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Possibility of Using Floating Solar Photovoltaics in the Hybrid Energy Systems in the Islands of El Hierro, Spain and Crete, Greece

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Abstract

Use of floating solar photovoltaics in man-made water dams is an emerging sustainable energy technology worldwide. Floating solar photovoltaics reduce the land area required for their installation, reduce water evaporation from water bodies while they have higher electricity yields. Aim of the current work is the investigation of the possibility of using floating solar photovoltaics in the hybrid energy systems in the islands of El Hierro, Canary islands, Spain and in Crete, Greece. The characteristics of the existed pumped-hydro-storage system in El Hierro and the planned pumped-hydro-storage system in Crete are used for the necessary estimations. Our results indicate 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. The annual electricity generation from the installation of floating solar photovoltaics in the planned pumped-hydro storage system in Crete, with 30 % coverage ratio, correspond 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. It is concluded that installation of floating solar photovoltaics in water dams in the abovementioned hybrid energy plants in these two islands could generate significant amounts of solar electricity complementing the generated wind and hydro power. Use of floating solar photovoltaics in these two islands transform the co-generation energy plants to tri-generation plants producing hydro, wind and solar electricity.

Keywords: Crete; El Hierro; electricity; floating solar-PV panels; hybrid energy systems; pumped-hydro-storage; water dam.

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1. Introduction

Solar energy is increasingly used nowadays for heat and electricity generation worldwide. The necessity to mitigate climate change and the advances in solar photovoltaic technology have boosted the use of solar-PV systems for green electricity generation particularly in areas with high solar irradiance. Recently the installation of solar-PV panels on the surface of man-made water reservoirs, instead of the land, has been grown rapidly due to many benefits of these systems [1,2,3,4]. This technology is considered mature and reliable while its potential for future development is high. Installation of floating solar photovoltaics (FPVs) on the dams of pumped-hydro-storage (PHS) systems offers the possibility of co-generating green electricity at the same location with solar energy and hydro turbines [5]. Our research is related with the installation of solar-PV panels in two hybrid energy systems in the islands of El Hierro, Spain and Crete, Greece. In the first island an existing hybrid energy system consisted of a wind park and a PHS system is providing more than 50% of the annual electricity requirements in El Hierro [6,7]. In the second island a similar hybrid energy system is planned and it is going to be constructed soon covering a smaller percentage - compared to El Hierro - of the annual electricity demand in Crete [8,9]. Our research is important since it indicates that installation of FPVs on the surface of water dams in these two hybrid energy systems could generate additional amounts of green electricity complementing the hydroelectricity that is generated in them. In both islands the solar irradiance is high while water conservation is important taking into account the future impacts of climate change on water availability.

2. Literature survey

The literature review is separated in three sections including: a) The hybrid energy system in El Hierro island, Spain, b) Hybrid energy systems in various islands, and c) Floating solar photovoltaics on water reservoirs.

2.1 Hybrid energy systems in El Hierro island, Spain

The hybrid energy system in El Hierro island has been analyzed [7]. The author stated that the hybrid energy system which was planned to cover all the annual electricity requirements in the island did not cover all the power demand. She also proposed that the existing hybrid energy system should be complemented with a solar-PV system. El Hierro island was awarded the best practice prize for its hybrid energy system based on renewable energies [10]. The sustainable energy system can cover a large part of the annual local electricity requirements while during some periods in the year it can cover 100% of the electricity demand**.** El Hierro island has received the second prize for responsible islands in 2020 [11]. The hybrid energy system in El Hierro is consisted of a wind farm and a PHS system which can cover on average around 60% of the annual electricity demand while during 25 consecutive days it has achieved 100% renewable electricity supply. The hybrid energy system in El Hierro island, Spain has been described [6].

The authors stated that the island has developed the first islandic sustainable energy system worldwide combining wind electricity generation with electricity storage using a PHS system. They also mentioned that the coverage of all the annual electricity demand in the island remains utopia while this has been achieved so far only for some consecutive days in a year.

