Solar sprawl in rural areas? A comparative study between Andalusia and Alentejo regions

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Resumo: O presente estudo analisa as alterações do uso do solo associadas às centrais solares na Região do Alentejo, Portugal. O método adoptado assenta no uso do SIG para sobrepor os dados relativos ao uso e ocupação do solo e as áreas das centrais solar instaladas nos últimos anos. Os resultados são comparados com o caso da Região da Andaluzia no sul da Espanha, onde já foi realizado um estudo similar. Esta comparação permite revelar o padrão de expansão destas tecnologias nesta zona da Península Ibérica. As políticas públicas e ordenamento do território devem ser reequacionadas de forma orientar o desenvolvimento destas tecnologias de acordo com regras para a concretização de modelos descentralizados que evitem a implantação de grandes centrais, evitando impactos irreversíveis nos uso do solo, paisagem e biodiversidade.

Palavras-chaves: centrais fotovoltaicas; alteração usos do solo; SIG; políticas públicas; ordenamento do território

Abstract: The present study analyses the land-use changes associated with solar power plants in the Alentejo Region of Portugal. The adopted method is based on the use of GIS to overlay land use and occupation data with the areas of solar plants installed in recent years. The results are compared with the case of the Andalusia Region in southern Spain, where a similar study has already been conducted. This comparison reveals the pattern of expansion of these technologies in this area of the Iberian Peninsula. Public policies and land use planning should be reconsidered to direct the development of these technologies according to rules that facilitate the establishment of decentralised models, avoiding implementing large plants and preventing irreversible impacts on land use, landscape, and biodiversity.

Keywords: photovoltaic power plants; land use change; GIS; public policies; spatial planning

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1. Introduction

In Europe, where energy sovereignty has become a core focus of the decarbonisation policy package, the transition toward a green generation paradigm is evolving toward a model where rural areas are becoming sacrifice territories for renewable exploitation, feeding central locations of cities and economic activities (Contreras & Matarán, 2023; Dunlap, 2023). The ambitious targets of achieving an elevated share of renewables by 2030 are accelerating such processes, with a surplus of putting pressure on landscapes and natural sources of these territories (Poggi et al., 2018). In this discourse, it is important to highlight that countries like Spain and Portugal, with a high level of solar radiation, are trying to opt for a more decentralised energy system based on a mix of different renewable energy sources. The present study takes the first approach to explore land use transformations related to installing largescale ground-mounted photovoltaic power plants, paying attention to the land use change trends in the Alentejo Region (southern Portugal) and comparing them with the case of the Andalusia Region (southern Spain). A GIS-based method has been adopted to analyse the expansion of photovoltaic power plants, overlapping land use and land cover (LUC) datasets with the installed solar capacity of more than 10 MW in the last years, disclosing the spatial dimension of these technologies in the two regions and collecting quantitative information to describe the transformations in land use. These results have been compared with the insights from the analysis of photovoltaic power plants in Andalusia in 2020, according to the study conducted by Díaz-Cuevas et al. (2023), to assess spatial patterns in the implementation and land use changes. In this context, the present study aims to contribute to understanding the importance of ensuring the implementation of photovoltaic power plants from a perspective of coherence. This involves ensuring that this process is carried out within sustainability principles and considering rural areas' interdependent relationships with ecological, biodiversity, cultural, and environmental factors.

2. Methods

The methodology adopted in this study is structured according to the following three differentiated phases.

In the first phase, we proceeded to the photointerpretation and digitisation of the area occupied by solar power plants in the region of Alentejo (Portugal), which has an approximate area of 27,250 km^2 and a population of 472,000 people. For this purpose, geospatial information on solar power plants has been used published in December 2016 as a Web Feature Service (WFS) by Direção-Geral de Energia e Geologia (DGEG, 2024). This information has been completed with the existing information on the photovoltaic plants published in the geoviewer (https://e2p.inegi.up.pt/), developed jointly by INEGI and APREN, (2017). This geoviewer continues to update the project e2p - Energias Endógenas de Portugal website, which gathers relevant information about all the power plants based on renewable energy sources installed in Portugal. The geometry of the digitised plants has been checked and updated using free satellite images such as those present in the HCMGIS plugin, installed in the QGIS software, which has global base maps from Google, Carto, ESRI, OSM Stamen, etc. Similarly, the Sentinel Hub Web Map Service (WMS) has also been used to access raw satellite data and processed products such as accurate colour imagery and NDVI. Access to the service is done via a custom server instance URL, which you will receive upon registration. Significant quality analysis has been required due to digitising errors in the existing layers.

