Towards nature inclusive east-west orientated solar parks

TNO innovation for life

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SUMMARY

Solar parks in rural areas are important in the energy transition in the Netherlands as this form of solar energy is very cost effective and can be deployed fast. Potential negative side effects of these solar parks are that they may affect the landscape, the biodiversity and the soil quality underneath the panels. Especially in many east-west oriented solar parks, the panels are placed close together covering almost the entire lot. In such a solar park design the amount of sunlight that reaches the ground is strongly reduced. This will lead to deterioration of the soil quality over the 25-year lifetime of the solar park.

East-west oriented solar parks become more popular in the Netherlands as they bring advantages on the business case and on grid connection. This TNO report addresses the question whether these east-west oriented solar parks can be designed differently, in order to mitigate the deterioration of the soil quality. We performed this study using the software tool BIGEYE that calculates both the yield of solar panels and the incidence and intensity of light below and alongside the panels in a solar farm.

We examined two south-facing solar park configurations from an earlier study by Wageningen University & Research (WUR) in more detail and compared these with conventional east-west systems. Two additional east-west variants were calculated: one with standard solar panels and one with panels that are semi-transparent and harvest solar power on two sides (bifacial).
A 77% coverage design with semi-transparent, bifacial panels performs better on soil quality than south-facing standard panels with 53% coverage. The reason is a more even distribution of the light on the soil. In the design with bifacial panels, almost 100% of the soil receives sufficient sunlight. The desired adjustments to the east-west design are possible without affecting the business case.

We conclude that a modified design of east-west solar parks can substantially reduce the deterioration of soil quality, while maintaining the economic feasibility.
TNO recommends the establishment of criteria for ground irradiation under and between solar panels.

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1 INTRODUCTION

Solar parks on land play an important role in achieving the national climate agreement targets for 2030 for the Netherlands. Because of their size and maturity of technology, solar parks on land are relatively easy and cost effective to install as compared to installations on buildings, water and infrastructure. This explains the rapid growth of solar parks on land in the last 5 years. While in 2016 nearly all solar panels in the Netherlands were installed on residential and industrial buildings, now 20% of panels are installed in solar parks on land (ref 1). In this densely populated country with scarcity of land, societal acceptance of these solar parks are of paramount importance for their local installation permits. This acceptance is affected by local financial participation, integration in the landscape, concerns about biodiversity and ecology as well as combining PV with other functions such as agriculture. The effect of land based solar parks on the ecology is often qualified in terms of biodiversity and the soil quality. In addition to public concerns about ecology, land owners, whether public or private, often demand that the soil quality remains equal or improves after the 20- 30 years lifetime of a solar park, to be able to assign the land to functions such as agriculture or nature. The topic of this paper focusses on the effect of various solar park designs on the soil quality.

In 2017 Kok and co-workers (ref 2) raised concerns that densely packed solar parks deprive the soil of essential supplies of sunlight and water, which are both critical for the development of vegetation which in turn is crucial for the development of high soil quality. In 2019 Van der Zee and co-workers provided an overview (ref 3) on the pathways through which vegetation is linked to the quality of the soil beneath solar parks. Earlier this year, Schotman and co-workers published on the present state of the biodiversity and soil quality in 25 solar parks in the Netherlands. It was concluded that only a few solar parks showed promising developments and that in most solar parks better green management could improve the current state significantly. Especially poor conditions for biodiversity and soil quality were observed in east-west configured solar parks. In these parks, solar panels are so densely packed that they cast a nearly continuous shadow on the soil that inhibits the development and survival of vegetation as illustrated in figure 1.These reports contributed to the awareness about biodiversity and soil quality in solar parks. And as a consequence nature-inclusive designs that promote biodiversity as much as possible are nationally pursued in several research projects which are well supported by industry (see frame).

Biodiversity development, in terms of vegetation and animals, is possible below and between the panel arrays but also in the peripheral areas between the active solar arrays and the solar project border or fence. Next to biodiversity of animal and plant life above and in the ground, a nature inclusive solar park should also maintain or improve the soil quality, for example the amount of minerals and organic matter.

As stated above, the development of soil quality over the economic lifetime of a solar park is closely related to irradiance and availability of water below and between the solar panel arrays. Soil quality depends on the continuous supply of organic matter and other nutrients from the vegetation.

This occurs in multiple pathways, via root growth, fungi, micro-fauna and insects. As a consequence there is a direct competition between the solar park's performance and the amount of photosynthesis and therefore soil quality below and between panel arrays. For this reason, the ground irradiance between and below panels is directly linked to the soil quality and thus to the societal and economic value of the land.

