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Possibilities of Installing Floating Solar Photovoltaics on Kaloni Bay, Geras Bay and Pagasitikos Bay in Greece

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Abstract

The use of floating photovoltaics in marine environment is an emerging technology without commercial applications worldwide. Although floating photovoltaics have been installed in several fresh water bodies their use in marine environment presents many challenges. Greece is a good candidate for installing offshore floating solar photovoltaic systems due to high solar irradiance and the long coastline in the country. The possibility of using floating solar photovoltaics in three gulfs in Greece has been investigated. These gulfs have been selected due to their calm environmental conditions and their low water depth. Several studies regarding the pilot use of floating photovoltaics in coastal areas have been reviewed and the problems related with their application have been considered. The main drawbacks of marine-related floating solar photovoltaics include the impact of environmental conditions such as wind, wave and current on the floating structures, the corrosive nature of sea water, the interference with the aquatic species and the mooring of the floating structures. The annual electricity generation from floating photovoltaics covering only 1% of the surface area in Kalloni Bay, Geras Bay and Pagasitikos bay, Greece has been evaluated at 148.5 GWh, 56.7 GWh and 236.25 GWh correspondingly. Our results could be useful to policy makers, to local authorities and to energy companies installing solar photovoltaic systems.

Keywords: Electricity, Floating Solar Photovoltaics, Geras Bay, Kalloni Bay, Lesvos Island, Pagasitikos Bay, Offshore

1. Introduction

The use of solar photovoltaic systems for electricity generation has been significantly increased nowadays due to their low cost and the need to generate carbon-free electricity. Apart from installing them on the fields and at rooftop of buildings their installation on water bodies is increasing mainly in floating structures [1, 2, 3]. However, their installation in marine environment has not been developed so far due to many reasons. The harsh marine environment does not favor the installation of floating solar photovoltaics (FPV) although in water bodies with freshwater their installation is increasing [4, 5, 6, 7, 8]. Several pilot installations of offshore FPV systems have been developed in coastal areas in several countries and the energy generation, the technologies used and their cost have been analyzed and evaluated [9, 10, 11, 12, 13, 14].

The aim of the current study is to evaluate the solar electricity generation from offshore floating solar photovoltaic installations in three gulfs in Greece characterized by calm weather conditions.

The current work is innovative since there are not many studies related with the installation of offshore FPV systems in Greece while it covers a gap regarding the installation of FPVs in several bays in the country. The results could be useful to policy makers, to local authorities and to energy companies installing solar photovoltaic systems.

The text is structured as follows: After the literature survey the concept of offshore FPVs is mentioned and their advantages and drawbacks are stated. In the following sections several characteristics of Kalloni Bay and Geras Bay in Lesvos Island and Pagasitikos Bay in Magnesia Prefecture are stated while the energy system in Lesvos Island is shortly described. Next, the electricity generation from the installation of FPV systems in the abovementioned three bays is evaluated. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

