European Journal of Energy Research
www.ej-energy.org

RESEARCH ARTICLE

Assessment of the Potential of Installing Floating Photovoltaic Systems in Existing Water Reservoirs in Greece

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ABSTRACT

Floating photovoltaics consists of a new and fast-growing technology worldwide. Installations of these novel green energy systems have not been developed so far in Greece. The aim of the current work is to investigate the potential of installing floating photovoltaic systems in Greek water bodies. The existing water reservoirs in Greece have been identified while their water surface that allows the installation of solar panels, the nominal power of the floating photovoltaics and the generated solar electricity have been estimated. The nominal power of floating photovoltaics which can be installed in the existing 128 water reservoirs in Greece covering 10% to 30% of their surface varies between 4.77 GW_p to 14.31 GW_p while the annual generated electricity at 6,435.2 GWh to 19,305.6 GWh corresponding at 12.40% to 37.20% of the total annual electricity consumption in the country. The annual water evaporation savings, due to installation of floating photovoltaics, have been calculated at 71.55 mil. M^3 to 214.65 mil. M^3 while the increased annual electricity gain at 321.76 GWh to 1,930.56 GWh. The results indicate that significant amounts of electricity can be generated with floating photovoltaics installed in water reservoirs in Greece. They could be useful to policy makers who are developing policies to achieve net zero carbon emissions by 2050 in Greece and to energy companies who are willing to invest in these novel green energy technologies.

Keywords: Electricity yield, floating photovoltaics, Greece, hydro-electric systems, water dams, water savings.

Published Online: April 27, 2023
ISSN: 2736-5506
DOI :10.24018/ejenergy.2023.3.1.100

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I. Introduction

Floating photovoltaics (FPVs) is an emerging technology worldwide complementing the technology of terrestrial photovoltaics (PVs) [1], [2]. It has been developed rapidly during the last decade due to their benefits compared to ground-mounted PVs [3], [4]. Although their installation cost is slightly higher compared to the cost of terrestrial PVs their electricity yield is higher while the water evaporation from the reservoirs is lower and less land resources are used [4]-[6]. FPVs are installed on the surface of inland water bodies usually covering part of the water surface. They are installed in various floating structures usually with a small tilt angle and anchored to the sides or the bottom of the water bodies. Studies regarding the potential of installing FPVs in various countries exist [3], [7]-[9]. However, studies regarding the use of floating photovoltaics in water reservoirs in Greece are lacking. The current work is focused on the estimation of the potential of installing FPVs in existing water reservoirs in Greece and the estimation of the solar electricity that can be generated. The work is going to fill the existing gap regarding the potential of installing FPVs in existing water bodies in Greece contributing in the existing knowledge related to development of renewable energies in the country achieving the EU target for carbon-free societies by 2050.

The aim of the current work is the estimation of the potential of installing floating photovoltaics in existing inland water reservoirs in Greece and the resulting benefits.

The text is structured as follows: After the introduction section and the literature review the existing water dams in Greece are presented followed by a description of floating photovoltaic systems which could be installed in them. Next the potential of generating electricity from FPVs in Greece is estimated followed by the presentation of the benefits of this technology. After that the discussion of the findings and the conclusions drawn are mentioned while the text ends with the citation of the references used.

II. Literature Survey

The literature survey is separated in three parts as follows: Part one is related with the characteristics of floating photovoltaics, part two with studies regarding the use of FPVs in various countries, while the third part with installation of FPVs in hydro-electric systems.

A. Characteristics of Floating Photovoltaics

Reference [5] have studied the environmental and technical impacts of FPVs. The authors stated that the main benefits of FPVs are related with:

a) reduced land-use conflicts,
b) water evaporation savings, and

c) higher electricity yield.

They also mentioned that there is lack of supporting policies and development roadmaps from governments regarding their sustainable growth. Reference [10] have investigated the effects of FPVs on wind speed, solar radiation and thermal structure of water bodies using mathematical models. The authors stated that low coverage of the water surface had negligible effect on the thermal structure of the water body while high coverage creates major changes. They also mentioned that FPVs provide an opportunity to manage the effects of climate change on lake systems. In any case FPVs is a major perturbation to water body's functions. Reference [6] have investigated the thermal and electrical performance of FPVs compared to terrestrial PVs. The authors stated that when the water body was partially covered with the FPV system the water evaporation was reduced by 17% while when it was fully covered it was reduced by 28%. They also mentioned that FPV systems produced up to 20-28% more energy than terrestrial systems. Reference [11] have compared the electricity yield of FPVs and terrestrial solar-PVs. The authors stated that the average panel's temperature in FPVs might be lower than in conventional PVs while the electricity yield in FPVs is higher. Reference [12] have studied the power generation in FPV systems. The authors stated that the panel's temperature of FPV systems is lower than the temperature in similar terrestrial PV systems while the electricity yield in FPVs is higher at 11%. Reference [13] have reviewed the floating photovoltaic technology. The authors stated that the electricity yield of FPVs is higher at 11% compared to the yield of terrestrial PVs. They also mentioned that by covering 30% of the water surface with solar panels the water evaporation can be reduced by 49%. Reference [14] has assessed the impacts of FPVs on water quality and evaporation reduction in semi-arid regions. The authors stated that the use of FPVs in agricultural ponds is very beneficial resulting in solar electricity generation and in water evaporation savings. They also mentioned that the observed water evaporation saving was at around 60%. Reference [15] have reviewed the concept of FPVs. The authors stated that the cost of FPVs is higher at 0.8-1.2 $\$/W_p$ compared to terrestrial solar-PVs. They also mentioned that the lack of design standards and best practice guidelines does not facilitate the progress of this technology.

