Macrothink Institute™

Environmental Management and Sustainable Development
ISSN 2164-7682
2022, Vol. 11, No. 4

Possibilities of Using Floating Solar Photovoltaic Panels on Water Reservoirs in the Island of Crete, Greece

John Vourdoubas

Consultant Engineer, 107B El. Venizelou str., 73132, Chania, Crete, Greece

E-mail: ivourdoubas@gmail.com

Received: August 22, 2022 Accepted: October 1, 2022 Published: October 8, 2022

doi:10.5296/emsd.v11i4.20200 URL: https://doi.org/10.5296/emsd.v11i4.20200

Abstract

Solar photovoltaic electricity generation is important for the energy transition to net zero carbon economy in the coming decades. The aim of the current research is the investigation of the possibilities of installing floating solar photovoltaic panels on the surface of two water reservoirs in the island of Crete, Greece. Solar photovoltaic electricity is currently generated in Crete while the solar panels are installed either on the fields or on the rooftop of buildings. Few natural water reservoirs exist in the island while many man-made water dams have been constructed to store water and use it for irrigation and drinking purposes. Installation of floating solar panels on the surface of Potamon dam and Aposelemis dam in Crete could generate significant amounts of green electricity. Additionally, it could result in water savings due to lower water evaporation from the dams while more land area will be available for cultivation. Installation of floating solar panels in the two above-mentioned water dams with coverage ratio 10% could generate 46.37 GWh_{el}/year corresponding at 1.52 % of the annual electricity generation in Crete while 528 000 m^3/year of water could be saved. When the coverage ratio in the two dams is at 30% the annual electricity generation could be at 139.12 GWh_{el}/year corresponding at 4.57 % of the annual electricity generation in Crete while 1 584 000 m^3/year of water could be saved. Our results indicate that floating solar panels is a promising alternative technology to ground-mounted solar-PV panels for “solar electricity” generation in Crete.

Keywords: Crete-Greece, Floating solar photovoltaics, Ground-mounted, Solar electricity, Water dams, Water evaporation

1. Introduction

Solar energy resources are abundant in many countries and their exploitation for heat and power generation assists in de-carbonizing our societies and in mitigating climate change. Floating solar panels installed on the surface of natural or man-made water bodies is an emerging, promising and challenging technology (Barbuscia, 2016, Essak et al., 2022, Kougias et al., 2016, Spencer et al., 2019). The possibility of using floating solar photovoltaics on water reservoirs in the island of Crete, Greece has been investigated. Use of solar energy for heat and power generation is necessary for climate change mitigation. Solar energy has been used for heat and electricity generation in Crete and in Greece while its further use is foreseen in the future. The solar irradiance in Crete is high and the use of solar-PV panels very attractive. Hundred small-scale solar-PV systems have been already installed in the fields and on rooftops of buildings. However, use of floating solar panels on lakes or on man-made reservoirs in Crete has not been investigated so far. In many countries the technology of floating photovoltaics is growing rapidly while in others preliminary studies have shown the advantages and the drawbacks of this technology (Abid et al., 2018, Elshafei et al., 2021, Farrar et al., 2022, Junianto et al., 2020, Kim et al., 2019, Lopez et al., 2022, Spencer et al., 2019, Sukarso et al., 2020).

The text is structured as follows:

After the literature review the concept of floating solar photovoltaics is analysed and several applications worldwide are presented. In the next section the large-size water reservoirs in Crete are presented followed by the current renewable energy installations in Crete generating electricity. In the following sections the possibility of using floating solar panels in water dams in Crete is examined followed by discussion of the findings and the conclusions drawn. In the end of the text the references used are cited. Our work has been focused in Potamon and Aposelemis artificial water dams located in the Prefectures of Rethymon and Heraklio in the island of Crete, Greece.

2. Literature Survey

The literature survey is separated in two sections including: a) Floating solar photovoltaics, and, b) Water and renewable energy resources in the island of Crete.

2.1 Floating Solar Photovoltaics

Kougias et al., 2016 have examined the installation of solar-PV panels on the downstream face of water dams. The authors stated that the generated electricity could be used for water pumping and treatment. The authors mentioned that many water dams in Africa could be used for solar electricity generation. Solomin et al., 2021 have studied various hybrid floating solar-PV systems. The authors stated that floating solar panels can be combined with other renewable energy technologies to provide green electricity. They also mentioned that the use of hybrid floating solar panels combined with hydro power plants is important for covering the energy demand in islands. Farrar et al., 2022 have studied the impacts of floating solar-PV panels installed on water dams in semi-arid regions in Jordan. The authors highlighted the benefits due to solar electricity generation and to lower water evaporation. They experimented with a floating solar-PV system at 300 KW_p installed on the surface of a water dam with tilt 15^o. The authors mentioned that water evaporation savings were at 12 700 m^3

