ASSESSMENT AND GUIDELINES FOR AN AGRIVOLTAIC PILOT IN ALENTEJO

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ABSTRACT: This paper presents a study of compatibility strategies for the interface of the new PV power plant of the Aquila Capital group at Cercal do Alentejo with agricultural and conservation activities, aiming at minimizing the environmental impact while engaging the local communities in the benefit of such approach. In the first phase, agricultural production and nature conservation compatibility strategies with the PV system were defined. For the agricultural interface, a one-year cultivation cycle of carrots followed by lettuce between the PV rows is proposed, and the integration of areas for sheep grazing and black pig holding. The nature conservation strategies are based on the improvement and recovery of the existing habitats, focusing on the existing floral species and the creation of new habitats through the introduction of native endangered vascular floral species. Furthermore, the incorporation of beehives is proposed such as the installation of shelters and nidification spots for birds. In the second phase, an agrivoltaic pilot was designed, aiming at studying the selected agricultural strategy.

Keywords: Agrivoltaic, Conservation, Environment, Photovoltaic

1 INTRODUCTION

Agrivoltaic presents new opportunities for the coexistence of agriculture with photovoltaic - PV electricity production. Recent research presents agrivoltaic projects and results with good potential when using aloe vera [1], lettuce [2], spinach and root crops (potatoes, beets, and carrots [3]). Other vegetables, like tomatoes [4] [5] and peppers, have also shown promising results. According to [6], all types of crops are generally suited for agrivoltaic application, but different effects on the yield are to be expected due to crop shading. Highly shade-tolerant crops such as leafy greens, stone fruits, berries, soft fruits, and special crops such as wild garlic, asparagus, and hops, show good potential.

Agrivoltaic can have a more pronounced effect in developed countries with arid and semi-arid regions, providing shade for plants and animals, while reducing water consumption [6]. The PV system can provide additional energy, for households, water treatment, food cooling, and processing, with even more benefits in decentralised systems in remote and impoverished areas. Adapted PV structures can also collect rainwater, which could fight desertification and soil degradation in affected countries, promoting ecosystem regeneration. Thus, agrivoltaic could also be used for nature conservation.

Considering the potentials of agrivoltaic, compatibility options of agriculture and nature conservation strategies with the new solar power plant at Cercal do Alentejo will be studied. The aim is to minimize the environmental impact linked to the construction and operation of the PV park and increase the land use potential.

2 CASE STUDY

2.1 Site and climate

Cercal do Alentejo, 37.8033º N 8.6708º W, is a parish located in the Alentejo province, near the Alentejo Coast (*Alentejo Litoral*), in the district of Setúbal and in the municipality of Santiago do Cacém [7], Portugal. Generally, the Alentejo is characterized by hot summers to very hot and fresh to moderate winters, with irregular and relatively low precipitation levels [8], especially in the last years due to climate change.

2.2 Cercal Power Plant

The new solar power plant at Cercal do Alentejo is being developed by the Cercal Power company of the Aquila Capital Group and will be located about 1.0 km from Cercal do Alentejo [9]. The project is still in the planning stage and is envisioned to have a nominal installed power of about 264 MWp [10]. The area that has been studied for the implementation of the PV plant is of almost 816 ha [9]. The area of PV arrays and inter rows has about 312.80 ha, of which only the panels occupy 125.79 ha [11]. The envisaged modules are of bifacial technology, supported by N-S single axis tracking structures fixed to the ground through directly driven metal piles and with an inter row spacing of 10.0 m [10].

2.3 Characterisation of the land

2.3.1 Soil

The implementation area includes some soils with good agricultural suitability integrated into the National Agricultural Reserve (*Reserva Agrícola Nacional* - RAN), although they have little significance [9]. Regarding the Land Use Capacity of the soils, the prevailing class is E followed by class D [12]. According to [13], soils of class E have very severe limitations for grazing, scrubland, and forest exploitation, very high erosion risks, and are not suitable for agricultural purpose, but instead for natural vegetation, protection, or forest restoration. Soils D in turn, have few or moderate limitations, high to very high erosion risk, and are generally not suitable for agriculture.

