

## ENVIRONMENTAL ASSESSMENT OF FLOATING PHOTOVOLTAIC SYSTEMS USED IN IRRIGATION IN DOBROGEA REGION

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**Abstract:** *The rising necessity of energy production with low to zero carbon emissions has challenged researchers to develop new technologies to meet population's requirement of reliable and continuous energy sources and have a minimum environmental impact. This led to exploring possibilities of energy production using renewable sources, such as wind, sun and water, used individually or sometimes combined.*

*In order to achieve the European goal of zero emissions by 2050, the International Energy Agency reported in a study from 2021 that there has to be an increase in solar energy production by 24% yearly [1]. Photovoltaic panels are now widely spread across the globe due to their lower cost of energy production and low maintenance. Some countries have also governmental programs that encourage households and small businesses by covering partially or totally the cost for PVs and most recently, storage solutions. These projects represented a success in the past and encouraged people to make use of green energies with minimum investment.*

*A new technology that has become more popular in the last years are floating photovoltaic systems. It has been observed that they have increased energy efficiency, 5-10% higher than on-ground photovoltaic systems and they help to reduce evaporation in water-scarce regions. They help to reduce global water crisis, especially when used in agriculture or irrigation systems assuring efficient water management. Such systems of energy resolve farmers' dependence on fossil fuels, such as diesel for diesel generators used for water pumps and allow them to provide sustainable farming with low carbon emissions.*

*Floating photovoltaics (FPV) have also multiple benefits in reducing the land occupation as they are installed over irrigation canals, irrigation reservoirs, and ponds. While conventional photovoltaic systems are in continuous increase, they become more accessible for farmers and households. However, the major inconvenience is that they require large areas of land, which is often hard to find and very expensive. To obtain 1MW from photovoltaic panels, it is necessary around of 15000 m<sup>2</sup> of land [2][4].*

*This research aims to present various floating photovoltaic systems and explore the environmental and social impact and energy efficiency of these technologies. The purpose of this study is to provide a comparison between on-ground and floating photovoltaic systems by calculating the potential energy production in Dobrogea region.*

*Site suitability for the installation of floating photovoltaic technologies require the following environmental aspects: low precipitation and limited periods of fog, no shadowing from mountains or existing buildings, compact soil for anchoring and bodies of water low salinity, low hardness and lower waves [3]. Environmental and geographical characteristics make Dobrogea the most suitable site for such, due to its multiple bodies of water: lakes, rivers, irrigation canals and sea. However, installation at sea might be challenging as Black Sea is unpredictable in the cold season and higher waves, between 6 to 9 meters height, have been reported in the last couple of years.*

*The study will cover the correlation between floating photovoltaics and irrigation following technical aspects of floating photovoltaics (FPVs) in irrigation, environmental and economic assessment, current challenges and limitations, case studies and further discussions.*

**Keywords:** *Renewable energy, photovoltaic systems, solar energy, floating photovoltaic, energy efficiency, irrigation, agriculture*

### 1. Introduction

Renewable energy sources have been a hot topic for energy engineering in the last few years, being extensively researched. With the growth of the population, the rising necessity of more power

sources has become the main subject of discussion in the research community. It has been agreed worldwide that there is a need to transition from fossil fuels to reduce greenhouse gases, such as CO<sub>2</sub>. Solar energy is currently preferred over other renewable sources of energy due to its global availability, sun energy is available in every part of the world, and to its limited amount of maintenance and gas emissions during its operability lifecycle. The main issue with current technology is land occupation, solar systems require a large area of land for power generation. This challenged the researchers to develop technologies that can be installed wherever there is a piece of land that cannot be used otherwise. In the past few years, floating photovoltaic systems have been researched and finally brought to life in water-scarce regions, such as Brasil. This technology has overcome its experimental phase and it has been demonstrated that it is efficient.

The main purpose of this study is to highlight the environmental benefits of floating photovoltaic systems in Dobrogea region for irrigation purposes.

Dobrogea hosts the largest wind farms available in Romania due to its landforms and wind, which promote the production of wind energy.

## 2. Study area

Dobrogea region is located in South-East of Romania and it is adjacent on the east by Black Sea, in the South by Bulgaria, in the North by Danube Delta and Ukraine and in the West by Danube River.

