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# Use of Solar Photovoltaic Systems for Meeting the Power Demand in the Island of Crete, Greece Avoiding the Land Use Conflicts

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**Abstract**

Solar photovoltaic systems are increasingly used for power generation worldwide replacing the use of fossil fuels and reducing the energy-related carbon emissions. The abundant solar energy resources in Crete can generate green electricity increasing the island's energy security and self-sufficiency. Apart from installing them on the ground new configurations for siting solar photovoltaics have been developed avoiding the conflicts related with land use. Several unconventional configurations regarding the installation of solar photovoltaic modules in Crete meeting the annual power demand have been investigated. These configurations include their installation on rooftops of buildings, on the surface of water bodies, on cultivated and uncultivated land allowing the dual production of energy and food and on the fields vertically sited. Evaluation of power generation from solar photovoltaics sited on rooftops of buildings in Crete indicated that they could generate a significant amount of the annual electricity demand of the island while the floating solar photovoltaics could only generate a small amount of its annual power demand. The use of agrivoltaics and of vertical photovoltaics in Crete could generate significant amounts of electricity although quantitative estimations have not been implemented. In conclusion, solar electricity generation in Crete can meet the annual power demand in the island allowing the dual use of valuable and fertile land for electricity generation and food production.

***Keywords:*** agrivoltaics; Crete-Greece; floating photovoltaics; land use; rooftops; vertical photovoltaics.

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## 1. Introduction

The use of solar photovoltaic systems meeting the power demand in the island of Crete, Greece has been investigated. Several non-conventional configurations of solar photovoltaic (solar-PV) modules, avoiding the use of valuable land in Crete, have been examined including their use on rooftops of buildings, on the surface of water bodies as well as the use of vertical photovoltaics and agrivoltaics. The potential use of rooftops of buildings for siting solar-PV modules in several cities and territories has been studied [1,2,3]. The installation of floating photovoltaic (FPV) modules on the surface of water bodies has been examined [4,5,6]. The use of agrivoltaics allowing the dual use of land has been studied [7,8,9]. The use of vertical photovoltaic modules has been also investigated [10,11].

*The aims of the current study are:*

a) *The estimation of the electricity demand in Crete, in 2025, and the evaluation of the required nominal power of solar photovoltaic systems to meet the demand, and*
b) *The investigation of several unconventional configurations for siting the solar photovoltaic modules allowing the use of valuable land for food production and for other uses.*

After the literature survey the electricity demand in Crete is evaluated as well as the power of solar-PV systems required for meeting the island's electricity demand. Next, several types of solar-PV systems are shortly mentioned followed by the evaluation of the generated electricity when they are sited on rooftops of buildings and on the surface of water bodies. After that the electricity generation from agrivoltaics in Crete is evaluated and the possibility of using vertical photovoltaics is examined. The text ends with discussion of the findings, the conclusions drawn and the citation of the references used.

The results could be useful to policy makers and to local authorities who are planning the clean energy transition in the island. It could be also useful to energy companies, to investors and to farmers willing to avoid conflicts related with the land use in Crete. Our study is innovative since there are no similar studies published on this issue for Crete. It covers an existing gap related with the required size of solar photovoltaic systems and their siting for achieving self-sufficiency in power generation in Crete avoiding undesired land use conflicts.

## 2. Literature survey

The literature survey is separated in five sections including: a) the use of solar photovoltaic systems, b) the use of solar photovoltaic systems on rooftops of buildings, c) the use of floating photovoltaic systems, d) the use of agrivoltaics, and e) the use of vertical photovoltaic systems.

### *2.1 Use of solar photovoltaic system*

The required land area for the installation of various renewable energy systems has been estimated [12]. It is stated that flat-plate solar photovoltaic technology is the most land-efficient renewable energy technology to generate green energy. It is also mentioned that the land area required for installation of solar-PV systems per