Figure 1: Landscape at the Cercal Power PV plant implementation area.

2.3.2 Water

The area has five groundwater abstractions, two vertical boreholes and some wells [12]. Through a hydrological study, seven main water lines were identified on the project area, which are limited by the hydrographic basins. Most of these watercourses have a markedly torrential regime and remain dry for much of the year.

2.3.3 Biodiversity

2.3.3.1 Flora and Habitats

The designated area for the plant is not situated within areas of high conservation interest classified under the Habitats Directive [12]. However, there are various scattered *montado* areas, which are human created oak forests considered as habitats with protective status. On the site, most *montados* are in poor conservation condition [12]. In the study area, the following habitats were identified: 1) cork oak *montado* units - Habitat 6310 - Evergreen *Quercus spp.*; and 2) units related to riparian vegetation that develops along the banks of existing watercourses: 2a) reedbeds - Habitat 6420 - Mediterranean tall herbaceous *Molinio-Holoschoenion* wet meadows, and 2b) willow stands - Habitat 92A0pt3 - *Psammophilous* wooded *Salix Atrocinerea* stands [12]. Furthermore, some main water lines are associated to the National Ecological Reserve (*Reserva Ecológica Nacional* – REN) [9].

On the site 49 floral species were identified, distributed across 27 families. However, given the size of the study area, it has a limited floral diversity [12]. According to the Red List of Vascular Flora of Continental Portugal [14], the region of Baixo Alentejo has most of the endangered plants.

2.3.3.2 Fauna

During the environmental impact analyses, a total of 138 species of fauna were inventoried in the implementation area [12]. The faunal group with the highest number of identified species is birds, with 96 species, followed by mammals with 23, amphibians with 13, and reptiles with six species. Out of the total inventoried species, 30 were found on the site and 18 are considered concerning from a conservation standpoint.

3 COMPATIBILITY STRATEGIES

3.1 Agricultural strategies

Agriculture compatibility strategies are defined as agricultural activities, such as crop cultivation and livestock grazing, that are compatible with the existing layout of the commercial PV power plant Cercal Power, following the agrivoltaic concept.

3.1.1 Cultivation of crops

The first step was to find suitable crops for the PV plant and site under study. This involved researching various crops, mainly horticultural and herbaceous, that are typically cultivated in Portugal and in Mediterranean climate. The second step consisted in selecting crops with shade tolerant characteristics, once in the PV park the same will experience higher shading levels provided by the modules. As the aim is to identify one or more crops that can be effectively integrated into the PV park, which already has a predefined layout concerning the height of structures and inter row spacing, the third step was selecting crops whose maximal height is lower than the minimum height of the modules. It must be ensured that the selected crops do not create any shading on the PV modules, thus affecting energy production.

After the research, a total of 35 horticultures and 16 herbs typical from Portugal and Mediterranean climate were found. Given that the modules have a minimum height of 0.30 m at their maximum inclination [10], the selected crops should have the same maximum height or less. Among the shade tolerant crops, and considering that many horticultural varieties exceed this height, only carrots and lettuce turn out as suitable options for the PV park, as both have a maximum height of 0.30 m [15]. Consequently, a cycle of carrots and lettuce is suggested.

To guarantee enough space for the machinery, the cultivated area must be between the arrays delimited by the modules' lower edge at their maximum inclination, suggesting a safety distance to the trackers of 1.40 m. Therefore, as the trackers are spaced 10.0 m between rows, the proposed agricultural area between the arrays will be 7.20 m wide.

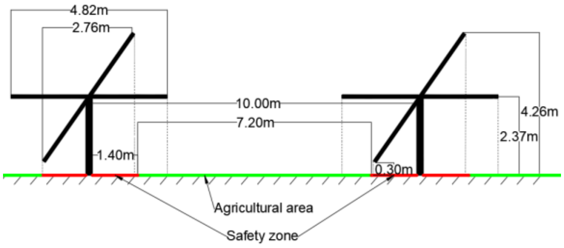

Figure 2: Proposed agricultural area between the PV arrays of the Cercal Power PV power plant.