In a second phase, the spatial analysis operations were carried out, intersecting the layer of previously digitised plants with Portugal's Carta de Uso e Ocupação do Solo COS 1995. This dataset is in vector format and divides the space into land units (polygons) that share the concepts of use and occupation according to 44 classes, not contemplating any linear or dotted elements. This dataset has been selected because it contains data from the oldest solar power plant in the region, PARQUE SOLAR DO INTERIOR ALENTEJANO, SA, which was licensed in 2004. The COS, just before the installation date, was from 1995, providing a reference for understanding land use transformation.

In the third phase, the power plant layer has been intercepted with the "Go-To Areas" layer for future renewable energy projects in revising the Renewable Energy Directive (European Union, 2023). Aligning with European standards, Simões et al. (2023) conducted an analysis, identifying mainland Portugal areas with lower sensitivity regarding environmental, heritage, and other factors. These areas have been earmarked as potential "Go-To Areas" for future renewable energy projects in the context of revising the RED Directive. On the other hand, the rest of the areas, although the implementation of solar or wind power plants is not excluded, can be considered as areas where implementation would be inadvisable due to non-compliance with environmental sensitivity criteria (Scenario 1), to which others are added depending on the scenario chosen (Table 1). For this work, solar power plants have been intersected with Scenario 4, the most restrictive scenario, where agricultural reserve areas are also considered.

Table 1. Restriction scenarios for the installation of renewable energies (Simoes et al., 2023)

Scenarios Description	**Area**	
	(Km²)	**(%)**
Scenario 1 (without exclusion conditions considering isolated polygons with more than 100 ha)	10,350	11.7
Scenario 2 (Scenario 1 & mineral resource protection areas)	8,977	10.2
Scenario 3 (Scenario 2 & removing areas from mainland Portugal aquifer systems, removing 500m buffer in residential buildings)	4,162.02	4.7
Scenario 4 (Scenario 3 & withdrawing National Agricultural Reserve and National Ecological Reserve areas)	2,652.20	3

Finally, throughout each phase, the results for plants in Alentejo were compared with the results for solar plants in Andalusia in 2020 (southern Spain), according to the study conducted by Díaz-Cuevas et al. (2023), to assess the existence of spatial patterns in implementation and land use changes.

3. Results and discussion

3.1. Spatial distribution of existing photovoltaic power plants in Alentejo

According to data obtained from the website of project e2p, (August 2024), the Alentejo region has 726.68 MW distributed between the districts of Beja (235.57 MW), Setúbal (232.18 MW in operation), Évora (128.38 MW) and Portalegre (24 MW). However, the 2016 layer includes plants do not present on this website but which represent an installed capacity of 813.6 MW, distributed as follows: Beja (376.98 MW), Setúbal (101.41), Évora (247.1 MW) and Portalegre (88.11 MW). In the case of Setúbal, this difference in installed capacity is due to the fact that the e2p project data considers the entire district, whereas the Alentejo region does not include all the municipalities in the district.

A total of 1,995.15 ha (0.07% of the Alentejo territory) is occupied by solar installations, all photovoltaic, and no solar thermal power plants are installed in the region. Comparison of these data with the results obtained in Andalusia by Díaz-Cuevas et al. (2023) show that in the Andalusian region, with a surface area of approximately 87,547 km², these installations occupy 6,690 ha (3,544.8 ha of photovoltaic and 3,145.2 ha of solar thermal), which also represents 0.07% of the Andalusian territory. Similarly, the data on the surface area required to install 100 KW of photovoltaic energy is similar for both regions, although somewhat less in the case of the Alentejo (0.25 ha/100 KW compared to 0.29 ha/KW in the case of Andalusia).

