Position paper

Producing food and electricity on the same square meter

Researchers see a future for agricultural solar parks, but also challenges

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Conclusions and recommendations

Generating solar power and growing crops on the same field is possible, and this multiple land use can substantially enhance societal value. Renewable energy can then be generated while maintaining agricultural production and soil quality. To do so, however, the agri-PV system must be properly designed so that negative impacts on crop cultivation and soil quality are limited. To underpin the models used to design agri-PV systems, research into the impact of shade on crops grown in the Netherlands is needed.

For large-scale rollout, the guidelines defining what constitutes agri-PV must be clarified. Guidelines from Japan, Germany, France and Italy can provide a starting point for defining the guidelines in the Netherlands. If a proposed agri-PV system complies with these guidelines, it should also be clear to the authorities issuing permits that no change is required in the zoning classification of the field. For the farmer it should also be clear that the CAP subsidy for the field will be retained, and that it is still allowed to apply fertilisers. A separate subsidy scheme (called SDE++ in The Netherlands) should cover the additional costs of construction so that agri-PV can be effectively realised, with sufficient societal added value to justify these extra costs.

Instead of large solar farms, the Netherlands wants to move towards multifunctional solar parks

Due to the growing demand for land for housing, food production, nature conservation, and renewable energy production, the same land must increasingly be used for more than one purpose. An important example of such 'multiple use' is combining food production and solar power generation on the same field. These ‘agricultural solar parks’ are referred to as 'agri-PV'. That 'PV' stands for 'photovoltaics', the technical name for generating solar electricity. Besides producing renewable energy and food, agri-PV provides societal added value by preserving agricultural land and soil quality and by reducing water evaporation.

In a recent position paper, Wageningen University & Research (WUR) and the coalition of environmental federations (De Natuur en Milieufederaties)[1] called on national politicians to take land-based energy generation to the next level. The development of multifunctional land-based energy projects is one of the solutions proposed in the position paper.

To date, solar parks in the Netherlands have been monofunctional: these solar parks only generate solar power. Due to growing opposition to monofunctional solar parks on agricultural land, several provinces have recently banned them. The Dutch government also requires multifunctionality (see Box 1), although it is not always clear how this should be implemented in practice. For biodiversity, this is detailed within the project EcoCertified Solar Parks[2]. With this supplementary position paper, we clarify what is needed to successfully realise agri-PV in the Netherlands.

Box 1. Definition of multifunctional solar parks[3]
Multifunctional use of space can be achieved through intelligent site selection: solar energy generation is added to the existing function or, in a solar project several new functions are developed or value is added. Intelligent site choices could include land owned by the State, water treatment plants, waste dumps, inland waters, and verges of roads and railways. New function combinations in a project could include solar parks together with nature restoration or climate adaptation, and combinations with agriculture, recreation or battery storage.

1 Verder met energieopwekking op land. Vijf interventies om de klimaatdoelen te halen, 27 maart 2023.
2 https://zoninlandschap.nl/projecten/i358/ecocertified-solar-parks
3 Letter on solar power from Minister Jetten to House of Representatives, 20 May 2022. https://www.rvo.nl/onderwerpen/zonne-energie/beleid

Agri-PV: combining food production with energy generation on the same field

Agri-PV is a more efficient way to use land: the total combined production is higher than when crop production and power generation are separated on two fields, even when power production and crop yield per hectare are lower (see Box 2). Agri-PV thus enables expansion of renewable energy production with no or minimal loss of agricultural production.

Besides enhancing land-use efficiency, agri-PV has other potential benefits. Underneath the panels, temperature extremes – both hot and cold – are lower, and in dry conditions the panels reduce evaporation. The Netherlands too is increasingly experiencing periods of drought. With effective agri-PV designs, a relatively good crop yield can still be achieved, even in drought conditions.