2. Literature Survey

A report regarding the best practice guidelines of FPVs has been published [1]. The report stated that offshore FPVs have several benefits such as: a) the solar resource at sea is superior to land, b) offshore FPVs have very high energy density, c) they have very low visual impact and, d) avoid the conflicts related to the use of land for energy generation. A report regarding the development of FPVs has been published [2]. The report stated several decisive factors in selecting a water body for installing FPVs. These factors included the location, the weather and climate, the water body characteristics, the ecology, the ownership, the underwater terrain et cetera. The FPV systems have been reviewed [3]. The authors stated that at 1% coverage of global water reservoirs with FPV systems would have a potential capacity of 404 GW_p of solar power. They also mentioned that there is a research gap regarding the impacts of FPVs on water quality and the living organisms in water bodies. The development of offshore FPV plants focusing on marine environmental protection has been explored [4]. The authors stated that the technology readiness level is really low and commercial applications are currently in the exploration stage. They mentioned that their impact during their total life cycle on marine environment is unclear. The FPV systems have been assessed [5]. The authors stated that offshore FPVs are attractive in nations with limited land availability. They mentioned that the enhanced performance of offshore FPVs is caused by water cooling. They compared the yield between land-based and offshore FPVs in 20 locations finding a yield difference in the range of 20% to -4%. The development of FPVs on marine environment has been reviewed [6]. The authors stated that the harsh marine environment threatens the reliability and the risk of offshores FPVs. They mentioned that issues hindering the deployment of offshore FPVs include: a) their response to wind and wave loads, b) the environmental and ecological interactions, c) the mooring design, and d) their sensing and digitalization. The design characteristics of FPVs in marine environment have been examined [7]. The authors stated that in contrast of freshwater offshore FPV design is required to endure extreme environmental loads, such as wind, waves and currents, to resist salt water corrosion and biofouling. The solar panels should also have a safe height from the sea level while they should have a mooring system. The development of offshore FPV systems has been reviewed [8]. The authors stated that thin-film FPVs might be a promising solution in marine applications while synergies with other marine systems might increase their attractiveness. They mentioned that design of FPVs in terms of survivability and long-term reliability is challenging. They also added that marine FPVs are not anticipated to decrease aquatic plant biomass while there is no consensus regarding their impacts on water quality. The siting methodology for installing FPVs in coastal areas has been explored [9]. The authors proposed the development of an integrated floating solar energy index for siting FPV systems in coastal areas. This index is based on three pillars: a) the exploitable resource, b) the cost of installation, and c) the socioeconomic and environmental aspects. The development of FPVs in Black Sea has been analyzed [10]. The authors stated that the levelized cost of electricity (LCOE) for a FPV park in the Romanian offshore area of Black Sea can reach 211.303 Euro/MWh which can be reduced by increasing the capacity and combine the solar park with offshore wind turbines. The life cycle cost of an offshore FPV system in the North Sea has been evaluated [11]. The authors estimated the LCOE of a 6 MW FPV system on two Norwegian offshore sites at 256.7 Euro/MWh and 287 Euro/MWh. The recent advances in offshore FPV systems have been reviewed [12]. The authors stated that offshore FPVs face practical problems related to corrosive nature of seawater and the sea conditions influenced by wind, waves and currents. They mentioned that offshore FPVs are classified in two categories including rigid float structures and flexible float structures. The combined use of offshore FPVs and wind farms reduce their operational and maintenance costs. The use of offshore FPVs for hydrogen production in Oman using desalinated water has been studied [13]. The authors studied an offshore 20 MW FPV system producing 1,755 kg H_2 daily. They estimated the levelized cost of hydrogen at 9.5 $/kg, the levelized cost of water at 1.80 $\$/m^3$ and the LCOE at 0.05 $/kWh. The use of offshore FPVs in Maltese islands has been explored [14]. The authors stated that due to limited land availability in Malta, offshore FPVs can be used for electricity generation. They mentioned that an offshore thin film FPV system at 120 MW can reduce the electricity generation cost in Malta. The development of offshore FPV systems has been examined [15]. The authors stated that submersion of photovoltaic cables with rubber sheath in saltwater can lead to a cable accelerated degradation with reduction of its electrical insulation and, consequently, copper release into the aquatic environment. The offshore FPVs and their integration with aquaculture and hydrogen generation have been studied [16]. The authors stated that the LCOE in offshore FPVs varies from 255 Euro/MWh to 664 Euro/MWh in northern Europe. They mentioned that offshore FPV systems remain at pre-industrial phase while universal solutions are not viable. The impacts of FPVs on water properties and on biodiversity in 26 FPV systems located in the Yangtze River, China have been investigated [17]. The authors stated that FPVs decreased the water temperature and the dissolved oxygen saturation causing a reduction in Plankton species altering the community composition. They also mentioned that they decreased the bird diversity. The effectiveness of using water as a coolant for floating bifacial photovoltaic cells has been