B. *Use of Floating Photovoltaics in Several Countries*

Reference [3] have investigated the prospects of FPVs in central and south Asian countries. The authors stated that the technology of FPVs is very important in water-scarce regions like south Asia and central Asia. They also mentioned that the technology is feasible, cost-efficient and environmentally friendly. It reduces water contamination and achieves sustainable water supply and clean energy production. Reference [7] have studied the effects of FPVs in Jordan. The authors stated that FPVs have higher electricity yield at 5.33% compared to ground-mounted solar-PVs. They also mentioned that with coverage ratio at 30% the water evaporation savings were at 31.2 % while with coverage ratio at 50% the water evaporation savings were at 54.5%. Reference [8] have studied the use of FPVs in India. The authors stated that the potential of installing FPVs in India is at 280 GW installed on 18,000 km^2 of water reservoirs. They also mentioned that FPVs represent a small fraction in the overall solar energy market while their installation cost is higher at around 25-45% than the cost of terrestrial PVs. Reference [16] has presented the characteristics of the existing water reservoirs in Greece. The report stated various characteristics of 128 water reservoirs in Greece including several hydro-electric dams. Reference [17] have investigated the use of FPVs in wastewater treatment plants in Australia. The authors stated that floating photovoltaics are different than terrestrial solar-PV systems while they can be used in water basins of wastewater treatment plants. They also mentioned that their estimations indicated that roughly around 15,000 M^3 to 25,000 M^3 of water can be saved annually for each MW_P of FPVs installed in basins that is very important in arid regions while the annual energy yield can be increased by 10%. Reference [18] has estimated the potential for electricity generation from FPVs installed in the existing water reservoirs in the island of Crete, Greece. The author stated that the estimated nominal power of floating photovoltaics that can be installed in these water dams, with coverage ratio at 0.1 to 0.3, varies between 55.76 MW_p to 167.3 MW_p while the annual electricity generation from the floating photovoltaics varies between 78.3 GWh to 234.9 GWh. Reference [9] have studied the impact of FPVs on water evaporation in reservoirs in Jordan. The authors stated that the use of FPV systems in agricultural irrigation reservoirs located in water-scarce regions can save water and generate solar electricity for water pumping. They also mentioned that the payback period of the FPV systems was 8.4 years while the water evaporation due to FPVs was lower at 42% compared to uncovered water dams. Reference [19] have studied the use of FPVs in the lake Nasser in Egypt. The authors stated that if only 20% of the lake is covered with FPVs, in an area at 1,000 km^2, it will produce low-cost green electricity which is enough for covering 16% of the EU needs. Reference [1] have reviewed the technology of floating photovoltaics globally. The authors stated that by covering 1% of the global water reservoirs with FPV systems the nominal solar-PV power will be at 404 GW_p. They also mentioned that there are numerous advantages of FPVs compared to ground-mounted solar panels while they stated that there is a knowledge gap regarding the impacts of FPVs on water quality and living organisms. Reference [20] has analyzed with simulation methods the benefits of FPVs compared to other solar-PV technologies. The author stated that FPVs can produced 10-12% more electricity than terrestrial solar-PVs. He also mentioned that a FPV system at 28,200 m^2 can prevent water evaporation at 23,600 m^3 per year. Reference [21] have studied the cooling effect of FPVs with reference the West Java, Indonesia. The authors stated that their estimations indicated that the energy yield of FPVs was higher at around 0.61% than ground-mounted solar-PVs while they also had lower levelized cost of electricity (LCOE) and higher rate of return at 6.08%. Reference [22] have studied the use of FPVs on lakes in Bengaluru city, India. The authors stated that FPVs can be installed in 32 lakes with total surface at 3,298 acres. They also mentioned that installation of FPVs with coverage ratio at 0.5-0.6 can generate solar electricity equal with 26% of the city's annual power demand. Reference [23] have assessed the potential of floating solar photovoltaic panels in water reservoirs in Spain. The authors stated that the country could meet about 31% of its annual electricity demand by covering only 10% of the available water surface area. Reference [24] have studied the development of FPVs in South Sumatra, Indonesia. The authors investigated experimentally the performance of a FPV system and a ground-mounted solar-PV system at 100 KW_p each. They stated that the FPV system had lower average surface temperature at 2°C than the terrestrial PV system while its electricity yield was higher at 1.2 % than the ground solar panel. Reference [25] have estimated the potential of installing FPVs in water dams in Korea. The authors estimated the potential of installing FPVs in 3,401 water reservoirs in Korea at 2,932 GWh per year. References [4] have analyzed the power efficiency and the prospects of FPVs. The authors stated that FPV systems can save land and water resources obtaining higher electricity yields. The authors mentioned that the operating temperature of FPVs was at 3.5-5 °C lower compared to terrestrial PVs while its energy yield was higher at 1.58% -2.00%. They also stated that the potential of installing FPVs in China can reach 100 GW_p covering about 2,500 km^2 of water surface and saving large amounts of water. Reference [26] have evaluated the FPV systems in southern European countries focusing on Portugal. The authors stated that the Portuguese national plan for energy and climate predicts that water reservoirs in Portugal will have new rules in order to encourage the increasing installation of FPV systems while it is foreseen that 20% of the water surface of the 50 largest reservoirs will be used for the installation of FPVs. They also mentioned that the payback period of these energy investments was estimated at 14 years.