$GW_p$ is in the range of 10-50 $km^2/GW_p$ while the required land area per generated GWh is at 5,000-23,000 $m^2$/GWh. The impact of solar-PV systems on farming has been investigated [13]. The author stated that solar power installations can boost crop's yield, save water and protect the biodiversity. He also mentioned the advantages of FPV on water bodies as well as of agrivoltaics. The potential land area requirements for the installation of solar energy systems in EU, India, Japan and South Korea has been evaluated [14]. The authors stated that a 25-80 % penetration of solar electricity in the energy mix in these regions by 2050 will require the occupation of 0.5-5 % of the total land with solar energy systems. They also mentioned that the land cover changes will cause a net-release of carbon in the range of 0 to 50 $grCO_2$/KWh depending on various parameters. The opportunities and challenges of bifacial photovoltaics (BPV) have been studied [15]. The authors stated that BPV have many advantages and they are going to prevail in the solar-PV market. They also mentioned that the gain of energy yield of BPV can be up to 5-15% on a flat roof while in several cases it could reach up to 30%. The performance of bifacial solar-PV modulus in Brazil has been studied [16]. The authors stated that more than 2/3 of the new solar power plants in Brazil are using BPV. They also mentioned that the power gain of the bifacial modulus compared to conventional panels is in the range of 3-7 % for typical installations. The use of solar energy technologies in Mediterranean region has been examined [17]. The authors stated that the current status of solar energy technologies allow: a) the photovoltaic power generation in large-scale plants at low cost, b) the use of solar-PV and solar thermal technologies in several types of buildings, and c) the replacement of internal combustion vehicles with battery electric vehicles recharged with solar electricity. The semi-transparent solar photovoltaic cells have been studied [18]. The authors stated that the development of semi-transparent PV cells allows the harvesting of solar energy through the windows and roofs of buildings and vehicles. They also mentioned that semi-transparent PV cells are currently based on silicon while the recent development of innovative organic and perovskite solar cells could offer new opportunities for power generation from semi-transparent modules in the future. The significant growth of solar-PV systems in Greece is foreseen [19]. The forecast for the installed solar photovoltaic capacity in Greece in 2020 is 40.3 $GW_p$ compared to 8.2 $GW_p$ in 2025. A recent report stated that solar energy could theoretically cover the world's electricity demand by just covering 0.3% of the global land area according to researchers in Aarhus University, Denmark [20]. The researchers mentioned that vertical PVs, agrivoltaics and FPVs are going to grow rapidly in the future. The solar energy development impacts on land cover change and protected areas with reference the state of California, USA has been studied [21]. The authors stated that the majority of utility-scale solar energy installations in California, USA are sited in natural environments. They concluded that the land in California is used for energy, food and conservation goals while the opportunities for environmental co-benefits should be explored. The land area requirements of solar and wind power generation have been studied [22]. The author stated that the potential space impacts of solar and wind energy systems depend on many factors and can vary widely while these systems are likely to affect significantly more land area than other electricity generation installations. He also mentioned that developing a 100% renewable energy system would be challenging from a land use policy perspective. A report related to photovoltaic energy has been published by the University of Michigan, USA [23]. The report stated that solar-PV systems, with intermediate efficiency, covering 0.6% of the land area in USA would generate enough electricity to meet the total power demand in the country. The solar-PV potential in croplands has been assessed [24]. The author stated that there is a growing concern that large-scale solar energy installations might displace other land uses. They also mentioned that the efficiency of solar panels depends on solar insolation, air temperature, wind speed and relative humidity. They proposed that agrivoltaic systems allow the dual use of land alleviating the land use competition. According to a recent study if solar-PV panels will be placed on the 50% of the world's rooftops they would meet the world's annual electricity demand [25]. The study also mentioned that the potential hotspots for rooftop solar energy generation are located in Asia, North America and Europe. A report from the Greek power distribution organization stated the electricity generation in Crete in 2018 was 3,042.8 GWh while the share of renewable energy sources (RES) in the energy mix was at 21.2 % [26]. The bifacial photovoltaic (BPV) technology has been reviewed [27]. The authors stated that a BPV system can offer 25-30% additional power compared to a conventional system. They also mentioned that BPV can be installed on the ground, on cultivated crops, on water bodies and on rooftops of buildings.