studied [18]. The authors stated that using water as coolant may greatly increase the effectiveness of FPVs. They mentioned that the yield increase in salt water is in the range of 0.3% to 15.89%. The decarbonization potential of FPVs in lakes worldwide has been studied [19]. The authors stated that with a conservative 10% surface water coverage, FPVs could produce sufficient energy to contribute a considerable fraction at 16% of the electricity demand in some countries. The onshore and offshore FPV systems have been reviewed [20]. The author stated that offshore FPV systems should withstand harsh environments such as high wind speed and waves as well as corrosion from salty water. He mentioned that very few offshore FPV systems have been reported today. However, for latitudes ranging from 45° N to 45° S thin film offshore FPV systems are competitive to offshore wind farms. The hydrodynamic characteristics of FPV systems under ocean loads have been studied [21]. The authors stated that a FPV system installed in the ocean will be subjected to the combined action of winds, waves and currents. They mentioned that the floating platforms have good stability while the wave load dominates for all conditions. The economic feasibility of offshore FPVs focused on Spain has been estimated [22]. The authors considered several restrictions related to the installation of offshore FPVs including: bathymetry restrictions, restrictions related to national maritime spatial planning, fishing grounds, electrical cables, maritime protected areas, Natura 2000, biosphere reserves and priority areas for biodiversity and national defense. They mentioned that the best LCOE achieved was in the range of 275.95 to 321.83 Euros/MWh. The offshore solar energy generation with reference the HelioSea concept has been analyzed [23]. The authors stated that this concept combines a dual-axis tracking system and a platform to raise the solar modules above the water surface to avoid wave impact. They estimated the LCOE of the HelioSea project between 160 and 270 Euros/MWh which is considered a promising solution for offshore solar energy. The differences between offshore and land-based solar-PV systems using simulation techniques have been examined [24]. The authors considered the effect of sea waves, wind speed and relative humidity in their model with reference two installations in Utrecht University, Holland and North Sea. They mentioned that the annual average output energy is about 12.96% higher at the sea compared to land. The trends in offshore FPV systems have been reviewed [25]. The authors stated that offshore FPVs present numerous benefits and a vast market potential. However, they should withstand the harsh conditions of sea environment. They mentioned that offshore FPVs can be integrated with offshore wind farms or other marine facilities. The offshore renewable energies including floating modular energy islands have been studied [26]. The authors stated that offshore energy islands provide renewable energy generation via offshore wind turbines, offshore FPVs and wave energy converters, energy storage and transport. The combined use of floating offshore wind farms and solar-PVs in Austurias, Spain has been studied [27]. The authors stated that hybrid energy systems increase the energy production per unit area by a factor of seven while the power output is significantly smoother. The possibilities of using offshore FPV systems have been examined [28]. The authors stated that offshore FPVs is a novel sector worldwide. They mentioned that they present various disadvantages related to wind and waves loads, the water salinity and the aquatic species which affect the energy generation. The potential of integrating offshore FPVs in existing offshore wind farms has been examined [29]. The authors stated that integrating FPVs around offshore wind turbines, the wind farm production will be increased by a factor of seven while FPVs require only 17% of the wind farm's area to generate an equal amount of electricity annually. The deployment of offshore FPV systems in Greece has been studied [3]. The authors studied a 100 kW_p floating module located in Pagasitikos Bay, Greece. They stated that there are significant variations in energy production due to the impacts of sea waves on the floating structure. The technological advancements of offshore FPV systems have been studied [31]. The authors stated that calm locations should be selected for installing offshore FPVs while their integration with offshore wind farms should be preferable. They mentioned that thin film, monocrystalline and polycrystalline bifacial silicon modules can be used in floating structures. The development trends of offshore FPV systems have been examined [32]. The authors stated that future developments of offshore FPVs include: a) complementation of offshore FPVs with offshore wind farms, b) complementation of offshore FPVs with aquaculture, c) development of wave adaptive flexible structures, and d) development of large-scale rigid floating structure. They mentioned that although offshore FPVs have several advantages they also face many challenges. A report regarding the use of offshore FPVs in Italy has been published [33]. It is stated that exploiting just 2% of Italy's technically feasible offshore solar area could theoretically generate enough electricity to meet the country's annual power demand. A model was developed incorporating ten key parameters to access the suitability of various offshore sites across Italy's exclusive economic zone. The potential of installing solar photovoltaics on existing water reservoirs in Greece has been assessed [34]. The author stated that the nominal power of floating photovoltaics which can be installed in the existing 128 water reservoirs in Greece covering 10% to 30% of their surface varies between 4.77 GWp to 14.31 GWp while the annual generated electricity varies between 6,435.2 GWh to 19,305.6 GWh corresponding at 12.40% to 37.20% of the total annual electricity demand in the country.