C. Installation of Solar Photovoltaics in Hydropower Stations

Reference [27] have assessed the floating photovoltaic potential in existing hydropower reservoirs in Africa. The authors studied the 146 largest hydropower reservoirs in Africa stating that the use of FPVs can co-generate hydro and solar electricity, achieving water evaporation savings which result in additional hydroelectricity generation. They also mentioned that by covering less than 1% of the water dam surface with FPVs the installed power capacity of the existing hydro-electric plants can double. Reference [28] have analyzed the benefits of pairing floating solar photovoltaics with hydropower reservoirs in Europe. The authors stated that installation of FPVs on existing hydropower reservoirs offers one solution to limited land availability while provides solar electricity and reduces water evaporation losses. They have also assessed the potential electricity generation of FPVs installed in 337 hydropower reservoirs in EU27 mentioning that the installation of FPVs of equal power capacity as the hydropower plants has the potential to generate 42.31 TWh/year covering only 2.3% of the total reservoir's area. Reference [2] have assessed the hybrid hydro-FPV systems. The authors stated that the estimated global potential for hybrid FPV and hydro-electric systems is in the range of 3.0 TW to 7.6 TW with annual electricity generation in the range of 4,251 TWh to 10,616 TWh. Reference [29] has investigated the possibility of using floating solar photovoltaics in the existing and planning hybrid energy systems in the islands of El Hierro, Spain and in Crete, Greece. The author stated that the annual electricity generation from the installation of floating solar photovoltaics in the existing pumped-hydro storage system in El Hierro, with 30% coverage ratio, corresponds at 6.06 % of the annual electricity generation by the hybrid energy plant and at 4.59 % of the total annual electricity consumption in the island. He also mentioned that the annual electricity generation from the floating FPVs which could be installed in the planned pumped-hydro storage system in Potamon dam Crete, with 30% coverage ratio, corresponds at 33.78% of the estimated electricity generation by the hybrid energy plant and at 2.52% of the annual electricity consumption in the island in 2018. Reference [30] have studied the installation of FPVs in two hydroelectric dams in Egypt, the high dam and the Aswan reservoir. The authors stated that the power of the two hydroelectric stations is at 2.65 GW while the installation of two FPV systems in the two dams with nominal power at 5 MW_p each has been studied. They also mentioned that both the two FPV systems can produce up to 23.2 GWh per year while they will result in annual water evaporation savings at 0.1 mil. M^3. Reference [31] have reviewed the hybrid floating photovoltaic designs. The authors stated that the most promising hybrid FPV technology is the combination of FPV systems with hydro-electric systems. They also mentioned that these hybrid energy systems have a tremendous implementation potential in islands. Reference [32] have estimated the installation cost of floating photovoltaic systems on artificial water bodies. The authors stated that the cost of a fixed-tilt FPV system is around 25% higher compared with a similar ground-mounted system while its LCOE is around 20% higher than the LCOE of a similar ground-mounted system. The electricity yield, the water evaporation savings and the cost characteristics of FPVs in several countries reported by various authors are presented in Table I.

