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Possibilities of Creating a Energy System Based on Renewable Energies in Karpathos Island, Greece

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Abstract

Mitigation of climate change is an important and urgent issue in our world. Many islands have autonomous energy systems generating electricity from fossil fuels. Many of them have abundant indigenous benign energy resources while their ecosystems are fragile. Aim of the current work is to investigate the possibility of creating a hybrid energy system based on local renewable energy resources in Karpathos island, Greece. Karpathos island has similar characteristics with El Hierro island, Spain which has already successfully installed a hybrid energy system generating around 60% of its annual electricity consumption from wind energy while it has received an EU prize for this achievement. The current study proposes that a similar hybrid energy system with smaller size can be constructed in Karpathos island increasing its energy sustainability. The size of the wind farm in Karpathos island was evaluated at 9.2 MW, of the pumping station at 4.8 MW, of the hydro-electric turbine, at 9 MW and of the two water reservoirs at 304,000 M^3 and 120,000 M^3. A floating solar-PV system with nominal power at 2.15 MW_p installed on the surface of the upper water dam could generate 3,226 MWh_{el} covering approximately 8.6% of the annual electricity demand in Karpathos island. The results indicate that local renewable energy resources could cover the most of the energy needs in non-interconnected Greek islands, like Karpathos, increasing their energy sustainability and assisting them to de-carbonize their economies complying with the Greek and EU targets for 2050.

Keywords: climate change; electricity storage; El Hierro island; floating solar panels; Karpathos island; non-interconnected islands; renewable energies; sustainability**.**

1. Introduction

Climate change mitigation is necessary for avoiding devastation and major catastrophes in the near future. Replacement of fossil fuels with renewable energies reduces GHG emissions into the atmosphere. Many remote islands worldwide have autonomous electric grids while they mainly use fossil fuels for power generation. The current study investigates the possibility of using renewable energies combined with electricity storage for covering the most of the electricity needs in Karpathos island, Greece.

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Karpathos island is rich in solar and wind energy resources which can be used with mature, reliable and cost-efficient technologies for electricity generation. Solar and wind energy are intermittent energy sources of stochastic nature. They generate electricity that might be not needed by the consumers when it is generated. Therefore, electricity storage is necessary to obtain their maximum utilization. El Hierro island, Spain has successfully installed a hybrid energy system consisted of a wind farm and a pumped hydro energy system which covers almost 60% of its annual electricity demand. Karpathos island has many similarities with El Hierro island and the investigation of the possibility of creating a similar hybrid energy system is challenging. Our study is important since it indicates the way that remote islands with non-interconnected electric grids can utilize efficiently their endogenous renewable energy resources for electricity generation reducing the use of fossil fuels and their CO_2 emissions and increasing their energy sustainability

2. Literature survey

This section is separated in five parts. The first is focused on the use of renewable energies and electricity storage in autonomous islands, the second on the use of renewable energies and electricity storage in the island of El Hierro, Spain while the third on the use of renewable energies and electricity storage in several Greek islands. The fourth section concerns the installation of floating solar-PV panels on the surface of water reservoirs while in the last section various electricity storage methods are presented.