### *2.2 Use of solar photovoltaic systems on rooftops of buildings*

The solar photovoltaic potential of buildings' rooftops in EU has been assessed [1]. The authors used geospatial information of the EU building stock to quantify the available rooftop area for the installation of solar-PV systems. They stated that the EU rooftops could potentially produce 680 TWh of solar electricity annually which corresponds at 24.4% of the current electricity consumption in EU. The potential of urban rooftops for solar-PV installations has been evaluated [28]. The authors stated that urban areas can easily produce solar electricity using rooftop mounted photovoltaic systems. They proposed a multi-criteria hierarchical methodology to estimate their potential analyzing the physical potential, the geographical potential, the technical potential and the economic potential. The solar photovoltaic potential of rooftops in south-east Ontario has been estimated [29]. The authors evaluated the total rooftop area at 70 $m^2$/capita while the potential of the rooftops for solar-PV installations corresponds at 157% of the region's peak power demand. They concluded that 30% of the region's electricity demand could be met with the installation of solar-PV panels on the rooftops. The solar photovoltaic potential of rooftops in the city Nanjing, China with population 8.44 mil has been evaluated [2]. The authors using satellite images estimated that the annual solar power potential of rooftops in Nanjing was 311,853 GWh while the solar-PV electricity generation from rooftops for 2019 was 49,897 GWh representing 16% of the total solar power potential. The solar potential of rooftops in urban environments with reference the Galapagos islands has been estimated [3]. The authors stated that their studies in two islands, Puerto Baquerizo Moreno and Puerto Ayora, indicated that a minimum of 21% and 27% of the total rooftop surface correspondingly must be covered with solar-PV panels to meet the current electricity demand in these two islands**.** The solar-PV potential at urban level with reference Ludwigsburg County in south-west Germany has been assessed [30]. The authors studied 157,724 buildings in the county stating that the technical potential of solar-PV generation from buildings' rooftops can meet 77% of the region's electricity consumption while the economic potential can meet 56% of its demand.

### *2.3 Use of floating photovoltaic systems*

The floating photovoltaic systems and the energy storage methods have been reviewed [4]. The authors stated that FPV have the potential to significantly increase the efficiency and reliability of renewable energy generation worldwide. They also mentioned that the countries with the highest potential for FPV are USA, China, Brazil, India and Canada. The FPV technology has been reviewed [5]. The authors stated that although the world is transitioning towards a net-zero emissions future the land area requirements for installing solar farms present a barrier due to the increase of population density and the rise of land prices. They mentioned that FPV is a promising solution to land scarcity estimating that coverage of 1% of global water reservoirs with FPV would have a potential capacity of 404 $GW_p$. The advantages and the challenges of FPV have been studied [6]. The authors stated that if 1% of the surface of the world's water reservoirs will be covered by FPV the solar power would be increased by 404 $GW_p$. They also mentioned that the effect of FPV on water quality and on aquatic life is not well known. The use of FPV on water reservoirs in Crete, Greece has been studied [31]. The author estimated that covering 10% of the major water bodies in the island with FPV significant amounts of electricity could be generated equal to 78.3 GWh/year corresponding at 2.10 % of the annual power demand in Crete, at 3,733 GWh, in 2025.

### *2.4 Use of agrivoltaics*

The global trends in agrivoltaic systems combining crop production and energy generation in the same land area achieving the dual use of land have been reviewed [32]. They authors mentioned that the majority of the relevant scientific publications were concentrated in the last three years. The potential and the challenges for agrivoltaics in the European Union have been studied [7]. The authors stated that agrivoltaics allow the continuation of agricultural activities. They also estimated that coverage of only 1% of the utilized agricultural area in EU with agrivoltaics corresponds at 944 $GW_p$ which is approximately five times more than the installed solar-PV capacity in EU in 2022. The multidimensional role of agrivoltaics in the era of the EU green deal has been analyzed [10]. The authors stated that one main pillar for the green energy transition in Mediterranean countries is the solar photovoltaic power. In this context the "symbiosis" of food and energy production under the same land is important. They also mentioned that agrivoltaics decrease the evapotranspiration rate in crops reducing the water demand for irrigation which is important in areas with water scarcity. A market research study for agrivoltaics has been published [33]. The study stated that USA is lagging behind Europe and Asia-Pacific region in the adoption of agrivoltaics. Agrivoltaics allow the simultaneous use of land for both agriculture and power generation while they can be used with livestock as well as with fruit and vegetable production. The agrivoltaics systems have been reviewed [9]. The authors stated that agrivoltaics have several benefits related with food and energy production as well as with water savings. They mentioned that various parameters should be examined before the installation of agrivoltaics including solar-PV technology, agronomy and engineering achieving synergies between solar energy generation and other ecosystem services. A report related with agrivoltaics which allow the dual use of land has been published [34]. The report stated that agrivoltaics offer the possibility to install large solar-PV systems on open land while keeping the ground clear for food production. The dual use of land for agriculture and solar electricity generation is particularly beneficial for areas which are good for farming and suitable for the installation of ground-mounted photovoltaics. Two types of landscapes with agrivoltaics in the Netherlands have been studied [35]. The authors investigated the perception of the residents regarding the quality of the landscape after the installation of agrivoltaics. They mentioned that local residents considered as important factors for the installation of agrivoltaics their environmental impacts, the wildlife habitats as well as health and well-being.

