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Technical, Economic and Environmental Benefits of Floating Photovoltaic Systems Installed on Irrigation Canals

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ABSTRACT

This article examines viable pathways for the rehabilitation and modernization of irrigation systems in Romania through the integration of renewable energy technologies, with a particular focus on the deployment of floating photovoltaic (FPV) systems on irrigation infrastructure. The transition towards low-carbon energy systems represents a major global and European objective, driven by the need to reduce greenhouse gas emissions, enhance energy security, and increase the resilience of critical infrastructures to climate change impacts [1–3].

In the agricultural sector, the coupling of renewable energy production with irrigation infrastructure is increasingly recognized as a strategic solution for improving operational efficiency, reducing energy costs, and strengthening the resilience of agricultural systems under conditions of increasing water and energy stress [4–6]. In this context, the proposed case study investigates the installation of a floating photovoltaic system with an installed capacity of 20 MW on an existing irrigation network, capable of generating approximately 25,000 MWh annually. The electricity produced is primarily intended for self-consumption by pumping and repumping stations, ensuring that at least 80% of the generated energy is utilized directly for irrigation-related operations, thereby reducing dependency on external energy sources and enhancing system autonomy [7,8].

The installation of photovoltaic panels on irrigation canals provides multiple co-benefits beyond renewable electricity generation. Previous studies have demonstrated that covering water conveyance infrastructure with photovoltaic systems can significantly reduce water losses due to evaporation—by up to 60–70%—while simultaneously limiting the proliferation of algae and mitigating eutrophication processes through reduced solar radiation on the water surface [9–11]. Moreover, the use of existing irrigation canals for photovoltaic deployment avoids competition with arable land, preserving agricultural productivity and supporting sustainable land-use planning in irrigated regions [12,13]. Collectively, these benefits position floating photovoltaic systems on irrigation canals as a promising techno-economic and environmental solution that directly contributes to both energy transition objectives and long-term agricultural resilience.

Keywords: Irrigation System; Floating Photovoltaic Panels; Renewable Energy; Irrigation Canals; Modern Solution; Technological Innovations; Pumping Station; Green Energy; Land Improvements; Agriculture; Evaporation; Irrigation Infrastructure.

1. Introduction

It is known that climate change has increased the frequency of dry years, significantly reducing the resilience and productivity of agriculture. A challenge of the energy transition towards the production of renewable solar energy in Romania is the lack of availability of land for the installation of high-power solar plants.

The irrigation infrastructure is a large consumer of conventional energy, and through the proposed irrigation project, it is aimed to obtain green energy with the help of floating photovoltaic panels, producing green energy at the point of consumption with significant cost reductions.

In recent years, important investments have been made from national and European funds in the irrigation infrastructure, to combat the effects of climate change with regard to drought, it is necessary and mandatory to continue investments in this area with a positive impact on the environment causing significant reductions in consumption of water and energy.

Considering the current context of rising energy costs, the development of alternative energy production mechanisms/systems is required, for which it is proposed to increase the share of renewable energy and reduce the carbon footprint.

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1.1. Objectives of the Study

The first objective of this study is to assess the technical and energy feasibility of integrating floating photovoltaic systems on existing irrigation canals, with an emphasis on the efficient use of hydraulic infrastructure without compromising its operational functionality. The analysis aims to determine the potential for renewable electricity generation, identify optimal design and operational parameters, and evaluate the impact of panel deployment on the overall energy performance of the system, including self-consumption at pumping and repumping stations. In addition, the study examines the influence of local environmental and climatic conditions on the performance of floating photovoltaic systems installed on irrigation canals.

The second objective of the research is to evaluate the economic, environmental, and operational benefits associated with the implementation of floating photovoltaic systems on irrigation canals, within the broader context of the energy transition and the enhancement of agricultural sector resilience. This assessment includes the estimation of reductions in energy costs and greenhouse gas emissions, as well as the quantification of indirect benefits such as decreased water losses due to evaporation, reduced risks of eutrophication, and the avoidance of competition with productive agricultural land. Overall, the study aims to provide an integrated analytical framework to support investment decision-making and public policies aimed at the sustainable modernization of irrigation infrastructure through renewable energy-based solutions.

2. Land Improvements

Land improvements involve complex irrigation and drainage works aim to promote the integral and sustainable development of agriculture and rural areas, for which reason the protection of rural and agricultural areas against floods becomes a priority for the National Land Improvement Agency (Balaj Iosif Ciprian: “Use of Solar Energy in the Field of Improved Land, Draining and Irrigation Systems”).