3. Offshore floating solar photovoltaics

Offshore floating solar photovoltaics are an emerging renewable energy technology that combines solar power generation with floating platform engineering in marine and coastal environments. As global energy demand continues to rise and nations seek cleaner energy systems, offshore FPV has attracted significant attention from researchers, governments, and energy companies. The technology represents a modern approach to electricity generation by utilizing open water surfaces for solar energy production. The basic principle of offshore floating solar systems is similar to conventional photovoltaic installations. Solar panels convert sunlight into electricity using semiconductor materials, primarily silicon-based photovoltaic cells. However, instead of being mounted on rooftops or land-based structures, the panels are installed on specially designed floating platforms positioned on offshore waters, coastal zones, or sheltered marine environments. These floating structures are engineered using lightweight and durable materials such as high-density polyethylene and corrosion-resistant metals to withstand continuous exposure to water and changing weather conditions. A typical offshore FPV system includes several integrated components. The photovoltaic modules are attached to floating pontoons or interconnected floating arrays that provide stability and buoyancy. Mooring and anchoring systems secure the structure to the seabed or coastal infrastructure, ensuring that the installation remains stable under wave motion and ocean currents. Power cables transmit the generated electricity from the floating platform to onshore substations, where the electricity is integrated into national or regional power grids. Modern offshore FPV projects also incorporate monitoring systems, sensors, and automated maintenance technologies to improve operational performance. Recent technological developments have significantly advanced offshore floating solar engineering. Researchers are developing flexible floating structures capable of adapting to wave movement while maintaining panel orientation for maximum solar exposure. Advanced materials with improved corrosion resistance and mechanical strength are being introduced to increase the lifespan of offshore installations. In addition, digital monitoring systems using artificial intelligence and remote sensing technologies are becoming increasingly important for system control, fault detection, and energy optimization. Offshore floating solar technology has a wide range of applications. One important application is large-scale electricity generation for coastal cities and industrial regions. Countries with limited land availability are exploring offshore FPV as an alternative solution for expanding renewable energy production without relying entirely on terrestrial installations. Another important application is the integration of floating solar systems with offshore wind farms. Hybrid renewable energy platforms combine solar panels and wind turbines within the same marine area, creating multi-source energy systems capable of supporting more stable power generation. Offshore FPV systems can also support island communities and remote coastal regions where access to conventional electricity infrastructure may be limited. In such cases, floating solar installations can provide local energy production for residential, commercial, and industrial needs. Furthermore, offshore solar technology is being examined for applications in desalination plants, hydrogen production, aquaculture facilities, and maritime infrastructure. The future potential of offshore floating photovoltaics is considered highly significant within the global energy transition. Many countries are investing in pilot projects and commercial-scale developments to expand offshore renewable energy capacity. International research programs are focusing on improving floating platform design, increasing energy efficiency, and developing scalable offshore systems suitable for deep-water environments. As technological innovation continues, offshore floating solar photovoltaics are expected to become an important component of future sustainable energy networks, contributing to diversified renewable electricity generation across coastal and marine regions worldwide. Table 1 indicates the criteria for site selection for installation of offshore solar photovoltaics.

Table 1: Criteria for site selection for installation of offshore solar photovoltaics

1	Wave height
2	Wave period
3	Wind speed
4	Current speed
5	Bathymetry
6	Distance to shore
7	Fishing activity
8	Protected marine area
9	Ferry routes
10	Recreational activities

Source: [33]

4. Advantages of offshore floating solar photovoltaics

The advantages of offshore floating solar photovoltaics include efficient land use, improved energy production, environmental benefits, and support for global energy sustainability.