### *2.5 Use of vertical photovoltaic systems*

The performance of vertically mounted photovoltaic modules has been investigated [10]. The authors stated that the investment cost of vertical bifacial photovoltaic modules (VBPV) does not differ from the cost of conventional PVs while for higher energy production the one face of the modules must be oriented to the east while the other face towards the west. They also mentioned that the annual electricity generation of vertical PVs is around 80-90% of the annual electricity generation of conventional PVs. The output characteristics of a VBPV in South Korea have been analyzed [11]. The authors investigated the performance of VBPV facing east and west. They stated that the peak power of VBPV was around 80% of the peak power of conventional bifacial PVs. The performance of vertical bifacial photovoltaics (VBPV) in high-latitude locations has been investigated [36]. The authors stated that VBPV have better performance in high-latitude locations with low solar elevation angle although they are exposed to a high risk of shadow losses. They mentioned that installation of VBPV on rooftops of buildings have high energy yields avoiding the shading effect of various objects.

## 3. Electricity demand in Crete

Island of Crete is the largest Greek island located in south-east Mediterranean region. Tourism industry is the main economic activity in Crete generating more than 50% of its wealth. The electric grid of Crete was so far isolated while it is nowadays interconnected with the grid of Continental Greece with two undersea water cables. The grids' interconnection is expected to be finalized by 2025. Several characteristics of Crete are presented in table 1.

**Table 1:** Several characteristics of the island of Crete

| Parameter | Value |
|---|---|
| Area | 833,600 ha |
| Population | 624,408 inhabitants (census 2021) |
| Electric grid | Currently isolated, the interconnection with the grid of continental Greece with two undersea electric cables is under implementation |
| Potential of renewable energy sources | Very high potential in solar and wind energy resources |
| Annual electricity generation from conventional ground-mounted silicon solar-PV modules without tracking system | 1,500-1,600 $KWh/KW_p$ |

Source: own estimations, [37]

The island of Crete has abundant solar and wind energy resources. However, due to the isolation of the electric grid and the requirement for its stability the electricity generation in Crete is so far dominated by oil-based fuels while the share of RES in the total power generation is limited. The electricity generation in Crete from fossil fuels and RES is presented in table 2.

**Table 2:** Electricity generation from renewable energies and fossil fuels in Crete (2018)

| Energy technology | Installed capacity (MW) | Electricity generation (MWh) | %, of electricity generation |
|---|---|---|---|
| Wind farms | 200 | 510,059 | 16.76 |
| Solar-PV systems (sited on fields) | 78 | | |
| Solar-PV systems (sited on rooftops) | 18 | | |
| Solar-PV systems (total) | 96 | 134,808 | 4.43 |
| Hydro power | 0.6 | 256.8 | 0.01 |
| Biogas burning | - | - | - |
| Total renewable energies | 297.6 | 645,124 | 21.20 |
| Thermal power plants using fuel and diesel oil | 824.6 | 2,397,876 | 78.80 |
| Total | 1,122.2 | 3,043,000 | 100 |

Source: [26]

Electricity demand is growing in Crete for many reasons. Assuming a 3% annual increase in power demand the island's annual demand until 2030 is presented in table 3.

**Table 3:** Annual electricity demand in Crete until 2030

| Year | Electricity demand (GWh) |
|---|---|
| 2018 | 3,043 |
| 2019 | 3,134 |
| 2020 | 3,228 |
| 2021 | 3,325 |
| 2022 | 3,425 |
| 2023 | 3,528 |
| 2024 | 3,634 |
| 2025 | 3,733 |
| 2026 | 3,845 |
| 2027 | 3,960 |
| 2028 | 4,079 |
| 2029 | 4,201 |
| 2030 | 4,327 |

Source: own estimations

Taking into account the electricity demand in Crete in 2025 at 3,733 GWh/year and the annual yield of solar photovoltaic modules in Crete at 1,600 $KWh/KW_p$ it is concluded that the nominal power of the required solar-PV systems to meet the electricity demand in the island in 2025 is 2,333.1 $MW_p$.

