SURVEY OF THE FLOATING PHOTOVOLTAIC POTENTIAL OF PORTUGAL

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ABSTRACT

Portugal is characterized by a high solar potential with annual global horizontal solar irradiation exceeding 1800 kWh/m2 [1]. Due to this radiation availability and the sharp reduction in costs that has occurred in the last decade, solar photovoltaic has shown a market growth and an increasing penetration in the Portuguese national electricity generation system. The application of floating photovoltaic (FPV) technology brings the advantage of using an otherwise potentially unused area and can present a yield increase due to its installation over water, at the same time providing a reduction in water evaporation [2]. This study provides a comprehensive analysis of the potential for FPV installation in mainland Portugal, using water body data by the Portuguese Environment Agency (APA). This analysis results in a mapping of the potential areas for FPV applications in the national territory, thus establishing a relationship between the availability of solar radiation and the geographical distribution of water bodies in the different regions of the country. This work intends to determine if the FPV potential in Portugal can contribute to the installed capacity target as defined in the Portuguese National Energy and Climate Plan 2030 (PNEC 2030), which defines the goal of 7GW of solar photovoltaic systems in 2030 [3].

Keywords: Floating Photovoltaic, Water, Solar Energy, Photovoltaic System.

1 INTRODUCTION

Floating photovoltaic systems represent a technical innovation, the first FPV systems date back to 2007 [5]. However, several gaps were identified in the state of art regarding this technological application, and this work intends to point out results to some of them, within the Portuguese context (e.g., territory, regulation, policies). No study was found on the potential for application and growth of this technology in Portuguese territory [6], and given the current context, this work aims at adding knowledge to the existing state of the art. The Portuguese government has recently launched the first floating photovoltaic public tender process, which presents a portfolio of 263 MW for new installed capacity for this technology, in seven dams [7]. This public tender marks the expansion of FPV technology in Portugal and is aligned with the policy defined in the National Energy and Climate Plan 2030 [8] and international decarbonization targets [9].
This work presents the analysis of the Portuguese potential for FPV systems, considering the total area available and establishing a correlation not only with the solar resource as well as the transmission infrastructure and coexisting assets, generating outcomes of both the technical and economic potential.

2 AIM AND METHODOLOGY

The main objective of this work is to survey the FPV potential of continental Portugal. For this purpose, a very broad approach was used to collect all the information concerning water bodies at national level, from dams, lakes, wetlands, near onshore water bodies, collecting georeferenced data on GIS files. After this collection, the next step consisted in the application of some boundary conditions, namely the exclusion of all the area crossing the boundaries of the Portuguese administrative regions, the exclusion also of the near onshore water bodies because there is no clear and evident study of the degradation curve in higher salinity water conditions and for this reason the study is restricted to onshore water bodies, and finally the last condition imposed was the exclusion of wetlands, since after a thorough analysis of these areas it can be concluded that they are intended for agricultural purposes which are an impeditive factor for FPV installations. With this analysis methodology and the application of these restrictions, a first preliminary result was obtained regarding the available potential area for FPV systems to be deployed and considering that the water surface area calculated is based at full storage level of the water bodies.
In order to closely align this study with the objectives of the Portuguese National Energy and Climate Plan 2030 (PNEC 2030). The PNEC 2030 defines a goal to install a total of 7GW of solar photovoltaic capacity in Portugal, in order to achieve the Portuguese decarbonization targets.
The methodology used is shown in Figure 1. After this broad and extensive data collection and exclusion criteria application, it was decided to applied a 85% reduction in the total net available area, in order to simulate further exclusion and selection criteria not considered at this stage of the work. Selection criteria will be addressed in future stages of this work and will allow the fine tuning of the end-results. Selection criteria will include application of some restrictions of both technical and environmental nature, in particular hybridisation or connection with existing assets such as hydroelectric dams, wind farms, centralized energy storage systems, proximity to available energy injection points of the

