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Solar Energy Production Planning in Antikythera: Adequacy Scenarios and the Effect of the Atmospheric Parameters

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Abstract: The National Observatory of Athens intends to operate a European Climate Change Observatory (ECCO) on the island of Antikythera, which meets the criteria to become a first-class research infrastructure. This project requires electricity that is unprofitable to get from the thermal units of this small island (20 km^2). Solar energy is the subject that was examined in case it can give an environmentally and economically viable solution, both for the observatory and for the whole island. Specifically, observational and modeled data were utilized relevant to solar dynamic and atmospheric parameters in order to simulate the solar energy production by photovoltaics (PV) and Concentrated Solar Power (CSP) plant technologies. To this direction, a synergy of aerosol and cloud optical properties from the Copernicus Atmosphere Monitoring Service (CAMS) and the Eumetsat's support to nowcasting and very short range forecasting (NWC SAF) with Radiative Transfer Model (RTM) techniques was used in order to quantify the solar radiation and energy production as well as the effect of the atmospheric parameters and to demonstrate energy adequacy scenarios and financial analysis. The ultimate goal is to highlight the opportunity for energy transition and autonomy for both the island itself and the rest of the community with the operation of ECCO, and hence to tackle climate change.

Keywords: solar energy; adequacy scenarios; effect of atmospheric parameters; Antikythera

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1. Introduction

For both technical and economic reasons, the transfer of electricity to islands is a special and difficult case common to remote places [1]. As a matter of fact, until recently, the difficulty of transporting electricity to many remote places is solved by burning non-renewable energy sources and specifically by burning fuel oil and diesel at Autonomous Power Stations (APS) [2]. The Aegean Archipelago in Greece is a typical example of a remote area that includes a few hundred habitable islands that mostly meet 100% of their energy needs, or most of them, from non-renewable energy sources. The total number of the islands exceeds 2500, but only approximately 165 of them are in inhabited [3]. Many of the inhabitable islands are far away from the mainland. So, they need to be electrified by autonomous electrical systems and grids following the Greek energy policy and sustainable strategy for energy transition and security. These islands are defined as Non-Interconnected Islands (NII) by the Greek legislation and the Regulatory Authority of Energy (RAE) [4].

The NII, according to the Hellenic Electricity Distribution Network Operator (HEDNO), have the following characteristics:

(1) The area and population of these islands present significant variance and are inaccessible in terms of coastal shipping lines;
(2) The renewable energy potential in terms of solar wind power is timeless and high;
(3) There is no interconnection with the electricity grid of the mainland, resulting in low energy adequacy, stability and overall security;

(4) The lack of interconnection with the main land introduces voltage and frequency issues, especially under high distributed energy incorporation levels from renewables [5].

Over the years, it seems that, one of the best alternatives is the use of RES [6,7]. Some of the islands that follow a path to energy independence are Chalki, Agios Eustratios, Astypalaia and Nisyros. An exception to the rule of using non-renewable energy sources is the island of Tilos that runs on renewable energy, under the European Commission Horizon 2020 TILOS program [8]. Of course, the challenges for such a project vary but when an extensive study of the data and appropriate simulations is done, the prospects are many and very likely to work as it has been studied with the most efficient results provided by the technology of RES [9]. The design and implementation of energy projects has increased in recent years on islands, such as those mentioned above, as they are quite small, remote and difficult to connect with the rest of the grid. So, this study focused on Antikythera (Figure 1) because it is still an island with these features and is considered, after a study by the National Observatory of Athens (NOA), an ideal place for the collection of climatic and geophysical data due to the minimal pollution and its small anthropogenic activity.