Land improvements represent the set of works, installations and technical measures intended to increase the productive capacity of agricultural lands by optimizing the water regime, improving the soil and ensuring a stable framework for carrying out agricultural activities. In the context of modern agriculture, these interventions constitute essential infrastructures for the efficient management of water resources, increasing the resilience of agricultural ecosystems and supporting stable productions in variable climatic conditions.

A central element of land improvements is irrigation systems, which include supply and distribution canals, pumping stations, regulation structures, accumulation basins and diversion or protection elements. They ensure the controlled transport and distribution of water to agricultural lands, contributing to maintaining an optimal soil moisture regime and reducing the annual variability of agricultural production. In Romania, the irrigation systems developed during the 1960s–1990s constituted one of the most extensive networks in Europe, but in recent decades their efficiency has been diminished by wear and tear, sedimentation processes and decreased investments in modernization.

In addition to irrigation, land improvements include drainage and drainage works, necessary in areas with excess humidity or high water table. They allow the evacuation of stagnant waters and the prevention of secondary salinization, ensuring optimal conditions for plant development and for the mechanization of agricultural work. In addition, agro-pedo-ameliorative improvements, such as land leveling, soil erosion control, torrent correction or protective afforestation, contribute to land stabilization and the improvement of the physical and chemical properties of the soil.

Nowadays, land improvements are increasingly viewed from the perspective of sustainability and the integration of modern technologies. The concept of smart irrigation introduces the automation of pumping operations, real-time monitoring of hydrological parameters and the use of algorithms to optimize water consumption. Also, existing infrastructures can become platforms for the implementation of renewable energy solutions, such as the installation of photovoltaic systems on irrigation canals or on unclaimed lands, transforming water distribution networks into multifunctional nodes with added energy and ecological value.

Therefore, land improvements play a crucial role in ensuring agricultural productivity and in adapting the agricultural sector to climate change. Their modernization, correlated with the integration of renewable sources and digitalization, represents a strategic direction for increasing water use efficiency and for developing resilient and sustainable agricultural systems.

2.1. Studied Area

The studied area is located in the complex hydro-improvement development, on the irrigation system, which has a total area of 75,197 ha.

The surface of the area for which the investment works are proposed is in the public domain of the state and is declared of public utility and economically viable.

The source of water for this development is the Danube River, through a floating base station, located on the left bank of the river, at km 388 + 250 and which discharges the water into the main action canals CA, up to the lake dumplings.

From the source, water is taken through the repumping station SRP.

The main rehabilitated irrigation canals, with a large opening, will serve as the location surface for the photovoltaic installations.

3. Procedures

The use of photovoltaic solar energy is considered to be an important resource for Romania where direct solar radiation can reach up to 1000 W/m^2 (Balaj Iosif Ciprian: “Use of Solar Energy in the Field of Improved Land, Draining and Irrigation Systems”).

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The area chosen for this case study is located in the irrigation development, according to the image:

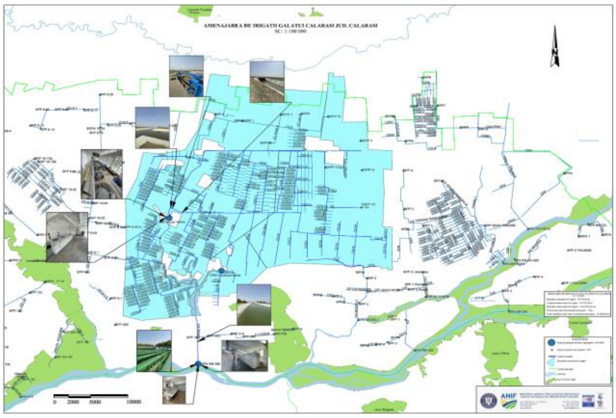

Figure 1. Location of the Main Irrigation Canals Already Rehabilitated (Source: ANIF)

Since the commissioning of this irrigation facility in 1970 - 1971 and until now, maintenance and repair works have been carried out on the pumping stations and the waterproofed surfaces on the canals.

The irrigation infrastructure also has a very good connection to the electricity transmission network, which will favor the distribution of the energy produced without substantial additional costs.