2.2 Hybrid energy systems in various islands

The increasing use of renewable energies in energy generation in Tenerife and Gran Canaria islands, Spain has been assessed [12]. The authors stated that the use of renewable energies in these islands can be increased from the low current level at 15-19% to around 60% in the future in a cost-efficient way. The economic feasibility of large-scale development of wind-PV systems combined with PHS has been studied [13]. The authors mentioned that hybrid wind-PV power systems combined with PHS are necessary in Greece. They also stated that the high solar and wind energy resources in the country combined with the complex morphology favor the development of these sustainable energy systems. Tilos island, an energy autonomous Greek island using sustainable energy systems has been presented [14]. The authors stated that Tilos is a small island with 533 permanent residents which has achieved its energy autonomy using sustainable energy systems. They also mentioned that the local energy system is consisted of hybrid electricity generation including a wind turbine and a solar-PV unit while electricity is stored in an electric battery. The use of renewable energy systems and energy storage in Astypalaia island, Greece has been studied [15]. The authors proposed the use of wind turbines for power generation and electric batteries for electricity storage. They also mentioned that the proposed sustainable energy system can cover more than 70% of the annual electricity demand in the island. TERNA energy is planning to install a hybrid power plant in Crete consisted of wind parks and a PHS system generating 227 GWh/year [16]. The installed capacity of the two wind parks is at 89.1 MW, the capacity of the hydroelectric turbines at 93 MW while of the pump complex at 140 MW. The hybrid energy project in Crete is currently the largest hybrid power project in Europe. The size of a PHS system located in Amari, Crete storing the excess electricity generated by two wind parks in the island has been optimized [8]. The authors stated that the PHS system in Amari, Crete could generate around 70,000 MWh annually covering around 2% of the total electricity consumption in Crete in 2025 which is estimated at around 3,200 GWh. The possibility of developing renewable energy systems in six islands worldwide has been investigated [17]. The authors stated that the use of indigenous renewable energy resources in these islands increases the production of carbon-free energy reducing their dependence on fossil fuels. They also mentioned that the increased use of RES in these islands is cost-efficient. The use of a wind-hydro-pumped storage station in the Greek island Ikaria has been examined [18]. The authors stated that the hybrid energy system will increase the penetration of RES in the island which may exceed 50% annually. The power system in Crete has been studied [9]. The author stated that the share of RES in the energy mix was at 21% in 2018. She also mentioned that the annual capacity factor of wind farms in the island reaches on average 30% while of solar-PV systems at 20%. The possibility of energy independence in Crete has been investigated [20]. The authors stated that high penetration of RES in Crete can be only achieved with properly sited electricity storage plants combined with power generation with RES preferably with wind energy. They have identified 14 candidate sites for PHS systems in the island combined with 14 favorable sites with high annual wind speed for installing wind parks. The possibility of installing FPV systems on water reservoirs in Crete has been studied [9]. The author investigated the installation of solar-PVs on two artificial water dams in Crete, in Potamon and Aposelemis dams. He stated that FPV systems installed on the dams with 30% surface coverage ration can generate 758.31 GWh_{el} annually corresponding at 24.9% of the annual electricity consumption in the island. The creation of a hybrid energy system based on renewable energies in Karpathos island, Greece has been examined [21]. The system was consisted of a wind farm and a PHS system.

The author estimated the size of the wind turbines, the pumping station, the hydroelectric turbines and the volume of the two water reservoirs. He proposed the installation of floating solar-PVs on the surface of the two water reservoirs of the PHS system with total nominal power at 2.15 MW_p which could generate around 8.6% of the annual electricity demand in this island. The interconnection of the electricity grids of Crete and continental Greece has been analyzed [22]. The authors stated that the grid of Crete will be connected soon with the grid of continental Greece with two undersea cables. The first will have a capacity at 2X140 MW, 150 KV, AC while the second at 2X350 MW, DC. The complementarity of electric vehicles and PHS systems in storing electricity in small isolated energy systems with reference La Palma, Canary islands, Spain has been investigated [23]. The authors stated that installation of additional energy systems based on RES at 25 MW supported by a PHS system at 20 MW and a fleet of 3,361 electric vehicles would allow the current share of renewables to increase from 11% to 49%. The use of PHS systems and electric batteries for energy storage in Terceira island, Azores has been examined [24]. The authors stated that a PHS system is the best option compared to energy storage in electric batteries while it is preferable to replace fuel-oil with wind energy for electricity generation.