2.1 Use of renewable energies and electricity storage in islands with autonomous grids

The renewable energy supply in Tenerife and Gran Canaria islands, Spain has been examined [1]. The authors stated that currently renewable energies contribute in the energy supply of Gran Canaria at 18.8% and of Tenerife at 15.5 %. They also mentioned that the penetration of renewable energies in these islands could reach at 60% while in that case the cost of electricity will be reduced by around 25%. The possibility of achieving a 100% renewable energy supply in Canary's islands archipelago, Spain has been investigated [2]. The authors used computer modelling stating that the use of renewable energies and electricity storage systems can eliminate the use of fossil fuels in these islands. The spatial inequalities and the development of wind farms in Dodecanese islands, Greece have been studied [3]. The authors mentioned that the lack of a spatial development plan is a significant barrier regarding the development of wind farms and their acceptance by the local residents. Sustainable energy plans for non-interconnected Mediterranean islands have been proposed [4]. Using energy modelling tools for the period 2016-2036 the author proposed that almost equal share of solar and wind electricity generation systems is necessary for achieving sustainability in Karpathos island. Deployment of renewable energies in Astypalaia island, Greece which has an autonomous electric grid has been investigated [5]. The permanent residents in the island were estimated, in 2011, at 1,334 while the total annual electricity consumption at 6,188 MWh/year. The authors proposed the use of wind parks, solar-PV systems and electric batteries for decreasing the use of fossil fuels in electricity generation. They examined various scenarios regarding the size of renewable energy plants and the electricity storage capacity stating that the penetration of renewable energies in the total energy mix might vary between 66.40% to 81.89%. Description of the carbon-free energy system in Tilos island, an autonomous Greek island, consisted of a wind turbine at 800 KW_{el}, a solar-PV plant at 160 KW_p and an electric battery $NaNiCl_2$ at 2.88 MWh has been realized [6]. Total annual electricity consumption in Tilos island, with 533 inhabitants, is at 3,200 MWh while the annual peak power demand at 1 MW. Several sustainable energy portofolios for small island states have been investigated [7]. The authors studied six islands worldwide for a period of 20 years (2015-2035). They proposed the use of solar-PV systems combined with electric batteries taking into account their high annual solar irradiance at 1,500-1,700 KWh/KW_p while the use of pumped storage systems has not been examined. The use of a hybrid energy system consisted of wind energy- pumped storage system in Ikaria island, Greece has been studied [8]. The authors proposed the use of a hybrid energy system consisted of wind farms, solar-PV systems and a pumped storage station. For electricity storage two water reservoirs with capacity 80,000 M^3 each were proposed combined with an existing water reservoir at 900,000 M^3. The pumped storage system in Ikaria island, Greece which is part of the hybrid sustainable energy system in the island has been evaluated [9]. The hybrid energy system is consisted of a wind park at 900 KW, two hydro-electric turbines at 3.1 MW, twelve pumps at 3 MW, two water reservoirs at 80,000 M^3 each and one more at 910,000 M^3. The local residents in Ikaria were 9,882 in 2011 while the total annual electricity consumption 27,912 MWh. The electricity generation from the local thermal power stations was 24,792 MWh/year (88.82%) while the generation from the local renewable energy plants 3,120 MWh/year (11.18%). The clean energy transition in the island of Crete, Greece has been studied [10]. The author mentioned that the sectors of electricity generation as well as of heat and cooling production can be easily decarbonized in the short and medium term in Crete. The availability of various renewable energy sources for energy generation in rural communities in the island of Crete, Greece has been investigated [11]. The author stated that solar energy, wind energy, hydro power, biomass, and low enthalpy geothermal energy are already used for heat and power generation while more applications are foreseen in the future. A hybrid power system including electricity generation from renewable energies and electricity storage has been installed in Tilos island, Greece [12]. The hybrid energy system is consisted of a wind turbine at 800 KW_{el}, a solar-PV system at 160 KW_p and a battery storage system with useful energy capacity at 2.4 MWh. It is also mentioned that the annual electricity consumption in Tilos island is around 3,000 MWh while the permanent residents are 500. A hybrid energy system based on renewable energies and battery storage installed in Tilos island, Greece has been described [13]. The system is consisted of a wind turbine, a solar-PV system, an electric battery and appropriate forecasting algorithms. The authors stated that the hybrid energy system is a real-world operating example that could be used in other remote islands.

2.2 Use of renewable energies and electricity storage in the island of El Hierro, Spain

A report related to a wind-pumped-hydro power station in the island of El Hierro, Spain has been published [14]. The report stated that the hybrid energy system was constructed by public private partnership while it was covering around 56.5 % of the island's annual electricity needs. It was also mentioned that for 2,300 hours annually the energy requirements were covered at 100% while the hybrid system was covering all the energy needs for 24 consecutive days. The hybrid energy system in El Hierro island, Spain has been studied [15]. The author stated that currently renewable energies have a share at around 60% in the annual electricity mix in the island without achieving its self-sufficiency. She proposed the use of a solar-PV system while she mentioned that greater capacity hydro reservoirs will increase electricity storage requiring though higher capital investments. The best practice award was offered to El Hierro island, Spain regarding the development of a hybrid renewable energy system [16]. The best practice award was mentioning that the hybrid energy system was consisted of a 11.5 MW_{el} wind farm and a 11.3 MW_{el} pumped-storage system covering around 60% of the annual electricity needs in the island. The island of El Hierro, Spain has received in 2020 the 2^{nd} EU prize for RES islands [17]. The prize mentioned that for 25 consecutive days the island was covering all its electricity needs by the hybrid energy system while around 60% of its annual electricity requirements were covered by this system. Description of the hybrid energy system in the island El Hierro, Spain has been reported [18]. The authors stated that the local inhabitants in El Hierro in 2020 were 11,734 while the power of the wind park was at 11.5 MW and of the hydro-power station at 11.32 MW. They also mentioned that the power of the water pumps was at 6 MW, the volume of the upper water reservoir in La Caldera crater at 380,000 M^3 while the volume of the lower water reservoir was at 150,000 M^3.