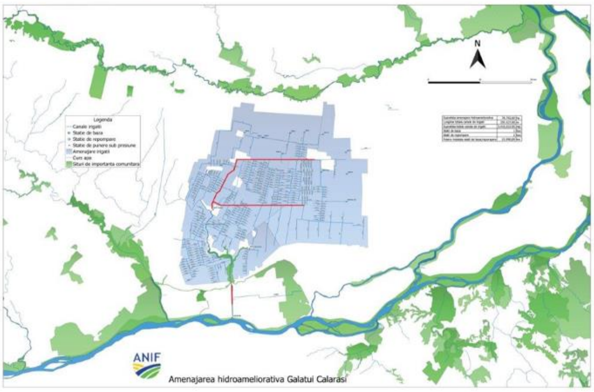

Figure 2. The Irrigation Infrastructure Canals (Source: ANIF)

It is proposed to install floating photovoltaic panels, exclusively on the surface of the following irrigation canals, under the administration of the National Land Improvement Agency:

- CA with a rehabilitated length of 4,000 m, B = 19.0 m, b = 2.5 m, h = 2.5 m, Q = 2.4 m^3/s;

- CA with a rehabilitated length of 3,100 m, B = 32.8 m, b = 8.0 m, h = 6.0 m, Q = 56 m^3/s;

- CA STORK with a rehabilitated length of 9,900 m, B = 20.7 m, b = 5.0 m, h = 4.5 m, Q = 16 m^3/s;

- CP - with a rehabilitated length of 8,838 m, B = 17.8 m, b = 2.0 m, h = 4.5 m, Q = 17.0 m^3/s.

The study consists in the installation on the main irrigation canals, of energy production facilities through photovoltaic plants with an installed power of 20 MW – 25,000 MWh of energy produced.

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The resulting green energy will be used for the self-consumption of the pumping/repumping stations, so at least 80% of the energy produced will be used for their operation, throughout the life of the investment.

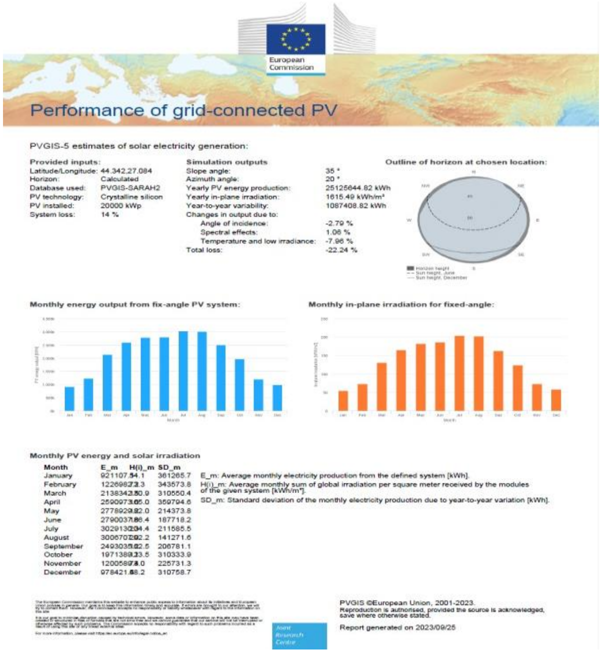

Figure 3. The Performance of the Photovoltaic Park (World Bank)

In the model applied for the simulation of photovoltaic production, only the produced electricity and the capacity factor of the installed power were taken into account, according to data from World Bank.

Each section of the photovoltaic park will have the following components:

- Photovoltaic modules made up of equipment whose role is to capture and transform solar energy into electricity. The photovoltaic modules used have a nominal unit power of 550 Wp;

- Power inverters are equipment whose main role is to transform the direct voltage, the usage voltage of the photovoltaic modules, into alternating voltage, the usage voltage for the consumers connected to the power plant busbars.

The power inverters used are unidirectional three-phase power inverters;

- The mounting structure of the photovoltaic modules has the role of fixing it on the mounting surface, which includes metal parts made of galvanized steel, sized and designed for the specific conditions of the project. The structure will be installed in a floating system;

- The electrical panels within the photovoltaic solar installation provide switching devices and protection and/or measuring devices specific to photovoltaic installations;

- Electric cable networks are laid underground up to the connection point of the cable distribution network station;

- The grounding installation within the photovoltaic solar installation includes:

• conductors and parts for making the connections between the metal elements related to the photovoltaic solar installation;

- conductors and parts for making the connection to the earth socket of the metallic elements, related to the photovoltaic solar installation.