III. Water Reservoirs in Greece

Greece like other countries has many natural lakes and man-made water reservoirs. According to a recent report [16] there are 128 water dams in Crete while many more are under construction. It should be noted that some regions in Greece have limited water resources while climate change might result in future water shortages. Consequently, it is expected that more water dams will be constructed in the future in the country to cope with the foreseen water shortages. The water is used for irrigation, domestic purposes and in some cases for electricity generation with hydro-electric systems. The 128 water dams are dispersed all over the country while the majority of them are located in continental Greece. The total surface of the existing water reservoirs in each region in the country is presented in Table II as well as their surface that can be used for installation of FPV systems. According to the data presented the reservoirs with the larger water surface are located in the regions of Macedonia and Attiki-Sterea Ellada. The total surface of the water dams in Greece corresponds at 0.36% of the country's area. The natural and man-made water reservoirs in Greece have not been used so far for installation of solar photovoltaics and generation of green energy while the published studies on this topic are rather limited.

TABLE I: ELECTRICITY YIELD, WATER EVAPORATION SAVINGS AND COST CHARACTERISTICS OF FLOATING PHOTOVOLTAIC INSTALLATIONS COMPARED TO TERRESTRIAL PHOTOVOLTAICS REPORTED BY SEVERAL AUTHORS

Reference	Country	Electricity yield	Water evaporation	Installation cost-profitability
[9]	Jordan		Lower water evaporation at 42%	The payback time of FPVs is at 8.4 years
[20]		Higher electricity yield at 10-12%		
[23]	Spain	Higher electricity yield at 10-17%		
[25]	Korea			The payback time of FPVs is at 3.8-4.7 years
[24]	Indonesia	Higher electricity yield at 20%		
[11]	Australia	Higher electricity yield at 3-15%		
[4]		Higher electricity yield at 1.6-2%		
[21]		Higher electricity yield at 0.61%		FPVs have lower LCOE compared to terrestrial PVs and higher internal rate of return at 6.08%
[17]		Higher electricity yield at 10%	Water evaporation saving at 15,000-20,000 M^3/year per MW_p of FPVs	
[31]		Higher electricity yield at 10-15%	Lower water evaporation at 80%	
[14]		Similar electricity yield with terrestrial solar-PVs	Lower water evaporation at 60%	
[32]				The installation cost of FPVs is higher at 25% than the cost of terrestrial PVs while their LCOE is higher at 20%
[28]			When the coverage ratio is at 2.3% the water evaporation is reduced by 5%	
[22]				The LCOE of FPVs is almost similar with the LCOE of terrestrial solar-PVs
[19]	Egypt	Higher electricity yield at 8-13%		
[15]				Installation cost is higher at 0.8-1.2 $/$W_p$ compared to terrestrial PVs
[6]		Higher electricity yield at 20-28%	Water evaporation savings are at 17% if the water surface is partly covered and 28% when it is fully covered	
[5]	Brazil	Higher electricity yield	For coverage ratio between 20%-70% the water evaporation is reduced by 15.3%-55.2 %	
[13]		Higher electricity yield at 11%	For coverage ratio at 30% the water evaporation is reduced by 49%	
[8]	India	Higher electricity yield at 5-15% higher		Floating photovoltaics have higher installation cost at 25-45% compared to terrestrial PVs while the LCOE is almost similar
[12]	Korea	Higher electricity yield at 11%		
[7]	Jordan	Higher electricity yield at 5.33 %	Lower water evaporation at 31.2% - 54.5 %	

TABLE II: SURFACE OF EXISTING WATER RESERVOIRS IN GREECE WHICH COULD BE USED FOR INSTALLATION OF FLOATING PHOTOVOLTAICS FOR VARIOUS COVERAGE RATIOS (KM^2) [16]

Region	Total surface of existing water reservoirs (km^2)	Surface of FPVs, 10% coverage (km^2)	Surface of FPVs, 20% coverage (km^2)	Surface of FPVs, 30% coverage (km^2)
Macedonia	204	20.40	40.80	61.20
Attiki-StereaEllada	140	14	28	42
Peloponnisos	50.5	5.1	10.2	15.3
Thessaly	33	3.3	6.6	9.9
Ipiros	33	3.3	6.6	9.9
Island of Crete	5.6	0.56	1.1	1.7
Dodekanisa islands	5.4	0.54	1.1	1.6
Thrace	2.2	0.22	0.44	0.66
North Aegean islands	1.3	0.13	0.26	0.39
Cyclades islands	1.1	0.11	0.22	0.33
Ionian islands	0.018	0.0018	0.0036	0.0054
TOTAL	476.12	47.66	95.32	142.98
%, total water and FPV surface to total area of Greece (131,957 km^2)	0.36%	0.036%	0.072%	0.108%