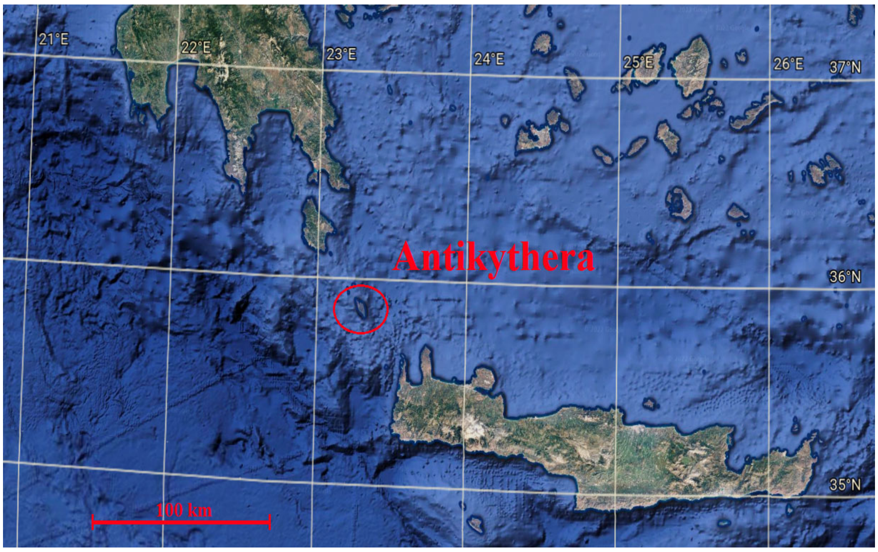

Figure 1. Study region and the specific location of Antikythera.

Antikythera is located at the crossroads of the gas masses coming from the Sahara Desert, the volcano of Mount Etna and important cities of the Mediterranean. Its position is privileged as it is located between the large electrical grid of the Peloponnese and Crete and at the same time near the island of Kythera, which has medium energy requirements. The area of the island reaches 20 km^2 and the population is 59 inhabitants according to the latest analytical census of 2011. The island has a very small population, so it has limited energy consumption of approximately 250–300 MWh/year and covers it through a Public Power Corporation (PPC) thermal plant. The maximum load of the island is 100 kW and the PPC station operates 4 thermal units, each one is 90 kW. Despite this, the average load of the island is 25 kW per hour and increases during the summer period due to tourism. The cost of electricity generation is quite high 1.500 euro/MWh, so it is 30 times higher than the average cost of the mainland country. Due the construction of the European climate change observatory (ECCO), the demand load will increase considerably, so a way had to be found to cover these energy needs which would be based on renewable energy sources (RES). Hence, the installation of RES as the most eco-friendly and economical solution was the subject of this study [10].

Greece has climatologically high solar energy potential levels based on long-term measurements and observations [11] and especially the island of Antikythera, as presented in Figure 2 by incorporateing all atmospheric and terrain effects [12].

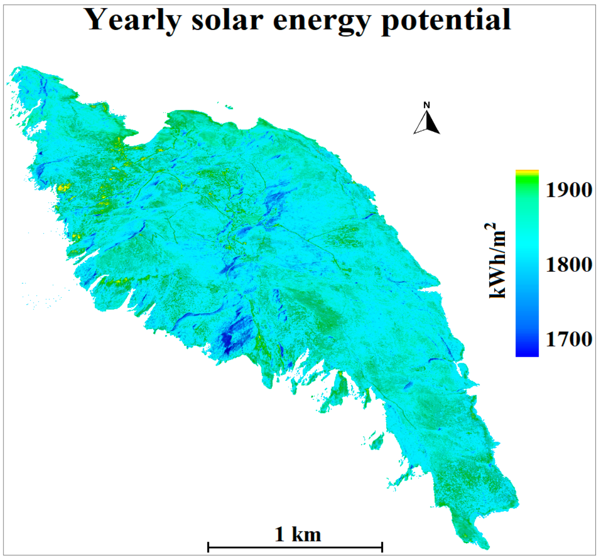

Figure 2. Annual solar energy potential of Antikythera.

The Greek islands that are located in this area are characterized by high solar potential even in the winter months [13]. This is combined with a poor electricity network infrastructure, which makes the study of PV and CSP technologies necessary as an alternative solution. According to other studies for islands of Greece and corresponding areas with high solar dynamic, such as Antikythera, it seems that the utilization of solar energy is efficient both at the environmental and economic levels [14,15]. Additionally, Antikythera is a passage of migratory birds, making the wind turbine technologies unsuitable for the local ecosystem and as a result, the selection of solar plants is a one-way decision for local energy transition. The two solar technologies (PV and CSP) could be a hybrid solution in order to take advantage of the features of each technology. Specifically, the advantages of those two are the low-cost power supply that is directly produced from PV during the daily hours with the higher solar irradiation, and the baseload dispatchable power produced by the CSP [16].

