173,241
Total revenue from electricity savings and sales to the electricity grid	€1,185,690	€1,164,348	€1,164,348
Total profit made over 25 years	€648,140	€416,478	€547,255

(non-discounted scenario)			
The non-discounted payback period (PBP)	9 years	11.2 years	14.5 years
The return on investment (ROI) over 25 years (non-discounted scenario)	120.57%	55.68%	88.68%

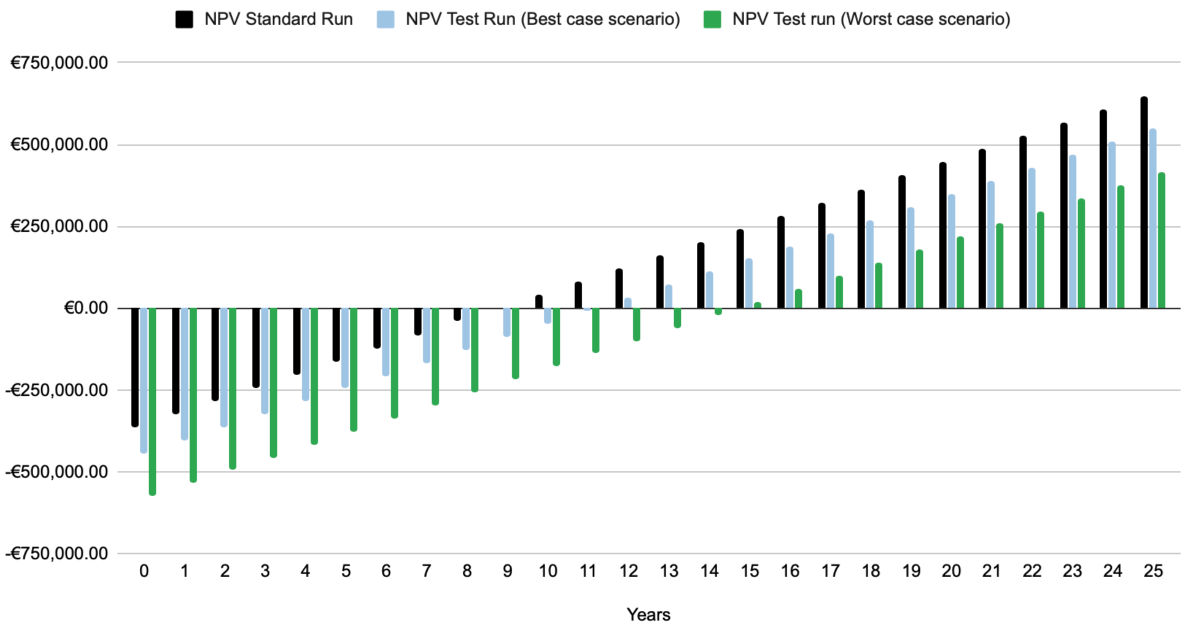

Figure 7: Non-discounted Net Present Value (in euros) over the facility lifetime for three different scenarios: Standard Run, Test Run (Best case scenario) and Test Run (Worst case scenario).

Discussion

With a non-discounted return on investment between 55.68% and 88.68% over 25 years, a photovoltaic solar farm promoting biodiversity is not an attractive opportunity for investors. Indeed, excluding interest, the yearly ROI is between 2.22% and 3.54%. Furthermore, as it can be seen in the appendix 6, with a high interest rate, there is a risk for the implementation of measures to improve biodiversity in PV solar fields to be prohibitively expensive. Indeed, with high interest rates, there is a risk of creating unsustainable debt. As a result, such a project can only be viable if it is made with nonprofit intentions by actors such as a community or the Dutch government. Moreover, because of its low profitability, such a project would need a loan with a low interest rate in order to breakeven. Nonetheless, the conclusion of this paper is that implementing measures advised by academics to promote biodiversity in photovoltaic solar farms is feasible. It is also important to note that the costs of implementing these measures are overestimated in the previous calculations, in order to give the worst-case scenario. Measures which have the potential to be less costly include monitoring the ecological park for the first five years, elevating the modules by 0.8m and the cost of building technical structures. Firstly, it is important to note the discrepancy in pricing between the university of Groningen biologist and the eco consultancy. Over the lifetime of the facility, it amounts to a difference of €116,000. It is possible that for the purposes of ecological monitoring in the context of a business setting, a budget lower than that proposed by academics would be sufficient to get an overview of the ecological situation, albeit, not as detailed. Secondly, in order to estimate the costs of elevating the PV panels by 0.8m, it is assumed that the costs would amount to 5% of the initial investment. If that cost was assumed to be 1.5% of the initial investment, it would amount to €5,476 instead of €18,254. Thirdly, the allocated cost of €5000 for technical structures is a very broad estimate, as the technical structures needed are expected to vary highly depending on each project. A more conservative allocated cost could be €3000. As a result, with a more conservative financial spending approach, measures to improve biodiversity in the modeled PV solar farm could be €130,778 cheaper. This is taken into consideration in the best-case scenario.