The Dutch solar industry association Holland Solar has drafted a code of conduct that includes the principle that after the lifetime of the PV project the land can return to its original function, including good soil quality. To achieve that principle, a maximum ground coverage by solar panel arrays is agreed of 75% of the project area. The uncovered area can be located between the PV arrays, but also as larger open areas for example the surrounding area between the active solar arrays and the project border of fence. While it can be helpful to designate an area next to the active panel arrays to develop wildlife, it is also important to maintain and in some cases improve the quality of the soil between and below the arrays of PV panels.

Figure 1 *Left South oriented configuration with ample vegetation below panels and right east-west orientation deprived of vegetation below panels. Photo: Alex Schotman WUR*

Until now studies on biodiversity and soil quality in solar parks are based on empirical observations and draw qualitative conclusions on the effect of ground irradiance on the soil quality. In this paper we quantify the ground irradiance in terms of intensity and distribution across a solar park. Moreover we focus on the relationship between direct and indirect ground irradiance and the panel configuration in various solar park designs. We will introduce a methodology, based on the BIGEYE software package to gain insight in the irradiance distribution on the ground (see also frame 2). We will apply this method to systems representing nature-inclusive solar parks as identified by the latest report of Schotman and co-workers (ref 4), and industry-standard solar parks with frequently occurring configurations. We propose improved solar park designs that have a similar or better potential for soil development and are more economical than the reference systems especially compared to the ones for good soil quality.

FRAME 1: NATIONAL COLLABORATION BETWEEN TNO AND WUR

In 2017, TNO and WUR initiated the knowledge platform “Nationaal Consortium Zon in Landschap”. This platform consists of members from government, industry, NGOs and knowledge institutes. The platform, chaired by the co-author of this paper, Kay Cesar, addresses research and innovation projects related to solar parks on land, with focal points on spatial quality, biodiversity, agrivoltaics and grid connection. Alex Schotman, from Wageningen University and Research, coordinates the topic of biodiversity. Two major research initiatives, financially supported by the Netherlands Enterprise Agency from the Ministry of Economic Affairs and Climate Policy, on biodiversity emerged from the knowledge platform, SolarEcoPlus and EcoCertified Solar Parks and will lay the groundwork for nature-inclusive design and green management of solar parks. This report represents a first step towards this goal and builds on the published work of Schotman and co-workers published earlier this year (Ref 3).

2 METHODOLOGY TO SIMULATE AND EVALUATE THE GROUND IRRADIANCE

As an example we take the solar park design that, according to WUR, has shown to have very good potential for soil quality and biodiversity. A cross section is shown in the figure 2, showing cross-sections of three south-facing tables of solar panels with 4 m width and 3.5 m distance between the tables. The total ground irradiance over period between March and October is simulated for the line indicated by the arrow. Starting directly below the bottom edge of the left table, we have a fairly high irradiance as most of the times the direct sun beam can reach the ground. Only part of the view towards the (Northern) sky is blocked by the table itself and a small portion of the Southern horizon is blocked by the tables in front of this spot. The irradiance, for each point, is compared to the irradiance in an open field without any solar panels.