2.3 Floating solar photovoltaics on water reservoirs

The massive use of FPVs over the lake Nasser in Egypt has been evaluated [25]. The authors stated that the surface of the lake is almost 5,000 Km^2 while due to the local warm climate the water evaporation is high. They also mentioned that the installation of FPVs on the surface of the lake can generate annually about 16% of the EU electricity demand saving also large quantities of fresh water. Use of solar-PV systems in countries with water shortage like Jordan has been studied [26]. The authors stated that installation of FPV systems on irrigation reservoirs will conserve water by reducing evaporation losses while the generated electricity can be used for water pumping. They also mentioned that these systems are cost-efficient achieving payback periods at around 8.4 years. The potential of installing FPVs in water bodies in Spain has been assessed [1]. The authors stated that Spain could cover about 31% of its electricity demand by covering only 10% of the available surface of its water reservoirs. They also mentioned that the potential of this technology is higher in southern regions while the variations in the level of water reservoirs and the restrictions in water depth should be taken into account for assessing these systems. The potential of installing FPV systems in water reservoirs in South Korea has been examined [2]. The authors evaluated the potential of 3,401 water reservoirs in this country to install floating solar panels. They estimated the annual electricity generation at 2,932 GWh. The opportunities and challenges of installing FPVs have been investigated [27]. It has been mentioned that FPV installations on water reservoirs have a promising and challenging future. It has been also stated that FPVs should be constructed and installed on the surface of water dams to avoid accidents and damages in extreme weather events. A report related with FPVs has been published by the World bank, the solar energy research institute of Singapore and the National University of Singapore [28]. The report stated that FPV installations reached 1.3 GW_p by the end of 2018 worldwide while the global potential is estimated at around 400 GW_p. It is also mentioned that although FPV technology is considered commercially viable given the number of large-scale projects that have been implemented several challenges related with their deployment still remain. The environmental impacts of FPVs have been assessed [29]. The authors stated that: a) FPVs have reduced environmental impacts during the allocation of the project, b) Advantages are observed during the operation of FPV plants, c) The impacts of FPVs in artificial lakes might differ from natural lakes due to microclimate, and d) More mitigation measures might be required during installation of FPV projects. The concept of photovoltaic geographic potential on land and water has been developed [30]. The authors stated that by using 1% of natural basin areas to install solar-PV systems about 25% of the world's electrical energy demand in 2014 could be supplied. The potential, challenges and feasibility of marine floating solar-PV plants have been overviewed [31]. The authors stated that the majority of the existing floating solar-PV systems have been installed on inland freshwater bodies while there is momentum to start installing such systems in marine environments. The authors stated that these systems installed on the surface of sea water could meet part of the energy demand of megacities which are located nearby coasts. However, they mentioned, marine solar applications are at a low technical maturity level while their development is a complex task. They also mentioned that hybrid off-shore wind farms and marine FPV systems could be developed in the future**.** The impacts of large-scale FPVs on water quality in two different locations in situ have been investigated [32]. The authors have monitored various water quality parameters in the largest installation of FPV in Europe located at the Bomhofsplas lake, Netherlands. They stated that there are not major differences in the key water quality parameters below the solar panels such as temperature or dissolved oxygen. The floating solar photovoltaic potential in existing hydropower dams in Africa has been evaluated [3]. The authors stated that installation of FPVs in existing hydropower dams in Africa will increase electricity generation and will reduce water evaporation. They have used accurate data concerning the water surface of the largest 146 hydropower reservoirs in Africa. They mentioned that by covering 1% of their surface with FPV systems the existing electricity generation will be increased by 58% while the annual water savings will be at 743 mil M^3. The benefits of pairing floating solar photovoltaics with hydropower reservoirs in Europe have been analyzed [4]. The authors have identified 337 hydropower reservoirs in EU27 assessing the energy generation by FPVs installed on them. They mentioned that installation of FPVs of equal installed capacity as the hydropower plants has the potential to generate 42.31 TWh covering 2.3 % of the total surface of reservoirs. In this case the water evaporation will be reduced by 557 mil. M^3 annually. The cooling effect of FPVs in two climate zones in the Netherlands and in Singapore has been studied [33]. The authors stated that that the FPV system in Netherlands had lower temperature at 3.2^{o}C compared with a land-based reference system while in Singapore the temperature was lower at 14.5^{o}C compared with a rooftop solar-PV system. They also mentioned that the energy gains due to cooling effect in the FPV system located in Netherlands is up to 3% compared to the reference system while in Singapore it was up to 6%. The use of FPVs over lakes in Bengaluru city, India has been investigated [34]. The authors stated that FPVs can be installed in 32 lakes in the city with total area 3,294 acres. They also mentioned that the panels with 0.5-0.6 coverage ratio can generate approximately 26% of the city's annual electricity requirements. The use of a stand-alone hybrid renewable energy/hydrogen system in Karpathos island, Greece has been studied [35]. The authors stated that the high solar and wind energy resources in Karpathos island, Greece could be used for covering all its energy requirements combined with energy storage through a H_2 production system. The exploitation of existing water dams for installation of solar-PV panels on their downstream face has been examined [5]. The authors stated that installation of FPVs in water dams complements electricity generation from hydro turbines with solar electricity. They also mentioned that many water reservoirs in Africa are underutilized and installation of FPVs in them will amplify their potential for electricity generation. The cost of FPVs compared to the cost of ground-mounted PVs has been evaluated [36]. The authors stated that the estimated installation cost of FPVs is 25% higher than the installation cost of ground-mounted PVs. They also mentioned that the levelized cost of electricity (LCOE) of FPVs is 20% higher compared to LCOE of ground-mounted PVs. The floating FPV systems have been reviewed and assessed [37]. The authors stated that the installation cost of FPVs is at around 15% higher than the cost of ground-mounted solar panels, the annual electricity yield is higher at around 3-6% while the water evaporation can be reduced up to 70%.