2.3 Use of renewable energies combined with electricity storage in Karpathos island

Investigation of the possibility of using a hybrid renewable energy system covering the energy and water needs in Karpathos island, Greece has been realized [19]. The authors stated that the hybrid energy system was consisted of a 12 MW_{el} wind park, a 1.8 MW_p solar-PV system, a pumped-storage system and a 1,000 M^3/day desalination plant. They also mentioned that the system was covering around 90% of the water needs and around 50% of the energy requirements in the island. Development of a hybrid energy system in Karpathos island, Greece with computer simulation has been examined [20]. The hybrid energy system was consisted of a wind park and a solar-PV system combined with hydrogen production and storage. The authors stated that, in the long term, 100% energy self-sufficiency is achievable in Karpathos using hydrogen for electricity storage and vehicle’s fuel taking into account the rich indigenous solar and wind energy potential. The use of wind powered pumped storage system in the autonomous electricity grid in Karpathos and Kasos islands, Greece has been investigated [21]. The authors examined the installation of a wind park in a location with very high average wind velocity, at around 11.5 m/sec, and three locations for the construction of the upper water reservoir of the pumped storage system. They mentioned that due to the local high wind speeds, the island’s geomorphology and the present high cost of electricity generation by oil the project is very profitable. The autonomous electrical systems in Greek islands have been studied combined with proposals of sustainable solutions for the future [22]. The author stated that in Karpathos and Kasos islands the installed power of the thermal electric plants is at 16.5 MW while of renewable energy plants at 2.39 MW. He also mentioned that the annual electricity generation, during 2014-2017, of the thermal power stations is at 32,916 MWh while of renewable energy plants at 4,584 MWh. A sustainable energy strategy for Karpathos island has been proposed [23]. The author stated that the cost of electricity generation in 2011 was at 345.94 €/MWh while the annual electricity consumption in 2050 is predicted at 47,129 MWh. She also mentioned that the share of electricity generated by RES in the total energy mix in 2011 was at 7.9 %.

2.4 Installation of floating solar-PV systems on the surface of water reservoir

The possibility of using existing water dams for the installation of solar-PV systems has been examined [24]. The authors stated that solar-PV systems can be installed on the downstream face of existing water reservoirs. The possibility of installing floating solar-PV panels over lake Nasser, Egypt has been examined [25]. The surface area of the lake is at around 5,000 Km^2 while the local climate favors the evaporation of fresh water.

The authors stated that preliminary studies indicated that the project could provide around 16% of the electricity needs in Europe while it would save 3 bil. M^3 of water. Generation of electricity with floating solar-PV panels over lakes in Bengaluru city, India has been investigated [26]. The authors stated that installing solar-PV panels on 32 lakes with total area at 13.33 Km^2 and coverage ratio at 0.5-0.6 the generated electricity could cover around 26% of the city's needs. The floating photovoltaic system potential in water reservoirs in Korea has been evaluated [27]. The authors have selected various suitable reservoirs in the country estimating that electricity generation by floating solar-PVs is at around 2,932 GWh/year. The potential of floating solar-PV panels in water dams and reservoirs in Spain has been assessed [28]. The authors stated that Spain could meet about 31% of its electricity demand by covering only 10% of the available water surface area. The potential of floating solar-PV panels on the water quality in reservoirs in the Netherlands has been studied [29]. The authors stated that floating solar panels are suited for the Netherlands. However, they mentioned, when the water is used for drinking purposes the effect of floating solar panels on water quality should be investigated.