while the water evaporation was 42% lower than the evaporation in a conventional water dam. The payback period of the solar energy investment was estimated at 8.4 years. Barbuscia, 2016 has reviewed various studies realized in Spain, Turkey and Australia regarding the installation of floating solar panels on water dams. The author stated that, in small farms, installation of floating solar-PVs on water irrigation reservoirs can generate electricity, reduce the water evaporation and decrease the growth of algae in them. He also mentioned that installation of floating solar panels in water dams of hydro-electric systems could result in generation of both "hydroelectricity" and "solar electricity". Mathijssen et al., 2020 have studied the impacts of floating solar panels installed on water reservoirs on water quality in the Netherlands. The authors stated that floating solar panels could affect the water quality and the natural occurring processes. They mentioned that leaching of heavy metals and chemical compounds is limited while the water treatment can remove all unwanted pollutants. A study on floating solar panels on water dams has been published, Hydropower & Dams, 2021. The study stated that the technology of floating solar panels is attractive in poor and developing countries while their cost is higher compared to ground-mounted solar-PV panels. It is also mentioned that among their drawbacks is their effect on water quality and biodiversity which needs further investigation while it is mentioned that 5% coverage of water dams has negligible impacts. It is also stated that the floating solar panels could be destroyed in extreme weather events. Abdelal, 2021 has assessed the impacts of floating solar panels on water quality and evaporation in areas with water scarcity. The author stated that floating solar panels have higher electricity yield, reduced water evaporation at around 60% while no impacts on water quality were detected. Essak et al., 2022 have reviewed the floating solar photovoltaics. The authors stated that use of solar energy is necessary to achieve net zero carbon emissions in the near future while the use of land for their installation should be avoided due to population increase and the rise of land prices. They also mentioned that floating solar-PV installations will double every year while they have more advantages than drawbacks. Friel et al., 2019 have evaluated different floating solar-PV panel's configurations. The authors mentioned that several configurations for installing floating solar panels are available, including different technologies and tracking systems, while the installation cost of floating solar panels is at 0.8-1.2 $\$/W_p$ higher than the cost of ground-mounted solar panels. A report on the floating solar market has been published by the World Bank Group, 2018. The report stated that floating photovoltaics are suitable in countries with high population density and competing land uses. It is also mentioned that floating platforms on reservoirs can generally be anchored to a bank, to a bottom, to piles or to a combination of the three. Municipality of Cohoes in New York State, USA with 17 000 inhabitants is building a floating solar farm on its 10-acre water reservoir. The investment cost is estimated at $ 6 mil and the annual benefit at $ 500 000, Energypost.eu, 2022. Yashas et al., 2021 have examined the possibility of installing floating solar-PV panels over lakes in Bengaluru city, India. The authors stated that there are 32 lakes in the city with total surface at 3 294 acres. Floating solar panels with coverage ratio at 0.5-0.6 can generate electricity covering 26% of the city's annual electricity demand. Elshafei et al., 2021 have investigated the possibility of installing floating solar-PV panels over the lake Nasser, Egypt. The authors stated that the average daily solar irradiance is at 6.72 KWh/m^2 while the lake's surface is at 5

000 Km^2. They mentioned that coverage 20% of the lake's surface with floating solar panels results in lower water evaporation by around 25-50%. They also stated that due to water cooling effect the electricity generation from the floating solar panels is higher at 10-17%. Lopez et al., 2022 have assessed the potential of floating installations of solar-PV panels on water dams in Spain. The authors stated that covering only 10% of the surface of the existing water reservoirs in Spain the "solar electricity" generation corresponds at around 31% of the country's power demand. Spencer et al., 2021 have assessed the technical potential of floating solar panels in water dams in USA. The authors mentioned that floating solar-PVs on water dams is an emerging technology with many advantages comprising: a) Solar electricity generation, b) Lower algae growth, c) Lower water evaporation, and d) Higher electricity yields due to water cooling effect. Kim et al., 2019 have analysed the potential of floating solar panels on water reservoirs in Korea. The authors stated that installation of floating solar panels on 3 401 water dams in Korea could result in electricity generation at 2 932 GWh. They also mentioned that the payback period of the solar energy investments is at around 3.8-4.7 years. Perera, 2020 has designed a 3 MW_p floating solar-PV system and has compared it with other solar-PV technologies. The author stated that the floating photovoltaic system generates 10-12% more electricity than a similar ground-mounted solar-PV system while according to published literature the hourly water evaporation reduction is at around 0.32 kg/m^2. Junianto et al., 2020 have experimented with two polycrystalline solar-PV systems, at 100 W_p each, in south Sumatra. One of them was placed on the ground while the other was floating on a water tank. The authors stated that the electricity yield was at around 20% higher in the floating solar panel while the temperature at its surface was 2^oC lower compared to the ground-mounted panels. Durkovic et al., 2017 have studied the possibility of installing floating solar-PV panels on the surface of the lake Skadar, Montenegro generating electricity for a nearby located Aluminium plant. The authors stated that a floating solar-PV system at 90 MW_p with an optimum tilt angle at 44^o can be installed on the surface of the lake covering 1.1% of its surface. The solar-PV system could generate 186.05 GWh_{el}/year covering at around 20% of the plant's power demand. Piana et al., 2021 have examined the criteria for selecting the best sites for installing floating solar panels on mountainous lakes. The authors stated that mountainous lakes can combine generation of "hydroelectricity" with "solar electricity". They also mentioned that more than 500 floating solar-PV systems with total power at around 2 GW_p have been installed worldwide up to 2020. The criteria for selecting the best sites comprise: a) Climate and atmospheric conditions, b) Lake accessibility, c) Lake shape, soil and water features, d) Environment, and e) Landscape services. Rosa-Clot et al., 2017 have examined the use of submerged solar-PVs in swimming pools. The authors mentioned that solar panels can co-generate heat and electricity while they can be placed either on the bottom of the pool (submerged panels) or at its edges. In both cases the generated electricity can cover part of pool's power demand while the co-produced heat can slightly increase the water temperature. Mohd Azmi et al., 2013 have compared the efficiency of conventional versus floating solar-PV panels. The authors stated that the floating solar panels had higher efficiency, in the range 3-15%, than the conventional due to cooling effect. Abid et al., 2018 have studied the use of floating solar panels in central and south Asian countries. The authors stated that the technology is attractive in water-scarce countries