Aim of the current work is to investigate the possibility of installing floating solar photovoltaics in the existing hybrid energy system in the island El Hierro, Canary islands, Spain and in the planned hybrid energy system in the island of Crete, Greece as well as to evaluate the electricity that could be generated by the floating solar-PV panels.

The text is structured as follows: After the literature survey the characteristics of the hybrid energy systems in El Hierro and Crete are presented followed by a description of the technology related with installation of FPVs in water dams. In the following two sections estimations of electricity generation with FPVs in these two hybrid energy systems are made and they are compared with the annual electricity consumption in the two islands. After that the discussion of findings and the conclusions drawn are presented while the text ends with citation of the references used.

3. The hybrid energy system in El Hierro island, Spain

El Hierro island is located in Atlantic Ocean in the archipelago of Canary islands, Spain. Canary islands have autonomous electric grids while they are depended on fossil fuels for covering their energy requirements. However, they are rich in renewable energy resources particularly in solar and wind energy. El Hierro has 11,734 permanent residents (2011) while its total energy demand in 2015 was at 56 GWh. An innovative energy project was designed and implemented in 2014 in this island aiming to reduce its dependency on fossil fuels as well as its carbon emissions [6].

The project included a wind farm generating electricity combined with a PHS system. The island won in 2020 the second EU prize for energy responsible islands [11].

The hybrid energy system covered almost 60% of its annual energy demand while for 25 consecutive days it covered all its electricity requirements. Several characteristics of El Hierro island are presented in table 1.

Table 1: Characteristics of El Hierro, Canary islands.

Characteristic	Value
Covered land area	268.5 Km^2
Inhabitants (2011)	11,734
Annual electricity consumption (2015)	56 GWh
Electricity intensity (2015)	4.77 MWh/capita

Source: [9]

The characteristics of the hybrid energy system in El Hierro island are presented in table 2.

Table 2: The characteristics of the existing hybrid energy system in El Hierro island.