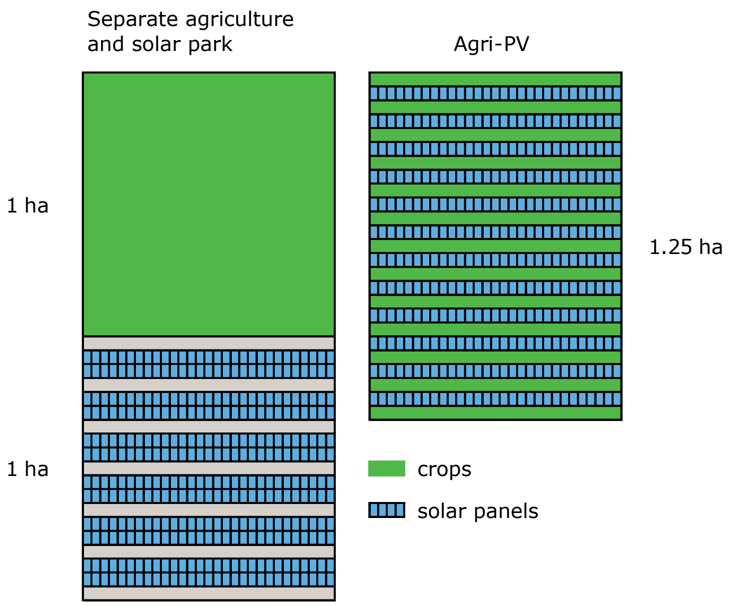
With monofunctional solar parks designed to produce as much power per hectare as possible, soil degradation is a major concern. With agri-PV, crop production adds organic matter to the soil, which helps to prevent soil degradation.

Box 2. Illustration of increased efficiency of multifunctional land use

In present day monofunctional solar parks, the solar panels are installed on a field without crop cultivation. In that case, crop production takes place on one ha of land without solar panels, and solar power production takes place on a separate ha of land. With agri-PV, the panels are installed slightly further apart, thus enabling crop production, but resulting in a slightly lower solar electricity yield per ha. Under Dutch climate conditions, the crop yield per ha is usually somewhat lower as well.

If both yields per hectare were 20% lower, for example, it would be possible to produce the same yields of crops and solar power on 1.25 hectare with agri-PV as on 2 hectares with monofunctional land use.

This combination of agriculture with solar panels then leads to a relative total efficiency of 160%. In southern Germany, relative total efficiencies ranging between 156% and 187% were determined for agri-PV with potatoes, winter wheat, celeriac or grass/clover[4]. The positive impact of combining agriculture with solar panels is greater in southern Europe than in northern Europe, and is greater for crops with low light requirements than for those that need higher light levels[5].



4 Trommsdorff et al., 2021. https://doi.org/10.1016/j.rser.2020.110694
5 Willockx et al., 2022. https://doi.org/10.1016/j.egyr.2022.06.076

How can agri-PV be realised?

There are several ways in which solar panels can be combined with crops or with grassland and grazing livestock. For example, crops can be grown under elevated panels or between rows of panels (see Figure 1). Unlike standard solar panels, those used for agri-PV often allow some light to pass through, and are therefore called 'semi-transparent'. The rows of panels can be static or follow the sun. The latter are called 'tracking systems'.

With agri-PV, the solar panel system has to be adapted to the crops being grown, and cultivation methods may need adjustment as well. Adaptations to the height, row spacing and transparency of the panels can ensure that sufficient light reaches the crops, and the agri-PV systems must match the height and width of farm machinery.
For example, panels above pear trees are installed at a greater height than those above raspberry vines.
In addition, mobile systems have been developed that can be temporarily moved for crop access (see Figure 2).

Compared to traditional solar parks, agri-PV systems are often less cost effective due to the elevated design or lower power density. Agri-PV therefore is most promising when the solar panels benefit crop production, i.e., when the combination is synergistic. The complex matching of cropping systems and panels and the effects on costs and yields require targeted research and optimisation, and corresponding legislation and regulations.

Figure 1 Above: red currants grown under solar panels; the panels are semi-transparent to ensure that sufficient light reaches the fruit (photo: Frank de Ruijter). Below: vertical panels, in between which crops can be grown (photo: Thomas Reher). The panels are double-sided (bifacial) and can generate electricity on both sides. The rows will be installed in a north-south alignment and the panels will then produce the most power in the morning on the east side and in the afternoon on the west side.

