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Discovering the sustainability conditions for future Agrivoltaic deployment via parameterized LCA

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1. Introduction

Changing diets and a growing population increase food demand in a context where agriculture already covers 38% of land. At the same time, climate change adds pressure on agriculture by threatening yields through extreme weather and water shortages. Furthermore, renewable energy like solar power, often proposed as part of a solution to climate change, also implies increased land requirements. The ongoing development of Agrivoltaic systems (AVS) could help solve these challenges by reducing land competition and offering protection and stable climates for crops or animals when the PV panels are placed above them (Sarr et al., 2023). AVS come in various configurations impacting electric and agricultural production differently. However, few Life Cycle Assessment (LCA) studies addressing AVS have been published and thus, only cover these configurations partially. Understanding the environmental impacts of all possible AVS configurations in different futures is, however, key to support policy decisions on their future deployment. The aim of our research was therefore to identify which AVS configurations should be favored because of their comparatively lower impacts than alternative conventional systems. To do so, we combine a highly parameterized consequential LCA model of AVS with a scenario discovery algorithm. The approach is meant to be as exhaustive as possible by studying a wide range of possibilities thus covering future possible climates, reactions of the AVS systems to demand (consequential modelling), agricultural yields and practices, technological improvements, and land market contexts.

2. Materials and Methods

2.1 Parameterized LCA model

We used Brightway2.5 to construct a consequential model for AVS capable of simulating two future trends for their development driven by the following consequential hypotheses: (1) electricity demand, where electricity is the primary product and crops substitute their conventional counterparts; and (2) crop demand, where crops are the main products and electricity substitutes its conventional counterpart. Our photovoltaic (PV) model, based on (Besseau et al., 2023), encompasses the product system for PV electricity and mounting structures. It further incorporates parameters defining manufacturing advancements in PV technology, such as refining silicon using electricity, improving panel efficiency, and reducing aluminium per panel frame. Additionally, crop production is parameterized using three ecoinvent 3.10 crop activities (wheat, soy, and alfalfa), representing three agricultural archetypes.

The overall model is parameterized based on three groups of parameters. The first group of parameters modifies the overall PV technology, the marginal electricity mix and the agricultural practices to simulate the general context in which AVS is developed. For instance, these parameters characterize the manufacture efficiency of the PV wafers and the reference crops yields which both affect conventional activities and constitute the baseline for the AVS. This baseline is affected by the second group of parameters that captures differences of technologies (e.g., mounting structures, land-cover ratio) and efficiencies (e.g., crop yield, PV yield, fertilizer efficiency, soil carbon accumulation) between AVS and conventional activities. Finally, some parameters enable switching between crops and characterize indirect land use changes (iLUC) based on the biophysical iLUC model by (Schmidt et al., 2015).

2.2 Monte Carlo input-output space and scenario discovery

Large uniform distributions were assigned to all parameters and the LCA impacts were calculated for several thousands of stochastic combinations (Monte-Carlo) of the input parameters values. Then, the PRIM algorithm used for scenario discovery (Bryant & Lempert, 2010) was applied to look for scenarios, i.e., sets of value intervals for each parameter, for which the LCA impacts met a certain condition. We searched for the parameter spaces (i.e., combinations of parameters ranges) corresponding to AVS configurations ranging from AVS products with higher impacts than conventional PV counterparts for a single impact category to AVS products 50% more impactful than their conventional counterparts for all impact categories. We then analyze the scenarios and discuss the real-life contexts that would facilitate such conditions.

3 Results and Discussion

The ongoing analysis revealed various AVS configurations with higher or lower impacts than their conventional counterparts, namely PV electricity or conventional crops and highly sensitive parameters, with tightly delimited value intervals in most scenarios. For example, it is not possible for AVS electricity to have at least a 10 % higher global warming impact than conventional PV electricity if the electric yield per kWpeak ratio between AVS and conventional PV is higher than 1.12, regardless of the other parameters values (cf. Figure 1). Conversely, some parameters value intervals remained not limited, indicating that regardless of their values within a wide range, AVS will have a higher impact if the constrained parameters fall within discovered intervals for the scenario. Analysing all the scenarios in details will help determine general conditions for higher environmental performance of AVS. We will assess whether current policies align with our findings or if AVS competitiveness requires specific technological, agronomic, and contextual conditions (e.g., iLUC effects and marginal electricity).

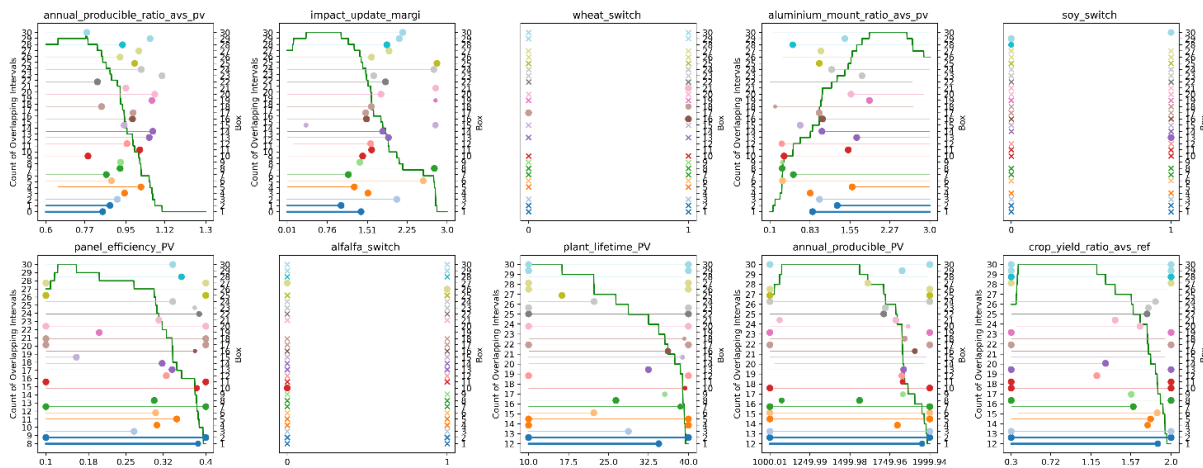


Figure 1: Discovered scenarios (“boxes”) when looking for configurations under which the Global Warming (GW) impact of AVS electricity is 10% higher than PV electricity (consequential hypothesis: electricity is the main product) and the GW impact of AVS crop is 10% higher than conventional crop (consequential hypothesis: crop is the main product). One subplot shows the constrained intervals for one parameter. Each line in one subplot corresponds to one scenario (“box”). The first scenario thus consists of the combination of all constrained intervals that are shown by the blue lines at the bottom of all subplots. The figure only shows 10 of the 45 variable parameters as the 35 others are substantially less constrained, i.e., they can take any value.

4 Conclusions

Our combination of a new highly parameterized model for Agrivoltaic systems (AVS) and a Scenario-Discovery approach, identified AVS scenarios which must be avoided or favored to ensure an improvement compared to conventional PV and crop productions. At a time of deployment of the emerging technology associated with interrogations regarding its future role, we use LCA in a prospective setting, not to “predict” the impacts of an emerging technology but to be able to orient its deployment in a planning perspective.

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