To facilitate the movement of workers and machinery for maintenance purposes of the PV system, the agricultural area should feature two uncultivated rows. These rows should have a width matching the machinery's tire dimensions and be separated by a distance equivalent to the axle length.

3.1.2 Livestock grazing

During the field visit, landowners, who lease their land to the company for the PV project, were met. Among them, some currently use the land for sheep and cow grazing. According to [16], the PV structure can have a minimum height of 1.3 m for livestock activity, therefore, as the PV plant predicts a structure height of about 2.4 m [10], the same is suitable for livestock. Given the substantial size and weight of cows, it is not advisable to continue their grazing after the installation of the PV park, mitigating the potential damage to the PV infrastructure and to ensure the safety of the animals. However, sheep can safely continue their grazing practices if the PV system fulfils specific safety requirements, such as protecting all cables and electric equipment to avoid any contact with the animals. In this approach, sheep can profit from the modules shade, especially during summer. Additionally, the modules' shade may enhance the natural pasture growth between the rows.

Considering that the project area has several *montado* zones, the option of including black or Alentejo pigs is considered. The black pig/*montado* binomial is the key for a sustainable development of this native species and is important for the equilibrium of the *montado*'s biodiversity [17]. Given that the pigs will primarily remain in the vicinity of the oak trees to consume acorns, this approach would not be categorized as agrivoltaic, as there is little expectation of meaningful interaction and mutual benefit between the PV system and the pigs. Consequently, the black pigs should be held in the zones with higher *montado* density, identified in Figure 3.

3.2 Nature conservation strategies

Nature conservation compatibility strategies refer to initiatives designed to safeguard and enrich the natural spaces within the PV power plant, while mitigating the environmental impact caused through the construction and operation of the PV park. Moreover, with these strategies it is intended to create new habitats and promote greater biodiversity in the project site. The following approaches are an initial study of possible actions for the PV plant under study, which will be later evaluated and adjusted in collaboration with experts in fauna and flora.

The easiest zones to undertake renaturation efforts are the REN areas, ponds, and the main watercourses. Some of these zones remain untouched during the operation and maintenance of the PV park, what allows establishing small ecosystems functioning as natural sanctuaries. The process of renaturing these areas involves enhancing the existing habitats by promoting the growth of the existing flora and establishing shelters for the associated faunal species. A special focus should be considered on the Habitat 6310 of *Quercus spp.* and the two units of riparian vegetation, Habitat 6420 and Habitat 92A0pt3.

Considering the limited floral diversity and recognising the presence of numerous flora species under conservation status in the Alentejo province, it is worth considering the incorporation of specific endangered species native to the Cercal do Alentejo region within the PV plant. According to the Red List of Vascular Flora [18], the following species could be integrated on the project site:

- *Bupleurum acutifolium*: vulnerable, living in dry and open scrubland and rocky areas only in Cercal do Alentejo [18], 0.30–1.00 m high [19];
- *Chaenorhinum serpyllifolium*: in danger, endemic of the south-west coast of Portugal, living in calcarenite rock outcrops [18], 0.20–0.30 m high [20];
- *Doronicum plantagineum*: vulnerable, endemic of the south Portugal, living on edges and in the undergrowth of evergreen or marcescent scrub and woodland [18], reaches heights up to 0.90 m [21];
- *Klasea algarbiensis*: vulnerable, living in clearings of scrubland on sandy soils [18], floral buds grow close to the ground [22];
- *Scorzonera hispanica*: in danger, herbaceous perennial that inhabits forest clearings [18], 0.60–0.90 m high [23].

A blend of the listed species could be planted across different zones within the project's implementation area. Since each species is linked to a distinct habitat with unique properties, it might be necessary to establish specific environments, e.g., incorporation of calcarenite rocks for *Chaenorhinum serpyllifolium*.

Additionally, given that some studies highlighted increased ground coverage in the partial shaded areas between module rows in PV parks ([24] [25] [26]), it's reasonable to consider implementing such actions in the inter rows of the PV plant. Furthermore, the PV plant's landscape features valleys coincident with some watercourses that, when shaded by the PV arrays, might exhibit higher soil moisture levels that in the surroundings, consequently enhancing the expansion of ground coverage. Hence, valleys within the inter rows of the PV area are potentially favourable sites for the reintroduction of floral species. As for agricultural crops, these species should ideally have a height of less than 0.30, for the same reason as for the latter. Consequently, only *Chaenorhinum serpyllifolium* and *Klasea algarbiensis* from the endangered species listed could be integrated into the PV area. Some potential valleys are highlighted on Figure 3.