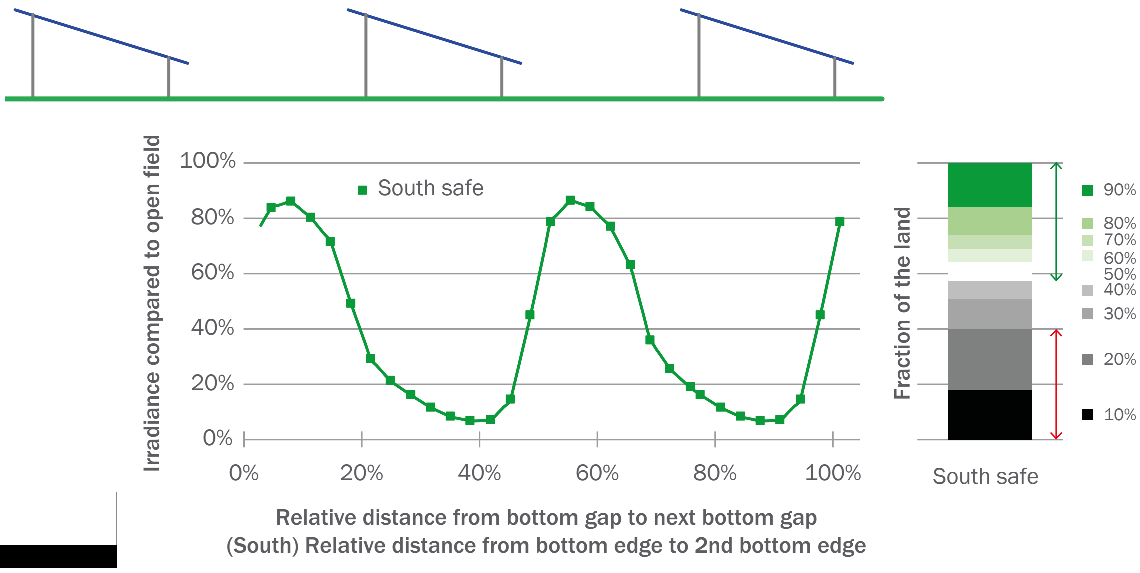

Figure 2 *South configuration of a solar array deemed safe for soil quality and its surface distribution of ground irradiance*

Moving along the arrow to the right (South) the irradiance stays high, until about halfway the empty space, the simulated irradiance starts to decrease as more and more of the sun's possible positions (viewed from that spot) are blocked by the PV table in front. Directly behind and under the middle table the irradiance is low, often less than 20% of the open field. Only when we approach the bottom edge of that table does the irradiance increase again. This pattern of ground irradiance is repeated for each table in the solar park, with minor deviations at the edges of the field.

As we will see, the ground irradiance patterns for south-facing and east-west facing solar park designs are quite different, we will have to compare them in a different way. We look at each irradiance level, in steps of 10% and measure what's the percentage of the land that receives that amount of irradiance. The bar diagram shows that just under 20% of the land gets between 0 and 10% of the open field irradiance, another ~20% gets between 10-20% etc. We also assign a red arrow for the range 0 to 20% as the low range, which could endanger the soil quality, and a green arrow for irradiances >50% signalling an abundance of light. Note, 50% of the open field irradiance sounds little, but it is more than sufficient for plant growth. Consider, for example, the land directly next to a north-south wall, which will receive about 50% of the open field irradiance as half of the sun's positions and half of the sky are blocked by the wall. From experience we know that the ground close to those walls will support plants.

FRAME 2: BIGEYE AND GROUND IRRADIANCE
TNO has developed a software package, named BIGEYE, that calculates the energy yield of solar systems. In particular, to simulate the irradiance on the rear of the bifacial panels, it is necessary to determine the irradiance distribution on the ground below and around the solar panels. This spatial irradiance distribution takes into account the patterns of hard shadows by the PV panels, but also the distribution of diffuse light, e.g. from clouds. Simulations from BIGEYE have been validated on small and large systems and have been published and benchmarked with international standards.
For energy yield calculations, the ground irradiance, which varies point by point but also with the time of the day and the seasons, is an intermediate result. However, these results can also be directly used to study the effect that objects have, like PV panels, on the amount of light that reach the ground. Whether you're interested in soil quality and biodiversity, or you want to combine the solar energy generation with agriculture.

3 EFFECT OF ARRAY DESIGN ON GROUND IRRADIANCE

We compare the nature inclusive east-west designs with several reference cases. Our research partner WUR has recently reported an overview of 25 existing solar parks in the Netherlands and their expected impact on soil quality and biodiversity.

One reference case was based on a set of South-facing solar parks that WUR regards as a safe choice for soil quality and biodiversity, based on present observations and understanding. It has smaller tables, 4 m wide, and a large row-row distance of 3.5 m resulting in a ground coverage of 53%. Figure 3 shows the cross-section of that “safe” reference case and the accompanying ground irradiance profile. This profile is scaled from 0 to 100%, the latter being indicated by the green horizontal line. All configurations are drawn to scale for direct comparison. Clearly the safe design has a fairly large area with high irradiance, > 50% of the open field. Also the area below the panels that receives very little light is rather small and due to the short repeating unit also rather fragmented.