2.5 Electricity storage methods

The advantages of electricity storage have been studied [30]. The authors mentioned that energy storage represents the critical link between the energy supply and demand chains, being a key element for increasing the role and attractiveness of renewable energy generation into the power grid, providing also numerous technical and economic benefits to the power system stakeholders. Several energy storage technologies used in the integration of renewable energies to electric grids have been reviewed [31]. The authors stated that the potential of using Li-ion batteries to mitigate the fluctuation of RESs in utility grid integration sector is high. Integration of renewable energies to electricity grids requires lower prices of Li-ion batteries. The strengths and weaknesses of various electricity storage technologies have been analyzed [32]. The authors stated that after 2030 the long-term energy storage in Europe will be dominated by hydrogen stored in salt caverns and the use of pumped hydro storage systems.

Aims of the current work are:

a) *The description of the current energy system in Karpathos island,*
b) *The description of the hybrid energy system in El Hierro island, Spain,*
c) *To propose and size a hybrid energy system in Karpathos island covering the most of the annual electricity requirements with renewable energies, and*
d) *To investigate the possibility of installing floating solar-PV panels on the surface of water reservoirs in the proposed pumped-storage system in Karpathos island and the evaluation of the electricity that could be generated.*

The text is structured as follows: After the introduction and the literature survey sections the existing energy system in Karpathos island is presented followed by description of the hybrid energy system in El Hierro island. The electricity storage methods are then stated followed by a proposal for a sustainable hybrid energy system in Karpathos island and the possibility of using floating solar-PVs on water dams. The text is ended with discussion of the findings, the conclusions drawn and some proposals for future work.

3. The existing electricity system in Karpathos island

Karpathos island is the second largest island of Dodecanese, Greece with covered area 301 km^2 and 7,310 inhabitants. It is estimated that during the summer months and due to high number of tourists the population in Karpathos island exceeds 20,000 residents. The average wind velocity in many locations exceeds 10 m/sec while the annual solar irradiance is also high at around 1,600-1,700 KWh/m^2. The rich solar and wind energy resources in Karpathos island favor the solar and wind electricity generation. The electric grid of the island is autonomous and electricity is currently generated by thermal power stations using oil. The installed power of thermal power stations in the island is at 16.5 MW while the power of the renewable energy installations is at 2.39 MW. Electricity generation from thermal power plants during the period 2014-2017 was estimated at 32,916 MWh/year while from renewable energy plants at 4,584 MWh/year. The total electricity generation was at 37,500 MWh/year. The maximum annual power demand in 2014 was estimated at 12 MW while the cost of electricity generation is at around 0.249 €/KWh to 0.346 €/KWh. The annual electricity intensity in Karpathos island has been calculated at 5.13 MWh/capita while the share of renewable electricity, in 2011, in the electricity mix at 7.9 %.

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

El Hierro island, with covered surface 268.5 Km^2, is located in Atlantic ocean in the Archipelago of Canary islands, Spain. Canary islands are fully isolated with autonomous electric grids while they are dependent on fossil fuels. However, they have rich endogenous renewable energy resources, including solar and wind energy, which can be developed to generate heat and electricity reducing their dependency and vulnerability on fossil fuels. El Hierro has 11,734 inhabitants while its total energy demand in 2015 was at 56 GWh. The electricity intensity in El Hierro in 2011 was at 3.8 MWh/capita. The cost of electricity generation with thermoelectric plants is at around 0.242 €/KWh while the annual total cost of electricity generation was at 10.79 mil. Euros. A hybrid energy system consisted of a wind park and a pumped storage system was designed and implemented in order to increase the energy sustainability and the use of intermittent energy sources in El Hierro island. It was predicted that El Hierro was going to be the first island that could achieve 100% energy autonomy with renewable energies globally. Wind power supplies directly the demand of El Hierro island in times of high wind electricity generation and indirectly during the rest of the time, through the discharge of water stored in an upper reservoir, which has previously been pumped from a lower reservoir when the generated wind electricity was in surplus. The technical characteristics of the hybrid energy system in El Hierro are:

A) The wind park is consisted of five wind turbines with nominal power 2.3 MW each totally 11.5 MW,

B) The hydroelectric power system was consisted of four hydro turbines each at 2.83 MW totally at 11.32 MW,

C) The water pumping station is consisted of eight pumps with total power at 6 MW,

D) The upper reservoir is located in La Caldera crater with volume 380,000 M^3 while the volume of the bottom lake is at 150,000 M^3. The maximum water level in the upper reservoir was at 12 m, and

E) The desalinated water flow from the upper dam to the lower dam is at 2 m^3/sec flowing at a head of 655 m.