One of the most significant advantages of offshore FPV systems is their ability to save land space. Traditional solar farms require large areas of land, which may compete with agriculture, housing, or industrial development. In densely populated countries where land availability is limited, installing solar panels offshore provides an effective alternative. By utilizing unused water surfaces, offshore FPV systems allow countries to expand renewable energy production without sacrificing valuable land resources. This is particularly beneficial for coastal regions and island nations where land is scarce and expensive. Another important advantage is the higher efficiency of offshore floating solar panels. Water naturally cools the solar panels, reducing overheating and improving their performance. Conventional land-based solar panels often lose efficiency when exposed to high temperatures. In contrast, offshore FPV systems benefit from the cooling effect of water and sea breezes, which helps maintain optimal operating temperatures. As a result, floating solar systems can generate more electricity compared to equivalent land-based installations. This increased efficiency contributes to greater energy output and improved economic returns. Offshore FPV systems also provide major environmental benefits. Since solar energy is a clean and renewable resource, these systems produce electricity without emitting greenhouse gases or air pollutants. Their use helps reduce dependence on fossil fuels such as coal, oil, and natural gas, which are major contributors to climate change. Additionally, FPV installations can reduce water evaporation when placed on reservoirs or lakes, helping conserve water resources in dry regions. Some studies also suggest that floating panels may limit algae growth by reducing sunlight penetration into the water, improving water quality. Another advantage is the potential integration of offshore FPV systems with existing offshore infrastructure. For example, floating solar farms can be combined with offshore wind farms, sharing transmission cables and maintenance facilities. This hybrid approach maximizes the use of offshore space and improves the reliability of renewable energy production. When wind conditions are low, solar panels can continue generating electricity during daylight hours, creating a more balanced and stable energy supply. In addition, offshore floating solar photovoltaics contribute to energy security and economic development. As global energy demand continues to rise, renewable technologies are essential for ensuring long-term energy availability. Offshore FPV systems enable countries to diversify their energy sources and reduce reliance on imported fuels. The development of floating solar technology also creates employment opportunities in engineering, manufacturing, installation, and maintenance sectors. Furthermore, investment in renewable energy encourages technological innovation and supports sustainable economic growth. Therefore, offshore floating solar photovoltaics offer numerous advantages, including efficient land use, improved energy efficiency, environmental protection, and enhanced energy security. Their ability to generate clean electricity while utilizing unused water surfaces makes them an attractive solution for the future of renewable energy. As technology advances and global interest in sustainable development increases, offshore FPV systems are expected to play a vital role in the transition toward a cleaner and more sustainable energy future. Table 2 indicates the advantages of offshore floating solar photovoltaics.

Table 2: Advantages of offshore floating solar photovoltaics

1	Land space saving
2	Higher efficiency compared to conventional land-based solar panels
3	Reduction on the dependence on fossil fuels and lower carbon emissions
4	Potential integration with existing offshore infrastructure such as wind farms or aquaculture facilities
5	Increase energy security and self-sufficiency
6	Creation of employment opportunities and energy-related investments

Source: own estimations

5. Disadvantages of offshore floating solar photovoltaics

Offshore floating solar photovoltaics face several important disadvantages and challenges. These include high installation and maintenance costs, environmental concerns, technical difficulties, and vulnerability to harsh marine conditions. One of the main disadvantages of offshore FPV systems is their high initial cost. Building floating solar farms offshore requires specialized materials and advanced engineering technologies. The floating structures, anchoring systems, underwater cables, and corrosion-resistant components are more expensive than those used in conventional land-based solar installations. In addition, transporting equipment and workers to offshore locations increases construction and operational expenses. As a relatively new technology, offshore FPV systems have not yet achieved the same economies of scale as traditional solar farms, making them less affordable for many countries and companies. Another significant challenge is maintenance and durability. Offshore environments are extremely harsh due to saltwater, strong waves, water currents, winds, storms, and high humidity. Saltwater corrosion can damage solar panels, electrical components, and metal structures over time, reducing the lifespan of the system. Regular maintenance is necessary to ensure safe and efficient operation, but offshore maintenance is often difficult and expensive. Workers may require specialized vessels and equipment to access offshore installations, especially during bad weather conditions. These factors can increase operational risks and reduce the overall reliability of the system. Environmental concerns also represent an important disadvantage of offshore FPV systems. Although solar energy itself is clean and renewable, large floating installations may negatively affect marine ecosystems. Offshore solar platforms can block sunlight from reaching underwater plants and marine organisms, potentially disrupting local habitats and food chains. Construction activities and anchoring systems may also disturb the seabed and aquatic life. In some cases, offshore FPV farms could interfere with fishing activities, shipping routes, and recreational water use, creating conflicts with local communities and industries that depend on marine resources. Technical limitations are another issue associated with offshore floating solar photovoltaics. Offshore conditions are more complex and unpredictable than land-based environments. Strong ocean currents, tides, and extreme weather events such as hurricanes or storms can damage floating platforms or reduce system stability. Designing structures capable of withstanding these conditions requires advanced engineering and constant monitoring. Energy transmission from offshore sites to onshore electrical grids can also be challenging. Underwater power cables are costly to install and maintain, and energy losses may occur during long-distance transmission. In addition, offshore FPV systems may face limited efficiency in certain locations. Weather conditions such as heavy clouds, fog, and sea spray can reduce sunlight exposure and lower electricity production. Marine growth, including algae and barnacles, may accumulate on floating structures and equipment, affecting performance and increasing cleaning requirements. These factors can reduce the economic viability of offshore solar projects in some regions. Therefore, while offshore floating solar photovoltaics provide an innovative source of renewable energy, they also have several disadvantages. High costs, maintenance difficulties, environmental impacts, technical challenges, and exposure to harsh marine conditions are major concerns that must be addressed for the technology to become widely successful. Despite these limitations, ongoing research and technological improvements may help reduce these challenges in the future. With proper planning and sustainable design, offshore FPV systems could still play an important role in the global transition toward cleaner energy sources. Table 3 indicates the disadvantages of offshore floating solar photovoltaics.