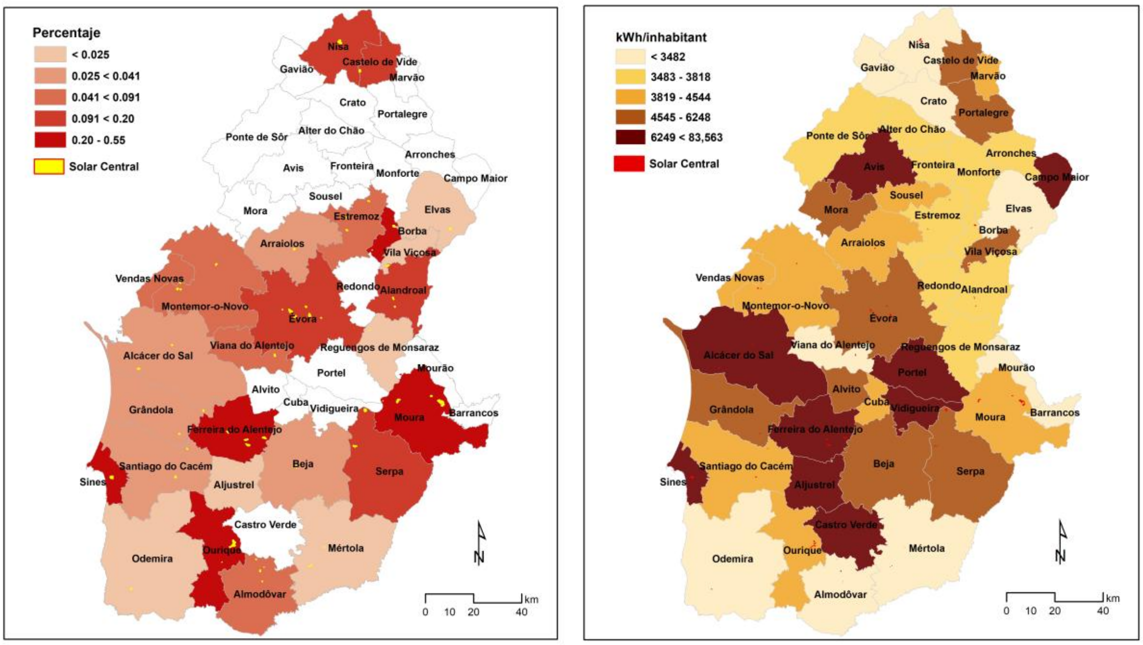

Figure 1. Ratio of per capita electricity consumption to an area occupied by photovoltaic power plants: (a) Area occupied by photovoltaic power plants; (b) Electricity consumption per inhabitant (kWh/inhabitant)

3.2. Land use transformations associated with existing photovoltaic power plants in Alentejo

To analyse the land use transformations in the region, those uses before the installations have been identified, using the layer of the land use and land cover map corresponding to 1995. The results show that nearly 40% of the installations led to the loss of productive dry or irrigated agricultural land. However, it was not possible to determine the percentage of each one separately because the map of land use and cover does not establish this differentiation of agricultural land. For its part, more than 32% of the area occupied involved the loss of forest areas (eucalyptus forests, holm oak, pine, olive and cork oak groves), almost a quarter was installed on pastureland and the rest was mainly scrubland, with only marginal occupation of artificial areas and vineyards. In the case of Andalusia, more than 41% of the area currently occupied by plants of this type corresponded to rainfed arable crops in 1999, while 23% were irrigated arable crops. Photovoltaic power plants are mainly concentrated in rainfed arable crops. However, in Andalusia, the loss of forested areas is somewhat testimonial.