national transmission and distribution grid, protected areas, reserved areas for recreational navigation or fishing and water sports. Another shortcoming identified in the present results concerns additional fine tuning according to different scenarios related to the surface limits of water bodies, due to shadowing, the bathymetry of dams and lakes, and impacts on water availability (water storage levels) due to climate changes.
A 1 to 1 relationship between area and installed power was used, i.e. 1MW of installed FPV power for an area (water surface) of 1 ha [11].
The next step of the methodology used was to use the SISIFO [4] software simulation tool to simulate the PV annual generation yields for each region, considering the final available areas. A standard tilt of 15º was used for the FPV modules, and South facing.

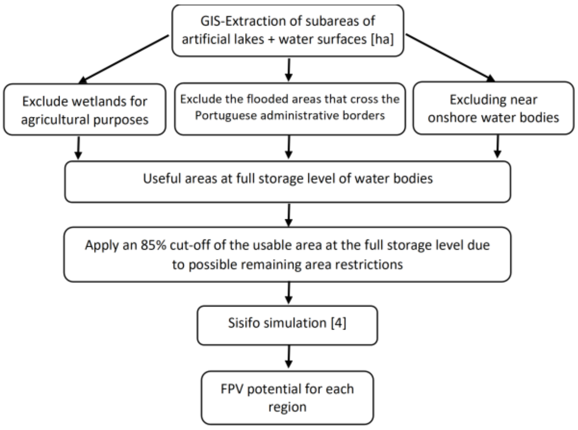

Figure 1: Methodology simplified Flowchart

3 RESULTS ANALYSIS

3.1 Distribution of installed FPV power in Europe

As first approach, the European FPV context and installed capacity is being monitored and updated in a internal database, enabling further in depth analysis and evaluation of the market and national policies evolution. The currently the installed FPV capacity distribution in Europe is represented in Figure 2. The Portuguese total installed capacity is about 3% of the total European installed power [10], currently being led by France with a total of 17MW, the largest installed FPV capacity in Europe, followed by Albania and Belgium. The total European installed capacity regarding FPV systems is 47.2MW, however several FPV investments can be identified through public data records, at different development stages (investment, engineering, installation, etc.), that will upscale this technology in the next years.

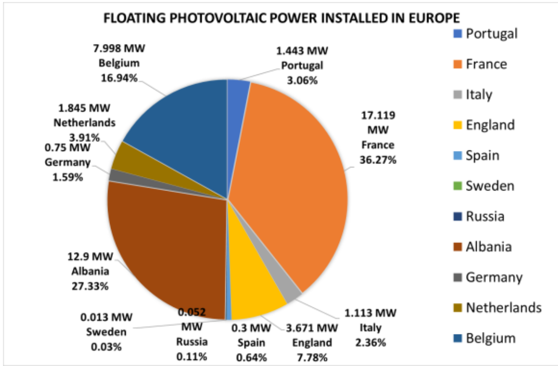

Figure 2: FPV installed power capacity in Europe [10]

3.2 Characterization of the Portuguese FPV potential

Concerning the Portuguese mainland territory, official administrative regions were considered to assess the potential FPV distribution scenarios. Mainland Portugal is then divided into five distinct regions, namely the Northern region (Norte), the Central region (Centro), Lisboa e Vale do Tejo, Alentejo (large region in the south) and Algarve (most southern region).
For each region a careful and detailed analysis of the existing water bodies was made, resulting in the illustrated potential, as shown in the next figure.