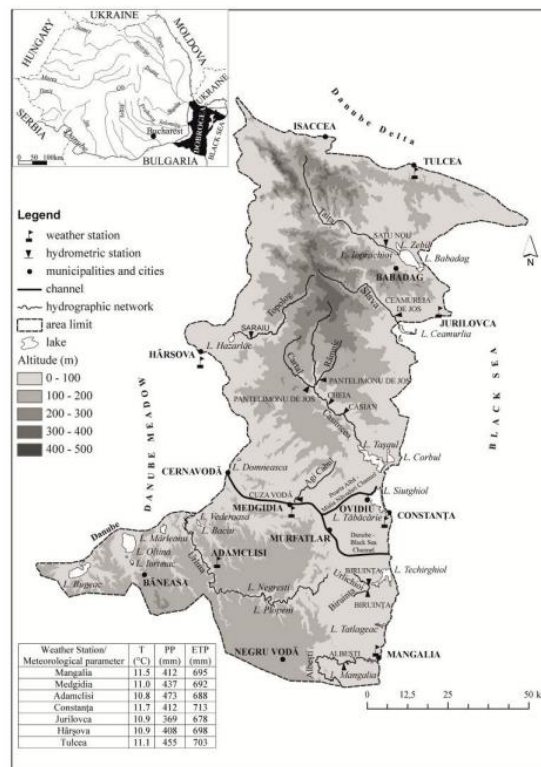


Fig. 1. Hydrographic map in Dobrogea and mean values of meteorological parameters [6]

Dobrogea is characterized by a continental climate with yearly mean air temperature between 10.8° C and 11.8° C, -1.2° C and 2° C in winter and 19° C – 22.5° C in summer. For precipitations, higher values are being recorded in the rainy months of May, June and November, when precipitations recorded are higher than 41 mm. Lower amounts are registered in January, February and October where values are lower than 27 mm. Yearly values recorded are comprised between 369 mm and 473 mm.

Evapotranspiration values recorded for Dobrogea region have yearly values between 678 mm and 713 mm, lowest values being recorded in winter and higher in summer, with mean values of 10 mm in winter and 110 mm in summer.

Dobrogea land is covered mostly by arable land, about 66.7% and 8.7% by temperate deciduous forests, rest of the land being covered mostly by urban and rural settlements [7].

## 2.1 Irrigation needs

Multiple studies conducted for precipitation regimes in Dobrogea confirm that there is a high need of irrigation, this being the most arid region of Romania. A study conducted by the Euro-Atlantic Resilience Centre (E-ARC) highlights that the lack of watering equipment and electricity infrastructure, along with gaps in the legislative system for the management of agricultural needs, resulted in an inefficient irrigation system in Romania. The study also shows that in 2022 only 32% of the planned land has been irrigated while in 2023 38% of the planned area has been irrigated [8]. Below table from Land Improvement National Agency (ANIF) summarizes all irrigation sources available in Dobrogea.

**Table 1:** Land surface and irrigation sources available in Constanta region [9]

Name	Land surface		Irrigation Source
	Gross (ha)	Net (ha)	
<b>Constanta North</b>			
Carasu – Nicolae Balcescu	29602	29172	CDMN – PAMN
Terasa Seimeni	22999	22819	Danube
Terasa Topalu	18885	18832	Danube
Carasu – Mihail Kogalniceanu	26914	26492	CDMN – PAMN
Terasa Sinoe	53096	52789	Golovita Lake
Terasa Harsova	31955	31749	Danube
Ciobanu – Girliciu	2689	2489	Danube
Orezaria – Harsova	3063	2954	Danube
Carasu – CDMN/PAMN North	3154	3108	CDMN – PAMN
Daeni – Ostrov - Peceneaga	5908	5904	Danube
<b>Total</b>	<b>198265</b>	<b>196308</b>	
<b>Constanta South</b>			
Carasu – Basarabi	5993	5907	CDMN - PAMN
Carasu – Galesu	4818	4750	CDMN - PAMN
Carasu – Poarta Alba	3694	3641	CDMN - PAMN
Carasu – Valea Seaca	7171	7067	CDMN - PAMN
Carasu – Faclia	8766	8640	CDMN - PAMN
Carasu – Topraisar	4624	4557	CDMN - CMNV
Carasu - Amzacea	2275	2242	CDMN - CMNV
Carasu – Biruinta	14854	14329	CDMN - CMNV
Carasu – Movilita	8172	8054	CDMN - CMNV
Carasu – Baaraganu	14794	14578	CDMN - CMNV
Carasu – Potirnichea	2304	2272	CDMN - CMNV
Carasu – Lanurile	7153	7049	CDMN - CMNV
Carasu – Mangalia North	805	793	CDMN - CMNV
Carasu – Mangalia South	9932	9788	CDMN - CMNV
Carasu – Tatara	11812	11640	CDMN - CMNV
Carasu – Mosneni	31603	31150	CDMN - CMNV
Rasova - Vederoasa	2297	1673	CDMN - CMNV
Oltina West	84136	80584	Danube
Carasu – CDMN/PAMN South	2452	2440	Danube
Carasu – Canal Negru Voda	1464	1443	CDMN - PAMN
Cochirleni	2695	2651	CDMN - PAMN
<b>Total</b>	<b>232565</b>	<b>225988</b>	
<b>Total North &amp; South</b>	<b>430830</b>	<b>422296</b>	