IV. FLOATING SOLAR PHOTOVOLTAICS

Floating photovoltaics consists of a recent technology which has been developed rapidly during the last decade mainly in Asian countries. The technology is complementary to terrestrial photovoltaics, usually installed on the ground and on building's roof-tops, while it is technically feasible, cost-efficient and environmentally friendly. However, the impacts of FPVs on water quality and on aquatic life require further investigation. When FPVs are installed on water bodies any coverage of the water surface less than 10% does not have any serious impacts on water quality. Usually, the solar panels installed on water dams have lower temperature compared with similar terrestrial panels which results in higher electricity yields. The main advantages of FPVs compared to ground-mounted PVs are related with less land use which is important in land-scarce regions, with water

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evaporation savings which is important in regions with limited water resources and with higher electricity yields compared to terrestrial PVs due to the cooling effect. Use of floating photovoltaics in irrigation ponds in arid countries is beneficial since they result in water evaporation savings and in electricity generation necessary for the operation of the water irrigation system. Use of FPVs on water dams in hydro-electric systems is also beneficial since the hybrid system has higher power capacity while it generates both hydro and solar electricity complementing each other.

V. Electricity Generation from Floating Photovoltaics installed in Water Dams in Greece

Installation of FPVs in Greek water dams can generate significant amount of electricity. FPVs can be installed either in hydroelectric dams or in reservoirs which are not used for power generation. The floating panels can cover only part of the water surface without impacting on water quality. Some water reservoirs are not suitable, for several reasons, for the installation of floating panels. However, in others their installation does not cause any major problems. Existing hydroelectric dams and dams in arid islands are prioritized for the installation of FPVs. In hydropower reservoirs installation of solar panels can provide solar electricity complementing the hydroelectricity already produced and increasing the overall power capacity of the plant while installation of solar panels in arid islands with abundant solar energy and lack of sufficient water resources can provide green electricity reducing the carbon emissions and saving water resources. The characteristics of FPVs which could be installed in ten existing hydro-electric dams in Greece are presented in Table III. The nominal power of the FPVs which can be installed in existing water reservoirs in Greece, for various coverage ratios of the water surface, is presented in Table IV. The estimations indicate that the power of the FPV systems that can be installed is high compared to the already existing electric power in the country. The electricity generation from FPVs which can be installed in water reservoirs in Greece, for various coverage ratios of the water surface, is presented in Table V. Table V indicates that electricity generation from FPV systems is high compared to the total annual electricity consumption in the country.

The nominal power of the FPVs installed in these ten hydropower reservoirs, with 10% surface coverage, at 974.69 MW_p corresponds at 5.11% of the total installed electric power in the country at 19,067 MW_{el}. The power of the installed FPVs is higher than the power capacity of the abovementioned ten hydropower stations, at 759 MW_{el}.

TABLE III: Characteristics of Floating Photovoltaics which could be Installed in Ten of the Existing Hydropower Stations in Greece [16]

Hydroelectric dam	Greek Region	Water surface (km^2)	Hydroelectric power (MW_{el})	Nominal power of FPVs with coverage ratio at 10% (MW_p)	Increase of the existing hydro-power capacity due to installation of FPVs (%)
Ladonas	Peloponnisos	4	70	40	57
Polifito	Macedonia	74	375	740	197
Assomata	Macedonia	2.6	24	26	24
Sfikia	Macedonia	4.3	14	43	14
Platanovrissi	Macedonia	3.3	28	33	28
Pramotitsa	Macedonia	0.109	105	1.09	105
Dafnozonara	StereaEllada	0.34	40	3.4	40
Messochora	Thessalia	7.8	48	78	48
Louros	Ipirus	0.37	36	3.7	36
Pournari II	Ipirus	0.65	19	6.5	19
Total		97.47	759	974.69	
%, percentage of FPV power to total installed power in 2020 in Greece (19,067 MW_{el})			3.98%	5.11%	

solar-PVs at 1 MW_p require 10,000 m^2 for their installation

TABLE IV: Nominal Power of the Floating Photovoltaics Installed in Water Reservoirs in Greece for Various Coverage Ratios (of the Water Surface)

