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Call for a clear definition of agrivoltaics

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DOI: https://doi.org/10.18174/676999,

On October 26, 2023, the Dutch government sent a letter to parliament regarding the ‘priority list for placing solar panels’, highlighting that the use of agricultural land for solar parks is generally undesirable. An exception is made only for agricultural land with a dual function, such as the combination of farming and solar energy generation (agrivoltaics or agri-PV), where farmers contribute to both food production and the energy transition. However, experts warn that the lack of a clear definition for agrivoltaics may lead to undesirable outcomes, as there is a risk that, in practice, agricultural land will primarily be used for energy production.

Why is a definition of agrivoltaics necessary, and what are the minimum requirements?

With the stricter order of preferred locations of solar panels, the government aims to strike a balance between sustainability and food security. Therefore, having a clear definition of agrivoltaics is crucial, experts from Wageningen University & Research, TNO, and Renergize Consultancy emphasize. “A clear definition provides farmers and policymakers with the necessary framework, reducing the risk of agricultural land being misused,” they state.

Without a well-defined definition of agrivoltaics, there is a risk that solar systems could be installed in ways that severely limit crop growth, resulting in low or even no crop yield. This would lead to inefficient land use, as the electricity generated per hectare would be less compared to that of a well-designed, monofunctional solar park. Clear requirements, the ability to assess them in advance, and control over implementation are therefore necessary.

For the first time in the Netherlands, a public discussion on the definition of agrivoltaics took place at the SunChain conference in Utrecht, October 2, 2024. Representatives from the government, the industry organization Holland Solar, LTO Nederland, and knowledge institutions like TNO and WUR shared their expertise. According to experts from WUR, TNO, and Renergize Consultancy, a good definition of agrivoltaics should meet the following minimum requirements:

1 *Pre-Project Assessment*: The agrivoltaics definition should allow for assessment during the planning phase to facilitate a smoother permitting process.
2 *Sunlight Distribution*: The assessment of agrivoltaic constructions is based on the intensity and distribution of sunlight over the crops.
3 *Resource Efficiency*: The combination of agriculture and PV yield should contribute to the efficient use of land, water, and pesticides.
4 *Continued Agricultural Activity*: It is essential to ensure that agricultural activities are maintained throughout the entire lifespan of the agrivoltaic system

In preparation for future legal definitions, this framework will be further refined in the coming years. The insights presented are based on ongoing agrivoltaics projects, especially the 5-year Sunbiose project, experiences with ground irradiance assessments for nature-inclusive solar parks (SolarEcoPlus and EcoCertified solar parks),[1,2] and information from national and international scientific literature. It also builds on the position paper[3] of 3 October 2023 that provides an overview of what is needed in terms of knowledge and policy for a successful implementation of agrivoltaics.

When do we speak of agrivoltaics?

Based on the previous position paper,[3] we propose the following primary definition:
"Agrivoltaics is a form of multiple land use where crop production and solar power generation are combined on the same plot of land, resulting in a higher overall yield than if both forms of land use were applied separately."

This definition can and should be made more specific. Further refinement is needed through consultation with the government and stakeholders, such as the agricultural and solar energy sectors.

Multiple land use is aimed at using land more efficiently. It is essential to determine what level of crop production is desirable to ensure that the agri-part remains viable, and what panel configuration requirements are needed to ensure that crops receive sufficient light for growth.

Examples of agrivoltaics Systems. Left: Solar panels over pear orchards (photo W. Eerenstein). Right: Rows of solar panels with space for cultivation in between. Top right: Vertically placed panels (photo WUR). Bottom right: Panels that follow the sun (tracking systems) (photo W. Eerenstein).

Minimum requirements for agrivoltaics systems

International definitions and different agrivoltaics configurations
Definitions of agrivoltaics vary by country. In the U.S.[4], for example, the term 'agrivoltaics' is broadly used to describe combinations of solar panels with crops, animals, or natural vegetation. In countries like Germany[5], France[6], Italy[7], and Japan[8], the focus is more on the combination of solar panels with crops and/or animals, with specific requirements for demonstrating that crop yields under agrivoltaics are sufficiently high compared to open-field cultivation or other reference scenarios.

These crop yield level requirements for agrivoltaics relative to the open field/reference situation are generally not assessed prior to the construction of an agrivoltaics system, and it requires significant monitoring and administration during the entire life cycle of the project. Additionally, the reliability of such comparisons can be questioned.

Another possible requirement is to specify the amount of land that remains available for agricultural activities. However, this alone is insufficient, as it does not address the distribution of solar panels (and thus light) over the land, and it does not guarantee that crop cultivation will continue. Therefore, requirements for agrivoltaics systems should focus on ensuring actual crop cultivation with sufficient yields.

There is no single agrivoltaics system; different system configurations can be used in combination with various crops. The two most common types of agrivoltaics systems are:
- Cultivation under solar panels (overhead systems)
- Cultivation between (and partially below) rows of solar panels

The rows of solar panels can consist of vertically placed panels, tracking systems (which follow the sun), or panels fixed at a specific angle. Mobile systems, which are still in development, can be moved across fields. However, their impact on crop production is uncertain, as it largely depends on panel density and the degree of movement. Also, for these systems, the average amount of light on the crops during the growing season must be sufficient to ensure a reasonable yield.
The main types of agriculture that can be combined with solar panel systems are:
- Grassland, which can be mown or grazed by livestock
- Arable farming and vegetable cultivation, involving tillage or no-tillage fields
- Fruit growing, both hard and soft fruits

For all these combinations, it is essential that crop yields are sufficient to ensure that agricultural land remains in production, and, of course, that farmers can earn an adequate income.