## 4. Solar photovoltaic technology

Solar photovoltaics is a fast-growing benign energy technology used for generation of carbon-free electricity worldwide. It is foreseen that due to their multiple advantages solar-PVs are going to be one major renewable energy technology used for power and heat generation by 2050. Generation of heat and electricity from solar energy is particularly beneficial in Crete due to the high solar irradiance in the island. Solar thermal heating systems are currently used for domestic hot water production and solar-PV systems for electricity generation. The power of the existing solar-PV systems in Crete are currently less than half of the installed power of the existing wind farms (table 2). Apart from the conventional silicon-based flat photovoltaic modules mounted on the ground and on rooftops of buildings several innovative solar photovoltaic systems have been developed [1,4,9,11] including:

a) Bifacial solar modules,
b) Building-integrated photovoltaics,
c) Semi-transparent photovoltaics,
d) Organic photovoltaics,
e) Floating photovoltaics,
f) Vertical mono-facial and bi-facial solar photovoltaics, and
g) Agrivoltaics.

Several of these innovative solar energy systems have been already commercialized while others need further development prior to their commercialization. Mounting solar-PV panels on the ground of fertile agricultural land in Crete might create conflicts with other land area uses including the use for food and animal feed production as well as for land preservation. Therefore, the installation of solar-PV modules on buildings' rooftops, on water reservoirs and on the ground allowing the dual use of land for energy generation and for food production should be examined.

## 5. Use of solar photovoltaics installed on rooftops of buildings

Solar photovoltaic modules can be mounted on the rooftop of public and private buildings including residential buildings. According to national census at 2011 the total number of buildings in Crete was 297,914 while the number of residential buildings 218,277. The average surface in residential buildings per person was evaluated 34.6 $m^2$/capita while the total surface of residential buildings in Crete was 21,604,517 $m^2$. Assuming that only 20% of the total surface of residential buildings will be potentially used for the installation of solar-PV modules on their rooftops the useful surface for power generation is 4,320,904 $m^2$. Assuming that the required surface for the installation of a conventional solar-PV system with nominal power 1 $KW_p$ is 10 $m^2$ the power of the solar photovoltaics which could potentially be installed in the area of 4,320,904 $m^2$ is 432 $MW_p$. The solar photovoltaics with nominal power 432 $MW_p$ could generate 691,200 MWh per year which correspond at 18.52

% of the annual electricity demand in Crete in 2025. The amount of electricity generation would be higher if the rooftops of non-residential buildings were considered for the installation of solar-PV modules or a percentage higher than 20% of the total surface of residential buildings was used for that. The potential power generation from solar-PVs installed on 20% of rooftops of residential buildings in Crete is presented in table 4.

**Table 4:** Potential of electricity generation from the installation of solar-PV modules on rooftops of residential buildings in Crete

| Parameter | Value |
|---|---|
| Number of residential buildings in Crete [37] | 218,777 |
| Average residential building surface per capita [37] | 34.6 $m^2$ |
| Population in Crete (census 2021) | 624,408 |
| Total surface of the residential buildings in Crete | 21,604,517 $m^2$ |
| Potential surface of residential buildings which can be used for the installation of solar-PV modules (20% of the total) | 4,320,904 $m^2$ |
| Nominal power of solar-PV modules that could be installed on buildings' rooftops (10 $m^2$ per $KW_p$) | 432 $MW_p$ |
| Annual electricity generation from the solar photovoltaics (1,600 KWh/$KW_p$ year) | 691,200 MWh |
| Total electricity demand in Crete (2018) | 3,733,000 MWh |
| Total energy demand in Crete which could be met from the electricity generated from the abovementioned solar-PV panels mounted on the rooftops of residential buildings | 18.52% |

Source: own estimations, [37]

## 6. Use of floating photovoltaics

Floating solar photovoltaics can be installed on water bodies saving the use of valuable land. Applications of FPV are growing worldwide particularly in countries with high population density. Crete has limited inland water bodies mainly used for irrigation of crops and domestic water use. The major water dams in Crete and the nominal power of FPV which can be installed on them covering 10% of their water surface are presented in table 5.