Figure 2 Above: solar panels over pears (Groenleven system; photo: Frank de Ruijter). Below: Mobile solar arches from GOLDBECK SOLAR/ Solarvation over grass/clover (photo: Jan-Rinze van der Schoot).

Impact of solar panels on crop growth

In hot and dry areas, excessive solar radiation on the crops is reduced by the solar panels, and the shade of the panels moderates temperatures, reduces evaporation and ensures more efficient use of water by the plants. Good results have been reported, for example, in the state of Arizona[6], where agri-PV leads to higher crop yields and the panels generate power more efficiently because the crop underneath cools the panels through transpiration. In southern France, the shade of solar panels also leads to less evaporation and to lower sugar content in grapes and thus to better quality wine[7] (see Figure 3).

Such high levels of synergy are unlikely for the Netherlands, where the solar radiation is much lower. Nevertheless, there are also opportunities for agri-PV here. In the Netherlands, the simplest application is in fruit growing, where adding solar panels requires only minor changes to the cultivation method: crops are already grown in permanent rows and smaller machinery is used. Synergy is possible because the support structure of the panels can also be used for crop support, and because crop protection covers or nets can be replaced by solar panels. Raspberries, for example, are grown under a plastic cover to keep the fruit dry and to protect it from too much solar radiation. This cover is currently renewed every five years. By replacing this plastic with semi-transparent solar panels (Figure 4), plastic waste can be substantially reduced. For pears, part of the hail protection net can be replaced by solar panels.

In arable farming and on grassland, where cultivation is mostly rain-dependent, reduced evaporation in agri-PV can also provide synergy. In these types of agriculture, agri-PV is expected to give higher yields in dry years, but lower yields in wet years.

Figure 3 Movable panels over grapes in Piolenc, southern France (photo: Sun'Agri[8])

6 Barron-Gafford et al., 2019. https://doi.org/10.1038/s41893-019-0364-5.
7 https://sunagri.fr/en/key-findings-vine-growing/.
8 https://sunagri.fr/en/solars-flexibility-can-be-agricultures-gain/.

In the Netherlands, agri-PV is being studied in the Sunbiose project (2021-2025; www.sunbiose.nl) in pilots with raspberries, strawberries, red currants, pear and grass-clover. Initial results have shown that production of strawberries decreases with less light (see Figure 5). Light requirements vary from crop to crop, underlining the need to look for optimised PV systems that allow enough light passing through for sufficient crop production.

To ensure realisation of agri-PV in practice, the associated crop production must be sufficiently profitable over the long-term. Otherwise, crop cultivation might eventually be terminated. To prevent this, broader knowledge of the impact of agri-PV on crop yields due to shading and changes in water management is required, as well as knowledge of the financial implications of any modifications to the cultivation method.

Figure 4 Above: conventional cultivation of raspberries under plastic covers (photo: Wilma Eerenstein).
Below: growing raspberries under partially transparent solar panels, Groenleven system (photo: Herman Helsen).