In 2015 the electricity generated by the thermoelectric plants was at 13.7 GWh, from the wind park at 35.9 GWh and from the hydroelectric power station at 6.4 GWh totally at 56 GWh. The total cost of electricity generation in El Hierro island in 2015 was at 3.24 mil. €, significantly lower than the cost in 2011 that was at 10.79 mil €. It is estimated that around 60% of the island's electricity consumption is covered by the hybrid power station while 25 consecutive days the total electricity requirements were covered without using fossil fuels. Some characteristics of El Hierro and Karpathos islands are presented in table 1.

Table 1: Characteristics of El Hierro and Karpathos islands

Island	Covered surface (Km^2)	Inhabitants	Annual energy consumption (GWh)	Electricity intensity (MWh/capita)	Cost of electricity generation (€/KWh)
El Hierro	268.5	11,734	56 (2015)	4.77 (2015)	0.242
Karpathos	301	7,310	37.5 (2014-2017)	5.13 (2014-2017)	0.249-0.346

Source: own estimations

5. Electricity storage methods

Various methods of electricity storage have been used in various applications. The different types of energy storage systems can be grouped into five broad technology categories:

5.1 Electric batteries

Batteries, the oldest, most common and widely accessible form of storage, are an electrochemical technology comprised of one or more cells with a positive terminal named a cathode and negative terminal or anode. Batteries encompass a range of chemistries. The best known and in widespread use in portable electronic devices and vehicles are lithium-ion and lead acid.

5.2 Thermal storage

Thermal storage in essence involves the capture and release of heat or cold in a solid, liquid or air and potentially involving changes of state of the storage medium, e.g. from gas to liquid or solid to liquid and vice versa. Technologies include energy storage with molten salt and liquid air or cryogenic storage. Molten salt has emerged as commercially viable with concentrated solar thermal power plants but this and other heat storage options may be limited by the need for large underground storage caverns.

5.3 Mechanical storage

Mechanical storage systems are arguably the simplest, drawing on the kinetic forces of rotation or gravitation to store energy. But feasibility in today's grid applications requires the application of the latest technologies. The main options are energy storage with flywheels and compressed air systems, while gravitational energy is an emerging technology with various options under development.

5.4 Pumped-hydro storage systems

Energy storage with pumped hydro systems based on large water reservoirs has been widely implemented over much of the past century to become the most common form of utility-scale storage globally. Such systems require water cycling between two reservoirs at different levels with the 'energy storage' in the water in the upper reservoir, which is released when the water is flowing to the lower reservoir.

5.5 Production of Hydrogen

Energy storage with hydrogen, which is still emerging, would involve its conversion from electricity via water electrolysis for storage in tanks. From there it can later undergo either re-electrification or supply to emerging applications such as transport, industry or residential as a supplement or replacement to gas. The global capacity of several electricity storage systems is presented in table 2.

Table 2: Global capacity of electricity storage systems

Storage system	Capacity (%)
Pumped hydro	92.7
Electrochemical	5.2
Thermal storage-molten salt	1.7
Other	0.4
Total	100

Source: Ayele Behabtu and his colleagues 2020

6. Description of a hybrid energy system based on renewable energies in Karpathos island, Greece

Taking into account the similarities and characteristics of El Hierro and Karpathos islands presented in table 1 it is proposed that a hybrid energy system based on wind electricity generation and electricity storage in a pumped hydro system can be constructed in Karpathos island. Both islands have:

A) Autonomous electric grids,
B) Electricity in both islands is mainly generated by fossil fuels,
C) They are rich in renewable energy resources mainly in solar and wind energy,
D) Their geomorphology favors the construction of water reservoirs in different heights,
E) Their renewable energy potential is underdeveloped,
F) The EU and the national policies for climate change mitigation favor the use of renewable energies instead of fossil fuels, and
G) The cost of electricity generation from oil in thermal power stations is high.