Greek Region	10%, coverage of water surface, (GW_p)	20%, coverage of water surface, (GW_p)	30%, coverage of water surface, (GW_p)
Macedonia	2.04	4.08	6.12
Attica – Sterea Ellada	1.40	2.80	4.20
Peloponnisos	0.51	1.02	1.53
Thessaly	0.33	0.66	0.99
Ipiros	0.33	0.66	0.99
Island of Crete	0.06	0.12	0.18
Dodekanisa islands	0.05	0.10	0.15
Thrace	0.02	0.04	0.06
North Aegean Islands	0.01	0.02	0.03
Kyklades islands	0.01	0.02	0.03
Ionian islands	0.002	0.004	0.006
TOTAL	4.77	9.54	14.31
%, percentage of FPV power to total installed power in 2020 in Greece (19.07 GW_{el})	25.02 %	50.3 %	75.05 %
%, percentage of FPV power to total installed solar-PV power in 2020 in Greece (2.75 GW_p)	173.45 %	346.91 %	520.36 %
Installed power of FPVs per capita (Population of Greece, 9,716,889 - census 2021)	0.49 KW_p/capita	0.98 KW_p/capita	1.47 KW_p/capita

solar-PVs at 1 MW_p require 10,000 m^2 for their installation

TABLE V: ELECTRICITY WHICH COULD BE GENERATED FROM FLOATING PHOTOVOLTAICS INSTALLED IN WATER RESERVOIRS IN GREECE FOR VARIOUS COVERAGE RATIOS

Greek Region	10%, coverage of water surface (GWh/year)	20%, coverage of water surface (GWh/year)	30%, coverage of water surface (GWh/year)
Macedonia	2,754	5,508	8,262
Attica – Sterea Ellada	1,890	3,780	5,670
Peloponnisos	688	1,376	2,064
Thessaly	445	890	1,335
Ipiros	445	890	1,335
Island of Crete	75.6	151.2	226.8
Dodekanisa islands	72.9	145.8	218.7
Thrace	29.7	59.4	89.1
North Aegean Islands	17.5	35	52.5
Kyklades islands	14.8	29.6	44.4
Ionian islands	2.7	5.4	8.1
TOTAL	6,435.2	12,870.4	19,305.6
%, percentage of FPV electricity to total electricity consumption in 2020 in Greece (51,900 GWh_{el})	12.40 %	24.80 %	37.20 %
Annual electricity generation from FPVs per capita (Population of Greece, 9,716,889 - census 2021)	660 KWh/capita	1,320 KWh/capita	1,990 KWh/capita

Solar panels at 1 MW_p produce 1,350 MWh annually

TABLE VI: SEVERAL BENEFITS RELATED WITH THE INSTALLATION OF FLOATING PHOTOVOLTAICS IN EXISTING WATER RESERVOIRS IN GREECE FOR SEVERAL COVERAGE RATIOS OF THE WATER SURFACE

	10%, coverage of water surface	20%, coverage of water surface	30%, coverage of water surface
Nominal power of installed FPVs (MW_p)	4,770	9,540	14,310
Annual energy generation from the FPVs (GWh/year)	6,435.2	12,870.4	19,305.6
Land area saved (Km^2)	57.19	114.38	171.58
Annual water evaporation savings from water dams (mil. M^3/year)	71.55	143.10	214.65
Increased electricity yield compared to electricity generation by similar terrestrial PVs (GWh/year)	321.76 - 643.52	643.52 - 1,287.04	965.28 - 1,930.56

VI. BENEFITS RELATED WITH THE INSTALLATION OF FLOATING PHOTOVOLTAICS IN WATER BODIES IN GREECE

Installation of FPVs in water reservoirs in Greece has several benefits. The most important are related with:

a) Increased electricity yields due to the cooling effect,

b) Water evaporation savings from the water reservoirs due to installation of floating structures covering part of their surface, and

c) Land area savings.

A. *Increased Electricity Yields*

The floating panels are installed on the water surface which has lower temperature than the temperature in nearby land's surface. Therefore, the temperature on the surface of the panels is lower compared to ground-mounted PVs resulting in higher annual electricity generation compared to terrestrial PVs. Although the increase in annual electricity yield in FPV systems varies according to various authors (Table I) it has been assumed that it is in the range at 5% to 10%.

B. *Water Evaporation Savings*

Floating photovoltaics are installed on water dams covering part of their surface reducing the incident solar radiation and decreasing the water evaporation. It has been assumed that the decrease in water evaporation is at 15,000 M^3/year per installed MW_p [17].

C. *Land Area Savings*

Installation of FPVs results in less land use required for installation of similar terrestrial PVs. It has been assumed that the required land for the installation of terrestrial PVs is 20% higher than the surface required for the installation of similar FPVs. The abovementioned benefits due to installation of floating photovoltaics in water reservoirs in Greece are presented in Table VI.