helping them to save water through less water evaporation and to produce clean energy. They also mentioned that the owners of water dams have the opportunity to achieve additional incomes. Liu et al., 2017 have compared the efficiency of conventional versus floating solar-PV panels in China. The authors stated that floating solar-PV panels had lower temperatures at around 3.5^{o}C than ground-mounted panels while their efficiency was higher at around 1.6-2.0 %. Sukarso et al., 2020 have studied the cooling effect of floating solar panels and their economic performance in Indonesia. The authors stated that the average annual temperature of water in lakes was at around 8^{o}C lower compared to the average annual temperature of the ground while the efficiency of floating solar-PV panels was at 0.61% higher than the efficiency of the ground-mounted solar-PV panels. Comparing the economic performance of both solar-PV panel configurations they mentioned that in both solar systems the net present value was negative while higher tariffs per KWh_{el} were required to achieve profitability.

2.2 Water and Renewable Energy Resources in the Island of Crete

Investments in floating solar-PVs on existing water reservoirs in Greece are planned. It has been mentioned that three companies are planning to install floating solar panels with total power at 800 MW_p in existing water reservoirs in continental Greece, PV Magazine, 2021. The technical characteristics of the artificial water dam Aposelemis located in Heraklion Prefecture, Crete have been mentioned and presented in table 7 (Dams of Greece, 2013, Tzanakakis et al., 2020). The water capacity is at 25.27 mil. m^3 while the surface area is at 1.6 Km^2. The dam is providing drinking water in the cities of Heraklion and Agios Nikolaos, Crete. The technical characteristics of the artificial water dam Potamon in Amari, Rethymno Prefecture, Crete have been also stated and presented in the same table. The dam provides drinking water in the city of Rethymno and irrigates various tree orchards around it. The water capacity is at 22.5 mil m^3, its surface at 1.7 Km^2 while its maximum depth at 54 m. Kagarakis, 1987 has estimated the average monthly and annual solar irradiance in different tilt angles in various locations in the island of Crete, Greece. Tzanakakis et al., 2020 have investigated the sustainable management of water resources in Crete. The authors stated that Crete is water sufficient with average annual precipitation at 967 mm while the evapotranspiration was estimated at 1 240-1 570 mm/year. They also mentioned that the annual water demand in Crete is at 610.94 mil. m^3 while agriculture is the main water user utilizing 78% of the water resources. HEDNO, 2018 has reported on the energy system in Crete, 2018. It is stated that the annual electricity generation by renewable energies in the island of Crete, at 645.12 GWh_{el}, had a share at 20.41% in the total electricity consumption. The total electricity generation, in 2018, was at 3 043 GWh_{el}, while the total installed power of renewable energy systems was at 297.6 MW. Vourdoubas, 2021 has studied the water-energy nexus in the island of Crete. The author stated that the annual electricity consumption in Crete, in 2018, was at 4 793 KWh_{el}/capita while the annual electricity consumption based on renewable energies was at 1 017 KWh_{el}/capita. Vourdoubas, 2022 has investigated the climate change impacts on the energy potential of renewable energies during 21st century in Crete. The author stated that during this century the solar energy potential in Crete is expected to increase by 4%. Kistara et al., 2009 have evaluated the annual precipitation and the pan evaporation in several locations in Greece. The authors stated than annual precipitation and pan evaporation in Heraklio Prefecture, Crete were at 470.52 mm and 1 631.03 mm, in Tympaki, Heraklio Prefecture, Crete at 452.89 mm and 1 740.19 mm while in Ierapetra, Lasithi Prefecture, Crete at 426.36 mm and 1 764.90 mm.