Taking into account the annual energy consumption in both islands a preliminary evaluation of the size of the hybrid energy system in Karpathos island indicates that it should be at around 80% of the size of the corresponding energy system in El Hierro island. Additionally, solar-PV systems should be developed in Karpathos island exploiting the rich solar energy resources while floating solar-PV panels could be installed on the surface of the water reservoirs of the pumped hydro system. The characteristics of the proposed hybrid energy system in Karpathos island compared to the existing energy system in El Hierro island are presented in table 3.

Table 3: Characteristics of the proposed hybrid energy system in Karpathos island, Greece

Parameter	El Hierro island [1]	Karpathos island [2]
Nominal power of wind turbines (MW)	11.5	9.2
Power of hydro-electric turbines (MW)	11.32	9
Power of the pumping station (MW)	6	4.8
Volume of upper water reservoir (M^3)	380,000	304,000
Volume of lower water reservoir (M^3)	150,000	120,000
Height between the two water dams (M)	655	650-700
Electricity generation by the hybrid energy system (GWh_{el})	42.3 (2015)	33.84
Annual electricity consumption (GWh_{el})	56 (2015)	37.5 (2017) [3]
Nominal power of the floating solar panels (MW_p)	-	2.15
Annual electricity generation by the floating solar panels (GWh_{el})	-	3.23
Percentage of electricity generated by the floating solar-PV panels to island's annual electricity generation (%)	-	8.61

Source: [1] Godina, 2015, [2] Katsoulakos, 2019 , [3] own estimations

Estimations regarding the characteristics of the hybrid energy system in Karpathos island are based on the assumption that the size of various equipment and the two dams in Karpathos island is equal at 80% to the corresponding size in El Hierro island. The results might be different under different assumptions.

7. Possibilities of installing floating solar-PV panels on the surface of water reservoirs in a pumped-storage system in Karpathos island

Installation of floating solar photovoltaic panels on water reservoirs has many advantages compared to conventional installation on the ground. Various studies in many countries have been realized, including Egypt, India, Korea, Spain, Netherlands etc indicating their multiple benefits. Installing floating solar-PV panels on the surface of water dams in hybrid energy systems has several benefits including:

a) Additional electricity generation from the floating solar-PV systems,
b) Higher yields regarding solar electricity generation due to the cooling effect of water on the solar panels,
c) Less water evaporation from water reservoirs. This is important due to scarcity of water resources in South-Eastern Mediterranean region, and
d) Less use of rural land necessary for the installation of solar-PV panels.

The upper water reservoir in El Hierro island has volume at 380,000 M^3 with maximum water depth at 12 m (*Frydrychowicz-Jastrzebska, 2018*). Assuming an average depth at 7 m its surface area is evaluated at 54,300 M^2. Taking into account that the upper water reservoir in Karpathos island will have surface at 43,000 M^2 (80% of El Hierro's) and 50% of it will be covered by floating solar panels it is concluded that the surface of the floating solar panels will be at 21,500 M^2. Assuming that the installation of floating solar-PV panels with nominal power 1 KW_p covers area at 10 m^2 in the water surface it is concluded that the nominal power of solar-

PVs installed in the upper water reservoir is at 2,150 KW_p. Taking into account that the electricity generated annually from solar-PVs in Karpathos island is at 1,500 KWh/KW_p it is concluded that the annual electricity generation from the floating solar-PVs installed in the upper water dam of the hybrid energy system in Karpathos is at 3,226 MWh. Additional electricity can be produced with floating solar-PV panels installed on the surface of the lower water reservoir of the hybrid energy system in Karpathos island. The characteristics of the abovementioned floating solar-PV system in Karpathos island are presented in table 4.