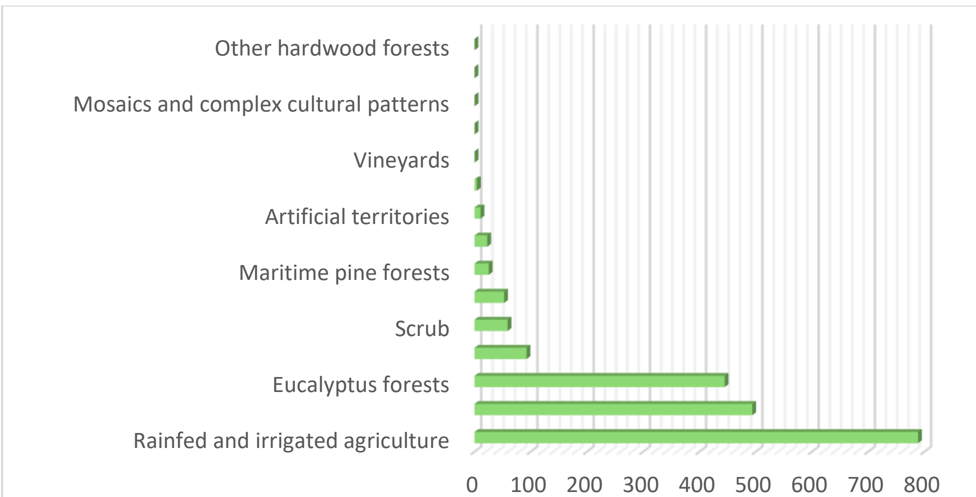

Figure 2. Photovoltaic power plants' surface area versus land use

3.3. Photovoltaic power plants in areas with exclusion restrictions in mainland Portugal

The intersection of the layer of photovoltaic power plants in the Alentejo with the layer of areas without exclusion conditions for the installation of wind and solar farms in Scenario 4 (Simões et al., 2023), shows how 1,387.8 ha of 1995 occupied by photovoltaic power plants, (i.e. 44 of the 63 digitised polygons, 69.56% of the occupied surface area) is located on territories where there are exclusion conditions due to their environmental sensitivity, mineral resource protection areas, areas from mainland Portugal aquifer systems, or National Agricultural Reserve and National Ecological Reserve Areas. This shows specific differences to that recorded in Andalusia, where of the 391 digitised polygons, almost 75% are located in areas of greater compatibility, catalogued by the Spanish Ministry for Ecological Transition and Demographic Strategy (MITECO, 2020) as low and moderate sensitivity for the implementation of photovoltaic plants, while 25% are located in areas of high or very high sensitivity (12%) or areas of maximum sensitivity where the installation of these plants is not recommended (13%).

4. Conclusions

The study has highlighted the inaccuracy of the data available in Portugal since the installed power data does not coincide with the available cartographic information, and there is a lack of updated cartographic information, such as aerial orthophotos, which has led to major systematic revisions. The proliferation of photovoltaic power plants, due to the absence of spatial planning orientations, shows in the Alentejo Region the lack of compatibility with pre-existing uses, finding a high loss of productive rain-fed or irrigated agricultural areas since practically 40% of photovoltaic power plants are located on land that was previously used for this purpose. There is also considerable forest loss, as almost a third of the solar plants are located on forest land where trees have been removed. Finally, nearly a quarter of the installations are located on pastureland, where livestock use after installation is often negligible. It should be noted that very few installations are located on disturbed or transformed land, so finding ways to better integrate photovoltaic power plants and pre-existing land uses would be necessary. The dispersion of photovoltaic power plants in Alentejo is lower than in Andalusia. However, even in Alentejo, energy production and consumption data do not coincide, as some large energy-consumer municipalities do not have any photovoltaic power plants in their territory. Many of them, where consumption is very low, have many photovoltaic power plants and a large area transformed by them. This shows that solar energy tends towards a concentrated model of energy production to be delivered to remote sites through the electricity grid and goes against the idea that it is distributed generation where production and consumption are coupled. Concerning the environmental compatibility of photovoltaic power plants, in Alentejo, they are located in areas of lower environmental compatibility than in Andalusia, with almost 70% of them being built in areas of high ecological sensitivity compared to 25% of Andalusian installations. However, neither one region nor another has been involved in any renewable energy planning. It is thus demonstrated that a process that would be supposed to contribute towards a more sustainable society is evolving toward a "solar sprawl" in rural areas, with particular impacts on soil quality, rural landscape, biodiversity, and local communities. These trends lead to the urgent need to elaborate more coherent energy and land use public policies and spatial planning orientations able to manage and regulate such new land uses in rural areas according to more decentralised models that avoid large power plant deployment.

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