**Table 5:** Estimation of electricity generation with floating photovoltaics covering 10% of the water surface in the major water dams in Crete

| Name of water dam | Useable surface (10% of total) ($m^2$) | Nominal power of FPVs ($MW_p$) | Annual electricity generation (MWh) | %, of annual electricity generation in Crete (2025) |
|---|---|---|---|---|
| Potamon | 170,000 | 17 | 23,872 | 0.64 |
| Aposelemis | 160,000 | 16 | 22,468 | 0.60 |
| Ini | 22,600 | 2.26 | 3,174 | 0.09 |
| Mpramianon | 105,000 | 10.5 | 14,745 | 0.39 |

| | | | | |
|---|---|---|---|---|
| Faneromeni | 100,000 | 10 | 14,042 | 0.38 |
| Total | 557,600 | 55.76 | 78,301 | 2.10 |

Source: [31], 1 $MW_p$ FPV= 10,000 $m^2$, Electricity demand in Crete in 2025 = 3,733 GWh

The potential electricity generation from the abovementioned FPV, at 78.3 GWh, consist of only a small percentage, at 2.10%, of the annual power demand in the island.

## 7. Use of agrivoltaics

Apart from solar-PV systems installed on the rooftop of buildings in Crete additional solar electricity can be generated with solar-PV systems mounted on the ground. The main problem related with the use of ground-mounted solar photovoltaics is the conflicts which might happen with other land uses particularly with food production. This is particularly important in densely populated countries or in territories with limited cultivated land area resources. This problem can be overcome with the use of agrivoltaics which allow the dual use of land for power generation as well as for food, animal feed production and cattle grazing. The use of agrivoltaics is gaining popularity due to their multiple advantages during their installation in fertile land areas. The total area of the cultivated and uncultivated land in Crete is presented in table 6 while the required land area for the installation of several renewable energy technologies in table 7.

**Table 6:** Total area of cultivated and uncultivated land in Crete

| Prefecture | Land area (ha) | % of Crete's surface |
|---|---|---|
| Chania | 40,851 | 4.90 |
| Rethymno | 37,152 | 4.46 |
| Heraklio | 130,760 | 15.69 |
| Lasithi | 31,373 | 3.76 |
| Region of Crete | 240,137 | 28.81 |

Source: [37]

**Table 7:** Required land area for the installation of several renewable energy technologies

| Technology | Required land area– $Km^2$/GW | Required land area– $m^2$/GWh |
|---|---|---|
| Flat-plate solar-PV systems | 10-50 | 5,000-25,000 |
| Wind turbines | 100 | 140,000 |
| Biomass | 1,000 | 500,000 |
| Solar thermal systems | 20-50 | 10,000-20,000 |

Source: [12]

The required nominal power of the solar photovoltaic systems generating the electricity demand in Crete in 2025, at 3,733 GWh, is estimated at 3,733 GWh/1,600 (KWh/$KW_p$) = 2,333.1 $MW_p$. The necessary land area for the installation of these solar photovoltaic modules is 2,333.1 $MW_p$ X 2 (ha/$MW_p$) = 4,660 ha which corresponds at 1.94% of the total area of cultivated and uncultivated land in Crete and at 0.56% of its total surface. The nominal power of the solar-PV systems which can be installed on the total cultivated and uncultivated land in Crete at 240,137 ha, is 120.14 $GW_p$ They can generate 192,436 GWh/year corresponding more than 50 times the annual power demand in the island. The electricity which could be generated from solar photovoltaics in Crete sited on rooftops of buildings, on the ground of the cultivated and uncultivated land and on the surface of water bodies in Crete is presented in table 8.