The objective of the current research is focused on the investigation of the possibility of using floating solar photovoltaics in two existing water dams in the island of Crete, Greece

3. Floating Solar Photovoltaics

Solar photovoltaic panels are often installed either on the fields or on rooftops of buildings. During the last decade a new technology of floating solar panels installed on water surfaces has been emerged and developed rapidly all over the world (Abid et al., 2018, Barbuscia, 2016, Essak et al., 2022, Kim et al., 2019, Kougias et al., 2016, Spencer et al., 2019). The rapid growth of floating solar panels is based on their advantages compared with ground-mounted solar panels. These include: a) higher "green electricity" generation due to water cooling effect and the lower temperature at the surface of the solar panels, b) water savings due to less water evaporation from water reservoirs that is important in areas facing water shortages like countries in central and south Asia and Africa (Farrar et al., 2022, Essak et al., 2022), and c) avoidance of land use that is important in areas where land is valuable for food and animal feed production. Installation of floating solar panels is easy avoiding soil preparation works while shading of the panels is limited. Often water dams are located nearby to electric grids. Therefore, the generated electricity can be easily injected into the grid avoiding its transmission in long distances. Floating solar panels reduce the light transmittance into the water dam resulting in lower algae formation. When floating solar panels are installed on the surface of water dams used for "hydroelectricity generation" the hydropower station is transformed to hybrid power station generating both hydro and solar electricity. Floating solar panels can be installed in any natural or man-made water reservoir in rural or urban areas with several configurations. They can be installed on the banks of water dams while installation of submerged solar panels in the bottom of swimming pools has been reported (Rosa-Clot et al., 2017). The economics of floating solar panels are attractive allowing their rapid growth while payback periods less than ten years have been reported. The installed capacity of floating solar panels worldwide is presented in table 1 indicating that Asian countries are pioneer in this technology while their advantages and drawbacks are presented in table 2.

Table 1. Installed capacity of floating solar-PV panels worldwide

Country	%, of floating solar-PV installations worldwide
China	75.04
Japan	15.98
Korea	6.01
UK	0.99
Others	1.98
Total	100

Source Essak et al., 2022

Table 2. Advantages and drawbacks of floating solar-PV panels

Advantages
They result in higher electricity yields due to cooling effect
The use of land area is avoided
They result in lower water evaporation from water dams
They do not need site preparation
Less algae are created in the water dam
Their installation is easy
The shading in the panels is often low
Their access to electric grids is easy
Floating solar panels installed on the surface of water dams in hydropower plants can increase generation of "green electricity"
Drawbacks
There are undesired effects of humidity on solar panels
Their effect on water quality requires further investigation
Floating solar panels could be destroyed in extreme weather events
Their installation cost is higher compared to ground-mounted solar-PV panels

Source: Essak et al., 2022, World Bank Group, 2018

4. Water Reservoirs in Crete, Greece

Island of Crete has few natural water reservoirs and lakes but many man-made water dams of different sizes using the water for irrigation and domestic purposes. Large-scale water dams in Crete are presented in table 3 while smaller-scale dams in table 4. There are also several small-scale water dams with water capacity less than 1 mil. m^3 using the water for crop's irrigation. Water resources in Crete are adequate but they are unevenly distributed across the island. The western part of Crete is richer in water resources than the eastern part. The average annual precipitation in Crete has been evaluated at 967 mm (Tzanakakis et al., 2020) while the annual evaporation rate at around 1 600 mm (Kistara et al., 2009). Total water demand in Crete has been estimated at 610.94 mil. m^3 while 78% of the water resources are used in agriculture and 21% in the domestic sector (Tzanakakis et al., 2020). Tourism industry is growing rapidly consuming increasing water resources while many efforts have been made to reduce water consumption in irrigation using several water saving methods and techniques in agriculture. Water temperatures in water dams are relatively constant all over the year while they are lower than air temperatures during the summer. Several criteria have been proposed for selecting the best surface water reservoirs for installing floating solar panels (Piana et al., 2021). Most of the man-made water dams in Crete are owned by public authorities including municipalities. They could install floating solar-PV panels on the water surface cooperating with energy companies having expertise in this technology according to public private partnership schemes. This would result in mutual benefits allowing to public authorities to obtain additional incomes.