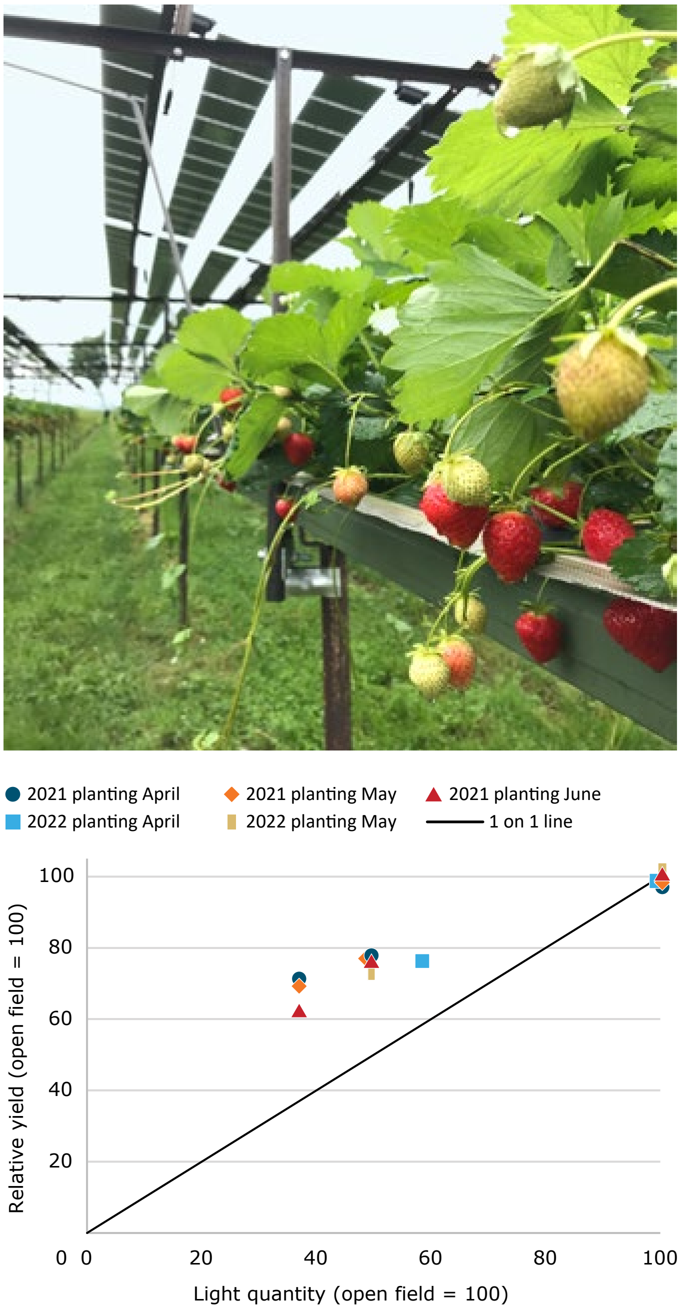


Figure 5 Above: growing strawberries under a partially transparent solar cover, Groenleven system (photo: Herman Helsen).
Below: Relative strawberry production as a function of transmittance of the solar roof cover (both relative to open field production). At 60% light permeability of the system, crops receive 40% less light than in the open field. Strawberry production is then 75% of that in the open field.

Financial aspects of agri-PV

Agri-PV requires a higher investment than a standard monofunctional solar park due to the elevated construction or the lower power density[9]. A profitable investment therefore requires a higher price for the generated electricity (see Box 3). Table 1 summarises the data for a monofunctional solar park, a cover with semi-transparent panels and a vertical system[10]. A range is given for investment costs due to the effects of scale: smaller projects are proportionally more expensive than larger-scale projects. An average price from this range was used for the calculations. Power production was estimated based on bifacial (double-sided) panels, with the temperature of the panels also taken into account. The lower the temperature, the better the power output.

An allowance to the farmer for the use of the land is important if a developer invests in a solar farm. For monofunctional solar parks, this amount is around €5,000 per hectare per year. For agri-PV, the height of the allowance should depend on the impact on crop cultivation, as explained below.
For the farmer, solar panels have advantages and disadvantages. In the case of the aforementioned raspberry crop, the farmer can save on the cost of a plastic cover.

Box 3: SDE++
Solar parks connected to high-volume connections can benefit from the SDE++ scheme[11], which guarantees a minimum electricity price for the operator. If the market price falls below the set minimum rate (base amount), the difference is accounted for from the scheme.

These base amounts are set annually by the Netherlands Environmental Assessment Agency based on the costs for solar parks, financing and maintenance at that time, and apply for a period of 15 years. The calculated costs are for monofunctional solar parks. For ground-mounted solar parks with a capacity between 1 MW and 20 MW, the base amount is presently €0.0701 per kWh.

For agri-PV, the cost price is higher than for monofunctional solar parks, and this is only partly offset by the use of more efficient bifacial (double-sided) panels. For agri-PV, these differences should be included in the SDE++ systematics.