For the island of Antikythera, Earth Observations were used in terms of solar irradiation and environmental parameters such as Global Horizontal Irradiation (GHI) and Direct Normal Irradiation (DNI) under all sky and clear sky conditions as well as Aerosol Optical Depth (AOD) and Cloud Optical Thickness (COT), on a climatological basis during the years of 2005–2020. Based on the aforementioned data, we calculated the Cloud Modification Factor (CMF) for both GHI and DNI, and the corresponding parameter for the Aerosols, which is named "Aerosol Modification Factor" (AMF). These parameters are of interest as they directly affect the operation of PV and CSP [17]. The combination of the Earth Observation data in conjunction with solar irradiation simulation set the ground for a number of realistic energy planning scenarios that will address the energy autonomy of the island. As a result, the formulation of the energy plans is based on Earth Observation data for Antikythera and modeling techniques that are necessary to utilize existing technologies. In this research the main interest is related to the current and the near future adequacy scenarios of the energy supply sources, as well as the effect of atmospheric parameters into the energy production, so both satellite and model based data were utilized in the direction of representative energy planning and management deployment. In such a nature of research, the utilization of the above and the specific approach are common [18–20]. Section 2 presents the data and methods used for the implementation of this study, Section 3 analyzes the results and the various solar energy planning scenarios, while Section 4 provides an interdisciplinary discussion that combines the energy related quantities with a financial analysis. Finally, in Section 5, the conclusions are presented, highlighting the main findings and the value of such studies for the islands energy transition, overall autonomy and sustainability.

2. Materials and Methods

2.1. Data Sources

For the purposes of this study, Earth Observation data sources and tools were exploited since there are no long-term ground-based measurements in the island of Antikythera in order to quantify the climatological levels of the solar energy potential as well as the atmospheric parameters effect. In this direction, for the aerosol effect on solar energy production, we used the Copernicus Atmosphere Monitoring Service (CAMS) with the total Aerosol Optical Depth (AOD) at 550 nm. CAMS is based on the reanalysis tool and its aerosol type classification identifier, which is named Monitoring Atmospheric Composition and Climate (MACC) [21]. In order to have consistent data correction, we included modeling aerosols and satellite AOD data assimilation from MODerate resolution Imaging Spectroradiometer (MODIS) and other data sources, to CAMS data set [22,23]. The AOD is a result of (a total of three) individual algorithms that works separately over dark continental and maritime places [24,25]. At the same time observations over land areas with limited vegetation coverage or high surface albedo (except for snow or ice covered places) are possible due to the Deep Blue Algorithm [26,27] applied in various studies [28,29]. The magnitude of uncertainty of model inputs to the Radiative Transfer Model (RTM), which in our case is the AOD, is from −0.1 in winter to 0.2 in summer in terms of mean bias against Aeronet sun photometer data [22]. In addition, the CAMS AOD is concerned to the period between January 2005 and December 2020 with time steps of 3 h and a 0.4-degree spatial resolution for the island of Antikythera. Concerning the cloud effect on solar energy, we used data from the Meteosat Second Generation (MSG) which accelerated the nowadays evolution of real time image processing techniques. With such Earth Observation techniques, we are given the opportunity to know numerous meteorological variables in almost real time [30]. In this study the cloud optical properties were extracted by using the Satellite Application Facility for supporting Nowcasting (SAFNWC) and very short range forecasting, which is distributed by EUMETSAT and is widely used such as in cloud microphysics algorithms [31], including the cloud optical thickness (COT) parameter [32]. For the purposes of this study, the COT was used collocated with the AOD time series.

2.2. Solar Energy Simulation

To estimate the power generation from solar plant systems, it is necessary to know the solar irradiance that reaches the PV panels and the CSP mirrors. The GHI is the irradiance that PV exploit while DNI is the corresponding irradiance that the CSP converts into thermal energy. Lower values for both GHI and DNI represent a higher occurrence of clouds, higher atmospheric pollution or higher water vapor content. For the solar radiation simulations, we based on Radiative Transfer Model (RTM) simulations that are produced by libRadtran [33] and its rapid version based on Look Up Tables and Artificial Intelligence methods [34]. In order to get data on solar radiation as well as the PV system energy production and to determine numerical calculations, we used the Photovoltaic Geographic Information System (PVGIS) [35]. For solar energy production planning, we took into account the energy that the island of Antikythera needs after the construction of ECCO will take its final fully operational form. It is estimated that the total energy that is required for both island and ECCO is approximately 811 MWh per year following the methodology of similar studies [36] from which the island's needs are 271 MWh and the rest, 540 MWh, is required by the ECCO (approximately 45 MWh per month).

In addition, it is very important to know the total amount of losses of systems based on real world solar applications. Thus, we used certificated and secure systems in the protocols from all around the world based on the International Energy Agency (IEA). Firstly, for the quantification of aerosols, some significant magnitudes have to be mentioned. Specifically, aerosols can block sunlight through scattering and absorption and the AOD is a dimensionless measure of the direct solar irradiation attenuation at ground level due to particulate matter. The CAMS daily forecasts provide values for total AOD as well as individually for sea salt, desert dust, organic matter, black carbon and sulphate aerosols. A value of 0.01 corresponds to an extremely clean atmosphere, and a value of 0.4 would correspond to a very hazy condition [19,20]. The aerosol effect on solar energy can be expressed by the aerosol modification factor (AMF), which is calculated by the formula:

$$AMF = GHI0/GHI00 \tag{1}$$

where GHI0 is the radiation under clear sky conditions and GHI00 is the radiation under clean (from aerosols) and clear (from clouds) sky conditions.