## 2.2 Floating Photovoltaic Systems in Irrigation

Despite low quantities of precipitation, Dobrogea has multiple sources of water which allow the installation of floating photovoltaic systems. These have benefits for land owners as they assure independence from national regulations, energy sources and fossil fuels. Floating photovoltaic systems (FPVs) ensure the energy necessity for irrigation even in remote areas and prevent evaporation from irrigation ponds or canals. FPVs reduce costs for irrigation.

## 3. Calculation of the Energy Generation

For the calculation made further in this study, the land area of Sinoe has been considered. Sinoe is located in the northern part of Constanta County, right at the border with Tulcea county. Arable land is being irrigated using water from Lake Golivita. The lake is 7.2 km long and 18 km wide, covering a surface of 7500 hectares.

Using the standard equation for the power generation it can be determined the energy generation of a photovoltaic installation on a determined area.

$$P = A \times G \times \eta \quad (1)$$

, where P represents the energy generated in kW, A is the area covered by panels (m<sup>2</sup>), G is solar irradiation in kWh/m<sup>2</sup>/day and  $\eta$  is the efficiency of the system, usually ranging between 15-20% [10]. Lake area considered for this study is 1 hectare, equivalent to 10000 m<sup>2</sup>.

Solar irradiation has been obtained utilizing online calculators which have collected solar data for 20 or more years and it has been calculated for panels facing directly south, positioned horizontally on a flat surface [11]. Values obtained have been summarized below table for  $\eta = 18\%$ .

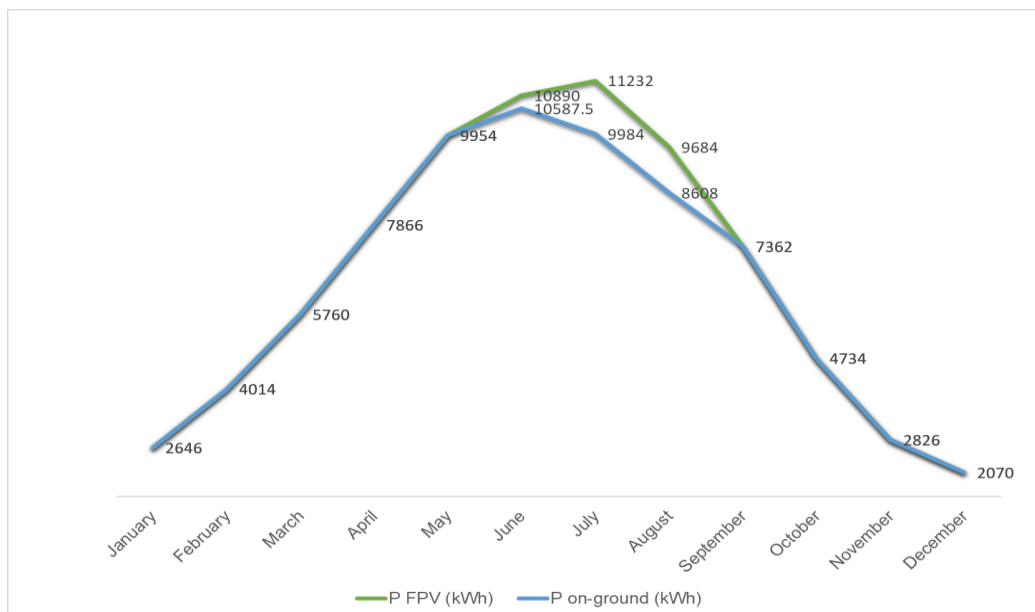
**Table 2:** Average monthly solar irradiation for Constanta County and energy generation for floating photovoltaic systems