**Table 8:** Electricity which could be generated from conventional solar photovoltaic systems in Crete sited on rooftops of buildings, on the ground of the cultivated and uncultivated land and on the surface of water bodies in Crete

| Type of solar-PV system | Nominal power ($MW_p$) | Area for the installation of the solar-PV systems (ha) | Annual electricity generation (GWh) | %, of the annual electricity demand in 2025 |
|---|---|---|---|---|
| Solar-PV sited on 20% of the surface of rooftops of residential buildings | 432.10 | 432.10 | 691.20 | 18.52 |
| Floating solar-PV on water bodies | 55.76 | 55.76 | 78.31 | 2.10 |
| Agrivoltaics | 120,140 | 240,137 | 192,436 | 5,155.00 |
| Total | 120,527.86 | 240,624.86 | 193,205.51 | 5,175.62 |
| Electricity demand in Crete in 2025 | | | 3,733 | 100 |

Source: own estimations

## 8. Use of vertical bifacial solar photovoltaic systems

Bifacial vertical solar-PV systems have been recently developed and used. They have slightly lower output compared to the conventional solar photovoltaic panels. According to experimental results in territories with almost the same latitude with Crete [11] the energy generation of VBPV was at around 66% of conventional bifacial PV. Their performance is better in high latitude locations while it is also influenced by the shading effect caused by trees and other objects located nearby them. Their main benefit is related with the limited land area that is required for their installation while their use is compatible with other land uses including food and animal feed production. Bifacial solar-PV panels are slightly more expensive than conventional "one face" solar-PV modules. However, the cost difference is often offset by their increased energy generation.

## 9. Discussion

The use of solar photovoltaic systems for meeting the power demand in Crete in several configurations avoiding land use conflicts has been studied. The nominal power of the required solar-PV systems has been evaluated and several unconventional configurations for their installation, different from their mounting on the ground, have been examined including: mounting them on rooftops of buildings, floating them on the surface of water bodies, siting them on the fields used for food production as agrivoltaics and as vertical photovoltaics. It has been indicated that the solar-PV technology is the most land-efficient renewable energy technology [12] while existing studies have estimated that many countries can generate all their power demand with solar-PV systems using less than 1% of their land surface [20], [23]. Installation of solar-PV systems of rooftops of buildings [1] and on the surface of water bodies [4], instead of mounting them on the ground, allows the use of valuable land for food production. Current advances in solar-PV technology including bifacial solar-PVs, semi-transparent solar modules, vertical solar-PVs [10] and agrivoltaics [32] allow the generation of solar electricity with less use of valuable and fertile land. Our results indicate that solar-PV systems can meet all the electricity demand in Crete in 2025 without hindering the use of valuable land areas for food production or for other uses. Installation of solar-PVs on the 20% of the rooftops' surface of residential buildings in Crete could meet the most of the power demand in the island while their installation on the rooftops of other types of private and public buildings could generate additional quantities of electricity. On the contrary their installation on the surface of inland water bodies could not generate significant amounts of electricity. It should be noted that only rough estimations regarding the electricity generation from agrivoltaics have been made while the electricity generation from vertical photovoltaics has not been evaluated. Further research should be focused on: a) a more accurate estimation of electricity generation from solar-PV modules sited on the rooftops of private and public buildings located in urban areas in Crete, b) an experimental investigation of the solar electricity yield from vertical bifacial solar-PV modules located in rural areas, and c) an estimation of the electricity generation from agrivoltaics sited on fertile land areas used for cultivation of several crops in the island.

## 10. Conclusions

The electricity demand in Crete, in 2025, and the evaluation of the required nominal power of solar photovoltaic systems to meet the demand as well as several unconventional configurations for siting the solar photovoltaic modules allowing the dual use of valuable land for food production and for other uses have been studied. Our results indicate that, apart from solar-PV panels mounted on the ground, solar photovoltaic modules can be sited on the rooftops of buildings, can float on the surface of water bodies, can site on fertile land allowing its use of food production and can be placed in vertical configuration without covering large land areas. The unconventional siting of solar-PV panels can generate significant amounts of electricity. Therefore, solar photovoltaics can meet the electricity demand in Crete achieving its energy self-sufficiency without creating conflicts with other land uses in the island. Our results indicate that a significant amount of electricity can be generated from solar-PV panels located on the 20% of the surface of rooftops of residential buildings, meeting 18.52% of the annual electricity demand, while the electricity generation from FPV on the existing water reservoirs in Crete is rather low meeting only 2.10% of the electricity demand. The electricity generation from VBPV has not been evaluated due to lack of experimental data in Crete while the lack of agrivoltaic installations on fertile or uncultivated land in Crete does not allow an accurate estimation of their potential in power generation. However, it has been evaluated that the potential of power generation from agrivoltaics, sited on cultivated and uncultivated land, in Crete is very high.

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