Moreover, the cloud's optical thickness (COT) is the corresponding dimensionless measure of the irradiation attenuation because of the clouds scattering and absorption through its optical properties and microphysics. Clouds do not absorb visible wavelengths of sunlight, but they scatter and reflect most visible light. In order to quantify the clouds' effect on solar energy, the cloud modification factor (CMF) is calculated by the formula:

$$CMF = GHI/GHI0 \tag{2}$$

where GHI is the radiation under all sky and GHI0 is the radiation under clear sky conditions. The aforementioned quantities of AMF and CMF take values between 0 and 1, indicating the clear sky GHI0 with 1 (i.e., no cloud effect) and all the lower values characterizing the GHI under the clouds effect. Similarly, the GHI00 with a 1 value indicates clean and clear sky irradiation. This approach gives the opportunity to separately estimate the independent effect of aerosols and clouds on solar energy.

2.3. Financial Analysis

The financial analysis was performed by simulating a series of hypothetical scenarios of PV and CSP systems and various combinations and nominal power outputs following the methodology described in [37,38]. For the solar PV energy production estimations, the most common PV materials were simulated with an average efficiency of 16% and at the same time the shadowing effect from the surroundings was set to 4% as a representative value unobstructed from the visual horizon solar plant installations [38]. Therefore, the remaining efficiency of 80% has been converted to PV output energy based on the nominal power and electricity converter technology and AC/DC efficiency. Our hypothetical scenarios and their nominal power levels include PV and CSP solutions by using the actual power performance in MW instead of peak power in MWp, which is based on the production under ideal conditions. In case of interconnection with the grid, the Feed in Premium (FiP) scheme can be exploited, which essentially replaces the Feed in Tariff (FiT) scheme, in European Union islands during December 2016 for solar farms bids ranged between 79.97 € and 88 € per MWh [39,40]. In fact, in a future financial analysis it could include the "FiT or FiP parameter" and definitely predict the maintenance cost of the solar panel cleaning, for example, after dust deposition [41–43]. The PV and CSP energy production was converted into the financial annual revenues and losses following the equations presented in [37,38]:

$$\text{Revenue (€)} = \text{Energy production (EP in kWh)} \times \text{Electricity price (€/kWh)} \tag{3}$$

The financial losses (FL) are described as:

$$FL = (EP_{max} - EP_{actual}) \times (\text{Electricity price}) \tag{4}$$

The FL is the financial loss in euro (€), EP_{max} is the maximum energy produced in kWh by assuming the absence of aerosols and a sky clear from cloud conditions. This technically means that the AOD and COT will be zero, while the EP_{actual} is the actual energy production under all sky conditions, i.e., the AOD and the COT are included in the calculations.

3. Results

3.1. Aerosol and Cloud Effect on Solar Radiation

Figure 3 presents the monthly average of the aerosol and cloud parameters and their effect on solar irradiation in terms of GHI and DNI. Firstly, in Figure 3a, we used the 3-h data of the Aerosol Optical Depth (AOD) and four major aerosol types, which are Dust (DUAOD), Black Carbon (BCAOD), Sea Salt (SSAOD) and Sulfate (SUAOD). From these observations, we calculated the concentration values of monthly AOD and the highest value levels were shown during spring (March, April and May) with values over 0.26, which is mainly due to high concentration of DUAOD and secondarily to the concentration of SUAOD. Figure 3b shows the monthly average of CMF, which is calculated based on the 15-min observations of COT following the periodicity that are obtained and collocated to the AOD data time-steps (i.e., 3 h). At the same time, a corresponding curve for aerosols (AMF) was calculated, which is based on the 3-h measurements of AOD. On one hand, CMF shows a normal gradual increase during the first 7 months of the year and a reduction in the remaining months, which means that the effect of clouds is minor during summer months and increases in the rest of seasons, following the climatological conditions of the wider region. AMF has an unpredictable development during a year with sharp fluctuations in agreement with Figure 3a findings. The higher dust levels during spring months is depicted with the lower AMF values during these months. The highest AMF climatological values were found in winter, highlighting the minor anthropogenic activities in the island and the subsequent low effect on solar energy. The quantification of both quantities is very important for the calculation of solar radiation losses and therefore the total energy production of PV and CSP technologies.