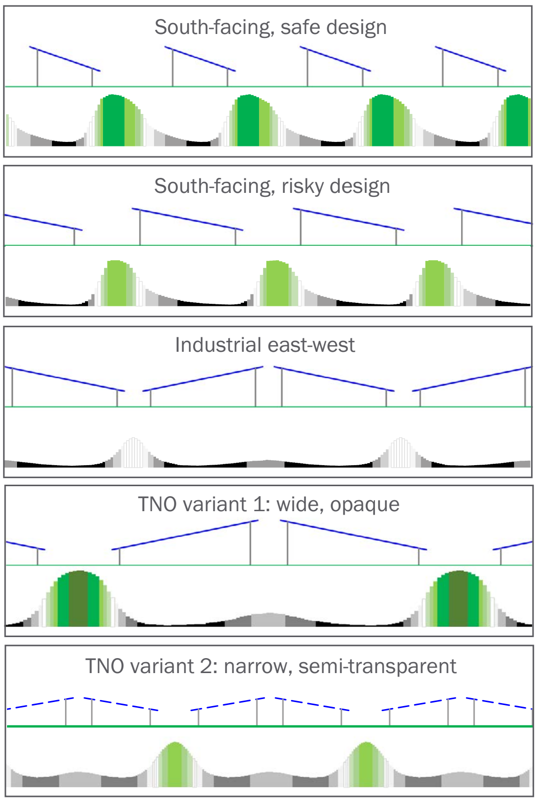

Figure 3, *various solar array configurations and ground irradiance. Drawn to scale.*

The second South-facing reference case is regarded as a more risky choice regarding soil quality. It has larger tables, 6 m wide, and a shorter row-row distance of 2.7 m resulting in a ground coverage of 69%. The resulting ground irradiance profile shows more narrow and less bright regions between the tables. Also the dark area under the tables is larger.

The final reference case is based on industry-standard east-west configurations as often applied in the Netherlands. It has large tables with narrow gaps at the top and somewhat larger gaps at the bottom, resulting in ground coverage ratios of > 90%. The narrow irradiance peak at the larger, bottom gap reaches only 50% of the open field value. The irradiance that falls through the narrow, top gap is distributed over a large area as the light beam is moving west to east with the sun's position during the day. The resulting irradiance below two adjoining tables is very low over a large area.

TNO shows two alternative designs that indicate how the various design parameters influence the ground irradiance and its distribution. TNO variant 1 consists of wide tables, 8 m, but also large gaps between the tables, resulting in a ground coverage of 77%. Clearly the irradiance below the bottom gap between an east- and a west-facing table is very high but it also allows more light in the immediate region below those tables. Also the larger top gap allows more light and distributes that light over a fairly large region. Clearly increasing the gaps (even at a larger table height), i.e. decreasing the coverage, has a positive effect on the ground irradiance.

TNO variant 2 has actually the same coverage ratio (77%). In addition, we half the table height to two panels in portrait orientation and half the size of the gaps. We also introduce semi-transparent solar panels that are typically based on bifacial solar cells. Ground under a PV table but close to a gap receives more light compared to an area under the centre of the table. As a result, when you decrease the table size, the fraction of the area under the table that receives light through the gaps increases. Thus, the wide dark valley as seen in the EW reference is becoming smaller with faster increases at the edges.
The effect of the semi-transparent panels is even more pronounced. A small fraction, typically between 5% and 10% of the total module area, basically is glass-encapsulant-glass, see the photograph in Figure 4. Whereas a traditional, white or black back-sheet module gives a hard shade on the ground, these semi-transparent panels will let some light through. In full sunshine, this would be a patchwork of bright lines and shadows from cells, boxes and cables, but with the movement of the sun, the light will be spread more or less evenly over the ground. The ground irradiance will thus increase, particular in areas that are shaded the most, that is, the central area below the PV panels.

Figure 4 *The patchwork of bright lines and hard shadow of the solar cells is visible in the bottom of the picture*

As can be seen in the infographic, the irradiance profile of TNO variant 2, has somewhat lower irradiance between the (more narrow) bottom gaps but still well above 50%. But more importantly, the area with lowest irradiance, well below 10% of the open field, is completely gone. The darkest area in this design receives 16% of the open field value.

Although not the main focus of this study, we did simulate the energy yield for the various solar park designs. The “South-facing safe” design gives per ha significantly less energy yield than the industrial east-west design. With the TNO variant 2 we have very similar potential for soil quality than the south safe design, but the energy yield per ha increases significantly. Note: detailed business case analysis is part of future work.

Finally, next to ground irradiance soil quality depends on proper watering. Below solar panel arrays, the watering occurs in the gaps between individual panels. In case panels are landscape oriented this happens every 1 meter. For the watering of the soil below the panels it is of no concern which direction the panel arrays are orientated towards. Therefore there is no difference in watering between the discussed east-west and south configurations.