- The low-current electrical installation includes data cables and equipment related to the remote monitoring of the installed power inverters and the command and control system of the installed power inverters;

- The surge and lightning protection installation includes:

- indoor surge protection system (IPS);
- lightning protection installation (IPT).

The surge protection installation (IPS) is represented by modular switching surge protection arresters;

- The NPM and PSI endowments include signs and indicators for safety and health at work, specific to the equipment and installations used, as well as fire protection materials.

4. Results and Discussion

The implementation of the project presented in this case study, provides benefits for society in general as it will lead to a reduction in budgetary effort, with electricity bills for irrigation infrastructure being.

According to the World Bank study the advantages of floating photovoltaic panels are:

a) the reduction of up to 70% of water losses through evaporation, estimated at 30% per year;

b) reduction of agricultural land allocated to photovoltaic installations;

c) the energy efficiency of the panels increases by 15%, having a reduced temperature of operation in the vicinity of water;

d) reducing the risk of eutrophication and that of green algae;

e) increasing water quality and aerating it with renewable energy.

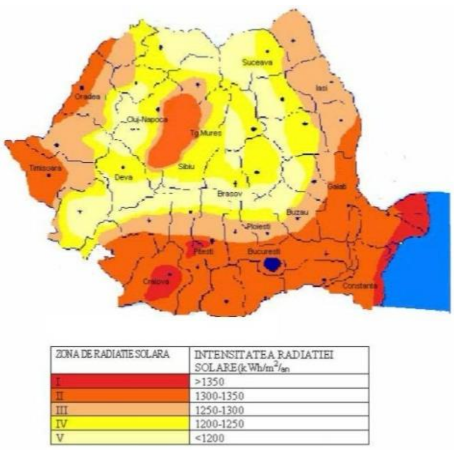

Figure 4. Study on the Evaluation of the Current Energy Potential of the Sources Renewable Energy in Romania

Romania has a valuable potential for the application of solar energy valorization measures due to its geographical position and local climatic conditions, which have a particular influence.

There are areas such as the Black Sea Coast and Dobrogea, but also in some areas in the south of the country, where the annual solar energy flow is between 1450 - 1600 kwh/m^2/year, which does not mean that in the other regions we do not encounter intensity high solar radiation.

In the rest of the country's regions, the sun has an average energy flow that exceeds 1250 - 1350 kwh/m^2/year. (D. Mihoc, S. St. Iliescu, I. Făgărășan, Gh. Țăranu, G. Matei, 2008).

Minimum service life 25 years, estimate made for 20 years according to the OS estimation system.

Table 1. The Energy Produced by the Panels during 20 Years

Year of operation	The efficiency of the photovoltaic system	Energy production in KWh
1	100%	25,125,644.00
2	99.18%	24,919,613.72
3	98.37%	24,716,096.00
4	97.55%	24,510,065.72
5	96.73%	24,304,035.44
6	95.92%	24,100,517.72
7	95.10%	23,894,487.44
8	94.28%	23,688,457.16
9	93.47%	23,484,939.45
10	92.65%	23,278,909.17
11	91.84%	23,075,391.45
12	91.02%	22,869,361.17
13	90.20%	22,663,330.89
14	89.39%	22,459,813.17
15	88.57%	22,253,782.89
16	87.75%	22,047,752.61
17	86.94%	21,844,234.89
18	86.12%	21,638,204.61
19	85.30%	21,432,174.33
20	84.49%	21,228,656.62
	TOTAL	**463,535,468.46**

Considering that mounting solar panels on land leads to the loss of valuable space, floating photovoltaic panels help to save it. In addition to mounting them on irrigation canals, they can also be mounted on spaces not used by water bodies such as wastewater treatment plants, drinking water tanks or hydroelectric tanks and reservoirs.

The implementation of these floating panels the fact that water evaporation from irrigation canals can be reduced by up to 70%. This technology is a win-win solution in drought-prone areas because water conservation and energy production can work simultaneously.

Figure 5. Water Transport Efficiency on the Distribution Network

The floating solar power plant, applied on the irrigation canals, has the role of solving the problem of the larger area of the traditional solar power plant.

The solar modules would be installed on the floating support which is made of high-density polyethylene.

Figure 6. Solar Panels Mounted On Irrigation Canals

Under the premise of ensuring its intensity, the professional design of the structure, the optimization of the floating structure and the simple and convenient design improve the installation efficiency of the project and then save the cost.