Table 3. Major water reservoirs in Crete with water capacity more than 10 mil. m^3

Reservoir	**Prefecture**	**Volume (mil. m^3)**
Potamon	Rethymno	22.50
Aposelemis	Heraklio	25.27
Faneromeni	Heraklio	19.67
Mpramianon	Lasithi	16
Plati Potamou	Rethymno	51
System of 3 dams	Chania	45
Dematiou	Heraklio	30
Agiou Ioanni	Lasithi	18.5

Source: Tzanakakis et al., 2020

Table 4. Water reservoirs with water capacity between 1 mil. m^3 and 10 mil. m^3

Reservoir	**Prefecture**	**Volume (mil. m^3)**
Valsamiotis	Chania	6
Ini	Heraklio	1.75
Damanion	Heraklio	1.50
Amourgeles	Heraklio	1.56
Chalavrianou	Heraklio	1.20
Patrinon	Heraklio	1.50
Armanogion	Heraklio	1.50
Gerakari	Rethymno	1.75
Lithinon	Lasithi	9
Agiou Georgiou	Lasithi	2.15

Source: Tzanakakis et al., 2020

5. Use of Renewable Energies for Electricity Generation in Crete

Island of Crete, Greece is rich in renewable energy resources particularly in solar and wind energy (HEDNO, 2018, Vourdoubas, 2021). Several wind farms distributed all over the island generate significant amounts of electricity. Solar energy is currently used for hot water production with solar thermal systems and for power generation with solar photovoltaics. Solar-thermal and solar-photovoltaic technologies are reliable, mature and cost-efficient while the interest for investments in these technologies in Crete is high. Existing solar photovoltaics are placed either on buildings' roofs (18 MW_p) or in the fields (78 MW_p). The solar irradiance in various locations in Crete is presented in table 5. Hydro electricity and biogas contribution to power generation is limited so far. Solid biomass is broadly used today but only for heat production. The renewable energy installations generating power in Crete are presented in table 6. The electric grid of Crete was so far autonomous. For grid stability reasons the permitted size of solar and wind energy installations in Crete was limited by law. However, the interconnection of the electric grids of Crete and continental Greece is under implementation with two undersea electric cables (Vourdoubas, 2022). After finalizing grids' interconnection by 2024 it is foreseen that more on-shore and probably off-shore wind parks as well as solar-PV systems will be installed in Crete taking into account the strong interest of several companies to invest in "solar and wind electricity" generation Crete. It should be mentioned that the government promotes with various incentives the deployment of solar energy for heat and power generation in the island.

Table 5. Solar irradiance in various sites in Crete

Location	**Prefecture**	**Annual solar irradiance (Tilt angle 0^o) (KWh/m^2)**	**Annual solar irradiance (Tilt angle 30^o) (KWh/m^2)**	**Average daily solar irradiance (Tilt angle 30^o) (KWh/m^2)**
Heraklio	Heraklio	1 631	1 744	4.78
Ierapetra	Lasithi	1 728	1 882	5.16
Rethymno	Rethymno	1 587	1 691	4.44
Sitia	Lasithi	1 630	1 743	4.59
Souda	Chania	1 616	1 731	4.56
Tympaki	Heraklio	1 703	1 847	4.89
Chania	Chania	1 630	1 738	4.57

Source: Kagarakis, 1987

Table 6. Electricity generation from several renewable energies in Crete (2018)

Renewable energy technology	**Installed capacity (MW)**	**Generated electricity (MWh_{el})**	**%, of total**
Wind farms	200	510 059	16.76
Solar-PVs on buildings' roofs and in the fields	(18+78) 96	134 808 (1 404.25 MWh_{el}/MW_p)	4.43
Small hydro-electric plants	0.6	256.8	0.01
Biogas burning	1		
Total	297.6	645 124	21.20
Thermal power plants using oil	824.6	2 397 876	78.80
Total generated electricity by fossil fuels and renewable energies in Crete	1 122.2	3 043 000	100

Source: HEDNO, 2018

6. Possibilities of Installing Floating Solar-PV Panels on Water Dams in Crete

Small, medium and large-size water dams in Crete could be used for the installation of floating solar photovoltaics. Evaluation of electricity generation and water savings related with installation of floating solar panels in Potamon dam and in Aposelemis dam has been made. The water surface in Potamon dam in Amari, Rethymno Prefecture is at 1.7 Km^2 while in Aposelemis dam, Heraklion Prefecture at 1.6 Km^2 (table 3). Assuming that only 10% of their water surface would be covered with floating solar panels the area of floating solar panels will be at 0.17 Km^2 in Potamon dam and at 0.16 Km^2 in Aposelemis dam. Assuming that solar photovoltaics with nominal power 1 MW_p require 10 000 m^2 for their installation (Spencer et al., 2019) the nominal power of solar panels installed in Potamon dam is at 17 MW_p while in Aposelemis dam is at 16 MW_p. The total nominal power of the floating solar panels installed in both water dams is at 33 MW_p which is approximately at two thirds of the total power of the terrestrial solar-PVs installed currently in Crete at 96 MW_p (table 6). Assuming that the electricity generation from the floating solar panels will be equal with the current power generation by the existing ground-mounted solar-PV panels in Crete, at 1 404.25 MWh_{el}/MW_p, (table 6) the annual generated electricity from the floating solar panels installed in both water dams will be at 46.34 GWh_{el} that is equal at 1.52 % of the total annual electricity consumption in the island (3 043 GWh_{el}). The same calculations are repeated for 30% coverage of the water dams' surface. The characteristics of the two water dams are presented in table 7 while electricity generation and water savings due to installation of floating solar panels at Potamon dam and Aposelemis dam in table 8.