Characteristic	Value
Power of the wind farm	11.5 MW
Power of the hydro turbines	11.32 MW
Power of the water pumping system	6 MW
Volume of the upper reservoir	380,000 M^3
Maximum height of the upper reservoir	12 m
Surface area of upper reservoir	42,180 M^2
Volume of the lower reservoir	150,000 M^3
Maximum height of the lower reservoir	15 m
Surface area of lower reservoir	15,000 M^2
Solar radiation in El Hierro [7]	1,200-1,450 W/m^2

Source: [6]

The energy generation from various energy sources and fuels in El Hierro island after the operation of the hybrid energy system is presented in table 3.

Table 3: Energy generation from various energy sources and fuels in El Hierro island after the operation of the hybrid energy system.

Source of energy generation	Electricity generation (GWh)	% of total energy
Wind	35.9	64.11
Hydro	6.4	11.43
Total hybrid system	42.3	75.54
Oil	13.7	24.46
Total	56	100

Source: [6]

4. The hybrid energy system planned in the island of Crete, Greece

Island of Crete is rich in intermittent renewable energy resources like solar and wind energy which are already used for power generation. Their further deployment and their higher penetration into the grid require electricity storage. Due to the geomorphology of the island electricity storage in PHS systems is favored. A large hybrid energy system is planned to be constructed in the island of Crete, Greece [16].

The hybrid system is consisted of wind parks located in the eastern part of Crete, in prefecture of Lassithi, and a PHS system located in prefecture of Rethymno.

The planned hybrid energy system in Crete is the largest in EU islands so far. According to TERNA ENERGY the hybrid energy plant is going to generate 227 MWh/year which corresponds at 7.45% of the annual electricity consumption in 2018 in Crete [16].

The total power of the existing wind farms in Crete, in 2018, was at 200.3 MW [38]. Several characteristics of Crete island are presented in table 4.

Table 4: Several characteristics of the island of Crete.

Characteristic	Value
Covered land area	8,336 Km
Inhabitants (2021)	617,360
Annual electricity consumption (2018)	3,043 GWh
Electricity intensity	4.93 MWh/capita

Source: [38]

The characteristics of the planned hybrid energy system in Crete are presented in table 5.

Table 5: Characteristics of the planned hybrid energy system in Crete, Greece.

Characteristic	Value
Power of the wind farms	89.1 MW
Power of the hydro turbines	93 MW
Power of the pump complex	140 MW
Annual electricity generation by the hybrid energy system	227 GWh
Volume of the first reservoir	22.5 mil. M^3
Maximum height of the first reservoir	55 m
Surface area of first reservoir	1.7 Km^2
Volume of the second reservoir	1.2 mil. M^3
Surface area of second reservoir	0.12 Km^2
Annual solar irradiance in Rethymno Prefecture, Crete	1,691 KWh/m^2 (tilt 30^o), 1,587 KWh/m^2 (tilt 0^o)

Source: [16], [39], [40]

It has been estimated that the planned PHS system is going to generate 70,000 MWh/year corresponding at 2.3% of the electricity consumption in Crete in 2018, [8].

5. Installations of floating solar photovoltaics in water reservoirs

Large-scale solar-PV deployment requires the use of large land areas which might not be available. In densely populated countries land is preferably used for food production while its use for electricity generation might be rather expensive. FPVs is a novel application where solar panels are installed on the surface of water bodies instead of the soil. Solar-PV electricity generation is sensitive to high temperatures of solar panels which reduce the electricity yields. Waterbodies which are not used for recreation or tourism are ideal for FPV installation. During the last decade FPVs have been installed in many countries mainly on non-salty water bodies. The main benefits of FPVs are: a) The floating solar panels reduce the water evaporation from the dam up to 70%, b) The floating solar panels have lower temperature and higher annual electricity yield, and c) Land area is not used for energy generation. However, anchoring of the solar panels on the bottom or the sides of water dams is required while the possibility of solar panel destruction in extreme weather events cannot be excluded. It has been reported that the installation cost of FPVs is higher at around 15-25% compared with the installation cost of ground-mounted PVs while the energy gain due to cooling effect has been estimated at around 3-6% It has been indicated that the benefits of FPVs exceed their higher installation cost [37,36]. Installation of FPVs on existing hydro-electricity dams has many advantages including: a) Increases the reliability and the productivity of the existing energy system, b) Water resources and solar energy can complement each other in power generation, c) The grid connectivity infrastructure, like transmission lines, transformers et cetera already exists, d) The water evaporation is reduced, and e) The water surface can be used for FPV installation avoiding the use of valuable land.