5. Advantages

Photovoltaic panels installed on irrigation canals offer significant advantages by combining renewable energy generation with the efficient use of existing hydrotechnical infrastructure. Mounting photovoltaic systems above the canals substantially reduces water evaporation, contributing to the conservation of water resources in agricultural areas vulnerable to drought. At the same time, positioning the panels above the water allows them to operate at lower temperatures, which increases their energy efficiency compared to ground-mounted installations. Using the surface area already occupied by the canals minimizes the need for agricultural land and reduces environmental impact. Additionally, the locally generated energy can directly power pumping stations, lowering operational costs and increasing the energy autonomy of irrigation systems.

6. Conclusion

Floating photovoltaic panels on irrigation canals (rehabilitation) present a series of significant advantages such as:

- reduction of evaporation;
- renewable energy production, in areas with limited available land;
- the hydro-improvement infrastructure is well connected to the Electric Distribution Network and the Electric Power Transmission Network, facilitating the distribution of the energy produced;
- such a project increases the synergy between water management and renewable energy production;
- the panels contribute to reducing evaporation and preventing the growth of algae that create blockages, and the water contributes to the cooling of the panels, thus increasing their efficiency;
- the floating solar panel solution offers an attractive option to free up additional space on land that can be used alternatively (densely populated cities and limited agricultural land);
- power plants with photovoltaic cells (PV) directly transform solar energy into electric current and have the advantage that they do not require permanent maintenance;
- the installation of these equipments on the main irrigation canals contributes to the improvement of the safety in operation of the National Energy System/Electrical Transport Network (SEN/RET), by ensuring the conditions of independent operation in case of breakdowns and in case of possible remedial processes, the supply without disruption of internal services being vital to the success of fault resolution and remediation processes;
- the resulting green energy will be used for the self-consumption of the pumping/repumping stations under the administration of the National Land Improvement Agency, thus at least 80% of the energy produced will be used for their operation, throughout the life of the investment.

However, there are also challenges associated with the implementation of floating photovoltaic panels on irrigation canals, such as high initial costs, the need to ensure their durability and resistance in the aquatic environment, and the proper management of maintenance and electricity supply of the systems.

However, with the right technologies and practices, these challenges can be successfully addressed, providing an innovative solution for sustainable energy production and irrigation.

Romania should consider adopting floating solar panels not only because it becomes cheaper, but also because it is an environmentally friendly way to conserve water and generate clean energy.

7. Future Perspectives and Recommendations

1. Optimization of structural and anchoring systems: Future research should prioritize the optimization of structural and anchoring solutions specifically adapted to irrigation canal geometries, in order to ensure long-term mechanical stability and hydraulic compatibility without compromising water conveyance or routine maintenance activities.

2. Integration with energy storage solutions: The integration of floating photovoltaic systems with energy storage technologies represents a key pathway for increasing self-consumption levels at pumping and repumping stations, while simultaneously enhancing the reliability and flexibility of energy supply.

3. Long-term environmental impact assessment: Comprehensive long-term studies are required to evaluate the impacts of floating photovoltaic installations on water resources and aquatic ecosystems, including changes in water temperature, quality, biodiversity, and eutrophication processes, in order to support environmentally responsible large-scale deployment.

4. Digitalization and smart system monitoring: The adoption of advanced digital monitoring and control systems based on real-time data acquisition, Internet of Things (IoT) technologies, and artificial intelligence could significantly improve operational performance, early fault detection, and the alignment between energy generation and irrigation demand.

5. Economic and regulatory framework development: From an economic and policy perspective, the development of dedicated regulatory frameworks, financial incentives, and targeted funding mechanisms is essential to facilitate the wider adoption of floating photovoltaic systems on irrigation canals, particularly in agricultural regions affected by water and energy stress.

6. Scalability and replicability assessment: Future studies should assess the scalability and replicability of floating photovoltaic solutions at regional and national levels, in order to support energy transition strategies while enhancing the long-term resilience of irrigation infrastructure and agricultural systems.

Declarations

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This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Competing Interests Statement

The author declares that she has no competing interests related to this work.

Consent for publication

The author declares that she consented to the publication of this study.

Authors' contributions

Author’s independent contribution.

Availability of data and materials

Supplementary information is available from the author upon reasonable request.

Institutional Review Board Statement

Not applicable for this study.

Informed Consent

Not applicable for this study.

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