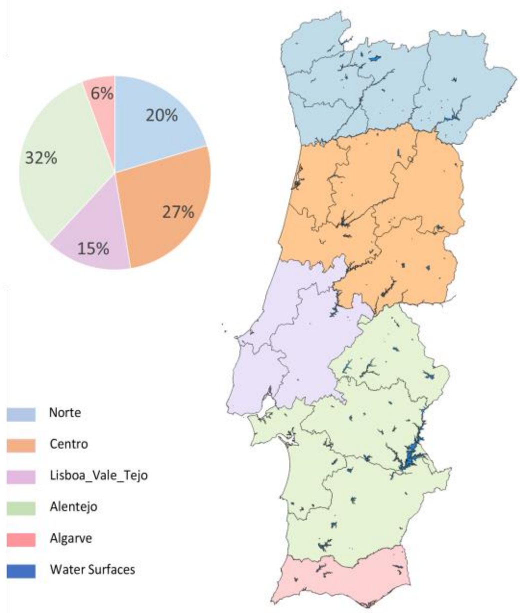

Figure 3: Portugal map with the distribution of available water bodies and surfaces

As shown in the graph of Figure 3, the Alentejo region leads with the largest available area for floating photovoltaic deployment with 32% of the total national available area, mainly due to Alqueva dam and artificial lake, one of the largest artificial water reservoirs in Europe. The Center region (in orange in the Figure) represents 27% and the 3rd largest available area is in the region of Lisboa e Vale do Tejo with 15%.
However, apart from water surface area availability, also the solar resource should be considered in order to assess the FPV potential for energy generation.

In order to assess this, solar PV simulations were conducted with the SISIFO simulation tool, for the entire potential water surface area in each region. A correlation of 1MWp per hectare was used, considering the average area usage per installed FPV power. The PV simulation was performed considering the centroid location (coordinates) for each region. No FPV simulation software is publicly available and with full model validation, so a standard PV simulation software was used, considering that this approach introduces some uncertainty in the end results.
The results for this correlation between available area and the solar radiation, are shown in figure 4.

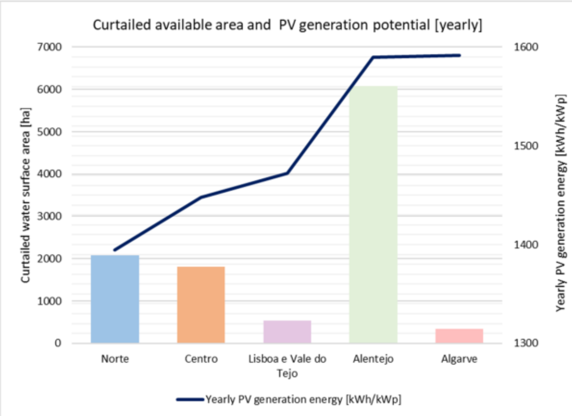

Figure 4: Curtailed available area [ha] (*columns*) vs yearly PV generation yield per region [kWh/kW$_p$] (*line*)

From the results presented, it can be concluded that Alentejo and Algarve are the regions with the highest solar radiation availability, justified by the higher annual PV yield [kWh/kW$_p$]. These two regions present very similar values of solar resource potential, and correlating it with water surface availability, the Alentejo region stands out, combining a large available area for FPV installations with one of the highest solar resource potential.
Table 1 presents further detailled results from these simulations, per region, as well as a ratio between the available water surface area and the region total area.

Table 1. FPV annual yields vs area per region

	Values obtained by curtailment 85% of the area at full storage level				
Region	**Water surface area [ha]**	**Maximum PV power [MW]**	**Yearly PV generation energy [kWh/kWp]**	**PV Generator Energy [GWh/year]**	**Ratio of curtailed areas [%]**
Norte	2076.76	2076.76	1394.66	2896.38	0.11
Centro	1804.86	1804.86	1447.96	2613.37	0.08
Lisboa e Vale do Tejo	537.09	537.09	1472.12	790.67	0.04
Alentejo	6071.61	6071.61	1589.46	9650.58	0.21
Algarve	345.42	345.42	1591.51	549.73	0.07
Total national	10835.75	10835.75	7495.71	16500.7	-

At a national level, the calculated maximum FPV potential for installed capacity is 10.8 GW, with a corresponding yearly energy generation of 16500.7 GWh. The Alentejo region presents the major contribution for this result, with a potential for the installation of 6.0 GW of FPV systems, representing 0.21% of the total region area. This FPV installed capacity will generate about 9650 GWh/year, this value being higher than the sum of the solar energy generation of all the other regions. On the other hand, despite having a very large territorial area, its ratio between area available water surface and total region area is 0.21%, pointing that Alentejo presents itself as a promising region for the installation of FPV systems.
The potential installed capacity of Alentejo and Algarve regions surpass the national target (PNEC 2030) of 7 GW.