At the same time, less income is generated from cultivation if crop yields fall. The system is financially beneficial for the farmer if the savings on crop cover exceed the losses from reduced crop yield.

Table 1. Summary of the characteristics of three systems (standard monofunctional solar park, semi-transparent roof cover, vertical system) with indicative economic calculations (per Watt peak and per hectare).

	Monofunctional solar park	**Semi-transparent roof cover**	**Vertical system**
Power density, MW/ha	**1.5**	**0.9**	**0.35**
Investment per ha, euro/Watt peak	**€0.45 - 0.6**	**€0.75 - 0.9**	**€0.6 - 0.75**
Average investment construction, euros/ha	€750,000	€738,000	€238,050
Annual O&M, per ha	€19,500	€12,150	€4,485
Financing costs/year, per ha	€16,875	€16,605	€5,356
Relative electricity production, kWh/kWp (in the Netherlands)	**950**	**1,000**	**1,100**
Annual electricity production, kWh per ha	1,425,000	900,000	362,250
Allowance for land use to the famer [12] (euros/ha per year)	€5,000	€1,000	€2,500
Gross annual turnover/ha at 7 cents/kWh	€99,750	€63,000	€25,358
Gross annual turnover/ha at 9 cents/kWh	€128,250	€81,000	€32,603
Payback period (years) at 7 cents/kWh	12.8	22.2	18.3
Payback period (years) at 9 cents/kWh	8.6	14.4	11.7

9 Installation costs of a solar park increase only slightly when the distance between the rows of panels is increased (slightly more cable is needed), but the use of partially transparent panels does increase investment costs per Watt peak (the maximum electrical energy that a photovoltaic panel can supply under standard test conditions).
10 Data from the Sunbiose project, with input from the SDE++ documents and from the project partners.
11 https://www.rvo.nl/subsidies-financiering/sde.
12 The hectare allowance is set by farmer and project developer on a project-by-project basis. The amounts shown here are assumptions (see text).

In field crops such as potatoes, sugar beets, grass or onions, generally no crop support facilities are used. These crops can be combined with rows of vertical panels, adjusting the row spacing according to the machinery used and the cultivation method[13]. Such a vertical structure reduces the land area available for crop production by about 10%[14] because there is a small strip on either side where no cultivation is possible. As a result, the farmer has a lower income per hectare and this has to be compensated by the 'hectare allowance'. Income losses are crop-dependent, and estimates from the Sunbiose project indicate a loss between €300 and €1,500 per hectare per year for crops such as grass, potatoes, sugar beets, carrots, cereals and onions.

In addition, it is reasonable to compensate the farmer for the limitations that are inherent to agri-PV, irrespective of the crops grown. These include restrictions on the use of large machinery, limited choice of crops and reduced marketability of land.

Taking all these aspects into account, in the calculation examples shown in Table 1 we see that a semi-transparent cover requires a rate of at least 9 cents per kWhkWh to recoup the investment within 14.4 years, which is longer than the payback period for a monofunctional solar farm at 7 cents/kWh. For a vertical system at a rate of 9 cents, the payback period is similar to that of a monofunctional solar farm at a rate of 7 cents/kWh.
For several crops, the income for farmers consists partly of subsidies from the Common Agricultural Policy (CAP). In addition, legislation specifies how much fertilisation can be used. Because agricultural functionality remains largely or even entirely intact with agri-PV, it is imperative that the farmers retain the right to CAP subsidies and the right to apply fertilisers, and that policymakers are aware of this. Clarity is also needed on continued zoning as agricultural land, both in the agri-PV phase and after possible removal of this system[15] (usually after about 25 years). For more precise interpretation, reference can be made to similar discussions that are taking place in Germany[16].