Table 3: Disadvantages of offshore floating solar photovoltaics

1	Higher initial cost
2	Maintenance difficulties
3	Lower durability due to harsh marine environment
4	Environmental degradation due to undesired impacts in marine organisms and ecosystems
5	Anchoring systems may disturb the seabed
6	Interference with fishing activities, shipping routes and recreational water use
7	Offshore conditions such as water currents, wind, waves and extreme weather events can damage the floating infrastructure
8	Marine growth including algae and barnacles may accumulate on floating structures
9	Energy transmission from offshore sites to onshore electrical grids may be challenging

Source: Own estimations

6. The island of Lesvos and the Gulfs of Geras and Kalloni

The island of Lesvos is distinguished by two remarkable semi-enclosed gulfs: the Bay of Geras (also called Gulf of Gera) and the Bay of Kalloni. These two bays dominate the geography, ecology, and economy of the island and are considered among the most important natural wetland ecosystems in the eastern Mediterranean. Both are protected under the Natura 2000 environmental network because of their exceptional biodiversity and ecological value. The Bay of Kalloni, situated in the central-southern part of Lesvos, is the larger of the two gulfs. It covers approximately 110 square kilometers, making it one of the largest enclosed marine basins in Greece. The gulf is connected to the Aegean Sea through a narrow strait about 4 kilometers long and 2 kilometers wide. Kalloni Bay is relatively shallow, with an average depth of around 10 meters and a maximum depth ranging from 20 to 25 meters. Geologically, Kalloni Bay is believed to be a drowned river valley formed during the Holocene period when rising sea levels flooded the area. The bay's shallow waters, combined with river inflows and extensive wetlands, create highly productive ecosystems rich in nutrients and plankton. These conditions support abundant marine life and make the gulf one of Greece's most important fishing grounds. The bay is especially famous for the "Kalloni sardine," regarded as one of the finest sardine varieties in the Mediterranean. Shellfish such as oysters, cockles, and scallops are also harvested there. Ecologically, the Bay of Kalloni is internationally important for birdlife. Wetlands, salt marshes, reed beds, and lagoons surrounding the gulf provide habitats for migratory and resident birds. Flamingos, white storks, avocets, ruddy shelducks, cormorants, and herons are frequently observed in the area. More than one hundred bird species have been recorded, making Kalloni one of Europe's leading birdwatching destinations. The gulf also has historical significance. The philosopher Aristotle is believed to have studied marine organisms and wildlife in the wetlands around Kalloni during the 4th century BCE. His observations contributed to some of the earliest scientific works on biology and zoology.

The Bay of Geras, located in southeastern Lesvos, is smaller but equally impressive. It covers approximately 42 square kilometers and has a maximum depth of approximately 20 meters while it is characterized by a very narrow, winding entrance that creates the impression of an inland lake. Unlike Kalloni, the Bay of Geras is more enclosed and sheltered, producing calm waters and a distinctive microenvironment. The seabed of Geras Bay contains extensive seaweed beds and large concentrations of plankton, making the waters biologically productive. The bay is known for shellfish, particularly ark clams and cockles, which have supported local fisheries for centuries. Olive groves surround much of the coastline, creating one of the most picturesque landscapes on Lesvos. The ecology of Geras Bay is equally rich. Wetlands and nearby forested areas support rare species of birds, reptiles, amphibians, and mammals. Species recorded in the region include purple herons, white storks, otters, freshwater turtles, and several bat species. The flora is also notable for orchids, reeds, willows, and endemic plants unique to Lesvos. An important geological characteristic of Geras Bay is its tectonic origin. The gulf was formed by major geological faults that created a depression later filled by seawater. These faults are still active and are associated with thermal springs in the area, where mineral-rich waters emerge at temperatures approaching 40°C. Together, the bays of Geras and Kalloni form the environmental heart of Lesvos. They support fisheries, tourism, agriculture, and scientific research while preserving fragile ecosystems of international importance.