With the available information, it is difficult to accurately quantify the ecological impact of these measures. Moreover, considering that each selected plot of land has a different ecosystem, the biological impact of the proposed measures is expected to be highly dependent on location. As a result, it is difficult to precisely determine which measures are most effective from a cost-benefit perspective. Nonetheless, sowing flowery vegetation and allocating 10% of the facility's land to ecological habitats are measures that have a positive ecological impact without entailing prohibitive costs. Furthermore, many other measures and practices presented in section III do not entail any costs. The remaining costly measures proposed should be evaluated on a case by case basis through an ecological management plan.

V-Conclusion

Photovoltaic solar farms can be useful for promoting biodiversity if managed properly. These benefits for the ecosystem are particularly important when this type of system is installed in lands which do not have a high biological value, such as, for example, farmlands used for intensive agriculture. These industrial facilities can act as ecological habitats for many different animals including mammals, birds, reptiles, amphibians and insects. More specifically, when flowery herbs are sown, it is observed that photovoltaic solar farms have positive effects on pollinizing insects such as bumblebees, which are endangered in the Netherlands. It is however important to note that many informational gaps are present, and more research should be made about the subject. As to the financial feasibility of the measures proposed by academics, with the information that was available, it was possible to conclude that promoting biodiversity in solar fields can be expensive. However, it is still feasible for non-lucrative organizations such as communities and the Dutch government, who are willing to give loans with low interests for such projects.