6. Installation of FPVs in the existing hybrid energy system in El Hierro island, Spain

FPVs can be installed on the surface of two water reservoirs in the PHS system in El Hierro.

They will provide solar electricity from an intermittent energy source complementing the hydro electricity generated by the water turbines. Assuming that the mean height of the upper water dam is at 9 m and of the lower at 10 m the surface of the upper dam is at 42,180 m^2 while of the lower dam at 15,000 m^2.

The generated electricity from FPVs in the two water reservoirs in El Hierro's PHS system for various surface cover ratio are presented in table 6.

Table 6: Electricity generation by FPVs that could be installed in two water dams in El Hierro's PHS system

	Surface coverage ratio 10%	Surface coverage ratio 20%	Surface coverage ratio 30%
Covered surface of FPVs in upper dam (m^2)	4,218	8,436	12,654
Power of FPVs in upper dam (KW_p) [1]	422	844	1,266
Annual electricity generation in upper dam (MWh) [2]	633	1,266	1,899
Covered surface of FPVs in lower dam (m^2)	1,500	3,000	4,500
Power of FPVs in lower dam (KW_p)	150	300	450
Annual electricity generation in lower dam (MWh)	225	450	675
Power of FPVs in both dams (KW_p)	572	1,144	1,716
Total power capacity of FPVs and of hydro-turbines (MW)	11.89	12.46	13.04
Total annual electricity generation from the FPVs (MWh)	858	1,716	2,574
Increase of annual electricity generation in the PHS system (%)	13.40	26.81	40.21
Increase of annual electricity generation in the hybrid energy system (%)	2.02	4.04	6.06
Annual electricity generation by FPVs to annual electricity consumption in El Hierro in 2015 (%)	1.53	3.06	4.59

[1] Surface required by FPVs at 1 KW_p = 10 m^2, [2] Annual electricity generation from FPV in El Hierro at 1 KW_p = 1,500 KWh

The annual electricity generation from FPVs that could be installed in two water reservoirs with 30% coverage ratio corresponds at 40.21 % of the annual electricity generated by the hydro turbines, at 7.16 % of the annual electricity generation by the wind turbines and at 6.06 % of the total annual electricity generation by the hybrid energy system. It also corresponds at 4.59 % of the total annual electricity consumption in El Hierro island.

7. Installation of FPVs in the planned hybrid energy system in the island of Crete, Greece

Floating solar photovoltaic panels can be installed on the surface of the two water dams in the planned PHS system in Crete. The solar panels can generate intermittent solar electricity complementing the hydro electricity generation by hydro turbines. In this case the planned hybrid co-generation system in Crete will operate like a tri-generation system increasing the green electricity generation.

The generated electricity from the installed FPVs in the two water reservoirs in the planned PHS system in Crete for various surface cover ratios are presented in table 7.

Table 7: Electricity generation by FPVs installed in two water dams in the planned PHS system in the island of Crete (Amari, Prefecture of Rethymno).

	Surface coverage ratio 10%	Surface coverage ratio 20%	Surface coverage ratio 30%
Covered surface of FPVs in the first dam (m^2)	170,000	340,000	510,000
Power of FPVs in first dam (MW_p) [1]	17	34	51
Annual electricity generation in the first dam (GWh) [2]	23.87	47.74	71.62
Covered surface of FPVs in second dam (m^2)	12,000	24,000	36,000
Power of FPVs in the second dam (MW_p)	1.2	2.4	3.6
Annual electricity generation in the second dam (GWh)	1.69	3.37	5.06
Power of FPVs in both dams (MW_p)	18.2	36.4	54.6
Total power capacity of FPVs and of hydro-turbines (MW)	111.2	129.4	147.6
Total annual electricity generation from the FPVs (GWh)	25.56	51.11	76.68
Increase of annual electricity generation due to FPVs in the hybrid energy system (%)	11.26	22.52	33.78
Annual electricity generation by FPVs to annual electricity consumption in Crete in 2018 (%)	0.83	1.68	2.52

Surface required by FPVs at 1 KW_p = 10 m^2, Annual electricity generation from FPV in Crete at 1 KW_p = 1,404.25 KWh [38], Annual electricity generation by the PHS system in Crete= 70 GWh, [8].