7. The power system in the island of Lesvos

Lesvos, one of the largest islands in Greece, has an autonomous energy system that is not yet fully interconnected with the mainland electricity grid. As a result, the island produces most of its electricity locally through a combination of thermal power generation and renewable energy sources. The energy system of Lesvos is representative of many Greek islands that face challenges related to isolation, high fuel costs, and environmental sustainability. The backbone of the island's electricity supply is the local thermal power station, which operates mainly with diesel and heavy fuel oil. According to the European Clean Energy for EU Islands initiative, the power station has an installed thermal capacity of approximately 102.6 MW, consisting of multiple generating units of different sizes. Because Lesvos is not connected to the national grid, the island depends heavily on imported fossil fuels to ensure a stable electricity supply throughout the year. At the same time, renewable energy has become increasingly important in the island's energy mix. Lesvos possesses excellent wind and solar potential due to its strong Aegean winds and high levels of sunshine. The island currently hosts several wind farms with a combined capacity of nearly 14 MW, as well as more than 130 photovoltaic installations totaling around 8.8 MW. Smaller rooftop solar systems and self-production units also contribute to electricity generation. Renewable energy presently covers roughly 12% of the island's electricity demand, although future plans aim to increase this percentage significantly. The annual electricity consumption of Lesvos has steadily increased over recent decades because of population growth, tourism, air conditioning demand, and economic activity. The annual electricity demand is estimated at approximately between 250 and 275 GWh per year. Peak electricity demand during the summer season can exceed 60 MW. Seasonal tourism strongly influences energy consumption, with demand rising considerably during the hot summer months. An important challenge for Lesvos is reducing dependence on expensive and polluting oil-based generation. Researchers and local authorities are exploring sustainable alternatives such as hybrid renewable systems, energy storage technologies, biomass utilization from olive tree waste, and interconnection with mainland Greece. Overall, the energy system of Lesvos is undergoing a gradual transition from fossil-fuel dependence toward a cleaner and more sustainable model. The island's abundant renewable resources provide strong opportunities for future energy independence and environmental protection while supporting economic development and tourism.

8. Pagasitikos Bay, Greece

Pagasetic Gulf, also known as Pagasitikos Bay, is a semi-enclosed gulf located on the eastern coast of mainland Greece near the city of Volos, Magnesia Prefecture. Surrounded by the mountainous landscapes of Pelion and Thessaly, the bay is an important natural and economic feature of central Greece. Its calm waters and sheltered geography have supported human activity since ancient times. The surface area of Pagasitikos Bay is approximately 175 square kilometers, forming a circular gulf connected to the Aegean Sea through a narrow channel. The bay has relatively moderate depths compared to the open sea. In most areas, the depth ranges between 50 and 100 meters, while some central parts exceed 100 meters. The shallow coastal zones provide ideal habitats for marine organisms and contribute to the bay's ecological richness. Ecologically, Pagasitikos Bay is highly significant. It hosts a variety of marine species, including fish, shellfish, dolphins, and seabirds. Seagrass meadows and coastal wetlands around the bay support biodiversity and help maintain water quality. However, increasing urbanization, industrial activity, and pollution from nearby settlements have raised environmental concerns in recent decades. Conservation efforts and monitoring programs aim to protect the delicate marine ecosystem and ensure sustainable use of its resources. The bay serves many important uses for local communities and the wider region. Fishing and aquaculture are major economic activities, providing seafood and employment. The port of Volos supports commercial shipping and transportation, connecting Thessaly with the Greek islands and other Mediterranean destinations. Tourism is also vital, as visitors are attracted by the scenic coastline, beaches, sailing opportunities, and traditional villages of Pelion. In addition, the calm waters of the bay are suitable for recreational sports such as kayaking, swimming, and sailing. Overall, Pagasitikos Bay is a valuable natural resource that combines ecological importance with economic and cultural significance for Greece.