VII. DISCUSSION

Our results indicate that the installation of FPVs in existing water bodies in Greece, covering a small percentage of their water surface, can generate significant amounts of solar electricity. At the moment there are not installations of FPV systems in Greek water reservoirs like in several EU countries and worldwide. In the current study it has been indicated that by covering with FPVs 10% of the water surface in the existing Greek water bodies the generated solar electricity corresponds at 12.40% of the annual electricity consumption in the country in 2020. This is lower than similar estimations reported in Spain whereby covering 10% of the surface of its water bodies the generated solar electricity corresponds at 31% of its annual electricity demand [23]. It has been also found that by covering 10% of the surface of the water bodies in Greece with FPVs the annual electricity generation is at 6.44 GWh compared to 2,932 GWh/year reported in Korea [25]. By installing FPVs in the existing water bodies in Greece, covering 10% of their surface, equal to 47.66 km^2, the calculated installed solar power is at 4.77 GW_p compared to 100 GW_p reported in China [4]. Our results are valuable since they indicate that FPV systems installed in water bodies in Greece can generate significant amounts of solar electricity complementing the electricity generated by ground-mounted PVs and solar-PVs installed on rooftops of buildings. Unfortunately, the results do not indicate which water reservoirs in Greece are appropriate for the installation of FPVs neither they give estimates related with their installation cost and their profitability. Future research should be focused on the assessment of the potential of installing FPVs in existing hydropower stations in Greece creating hybrid solar-hydro power plants as well as in the implementation of case studies regarding the installation of FPVs in existing water reservoirs in Greece.

VIII. Conclusions

The potential of installing floating photovoltaics in existing water bodies in Greece has been highlighted and the resulting benefits have been estimated. 128 water reservoirs have been identified in the country with total water surface at 476.12 Km^2. The nominal power of FPVs which can be installed in these water reservoirs covering 10% to 30% of their surface varies between 4.77 GW_p to 14.31 GW_p while the annual generated electricity at 6,435.2 GWh to 19,305.6 GWh corresponding at 12.40% to 37.20% of the total annual electricity consumption in Greece. The annual water evaporation savings, due to installation of FPV systems, have been calculated at 71.55 mil. M^3 to 214.65 mil. M^3 while the increased annual electricity gain at 321.76 GWh to 1,930.56 GWh. Our work indicates that installation of FPVs in water bodies in Greece generates significant amounts of electricity having several co-benefits related with increased energy production, water evaporation savings and less use of land resources. Taking into account the lack of similar studies in Greece the results could be useful to national and regional authorities who should promote and facilitate the implementation of these sustainable and benign energy investments. It could be also useful to energy companies who are interesting to invest in solar energy technologies in Greece taking into account the rich solar energy potential of the country as well as to the owners of the water reservoirs who could achieve additional incomes.

References

[1] Essak L, Ghosh A. Floating Photovoltaics: A Review. *Clean Technologies*. 2022; 4: 752-769.

[2] Lee N, Grunwald U, Rosenlieb E, Mirletz H, Aznar A, Spencer R, et al. Hybrid floating solar-photovoltaic-hydropower systems: benefits and global assessment of technical potential. *Renewable Energy*. 2020; 162: 1415-1427.

[3] Abid M, Abid Z, Sagin J, Murtaza R, Sarbassov D, Shabbir M. Prospects of floating photovoltaic technology and its implementation in central and south Asian countries. *International Journal of Environmental Science and Technology*. 2018; 16(3): 1755-1762.

[4] Liu L, Wang Q, Lin H, Li H, Sun Q, Wennersten R. Power generation efficiency and prospects of floating photovoltaic systems. *Energy Procedia.* 2017; 105: 1136-1142.

[5] Pouran HM, Padilha Campos Lopes M, Nogueira T, Castelo Branco DA. Environmental and technical impacts of floating photovoltaic plants as an emerging clean energy technology. *iScience*. 2022; 25: 105253.

[6] Nisar H, Janjua Kashif A, Hafeez H, Shakir S, Shahzad N. Thermal and electrical performance of solar floating PV system compared to on-ground PV system- an experimental investigation. *Solar Energy*. 2022; 241: 231-247.

[7] Al-Widyan M, Khasawneh M, Abu-Dalo M. Potential of floating photovoltaic technology and their effects on energy output, water quality and supply in Jordan. *Energies*. 2021; 14: 8417. https://doi.org/10.3390/en14248417

[8] Rajesh Kumar JC, Majid MA. Floating solar photovoltaic plants in India-A rapid transition to a green energy market and sustainable future. *Energy and Environment*. 2021; 1-55.

[9] Farrar LW, Bahaj AS, James P, Anwar A, Amdar N. Floating solar PV to reduce water evaporation in water stressed regions and powering water pumping: Case study Jordan. *Energy Conversion and Management*. 2022; 260: 115598.

[10] Exley G, Armstrong A, Page T, Jones ID. Floating photovoltaics could mitigate climate change impacts on water body temperature and stratification. *Solar Energy*. 2021; 219: 24-33.