The annual electricity generation from the FPV systems in two water reservoirs with 10% coverage ratio corresponds at 11.26 % of the estimated annual electricity generation by the hybrid energy plant and at 0.83 % of the annual electricity consumption in 2018 in Crete.

The annual electricity generation from the FPV systems in two water reservoirs with 30% coverage ratio corresponds at 33.78 % of the estimated annual electricity generation by the hybrid energy plant and at 2.52 % of the annual electricity consumption in 2018 in Crete.

8. Discussion

The experience regarding installation of FPVs in PHS systems worldwide is limited. Our results indicate that the installation of FPVs on the water dams in the existing hybrid energy system in El Hierro island and in the planned hybrid energy system in the island of Crete could generate solar electricity complementing the generated wind and hydro power. The nominal power of the installed FPVs depends on the surface of the water dams and the surface covered ratio which has been assumed to be in the range 0.1-0.3. Taking into account that the surface of the water dams in El Hierro is low the potential solar electricity generation annually by FPVs, with coverage ratio at 30%, is at 4.59 % of the annual electricity demand in the island in 2015. The installation of FPVs in both PHS systems increases their power capacity. The increase in power capacity is higher in Crete than in El Hierro. However, in the island of Crete, the potential solar electricity generation annually due to FPVs with coverage ratio 30% is at 2.52 % of the annual electricity consumption in the island in 2018, which is around the half of El Hierro. The results in the island of Crete indicate that the use of additional man-made water dams for installation of floating solar panels could generate significant amounts of electricity without using valuable land areas. Installation of FPVs on the water dams in both islands results in side benefits related with water saving and land use saving. Our results could be useful for companies which are interesting to invest in solar-PV systems in Crete. They could be also useful to policy makers who are interesting to promote the energy transition in Crete towards low carbon economy in the coming decades. Further research should be focused in the estimation of the levelized cost of electricity generated by FPVs in the islands El Hierro and in Crete as well as in estimating of net present value of the investments in FPVs in two islands. It should be also focused in the estimation of solar electricity generation with FPVs in the existing man-made water dams in Crete.

9. Conclusions

The possibility of installing FPVs in the hybrid energy systems in the islands of El Hierro, Spain and Crete, Greece has been investigated. Both hybrid systems store electricity using PHS technology and water dams. FPVs with nominal power at 1,716 KW_p can be installed in the existing two water dams in El Hierro island, with coverage ratio 30%, generating 2,574 MWh/year corresponding at 4.59% of the total annual electricity consumption in the island in 2015. The solar electricity that could be generated increases the annual electricity generation in the existing hybrid energy system by 6.06 %. FPVs with nominal power at 54.6 MW_p can be installed in the planned water reservoirs of the PHS system in the island of Crete, with coverage ratio 30%, generating 76.68 GWh/year corresponding at 2.52 % of the total annual electricity consumption in the island. The solar electricity that could be generated increases the annual electricity generation in the planed hybrid energy system by 33.78 %. The results of our study indicate that additional solar electricity could be generated from the PHS plants in these two islands increasing the energy potential of the hybrid energy systems. The solar irradiance in both islands is high allowing the use of solar photovoltaic panels for power generation transforming the co-generation systems to tri-generation systems. Taking into account that, in the case of Crete, the water surface of one water dam located in Potamon, Amari, is large the solar electricity that could be generated by FPVs is high covering a significant amount of the total annual electricity consumption in the island. Although the cost of installing FPVs in water dams is higher than the cost of ground-mounted PVs their benefits comprising water evaporation savings, higher electricity yield and avoiding the use of valuable land area counterbalance their higher installation costs.

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