9. Installation of floating solar photovoltaics in the Bays of Kalloni and Geras, Lesvos and in Pagasitikos Bay

For the estimation of the solar electricity generation from FPVs in Kaloni Bay, Geras Bay and Pagasitikos Bay the following assumptions have been made:

a) Two coverage ratios with FPVs in the three Bays at 1% and 2% have been considered,
b) The surface area of Kalloni Bay is 110 km^2, of Geras Bay is 42 km^2 and of Pagasitikos Bay is 175 km^2,
c) Installation of 1 kW_p of floating FPV requires surface of 10 m^2,
d) The annual electricity generation from FPVs is 1,350 kWh/kW_p
e) The annual electricity demand in Lesvos Island is 270 GWh

The results from the evaluation are presented in Table 4.

Table 4: Evaluation of electricity generation from floating photovoltaics installed in Kalloni Bay, Geras Bay and Pagasitikos Bay, Greece

	Kalloni Bay	Geras Bay	Pagasitikos Bay
Total Surface	110 km^2	42 km^2	175 km^2
Surface for FPV installation with coverage ratio 1%	1.1 km^2	0.42 km^2	1.75 km^2
Water surface required from FPV with nominal power 1 kW_p	10 m^2	10 m^2	10 m^2
Nominal power of FPV installed in 1% of Bay's surface	110 MW_p	42 MW_p	175 MW_p
Annual electricity generation	148.5 GWh	56.7 GWh	236.25 GWh
%, Annual electricity generation to annual electricity demand in Lesvos Island	55 %	21 %	
Surface for FPV installation with coverage ratio 2%	2.2 km^2	0.84 km^2	3.5 km^2
Nominal power of FPV installed in 2% of Bay's surface	220 MW	84 MW	350 MW
Annual electricity generation	297 GWh	113.4 GWh	472.5 GWh
%, Annual electricity generation to annual electricity demand in Lesvos Island	110 %	42 %	

Source: Own estimations

10. Discussion

There are no commercial applications of offshore FPVs so far although there are pilot systems installed in several sites worldwide for experimentation. The experience gained from the operation of FPVs in bodies with fresh water are useful in the deployment of offshore FPVs. Several technological problems related with the impacts of the harsh marine environment on the floating structures such as the impacts of wind, waves, currents and salinity should be solved before the commercial deployment of offshore FPVs. The estimated LCOE of offshore FPVs in several studies is high compared with the cost of other renewable energy systems. Their impacts on aquatic species and on marine environment are not clear and further studies are required. Greece is a good candidate for installing offshore FPV systems due to high solar irradiance and the long coastline of the mainland and the islands. The three bays studied have calm weather conditions that minimize the impacts of wind, waves and currents and low depth that facilitates the anchoring of the floating structures. However, they host sensitive ecosystems which might be affected from the floating structures although the coverage ratio of their surfaces at 1% and 2% is very low. The estimated amount of electricity generation from the FPVs in the three bays with low coverage ratio is considerable. The accuracy of our results depends on the accuracy of the assumptions made. However, our results should be considered as indicative showing that installation of FPVs in relatively small marine surface areas can generate significant amounts of electricity. Future research should be focused in the estimation of electricity generation in other marine areas in Greece which are suitable for installation of FPV systems.

11. Conclusions

Evaluation of solar electricity generation from offshore floating solar photovoltaic installations in three gulfs in Greece characterized by calm weather conditions has been conducted. The findings can be summarized as follows:

a) The Bays of Kalloni, Geras and Pagasitikos studied have favorable conditions for the installation of FPV systems such as calm weather conditions which minimize the impacts of wind, waves and currents and low depth which facilitates the anchoring of the floating structures. However, they host sensitive ecosystems which might be harmed from the installation of FPVs,
b) A FPV system with nominal power 110 MW_p generating 148.5 GWh/year can be installed in Kalloni Bay covering only 1% of its surface area,
c) A FPV system with nominal power 42 MW_p generating 56.7 GWh/year can be installed in Geras Bay covering only 1% of its surface area,
d) A FPV system with nominal power 175 MW_p generating 236.25 GWh/year can be installed in Pagasitikos Bay covering only 1% of its surface area,
e) The electricity generation from FPVs covering 1% of the surface area in Kalloni Bay and Geras Bay in Lesvos Island is equal to 55% and 21% correspondingly of the annual power demand in the island.

The main take away from our work is the fact that installation of FPVs in coastal areas in Greece could generate significant amounts of electricity exceeding the annual power demand in the country.

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