Based on a visual impact assessment of the PV park, specific zones require obstruction, which can be created using "green curtains" of indigenous trees, such as the *Arbutus unedo L.* [27]. The *Arbutus unedo L.* serves various purposes, including leather tanning, traditional medicine, and the production of the renowned *medronho* brandy, which makes it economically attractive. Additionally, it thrives on nutrient-poor soils and is fire resistant. Its blossoms provide bees with nectar and pollen, fruits serve as sustenance for birds, and its dense foliage offers shelter to insects and small animals in winter.

Furthermore, integrating beehives across the entire area for pollination could be explored to enhance the natural propagation of the floral species, while preventing the collapse of the bee populations. Additionally, this practice could lead to the production of local honey.

Actions aimed at enhancing floral biodiversity will consequently enhance faunal biodiversity, once a healthy and diverse plant community can provide a wide array of food, shelter, and other resources that the faunal species depend on. Although, it is advised to introduce supplementary wildlife measures, especially for birds, since the same are the predominant faunal group at the project site, having 17 endangered species. Thus, incorporating shelters for birds within the REN and forest areas could be considered. These shelters can include hidden nidification spots on trees or on artificial structures across the project site.

4 AGRIVOLTAIC PILOT DESIGN

In addition to the compatibility strategies, the design of a dedicated agrivoltaic system was caried out. The initial use of the agrivoltaic pilot is for research, such as a selected area with the proposed agriculture compatibility strategy at the PV area. Thus, three experimental plots with the same cultivated crop are suggested, allowing a comparative assessment of the crop development in three distinct scenarios:

1. The agrivoltaic approach;
2. Retrofitting with agrivoltaic of commercial PV plants;
3. The reference situation with full sun exposure.

Furthermore, within the agrivoltaic plot, three different shade patterns are proposed. With the proposed areas and different shading levels in the agrivoltaic pilot, it is intended to answer the following questions:

Q1: Can we integrate agricultural activities in pre-existing commercial PV power plants without modifying their design?

Q2: How does the configuration of the PV modules influence the yield?

Q3: Is agrivoltaic a solution for the Alentejo province?

4.1 Selecting the areas

For implementing an agrivoltaic project, a suitable area for the same had to be identified on the project area. For the later comparison of the results of the pilot with the observations made at the PV arrays and reference areas, the three plots should be relatively close so they experience similar environmental conditions. The selection of the area for implementing these three plots was based on the following criteria: proximity to a water source; gently sloping topography; easy access by agricultural machinery; and representative size. Three areas were selected of 25 m x 80 m each (Figure 3), which are near to each other and to a well for the further irrigation of the crops. At the PV park, the area will cover three PV rows, equivalent to two inter row spacings for cultivation.

4.2 Design of the PV system

The following design of the agrivoltaic pilot is conceptual and purely based on engineering considerations.

4.2.1 Structure

Following the recommendations of [28] and [29], the structure should be at least 5 m high to allow agricultural machinery to work safely. Therefore, this height was chosen for the agrivoltaic pilot. Moreover, fixed structures were selected for being economically more attractive, with a module inclination of 33 º which is the optimal angle for Cercal do Alentejo [30]. Regarding the interrow spacing, 3 m are assumed to be adequate to allow enough light to reach the crop while still achieving satisfactory energy yields [29].

4.2.2 PV module technology

Once it is intended to study the impact of different shading levels or patterns, three different zones are suggested which are provided by different PV technologies and densities:

- High shade: opaque with full density;
- Partial shade: opaque with half density;
- Light shade: semi-transparent with half density.

To reduce the CAPEX expenses associated with the pilot project's higher structures, it is proposed to use second-life opaque modules.