Table 4: Characteristics of the floating solar-PV system installed in the upper water reservoir in Karpathos island

Parameter	Value
Volume of upper water reservoir	304,000 M^3
Average depth of upper water reservoir	7 m
Surface of upper water reservoir	43,000 M^2
Surface covered by solar panels	50 %
Covered surface with floating solar panels in the upper water reservoir	21,500 M^2
Surface required for the installation of solar-PV panels at 1 KW_p	10 M^2
Annual productivity of solar panels in Karpathos island	1,500 KWh/KW_p
Nominal power of the floating solar panels	2,150 KW_p
Annual electricity generation by the floating solar panels	3,226 MWh_{el}
Annual electricity consumption in Karpathos island (2014-2017)	37,500 MWh_{el}
Annual electricity generation by the floating solar panels to annual electricity consumption in Karpathos island (2014-2017)	8.6 %

Source: own estimations

8. Discussion

The success of the hybrid energy system based on renewable energies in El Hierro island, Spain can be transferred as a good practice example in other remote EU islands like Karpathos island, Greece. Both islands have isolated electric grids while they have abundant solar and wind energy resources. They also have similar geomorphological characteristics that favor the construction of a pumped hydro storage system for electricity storage. Electricity storage in pumped hydro systems is the main storage technology dominated so far worldwide particularly when large quantities of electricity should be stored. Electricity storage in batteries, in MW-scale, has been used in the smaller Tilos island, Greece while in El Hierro and in Karpathos island pumped hydro storage has been chosen. Karpathos island could be transformed to a green island generating the most of the energy required from its own renewable energy resources. The possibility of installing floating solar-PV panels on the surface of the two water reservoirs in El Hierro island has not been considered. The floating solar panels would generate solar electricity complementary to wind electricity increasing the share of renewable energies in the annual energy mix. The results indicate that many non-interconnected Greek islands could reduce their dependency on fossil fuels using smartly their benign own energy resources and the existing mature, reliable and cost-efficient energy technologies. Installing floating solar-PV panels on the surface of the water reservoir could generate additional solar electricity improving the energy sustainability in Karpathos island. Although similar innovative applications do not exist currently in Greece, they have many advantages and their future deployment is challenging. The results can be used by policy makers, the local authorities in

Karpathos island, the environmentally conscious citizens as well as by energy companies and engineers who are interested to promote the energy transformation of the island zeroing by 2050 its energy related carbon emissions. Our results do not indicate the investment cost that is required for the construction of a hybrid energy system in Karpathos island neither the cost of electricity generation after the implementation of the hybrid energy system while the size of the different subsystems presented is only indicative. They do not either indicate the sizing of a solar-PV system that could complement the wind park generating additional solar electricity in the island.

9. Conclusions

The current study investigates the possibility of creating a hybrid energy system based on renewable energies in Karpathos island, Greece covering the most of its electricity needs with its abundant indigenous renewable energy resources. The existing hybrid energy system in El Hierro island, Spain which has received the 2^{nd} EU prize of the 2020 REsponsible islands has been taken as good example.

The installed power of thermal power stations in Karpathos island is at 16.5 MW while the power of the renewable energy systems is at 2.39 MW. The total electricity generation during 2014-2017 was at 37,500 MWh/year. The maximum annual power demand in 2014 was estimated at 12 MW.

The hybrid energy system in El Hierro island includes: a) a wind park that is consisted of five wind turbines with nominal power 2.3 MW each, totally at 11.5 MW, b) the hydroelectric power system consisted of four hydro turbines each at 2.83 MW, totally at 11.32 MW, c) the water pumping station consisted of eight pumps with total power at 6 MW, and d) two water reservoirs. The upper reservoir is located in La Caldera crater with volume 380,000 M^3 while the volume of the bottom water dam is at 150,000 M^3.

The proposed hybrid energy system in Karpathos island includes: a) a wind park with total nominal power at 9.2 MW, b) a hydroelectric power system at 9 MW, c) a water pumping station with total power at 4.8 MW, and d) two water reservoirs. The volume of the upper reservoir is at 304,000 M^3 while the volume of the bottom lake is at 120,000 M^3.

The floating solar-PV panels which has been proposed to be installed on the surface of the upper water reservoir covering 50% of its surface have nominal power at 2,150 KW_p while they generate electricity at 3,226 MWh_{el}/year corresponding at 8.6 % of the annual electricity consumption in the island. This will transform the abovementioned hybrid energy system to a tri-generation system generating power with solar energy, wind energy as well as with hydro-electric turbines.

The results indicate that the successful hybrid energy system in El Hierro island can be transferred to Karpathos island that has similar geomorphological, energy and population characteristics with El Hierro island. Further work should be focused on cost estimations of the abovementioned hybrid energy system in Karpathos island as well as on studying the possibility of generating both solar and wind electricity instead of using only the abundant local wind energy resources.

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