13 Currently, equipment is used for fields on which a single crop is grown. However, developments are taking place in strip farming, whereby different crops are grown on strips (about 6m wide). Because this method of cultivation is not yet widely used, the Sunbiose project based its calculations on current cultivation systems and methods.
14 Depending on the spacing between the rows of vertical panels, here a 13m row spacing was used for the calculations.
15 https://www.rtvdrenthe.nl/nieuws/15673003/bosboeren-krijgen-nieuwe-aanslag-van-belastingdienst-de-contractbreuk-is-het-ergst.
16 https://www.ise.fraunhofer.de/de/presse-und-medien/presseinformationen/2022/agri-photovoltaik-bessere-chancen-fuer-kleinere-anlagen-hoch-aufgestaenderte-systeme.html.

What knowledge and policy is needed?

1. More knowledge about the impact on crop growth
Effective design of agri-PV requires knowledge of the response of crops to shade and to changes in rainfall distribution, soil moisture and microclimate. Shade not only reduces light, but also evaporation, and the effect of shade on crop yield will vary between years.
Measurements are needed in test setups with a range of shade levels. By incorporating the results into crop growth models and linking them to electricity production and light transmission models, extrapolations can be made to the impact over several years under various weather conditions. This knowledge can be used to design optimal agri-PV systems. Such designs can account for costs, yields and requirements for aspects such as the use of desired machinery.

2. Clear government guidelines
Japan[17], Germany[18], France[19] and Italy[20] now have government guidelines for agri-PV. Japan mandates that crop yields must be at least 80% of yields that are achieved in full sun. Germany has a guideline that crop yields in agri-PV should be two-thirds of yields in an open field. However, these guidelines are still problematic because it cannot be verified in advance whether a design

17 Tajima & Iida, 2021. https://doi.org/10.1063/5.0054674.
18 DINSPEC 91434. https://www.beuth.de/de/technische-regel/din-spec-91434/337886742.
19 https://agriculture.gouv.fr/loi-relative-lacceleration-des-energies-renouvelables-un-cadre-pour-les-installations.
20 https://www.mase.gov.it/notizie/impianti-agri-voltaici-pubblicate-le-linee-guida.

meets these requirements. It would be better to clarify, based on acquired knowledge and model calculations, what the impact of agri-PV on crops will be, which also provides clarity to the farmer.

The Netherlands does require solar parks to be 'multifunctional' (see Box 1), but does not yet have specific guidelines for agri-PV. A guideline is needed to avoid a situation where an agri-PV applicant intends to grow a crop, but where crop production is hardly possible because of lack of light under the panels. The result would then be a solar park without crop cultivation and a power production that is likely to be less efficient than in a well-designed monofunctional park. Clear preconditions for agri-PV, with ex-ante verifiability and monitoring of implementation, are therefore necessary.

3. Unchanged zoning status of the land

When a solar park complies with the guidelines for agri-PV, the agricultural functionality is maintained, and the land should continue to be zoned for agricultural use. This zoning status should also be taken into account in the permit and implementation process. As crops are still being grown, the farmer should retain all the rights and obligations that come with agricultural land.

4. Financial instruments

Due to the higher investment for agri-PV relative to monofunctional solar parks and the risk of negative financial impact on farmers, government financial support for agri-PV should be adapted accordingly.

The higher investments for agri-PV require a higher subsidy than for monofunctional solar parks. The exact costs and benefits of agri-PV vary according to the crop. The impact on the farmer and the required 'hectare allowance' should also be taken into account. All these aspects together provide a clear picture of the power price that is needed to ensure a profitable system for both the farmer and the project developer. Initial calculations from Sunbiose show that this is currently possible at a price of 9-10 cents per kWh. This is slightly higher than the current SDE++ base rates for ground-mounted solar parks of around 7 cents/kWh. Considering current consumer electricity rates, this is still a very reasonable price for electricity. Currently, basic delivery rates for residential customers and SMEs are around 16 cents per kWh. Higher subsidies for agri-PV are also being proposed in Germany[21].

21 https://www.ise.fraunhofer.de/de/presse-und-medien/presseinformationen/2022/agri-photovoltaik-bessere-chancen-fuer-kleinere-anlagen-hoch-aufgestaenderte-systeme.html.

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