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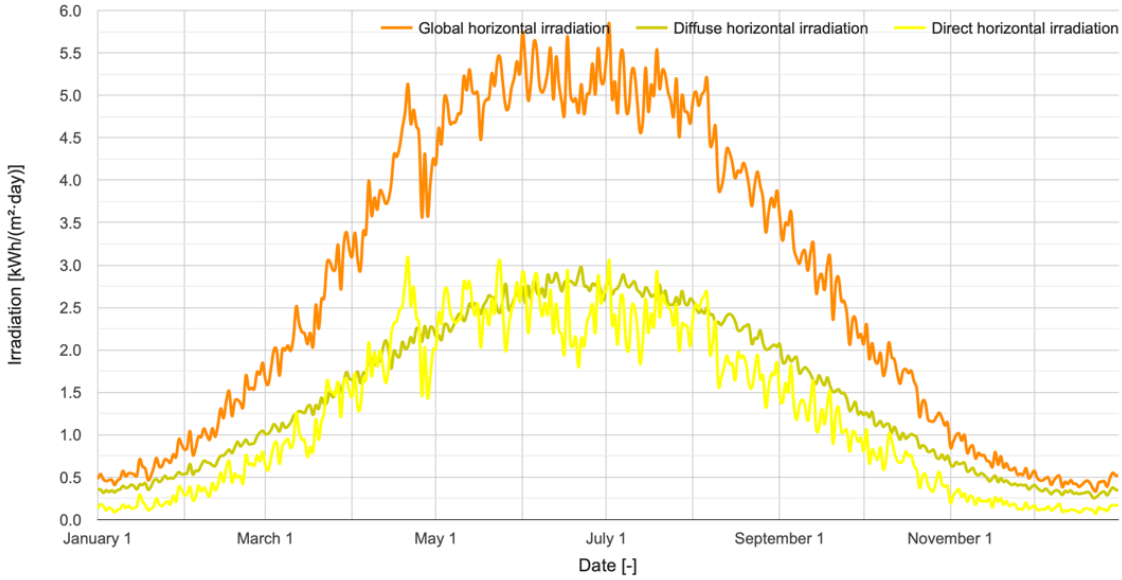
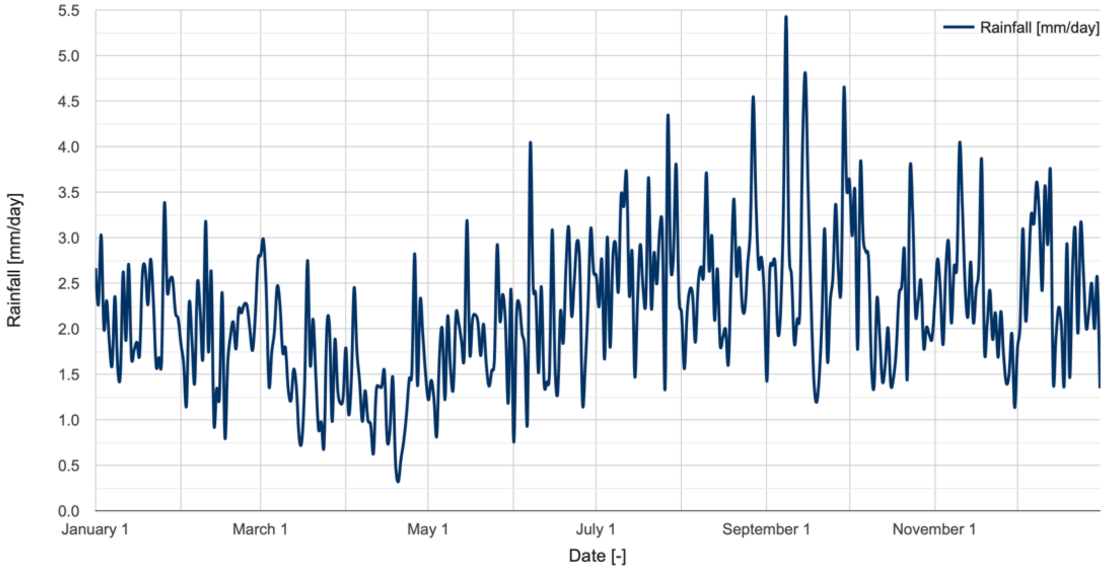
Appendix



Appendix 1: Daily horizontal irradiation during an average year for Groningen



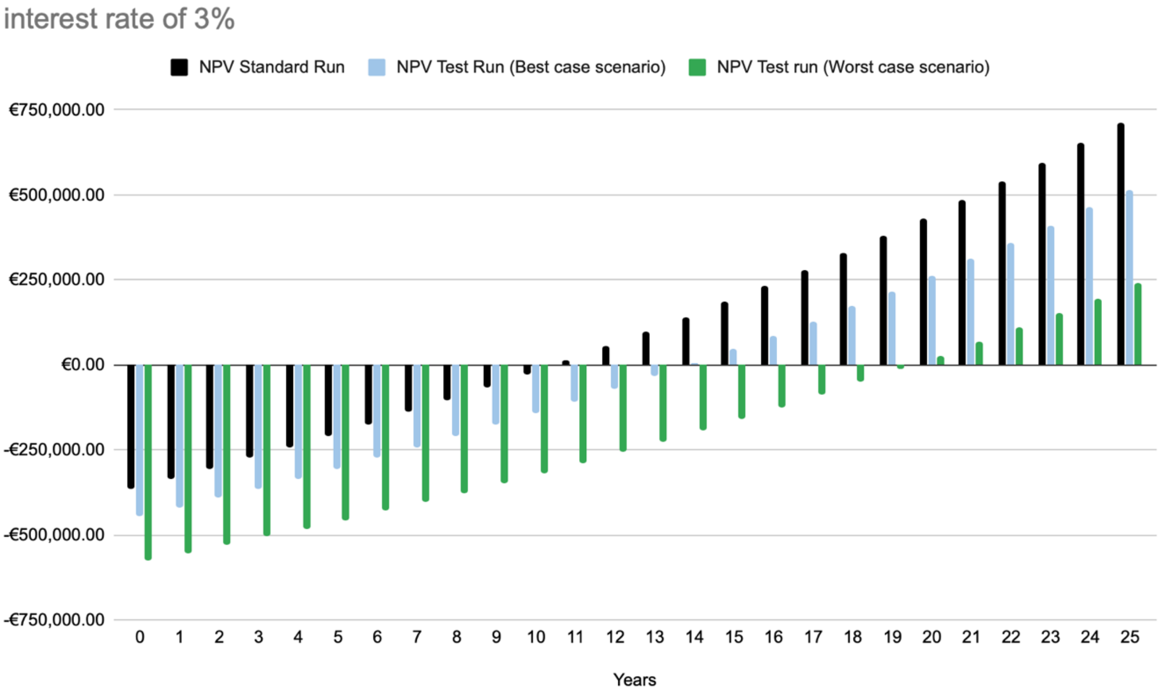
Appendix 2: Daily sum of rainfall during an average year for Groningen