Impact on crops

Crop yield is central to agrivoltaics and is what differentiates it from other types of solar parks, such as nature-inclusive or economically optimized monofunctional solar parks. In general, less light in the Netherlands gives less crop yield[3]. Dupraz[9] (2023) provides an overview of scientific studies on crop yields in agrivoltaics systems and shows that, broadly speaking, crop yields decrease as panel density increases. In other words, more shading from panels leads to lower crop yields.

In the Sunbiose project, it was measured that strawberry and pear yields decrease by about 0.5% for every 1% reduction in light. For raspberries, the reduction ranges from 0-0.8%[10]. These findings align with comparable results from pear orchards in Belgium[11] and with the review by Dupraz[9] (2023). In a grass-clover field in the Sunbiose project, the yield reduction varied with increasing shade, and literature[12] also shows a range of effects, from a proportional decrease in grass yield with light reduction to almost no impact at all.

Overall, practical experience confirms that sufficient light is necessary to guarantee adequate crop growth.

Crop irradiance assessment

The amount of light reaching crops in agrivoltaics systems depends on factors such as the density of the solar panels, their transparency, height, and orientation. The coverage of a solar park is often indicated by the ground coverage ratio[13] (GCR), which is the ratio of the area of the solar panels to the area of the land on which they are placed. However, GCR alone does not account for the impact of panels on shading and, consequently, the amount of light available for crops. For example, with the same GCR, crops between vertical panels receive more light than those under an overhead system. This difference becomes even more pronounced if the panels are mounted on a sun-tracking system.

Therefore, instead of using GCR as an indicator for crop production, as suggested by Dupraz[9] (2023), we propose conducting a crop irradiance assessment. In this assessment, the amount of light reaching the crops is calculated by considering the full design of the agrivoltaics system: the number and position of the solar panels (including the effects of tracking), the panels' light transmittance, and any other objects that may create shade. This assessment can be performed during the planning phase, ensuring the agrivoltaics system is suitable for crop growth before its construction.

Minimum amount of light for crops

A key question is determining how much light crops need to grow effectively. Agrivoltaics pilot projects worldwide are currently gathering data to understand the relationship between shading and crop growth. However, much is still unknown. As mentioned above, effects have been observed in the Netherlands and Belgium for fruit and grass-clover. These studies and international literature[9] show that panel density in agrivoltaics systems must be significantly lower than in conventional, monofunctional solar parks.

To establish a minimum light requirement as a requirement of the definition of agrivoltaics, we can initially estimate a reasonable fraction of light based on existing national and international data. This estimate can also be used to assess the financial viability of crop cultivation under these conditions. Subsequently, targeted practical research should be conducted for each of the above-mentioned crop categories in solid pilot projects (large enough to exclude edge effects, and including reference plots). Over time, based on advancing insights, the minimum light fraction required for each crop category can be refined. A reasonable minimum light requirement should be based on a target crop yield (relative to unshaded conditions) which should be determined in consultation with research, government, and stakeholders.

Other synergies

Agrivoltaics systems can also provide synergies in terms of water management. Initial findings suggest that water consumption may decrease significantly. While this is not yet a major benefit in the Dutch context, it is likely to become more important as the climate crisis progresses. This factor should therefore also be considered.

Other requirements

In addition to a clear definition of agrivoltaics, several other conditions must be met. It is crucial that the land where the agrivoltaics system is installed remains designated as agricultural land, e.g. in the zoning plan. This designation is important for other regulations and subsidies available to farmers and helps to keep these lands in production. For instance, EU subsidies are only provided for land that is actively cultivated, and manure can only be spread on agricultural land.

It is equally important that cultivation continues on the portion of the land that is available for agriculture. This will require clear regulations and agreements between all parties involved. If the farmer ceases cultivation, the system no longer qualifies as agrivoltaics, and the solar park owner's license to operate could be revoked.

Recommendations

The Dutch government should establish a clear and effective definition for agrivoltaics as soon as possible. We propose that this can be achieved by introducing a crop irradiance assessment, which would set a minimum light requirement for crops and calculates light for the crop based on the design of the solar park, in particular the number, positioning and light transmission of the solar panels and construction. As further research develops, the maximum permitted shading for crops should be adjusted accordingly. This will require ongoing practical testing and the development of predictive models.

While some countries require a comparison of crop yields between agrivoltaics systems and reference fields, we recommend not adopting this approach. This method cannot be reliably evaluated in advance of permitting, requires extensive long-term monitoring (as the lifespan of an agrivoltaics system is typically at least 25 years), and may produce unreliable results due to differences in cultivation methods between agrivoltaics and reference fields.

Instead, we suggest using the calculated light fraction for crops, which can be determined during the planning phase. In combination with the portion of land that is available for agriculture, this provides a clear criterion for permit issuers to assess applications for agrivoltaics. We urge the government to adopt this method and, in consultation with researchers and stakeholders, further develop the definition of agrivoltaics into a practical and widely supported standard.

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13 Ground coverage ratio = solar panel surface/ground surface (m^2/m^2)

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