Table 7. Characteristics of Potamon dam and Aposelemis dam

Parameter	**Potamon dam**	**Aposelemis dam**
Capacity	22.50 mil. m^3	25.27 mil. m^3
Water surface	1.7 Km^2	1.6 Km^2
Hight	55 m	62 m

Source: Dams of Greece, 2013, Tzanakakis et al., 2020

Table 8. Electricity generation and water saving due to floating solar panels at Potamon dam in Crete, Greece (water surface coverage 10% and 30%)

Parameter	**10%, water surface coverage**	**30%, water surface coverage**
Floating solar panels' surface (Km^2)	0.17	0.51
Nominal power of floating solar panels (MW_p)	17	51
Annual generated electricity (GWh) (1)	23.87	71.62
Annual water saving in dams due to floating solar panels (m^3) (2)	272 000	816 000
Land area saving due to installation of floating instead of ground-mounted solar panels (m^2) (5)	204 000	612 000
Percentage of generated electricity to total electricity consumption in Crete (%) (3)	0.78	2.35
Percentage of water saving to total water demand in Crete (%) (4)	0.04	0.12

Source: Own estimations, (1) Annual electricity generation from floating solar panels 1 404.25 KWh/KW_p, (2) Annual water evaporation rate, 1.6 m, (3) Annual electricity consumption in Crete in 2018 = 3 043 GWh, (4) Annual water demand in Crete 610.94 hm^3, (5) Required land area is 20% higher than the surface of the floating solar panels, Water surface of the dam =1.7 Km^2

Table 9. Electricity generation and water saving due to floating solar panels at Aposelemis dam in Crete, Greece (water surface coverage 10% and 30%)

Parameter	**10%, water surface coverage**	**30%, water surface coverage**
Floating solar panels' surface (Km^2)	0.16	0.48
Nominal power of floating solar panels (MW_p)	16	48
Annual generated electricity (GWh) (1)	22.5	67.5
Annual water saving in dams due to floating solar panels (m^3) (2)	256 000	768 000
Land area saving due to installation of floating instead of ground-mounted solar panels (m^2) (5)	192 000	576 000
Percentage of generated electricity to total electricity consumption in Crete (%) (3)	0.74	2.22
Percentage of water saving to total water demand in Crete (%) (4)	0.04	0.12

Source: Own estimations, (1) Annual electricity generation from floating solar panels 1 404.25 KWh/KW_p, (2) Annual water evaporation rate, 1.6 m, (3) Annual electricity consumption in Crete in 2018 = 3 043 GWh, (4) Annual water demand in Crete 610.94 hm^3, (5) Required land area is 20% higher than the surface of the floating solar panels, Water surface of the dam =1.6 Km^2

7. Discussion

The technology of floating solar panels installed on water reservoirs is growing rapidly worldwide. Several systems have already been installed in many countries while in others existing studies have indicated their importance in "green electricity" generation and their contribution to climate change mitigation. The possibility of installing floating solar-PV panels on water dams in Crete has not been investigated so far although similar projects have been designed in continental Greece. Our results indicate that floating solar panels installed on man-made water dams in Crete could generate significant amounts of "green electricity" contributing in the future elimination of energy-related carbon emissions in the island. They also indicate the water savings achieved due to less water evaporation from water reservoirs and the land area saved due to installation of solar panels on the surface of water dams. The results are important to policy makers who are promoting de-carbonization of the island in the coming decades complying with the National and European targets. They are also important to investors who are interesting to identify places for installing solar-PV systems in Crete particularly after the interconnection of the electric grids of Crete and continental Greece. Our results do not indicate the additional cost of installing floating solar-PV panels on water dams compared to ground-mounted and the economic feasibility of the technology for the specific environmental conditions in the island. Future work should be focused on the evaluation of electricity generation and water savings in more water reservoirs in Crete after the installation of floating solar-PV panels. It should also compare the cost of ground-mounted solar-PV panels with the cost of floating solar-PV panels evaluating the cost efficiency and the profitability of the new technology with and without financial support.

8. Conclusions

The possibility of installing floating solar-PV panels on the surface of water reservoirs in the island of Crete, Greece has been investigated. Floating solar-PV panels is an emerging solar energy technology which is expanding rapidly worldwide. Studies in many countries have highlighted their benefits compared to ground-mounted solar panels. The main advantages compared to ground-mounted solar panels comprise their higher efficiency due to cooling effect, the water savings achieved due to reduced water evaporation and the absence of land utilization for electricity generation. Their drawbacks are related with higher installation cost and their unknown effects on water biological life. Floating solar panels have not been used so far in Crete or in other Greek territories for power generation. Island of Crete has few natural water reservoirs but several man-made dams. The majority of water resources in Crete is used for irrigation of various crops while the existing water dams can host floating solar-PV panels placed on their surface. Solar-PV panels are currently used for electricity generation in Crete. They are mainly ground-mounted solar panels installed on the fields and on rooftops of several buildings. Installation of floating solar panels on the surface of Potamon dam and Aposelemis dam covering 10% of their total surface area can generate annually 46.37 GWh which correspond at 1.52 % of the total electricity consumption in Crete in 2018. These floating solar panels will result in annual water evaporation savings at 528