FRAME 3: WHY ARE EAST-WEST ORIENTED SYSTEMS POPULAR IN THE NETHERLANDS?
In the Netherlands solar panels generate the highest power output when oriented to the south with a tilt angle of 37°. However, there are many solar parks with panels oriented to the east and west at much smaller tilt angles. This prevalence is caused by three factors: high land lease costs, grid connection limitations and Dutch subsidy rules. The high land lease cost push the business case towards high packing densities of panels. To prevent shading losses on neighboring panels the tilt angle is reduced to 10-15°, just enough for water to rinse off the panels. Secondly, east-west orientation spreads the yield across the day and lowers the peak performance at noon which allows for smaller cable connections. Finally, the SDE+ subsidy is limited to a maximum utilization of 950 kWh/kWp while optimal south orientations can yield up to 1050 kWh/kWp which decreases the attractiveness of the optimal orientation. For similar reasons, flat oriented arrays can be oriented to the south as well, as the orientation at these tilt angel has a smaller impact on the yield. It is clear that high land lease cost exerts pressure to increase the ground coverage in solar parks which in turn puts a strain on the development of soil quality which is the topic of this paper.

4 CONCLUSIONS

We summarize these results in the bar diagram. The east-west standard is dominated by over 80% of the land receiving less than 20% of the open field light. And a major part of that is even (well) below 10%. In contrast, the close to safe and safe choices have 60% and 40% of the area with such low irradiance.

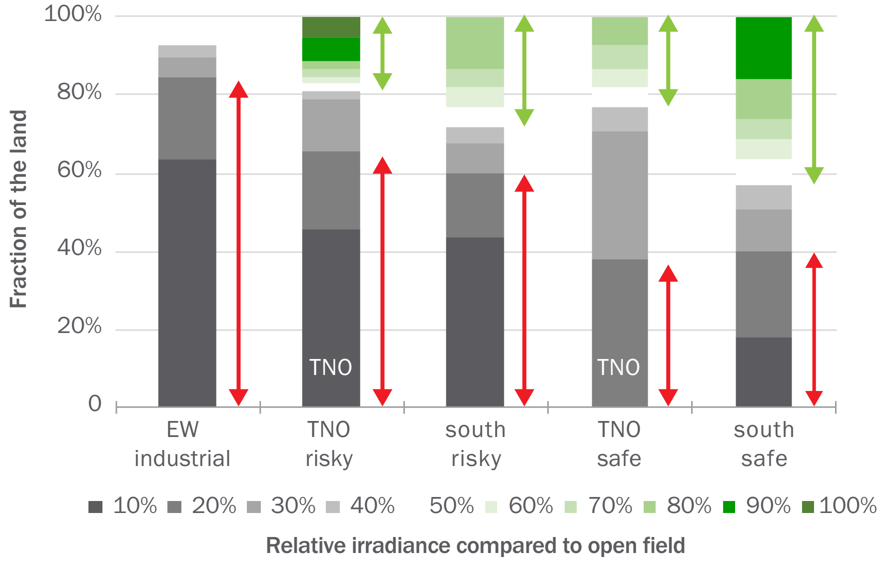

Figure 5 *Ground irradiance distribution for the designs of Fig. 3. Red and green arrows indicate the area with respectively <20% and >50% irradiance*

The proposed east-west TNO variants result in similar amounts of low irradiance fractions. On the bright side, TNO variant 1 has also a similar amount of area with high irradiance. Actually, TNO variant 2 has also about 20% of the land with over 50% irradiance. But, most likely more important for biodiversity and soil quality, the minimum irradiance is significantly higher compared to all other designs (ref 5).
There is a further optimisation possible between the high irradiance in the bottom gaps that could favour the biodiversity and the intermediate level of irradiance below the panels and the top gaps that is sufficient to support the soil quality.

4.1 OUTLOOK

At the moment, there is limited empirical data about the effect of park design on soil quality due to the slow response of the soil upon park installation. The research projects SolarEcoPlus and EcoCertified Solar Parks funded by the Netherlands Enterprise Agency will focus on the relation between solar park design and the soil quality and biodiversity. These projects will develop new insights in the coming years. Ground irradiance assessments as conducted here will become of paramount importance in designing the solar parks of the future. In addition, more work is required to further optimize the park design with respect to the business case of these nature inclusive solar park designs. Finally, we recommend to introduce criteria for minimum ground irradiance below and between solar panel arrays to ensure soil quality after the project lifetime.

4.2 ACKNOWLEDGEMENTS

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