Nummer beheertype		Oppervlakte in terrein in ha	Herkomst norm	Normbedrag	per ha of stuk
	Solarpark				
5	sloot - zonnig	0,21			
	aanleggen flauw talud		STOWA 2011	€ 50,00	per m
8	struweel	2,00			
	aankoop (1 per m2)			€ 0,50	per stuk
	aanplanten		NBL 2016	€ 1.100,00	per ha
10	bloemrijk grasland - zonnig	2,21			
	zaadmengsel		Gem. Groningen	€ 0,35	per m2
	inzaaien (handmatig)		NBL 2016	€ 452,00	per ha
11	[redacted] bloemrijk grasland - schaduw	11,36			
	zaadmengsel (gehele opp)		Cruydt Hoeck	€ 0,32	per m2
	zaadmengsel (alleen paden tussen panelen)		Cruydt Hoeck	€ 0,32	per m2
	inzaaien (gehele opp)		NBL 2016	€ 452,00	per ha
	inzaaien (alleen paden tussen panelen)		NBL 2016	€ 452,00	per ha
	* nader te bepalen, ook afhankelijk van boomkeuze				

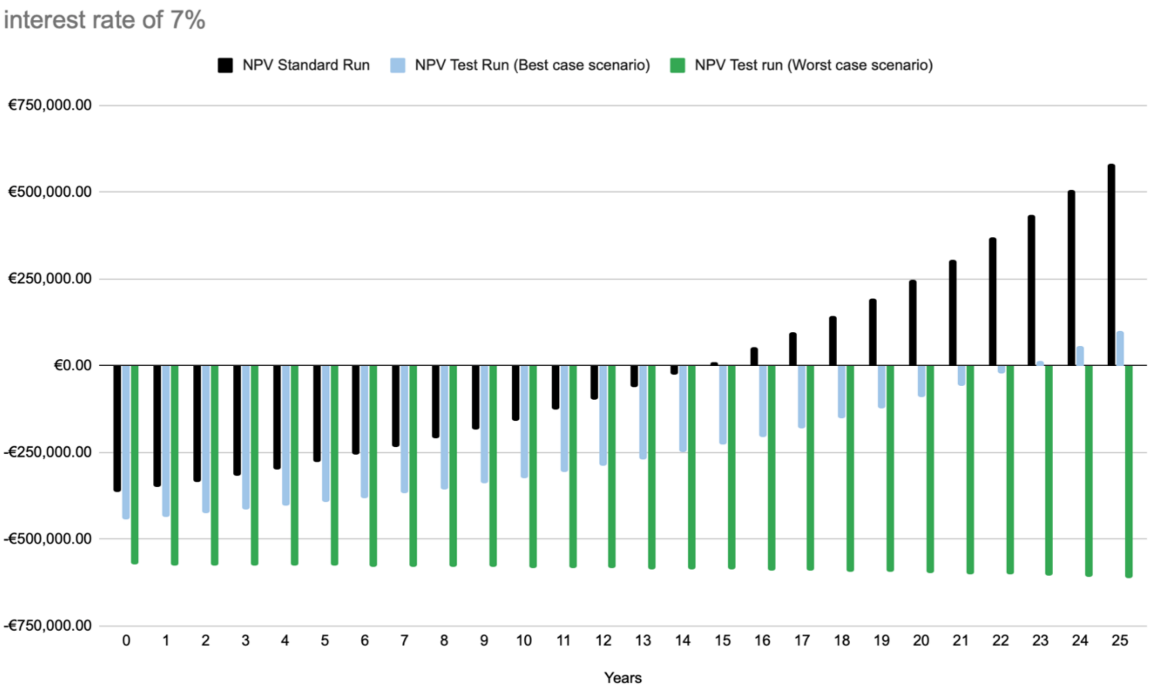
Appendix 3: Table of costs concerning the ecological design of a PV farm (provided by an ecological consultancy operating in Groningen, through the intermediate of a biology lecturer at the university of Groningen)