000 m^3 corresponding at 0.08 % of the annual water consumption in the island. Installation of floating solar panels on the surface of these two water dams, with 30% coverage, can generate annually 139.12 GWh which correspond at 4.57 % of the total electricity generation in Crete in 2018. The floating solar panels will result in annual water evaporation savings at 1 584 000 m^3 corresponding at 0.24 % of the annual water consumption in the island. Our results indicate that the potential of installing floating solar-PV panels on several water reservoirs in Crete is high and promising while they can generate large amounts of "solar electricity" contributing to climate change mitigation. Their installation on the surface of water dams will result in water evaporation savings and in less land area utilization for energy generation in Crete.

References

Abdelal, Q. (2021). Floating PV; an assessment of water quality and evaporation reduction in semi-arid regions, *International Journal of Low Carbon Technologies, 16*, 732-739. https://doi.org/10.1093/ijlct/ctab001

Abid, M., Abid, Z., Sagin, J., Murtaza, R., Sarbassov, D., & Shabbir, M. (2018). Prospects of floating photovoltaic technology and its implementation in central and south Asian countries, *International Journal of Environmental Science and Technology, 16*(3), 1755-1762. https://doi.org/10.1007/s13762-018-2080-5

Barbuscia, M. (2016). Preliminary study on floating Photovoltaics systems on dams. DOI: 10.13140/RG.2.2.36168.11523

Dams of Greece, Greek committee on large dams, Athens, 2013. [Online] Available: https://docslib.org/doc/2651053/the-dams-of-greece

Durkovic, V., & Durisic, Z. (2017). Analysis of the potential for use of floating PV power plant on the Skadar lake for electricity supply of Aluminium plant in Montenegro, *Energies, 10*, 1505. https://doi.org/10.3390/en10101505

Elshafei, M., Ibrahim, A., Helmy, A., Abdallah, M., Eldeib, A., Badawy, M., & Abdelrazek, S. (2021). Study of massive floating solar panels over lake Nasser, *Hindawi Journal of Energy, 2021*, 6674091. https://doi.org/10.1155/2021/6674091

Essak, L., & Ghosh, A. (2022). Floating Photovoltaics: A Review. *Clean Technologies, 4*, 752-769. https://doi.org/10.3390/cleantechnol4030046.

Farrar, L. W., Bahaj, A. S., James, P., Anwar, A., & Amdar, N. (2022). Floating solar PV to reduce water evaporation in water stressed regions and powering water pumping: Case study Jordan, *Energy Conversion and Management, 260,* 115598. https://doi.org/10.1016/j.enconman.2022.115598

Floating solar PV on dam reservoirs: The opportunities and the challenges. (2021). *Hydropower & Dams, 4*, 82-101. [Online] Available: file:///C:/Users/%CE%B3%CE%B9%CE%B1%CE%BD%CE%BD%CE%B7%CF%82%20%CE%B2%CE%BF%CF%85%CF%81%CE%B4%CE%BF%CF%85%CE%BC%CF%80%

CE%B1%CF%82/Desktop/[2-8-22]%20-%20FLOATING%20SOLAR-PV%20%20IN%20CRETE/16%20-%202021%20-%20FPV_report.pdf

Floato-voltaics: floating solar farms on existing municipal water reservoirs. (2022). Energypost.eu. [Online] Available: https://energypost.eu/floato-voltaics-floating-solar-farms-on-existing-municipal-water-reservoirs/

Friel, D., Karimirad, M., Whittaker, T., Doran, J., & Howlin, E. (2019). *A review of floating photovoltaic design concepts and installed variations.* Proceedings in 4th International Conference on Offshore Renewable Energy, CORE2019, Glaskow, U.K., Publisher ASRANet Ltd.

Hellenic Electricity Distributor Network Operator (HEDNO) (2018). *The electricity system in Crete*. (In Greek).

Junianto, B., Dewi, T., & Sitompul, C.R. (2020). Development and feasibility analysis of floating solar panel application in Palembang, South Sumatra. *Journal of Physics: Conference Series*, *1500*, 012016. https://doi.org/10.1088/1742-6596/1500/1/012016

Kagarakis, K. (1987). *Photovoltaic Technology*. Athens, Greece, Symmetria Publications. (In Greek).