4 CONCLUSIONS

This work intends to carry out the first analysis of the Portuguese potential for the installation of floating photovoltaic systems technology. The results obtained in this preliminary analysis allow to conclude that the potential FPV capacity exceeds the national target of 7 GW, as defined in the PNEC 2030 for the photovoltaic energy sector.
The analysis of the results at a regional level point to the Alentejo region as having the greatest potential, in terms of both water surface and solar resources.
Despite the use of a conservative approach, applying a curtailment of 85% of the total available area at the full storage level, according to the simulation results, the FPV national capacity potential is 10.8 GW.
The software tool (SISIFO) does not allow the accurate simulation of a FPV system and, without a validated simulation model at the moment, it was, nevertheless, used. The accuracy of the results would be improved with a FPV simulation software/model, taking into account, for instance, the cooling effect due to the aquatic environment or suitable losses scenario for FPV systems (soiling, misalignment, electric isolation failures, etc.).

5. NEXT STEPS

Several shortcomings were identified during this work, that will be addressed in the next steps, in order to reduce the results associated error:

- Update the results with a simulation model developed and validated specifically for floating photovoltaic systems;
- Collect all the shapefiles referring to the bathymetry of water bodies, in order to be able to calculate the available area for any water storage level;
- Collect and apply diverse existing restrictions for each water body, such as nature reservations, hydro-generation reserved areas, water sports or fishing areas.
- Analyze scenarios taking into account the proximity of strategic co-existing assets such as grid connection points, power lines and transformer stations, or other renewable energy power plants;

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7 REFERENCES

[1]"GLOBAL SOLAR ATLAS," 26 01 2022. [Online]. Available: https://globalsolaratlas.info/map?c=39.391918,-4.134201,5&s=39.774871,-8.230036&m=site.

[2] R. Gonzalez Sanchez, I. Kougias, M. Moner-Girona, F. Fahl and A. J€ager-Waldau, "Assessment of floating solar photovoltaics potential in existing hydropower reservoirs in Africa," ELSEVIER, 2020.

[3] PNEC 2030 “PLANO NACIONAL ENERGIA E CLIMA 2021-2030”

[4] IES-UPM, “SISIFO – PV simulation framework”, available at: www.sisifo.info

[5] M. Acharya and S. Devraj, "Floating Solar Photovoltaic (FSPV): A Third Pillar to Solar PV Sector?," 2019.

[6] M. Rúben Rodrigues Sobral, Avaliação do potencial fotovoltaico flutuante em Portugal, Lisboa: UNIVERSIDADE DE LISBOA, 2018.

[7] J. d. negócios, "Primeiro leilão solar em barragens terá 263 MW," [Online]. Available: https://www.jornaldenegocios.pt/empresas/energia/detalhe/primeiro-leilao-solar-em-barragens-tera-262-mw. [Accessed 02 2022].

[8] Ministério do Ambiente e Transição Energética, "Plano Nacional Integrado Energia e Clima 2021-2030, PNEC 2030," 2019.

[9] U. Nations, "The Paris Agreement," [Online]. Available: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement. [Accessed 26 05 2020].

[10] R. Alexandre Rodriguez Reb, Estudo do potencial de sistemas fotovoltaicos flutuantes em massas de água doce e marinhas, Évora: Universidade de Évora, 2021.

[11] Rádio Renascença [Online] Available:EDP inaugura "maior central solar flutuante" em albufeira na Europa - Renascença (sapo.pt)