[11] Mohd Azmi MS, Othman MYH, Ruslan MHH, Sopian K, Abdul Majid ZA. Study on electrical power output of floating photovoltaic and conventional photovoltaic. *AIP Conference Proceedings*. 2013; 1571: 95-101.

[12] Choi Y-K. A study on power generation analysis of floating PV system considering environmental impact. *International Journal of Software Engineering and Applications*. 2014; 8(1): 75-84.

[13] Yousuf H, Quddamah Khokhar M, Aleem Zahid M, Kim J, Kim Y, Cho E-C, et al. A review on floating photovoltaic technology. *Current Photovoltaic Research*. 2020; 8(3): 67-78.

[14] Abdelal Q. Floating PV; an assessment of water quality and evaporation reduction in semi-arid regions. *International Journal of Low Carbon Technologies*. 2021; 16: 732-739.

[15] Friel D, Karimirad M, Whittaker T, Doran J, Howlin E. A review of floating photovoltaic design concepts and installed variations. *In Proceedings in 4th International Conference on Offshore Renewable Energy, CORE2019*, 2019, Glaskow, U.K., 30 August 2019.

[16] Dams of Greece, Greek committee on large dams, Athens, 2013. [Internet] 2013 [updated 2023 January 3]. Available from: https://docslib.org/doc/2651053/the-dams-of-greece

[17] Rosa-Clot M, Tina GM, Nizetic S. Floating photovoltaic plants and wastewater basins: an Australian project. *Energy Procedia*. 2017; 134: 664-674.

[18] Vourdoubas J. Estimation of solar electricity generation from floating photovoltaics installed in water dams in the island of Crete, Greece. European Journal of Environment and Earth Sciences. 2023; 4(1): 27-33.

[19] Elshafei M, Ibrahim A, Helmy A, Abdallah M, Eldeib A, Badawy M, et al. Study of massive floating solar panels over lake Nasser. *Hindawi Journal of Energy*. 2021; 6674091.

[20] Perera HDMR. Designing of 3 MW floating photovoltaic power system and its benefits over other PV technologies. *International Journal of Advances in Scientific Research and Engineering.* 2020; 6(4): 37-48.

[21] Sukarso AP, Kim KN. Cooling effect on the floating solar PV: Performance and economic analysis on the case of West Jave Province in Indonesia. *Energies.* 2020; 13: 2126.

[22] Yashas Y, Aman B, Dhanush S. Feasibility study of floating solar panels over lakes in Bengaluru city. *Proceedings of the Institution of Civil Engineers, Smart Infrastructure and Construction*. Paper 2100002a.

[23] Lopez M, Soto F, Hernandez ZA. Assessment of the potential of floating solar photovoltaic panels in bodies of water in mainland Spain. *Journal of Cleaner Production.* 2022; 340: 130752.

[24] Junianto B, Dewi T, Sitompul CR. Development and feasibility analysis of floating solar panel application in Palembang, South Sumatra. *Journal of Physics: Conference Series.* 2020; 1500: 012016.

[25] Kim S-M, Oh M, Park H-D. Analysis and prioritization of the floating photovoltaic system potential for reservoirs in Korea. *Applied Sciences.* 2019; 9: 395.

[26] Baptista J, Vargas P, Ferreira JR. A techno-economic analysis of floating photovoltaic systems for southern European countries, *in the 19th International Conference on Renewable Energies and Power Quality*, Almeria (Spain), 28th to 30th July 2021.

[27] Gonzalez-Sanchez R, Kougias I, Maner-Girona M, Fahl F, Jager-Waldaw A. Assessment of floating solar photovoltaics potential in existing hydropower reservoirs in Africa. *Renewable Energy*. 2021; 169: 687-699.

[28] Kakoulaki G, Gonzalez Sanchez R, Gracia Amillo A, Szabo S, De Felice M, Farinosi F, et al. Benefits of pairing floating with hydropower reservoirs in Europe. *Renewable and Sustainable Energy Reviews*. 2023.

[29] Vourdoubas J. Possibility of using floating solar photovoltaics in the hybrid energy systems in the islands of El Hierro, Spain and Crete, Greece, *American Academic Scientific Research Journal for Engineering, Technology, and Sciences*, 2022; 9(1): 461-475.

[30] Ravichandran N, Fayak HH, Rusu E. Emerging floating photovoltaic system-case studies high dam and Aswan reservoir in Egypt. *Processes*. 2021; 9: 1005.

[31] Solomin E, Sirotkin E, Cuce E, Priya Selvanathan S, Kumarasamy S. Hybrid floating solar plant designs: A Review. *Energies.* 2021; 14: 2751.

[32] Ramasamy V, Margolis R. Floating photovoltaic system cost benchmark: Q1 2021 installations on artificial water bodies. National Renewable Energy Laboratory, NREL/TP-7A40-80695.