Kim, S-M., Oh, M., & Park, H-D. (2019). Analysis and prioritization of the floating photovoltaic system potential for reservoirs in Korea, *Applied Sciences, 9*, 395. https://doi.org/10.3390/app9030395

Kistara, G., Floros, G., Papaioannou, G., & Kerkides, P. (2009). *Spatial and temporal analysis of pan evaporation in Greece.* 7th International Conference of European Water Resources Association (EWRA), Resources conservation and Risk Reduction under Climatic Instability, Limassol, Cyprus.

Kougias, I., Bodis, K., Jager-Waldaw, A., Monforti-Ferrario, F., & Szabo, S. (2016). Exploiting existing dams for solar PV system installations. *Progress in Photovoltaics, 24*, 229-239. https://doi.org/10.1002/pip.2640

Liu, L., Wang, Q., Lin, H., Li, H., Sun, Q., & Wennersten, R. (2017). Power generation efficiency and prospects of floating photovoltaic systems, *Energy Procedia*, *105*, 1136-1142. https://doi.org/10.1016/j.egypro.2017.03.483

Lopez, M., Soto, F., & Hernandez, Z. A. (2022). Assessment of the potential of floating solar photovoltaic panels in bodies of water in mainland Spain, *Journal of Cleaner Production, 340*, 130752. https://doi.org/10.1016/j.jclepro.2022.130752

Mathijssen, D., Hofs, B., Spierenburg-Sack, E., van-Asperen, R., van der Wal, B., Vreeburg, J., & Ketelaars, H. (2020). Potential impact of floating solar panels on water quality in reservoirs; pathogens and leaching, *Water Practice and Technology, 15*(3), 807-811. https://doi.org/10.2166/wpt.2020.062

Mohd Azmi, M. S., Othman, M. Y. H., Ruslan, M. H. H., Sopian, K., & Abdul Majid, Z. A. (2013). Study on electrical power output of floating photovoltaic and conventional photovoltaic, *AIP Conference Proceedings, 1571*, 95-101. https://doi.org/10.1063/1.4858636

More than 800 MW of floating PV under development in Greece. (2021). *PV Magazine.* [Online] Available: https://www.pv-magazine.com/2021/01/22/more-than-800-mw-of-floating-pv-under-development-in-greece/

Perera, H. D. M. R. (2020). Designing of 3 MW floating photovoltaic power system and its benefits over other PV technologies, *International Journal of Advances in Scientific Research and Engineering*, *6*(4), 37-48. http://doi.org/10.31695/IJASRE.2020.33782

Piana, V., Kahl, A., Saviozzi, C., & Schumann, R. (2021). Floating PV in mountain artificial lakes: a checklist for site assessment, *Renewable Energy and Environmental Sustainability, 6*, 4. https://doi.org/10.1051/rees/2021002

Rosa-Clot, M., Rosa-Clot, P., & Tina, G. M. (2017). Submerged PV solar panel for swimming pools: SP3, *Energy Procedia*, *134*, 567-576. https://doi.org/10.1016/j.egypro.2017.09.565

Solomin, E., Sirotkin, E., Cuce, E., Priya Selvanathan, S., & Kumarasamy, S. (2021). Hybrid floating solar plant designs: A Review. *Energies, 14*, 2751. https://doi.org/10.3390/en14102751

Spencer, R. S., Macknick, J., Aznar, A., Warren, A., & Reese, M. O. (2019). Floating photovoltaic systems: accessing the technical potential of photovoltaic systems on man-made water bodies in the continental USA, *Environmental Science and Technology, 53*(3), 1680-1689. https://doi.org/10.1021/acs.est.8b04735

Sukarso, A. P., & Kim, K. N. (2020). Cooling effect on the floating solar PV: Performance and economic analysis on the case of West Jave Province in Indonesia, *Energies*, *13*, 2126. https://doi.org/10.3390/en13092126

Tzanakakis, V. A., Angelakis, A. N., Paranychianakis, N. V., Dialynas, Y. G., & Tchobanoglous, G. (2020). Challenges and opportunities for sustainable management of water resources in the island of Crete, Greece, *Water, 12*, 1538. https://doi.org/10.3390/w12061538

Vourdoubas, J. (2021). The water-energy nexus in the island of Crete, Greece, *Environmental Management and Sustainable Development*, *10*(2), 44-57. https://doi.org/10.5296/emsd.v10i2.18504

Vourdoubas, J. (2022). Climate change impacts on energy generation from renewable energies in the island of Crete, Greece, *Environmental Management and Sustainable Development, 11*(3), 1-12. https://doi.org/10.5296/emsd.v11i3.19830

World Bank Group. (2018). Where sun meets water, Floating solar market report. [Online] Available: https://documents1.worldbank.org/curated/en/579941540407455831/pdf/Floating-Solar-Mark et-Report-Executive-Summary.pdf

Yashas, Y., Aman, B., & Dhanush, S. (2021). *Feasibility study of floating solar panels over lakes in Bengaluru city.* Proceedings of the Institution of Civil Engineers, Smart Infrastructure and Construction. Paper 2100002a. https://doi.org/10.1680/jsmic.21.00002a

Copyright Disclaimer