Month	Solar Irradiation G (kWh/m <sup>2</sup> /day)	Energy Generation (kW)
January	1.47	2646
February	2.23	4014
March	3.20	5760
April	4.37	7866
May	5.53	9954
June	6.05	10890
July	6.24	11232
August	5.38	9684
September	4.09	7362
October	2.63	4734
November	1.57	2826
December	1.15	2070
<b>Yearly mean value</b>		6586.5

Usually, photovoltaic panels lose their efficiency when they reach temperatures above 25° C. For each degree over 25, panels lose 0.5% of their efficiency. Considering the above information and assuming on-ground photovoltaic panels do not have any cooling systems, data has been summarized in the below table.

**Table 3:** Average monthly solar irradiation for Constanta County, mean temperatures and energy generation for on-ground photovoltaic systems

Month	Solar Irradiation G (kWh/m <sup>2</sup> /day)	Higher mean monthly temperature (° C)	$\eta$ (%)	Energy Generation (kW)
Jan	1.47	4	18	2646
Feb	2.23	6	18	4014
Mar	3.20	10	18	5760
Apr	4.37	15	18	7866
May	5.53	21	18	9954
Jun	6.05	26	17.5	10587.5
Jul	6.24	29	16	9984
Aug	5.38	29	16	8608
Sep	4.09	24	18	7362
Oct	2.63	18	18	4734
Nov	1.57	12	18	2826
Dec	1.15	6	18	2070
<b>Yearly mean value</b>				6367.63



**Fig. 2.** Monthly Energy Generation for on-ground PVs and FPVs.

#### 4. Efficiency gains

Efficiency gains between on-ground PVs and FPVs is calculated with the following formula:

$$\Delta\eta = \eta_{FPV} - \eta_{on-ground} \quad (2)$$

$$\eta = \frac{P}{A \times G} \quad (3)$$

$$\eta_{FPV} = \frac{6586,5 \text{ kW}}{10000 \text{ m}^2 \times 3,66 \text{ kWh/m}^2/\text{day}} = 18\% \quad (4)$$

$$\eta_{on-ground} = \frac{6363,63 \text{ kW}}{10000 \text{ m}^2 \times 3,66 \text{ kWh/m}^2/\text{day}} = 17\% \quad (5)$$

Therefore  $\Delta\eta = 1\%$  the efficiency gains yearly.

#### 5. Water conservation from evaporation

One of the benefits FVPs installed over irrigation ponds or canals is the reduction of water evaporation. The panels act as a barrier between the water body of the irrigation source and direct sunlight. Since evaporation is strictly linked to heat, the barrier acts as a heat protectant for the body of water. The physical panel barrier acts as a shield from winds that carry away water particles and promote the transportation and evaporation of water. Studies have shown that evaporation is reduced by 30 to 60% by using floating photovoltaic systems [12, 13]. Water savings can be calculated with the formula

$$\text{Water saving} = E_{baseline} \times A_{FPV} \times C \quad (6)$$

, where  $E_{baseline}$  represents baseline evaporation yearly evaporation rate expressed in meters,  $A_{FPV}$  is the area covered by FPVs and  $C$  is the percentage of reduced evaporation by FPVs covering. This percentage is an empirical value which ranges from 30 to 60%. For this study,  $C$  is assumed to be 40% and a higher evaporation rate has been considered for Dobrogea region (7,13m).

$$\text{Water savings} = 7,13 \text{ m} \times 10000 \text{ m}^2 \times 40\% \quad (7)$$

$$\text{Water savings} = 28520 \text{ m}^3$$

In conclusion, 1 hectare of water covered by FPVs in Dobrogea region would save 28520 m<sup>3</sup> of water yearly.

#### 6. Limitations and uncertainties

All data used for conducting this study has been collected from other studies or public reports from Romanian national agencies and it refers to Dobrogea region. In reality, values might differ from north to south. So, in order to have accurate results, in situ measurements over long period of time have to be carried out.

#### 7. Conclusions

Floating photovoltaic panels represent an alternative to traditional on-ground photovoltaic panels. Both types of systems carry advantages and disadvantages. In terms of energy efficiency, floating photovoltaic systems resulted might generate more power as they do not require cooling systems,

water acting as coolant and keeping a constant temperature. In reality, their efficiency depends on multiple factor such as their position, cleaning and maintenance.