			Normgegevens		
Nummer beheertype		Oppervlakte in terrein in ha	Herkomst norm	Normbedrag	per ha of stuk
	Solarpark				
5	sloot - zonnig 1x per jaar, 1 zijde van sloot	0,21	NBL 2016	€ 605,00	per 1000m
6	sloot - schaduw 1x per jaar, 1 zijde van sloot	0,36	NBL 2016	€ 605,00	per 1000m
8	struweel 1x per 10 jaar dunnen (max 30%)	2,00	NBL 2016	€ 612,00	per ha
9	groenstrook 1x per 10 jaar dunnen (max 30%)	0,50	NBL 2016	€ 858,00	per ha
10	bloemrijk grasland - zonnig 2x per jaar gefaseerd maaien en afvoeren (30% laten staan)	2,21	NBL 2016	€ 181,00	per ha
11	[redacted] bloemrijk grasland - schaduw	11,36			
	1x per jaar maaien en afvoeren (paden tussen panelen)		NBL 2016	€ 323,00	per ha
	1x per 3 jaar maaien (onder panelen)*		-	€ 323,00	per ha
15	wandelpad 1x per 3 weken maaien (zomerhalfjaar)	0,08	NBL 2016	€ 120,00	per ha
	Totaal				
	* geen normbedrag bekend ** geen normbedrag voor gazonmaaien, uitgegaan van klepelmaaien				

Appendix 4: Table of costs concerning the ecological management of a PV farm (provided by an ecological consultancy operating in Groningen, through the intermediate of a biology lecturer r at the university of Groningen)



Appendix 5: Net Present Value (in euros) over the facility lifetime for three different scenarios: Standard Run, Test Run (Best case scenario) and Test Run (Worst case scenario) if the yearly interest rate is 3%.



Appendix 6: Net Present Value (in euros) over the facility lifetime for three different scenarios: Standard Run, Test Run (Best case scenario) and Test Run (Worst case scenario) if the yearly interest rate is 7%.

Appendix 7: Overview of information collected through personal communication

Initial message

My name is Ziad Matar and my bachelor thesis is about estimating the cost of measures to improve biodiversity in PV solar farms. I was wondering if maybe you knew where i could find the following information :

Ideally, I would like the following information about a single project. However, I understand that this might not be possible and any information would be helpful.

1- Cost of making an ecological study on a specific land and monitoring its biodiversity over the next 5 years.
2-Cost of elevating PV panels installations by 0.8 m
3- Estimated cost needed for installing technical structures (ex bird nests fox dens)
4-Cost of sowing floral and wild herbs
5-Cost of land in the province of Groningen

Response from a biology professor at the University of Groningen

1- Cost of making an ecological study on a specific land and monitoring its biodiversity over the next 5 years.
Basic ecological monitoring of one PV solar plant is about 35 000 euros per year.

2-Cost of elevating PV panels installations by 0.8 m
No idea.

3- Estimated cost needed for installing technical structures (ex bird nests fox dens)
Very low, maybe 5000 euros per PV solar plant is even a high number.

4-Cost of sowing floral and wild herbs
Between 200-400 euros per ha.

5-Cost of land in the province of Groningen
70 000 euros per ha (through boerderij.nl).

Response from a professor working on an ecofriendly solar field project at TNO

1-Cost of making an ecological study on a specific land and monitoring its biodiversity over the next 5 years.

*** The budget for our project is publicly available: it is of more than 3 million euros. Unfortunately, a detailed breakdown of total costs is confidential.

2-Cost of elevating PV panels installations by 0.8 m

*** I have no idea. An installer should know. I don’t expect it to be a big cost factor on the total of a turn-key system.

3-Estimated cost needed for installing technical structures (or example bird nests fox dens)

*** I would not know.

4-Cost of sowing floral and wild herbs

*** Same, you need to ask people who actually do this.

5-Cost of the land

*** This number varies widely per location. 0.5 Euro m2 per year is a typical number, I think.