4.3 Design of the agricultural system

In order to enable a meaningful comparison, given that the suggested crops for the PV arrays of the Cercal Power plant are carrots and lettuce, these will also be proposed for the agrivoltaic and reference plots. Moreover, the cultivated area in all three plots needs to be consistent. Given that the PV park and its layout impose restrictions on the available cultivated space, both the reference and agrivoltaic plots have the same cultivated area as defined for the PV plant. Thus, the area effectively cultivated in each plot will be of 2 x 7.2 m x 80 m, equivalent to 1152 m^2. Further, an appropriate irrigation system must be designed to satisfy the water requirements of the crops.

4.4 Monitoring

To understand the impact of the different PV configurations on agricultural conditions and yields, it is necessary to define an appropriate monitoring system to install in each study area. Besides the meteorological conditions measured at the weather station, the following agronomic parameters should be monitored:

- Agricultural yield;
- Evapotranspiration;
- Leaf area index;
- Photosynthesis;
- Photosynthetically Active Radiation - PAR;
- Soil quality through point demonstrations over time;
- Soil moisture and temperature.

4.5 Procedures

For the installation of the agrivoltaic pilot, the following steps were defined:

1. Installation of the modules structure, avoiding soil compaction and land movement, preferably during a dry period and outside the growing season;
2. Installation of the modules and inverter.

The next actions, besides being for the agrivoltaic pilot, are also applicable to the adapted PV area:

3. Installation of all cables at an appropriate and safe height (2 m or more) under the modules and along the mounting structures using additional protection elements [31];
4. Design and installation of the irrigation system according to the hydric needs of the crops;
5. Installation of the monitoring systems;
6. Soil quality analysis;
7. Soil fertilisation based on the crop requirements;

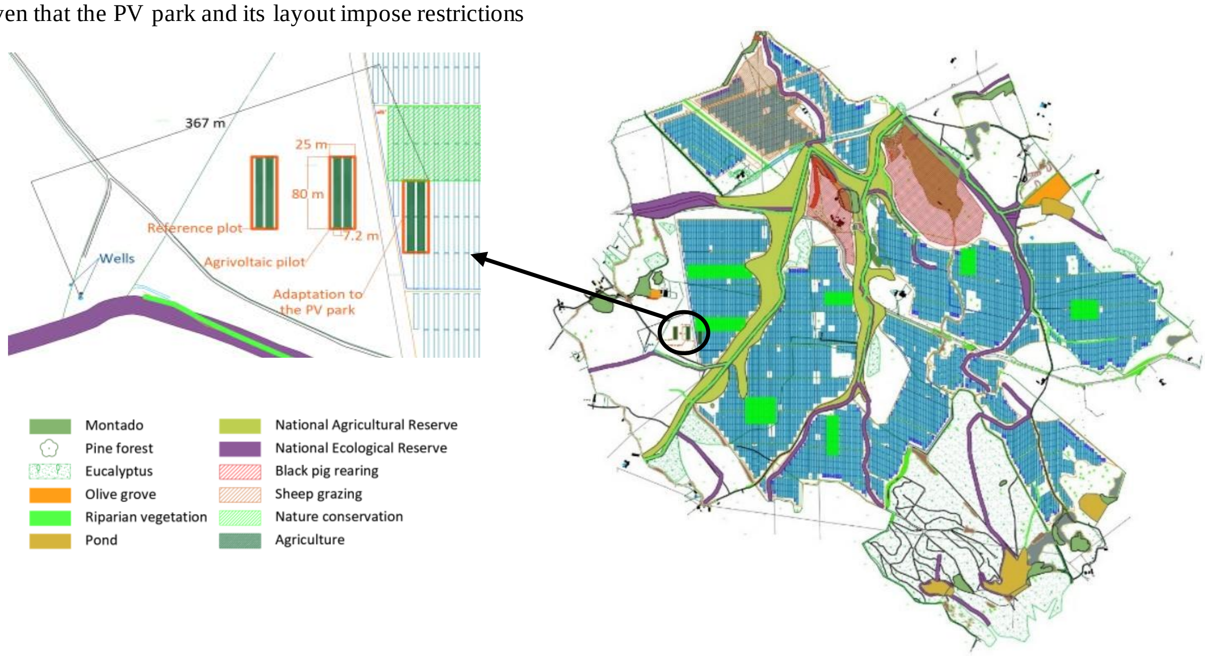

Figure 3: Proposed areas for livestock, nature conservation within valleys with PV arrays, and agrivoltaic experiment plots.