For the environmental aspects, studies carried on the topic shown that FPVs have a lower impact due to water conservation and no need for land occupation. However, an environmental assessment has to be carried to ensure marine life is not disturbed during the installation of these systems.

In terms of costs, compared to on-ground solutions, floating photovoltaic systems are not very popular. However, with the increasing necessity of energy production and lower cost of operability, floating photovoltaic systems start to gain more popularity which might result into lower cost for the panels and installation. The energy source for the pumping system is in the immediate vicinity, eliminating additional energy losses during transport.

Other challenges might be related to regulatory and permitting. Currently Romanian laws for offshore green energy production are not complete and permits for installation of floating photovoltaic systems over water surface might be difficult to obtain.

In conclusion, floating photovoltaic systems are representing a promising technology for energy production in arid and water-scarce regions.

## References

- [1] IEA. "Solar, P.V. Technical Report". IEA: Paris, France, 2021. Accessed September 22, 2024. <https://www.iea.org/reports/clean-energy-transitions-programme-2020>.
- [2] Cuce, E., P.M. Cuce, S. Saboor, A. Ghosh, and Y. Sheikhejad. "Floating PVs in Terms of Power Generation, Environmental Aspects, Market Potential, and Challenges." *Sustainability* 14, no. 5, (2022): 2626.
- [3] Solar Energy Institute of Singapore. "Where Sun Meets Water: Floating Solar Market Report. Technical report". World Bank: Washington, DC, USA, 2019.
- [4] Essak, Laura, and Aritra Ghosh. "Floating Photovoltaics: A Review." *Clean Technol.* 4, no. 3 (2022): 752–769. <https://doi.org/10.3390/cleantechnol4030046>.
- [5] Yousuf, Hasnain, Muhammad Quddamah Khokhar, Muhammad Aleem Zahid, Jaeun Kim, Youngkuk Kim, Eun-Chel Cho, Young Hyun Cho, and Junsin Yi. "A Review on Floating Photovoltaic Technology (FPVT)." *Current Photovoltaic Research* 8, no. 3 (2020): 67-78.
- [6] Telteu, Camelia-Eliza, F. I. Stan, and O. Oprean. "Runoff characteristics in Dobrogea." Paper presented at Air and Water Components of the Environment International Conference, Cluj-Napoca, Romania, March 17-19, 2023.
- [7] Telteu, Camelia-Eliza, and Liliana Zaharia. "Morphometrical and dynamical features of the South Dobrogea lakes, Romania." *Procedia Environmental Sciences* 14 (2012): 164-176.
- [8] Ciobotaru, Miruna-Ecaterina. "The ongoing challenge. Why doesn't Romania irrigate to its potential?" *Euro-Atlantic Resilience Centre / Centrul Euro-Atlantic pentru Reziliență - E-ARC*, August 15, 2023. Accessed October 10, 2024. <https://e-arc.ro/en/2023/08/15/the-ongoing-challenge-why-doesnt-romania-irrigate-to-its-potential-2/>.
- [9] Romanian Land Improvements National Agency (ANIF). Annex II6e. "Irrigation systems administrated by Land Improvements National Agency (ANIF) – Territorial Region of Dobrogea / Sisteme de irigații administrate de Agenția Națională de Îmbunătățiri Funciare (ANIF) – Regiunea Teritorială Dobrogea". Accessed October 10, 2024.
- [10] Masters, Gilbert M. *Renewable and Efficient Electric Power Systems*. Chapter 7 - The Solar Resource. 2nd Edition, IEEE Press, 2013.
- [11] Boxwell, Michael. *Solar Electricity Handbook: A Simple, Practical Guide to Solar Energy - Designing and Installing Photovoltaic Solar Electric Systems*. Greenstream Publishing, 2010.
- [12] Paul, D., D. Devaprakasam, S. Patil, and A. Agrawal. "Floating solar: A review on the comparison of efficiency, issues, and projections with ground-mounted solar photovoltaics." *International Journal of Sustainable Development and Planning* 18, no. 10 (October 2023): 3213-3228. <https://doi.org/10.18280/ijstdp.181021>.
- [13] Perez, M., R. Perez, C.R. Ferguson, and J. Schlemmer. "Deploying effectively dispatchable PV on reservoirs: Comparing Floating PV to other renewable technologies." *Solar Energy* 174 (November 2018): 837-847. <https://doi.org/10.1016/J.SOLENER.2018.08.088>.