Table I: Characteristic of the experiment plots.

		Agrivoltaic Pilot			*Agrivoltaic adaptation to PV park*	*Reference plot*
		High shade	***Partial shade***	***Light shade***		
Plot dimensions		25 m x 80 m; 2000 m^2				
PV system	***Height***	5.0 m			2.4 m	-
	Interrow spacing	3.0 m			10.0 m	-
	Orientation	N-S			N-S	-
	Flexibility	Fixed, 33 º			Single-axis	-
	Foundation	Driven metal piles			Driven metal piles	-
	Module technology	Opaque 2nd life	Opaque 2nd life	Semi-transparent	Bifacial	-
	Module density	Full density	Half density	Half density	-	-
Agricultural activity		Carrots-Lettuce cycle				
Agricultural area		2 x 7.2 m x 80 m; 1152 m^2				

8. Field works according to the crop requirements. It must be ensured that these works do not coincidence with the maintenance procedures of the PV system;
9. Cultivation of the crop;
10. Module cleaning if any of the previous steps causes elevated soiling levels;
11. Data collection of the different parameters monitored during the crop cycle;
12. Final crop product quality evaluation after harvest;
13. Data analyses and comparison between plots;
14. Assessment of each set up and identification of improvements.

5 CONCLUSIONS

This paper introduces initial agricultural and nature conservation compatibility strategies for the planned PV park at Cercal do Alentejo. The agricultural strategies fall under the concept of agrivoltaic and were defined according to the existing layout of the PV system, which determined the maximum crop height and the available area for cultivation. The proposed compatibility strategies focus on integrating a crop cycle of carrot and lettuce into the predefined layout of the commercial PV park. Additionally, the existing areas for sheep rearing can continue on the PV area where the animals can profit from the shading. Furthermore, besides not being an agrivoltaic approach, rearing of black pigs is proposed on the *montado* areas. Nature conservation strategies are initiatives to enhance the local biodiversity by improving, recovering, and creating habitats for floral and faunal species. These actions include, among others, the introduction of endangered floral species, beehives, and shelters for birds. Furthermore, an agrivoltaic pilot was designed to explore how different PV system configurations influence agronomic parameters. For comparison purposes, it is planned to carry out an experiment with the same crop cycle of lettuce and carrots at the agrivoltaic pilot, a cultivated area within the arrays of the PV park and at a reference plot. It is forecasted to observe variations between the distinct study areas, once different shading conditions and potentially diverse microclimatic conditions are generated by each PV system configuration. It is expected to have an enhanced crop quality in the agrivoltaic and PV areas, since during summer the modules will protect the crops from the intense solar radiation. Additionally, this shelter can help maintaining the moisture levels in the soil. The aim of this pilot and procedure is to understand whether the integration of agricultural activities with PV energy generation, without compromising the respective yields, demands the development of an entirely new system. Simultaneously, the investigation seeks to determine the feasibility of incorporating such activities into existing commercial PV facilities. Should this conjecture hold true, technical guidelines and practices can be defined for the incorporation of agricultural activities at pre-existing PV power plants. Furthermore, this study is the first implemented in the Alentejo region on large scale. If the results are promising, this approach may present a solution to local farmers who are tackling the higher temperatures and less precipitation levels due to climate change, while profiting from cheap and clean energy.

6 FUTURE WORK

In the scope of this project, the following future tasks are planned:

- Procurement of the materials and equipment for the agrivoltaic pilot and monitoring systems;
- Conducting the experimental study on the agrivoltaic pilot, adapted PV area and reference plot;
- Development of guidelines and best practises for the implementation of agrivoltaic systems in Portugal;
- Assessment and adjustment of the nature conservation strategies with experts of the flora and fauna areas;
- Developing a pilot for the nature conservation strategies to study the feasibility of renaturation in PV parks. If this is demonstrated, best practises can be identified which can then be applied to every preexisting commercial PV park.

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