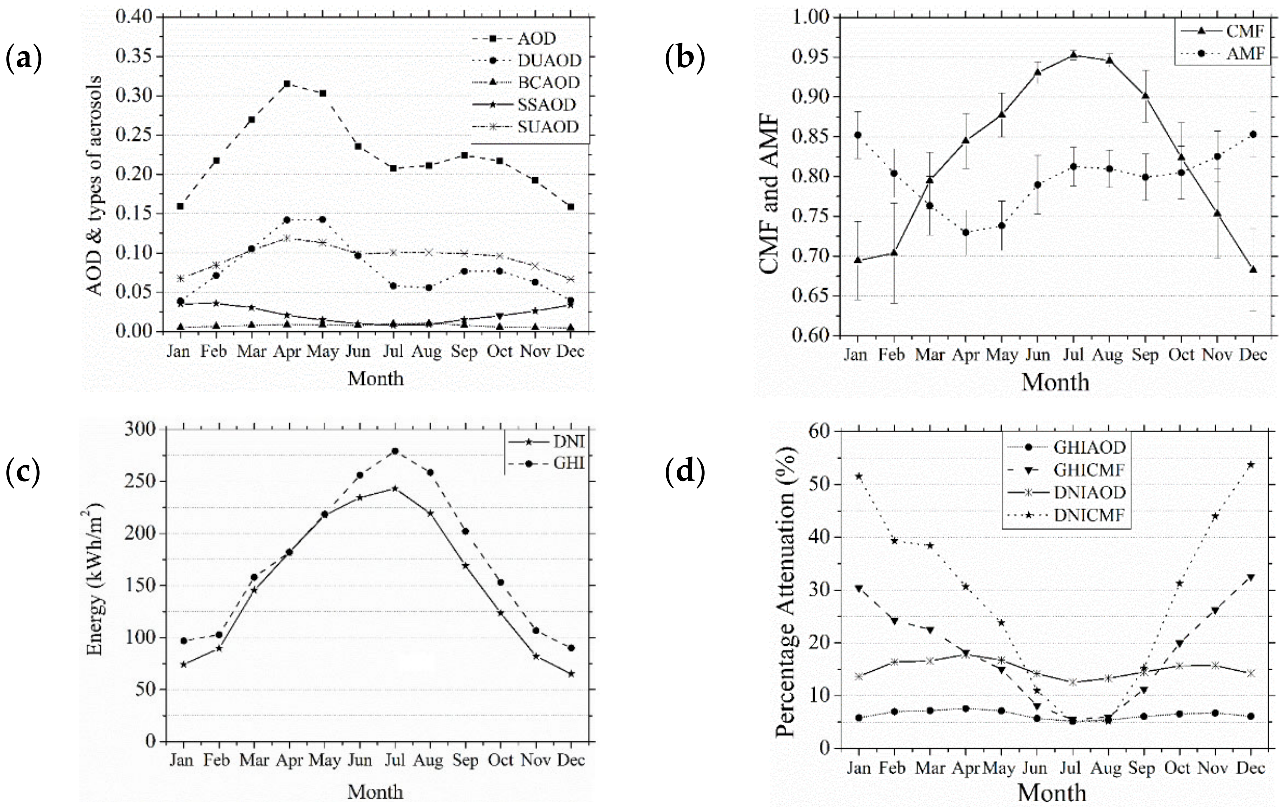

Figure 3. Monthly panels plot for (**a**) average of AOD and specific types of aerosols, (**b**) average of CMF and AMF, (**c**) average of GHI and DNI and (**d**) percentage attenuation of DNI and GHI because of CMF and AMF.

Figure 3c presents the monthly average of GHI and DNI which emerge from the COT and AOD effect in the climatological database. The monthly averages of GHI and DNI are necessary in order to calculate the monthly production of energy by PV and CSP, respectively, and to organize the most efficient energy plans, both environmentally and economically, for the island of Antikythera. As far as Figure 3c is concerned we observe that the amount of GHI is as expected, greater than the DNI following the radiation geometries. At this point, it is important to emphasize that the superiority of DNI does not mean that CSP produces more energy than PV. On the contrary, for the same energy input for the same areas, as can be seen from the energy plans, PV produces more energy. The purpose of Figure 3d is to highlight the percentage attenuation of GHI and DNI, which are represented in absolute value, due to AMF and CMF. These values are a result of simulations performed through the Radiative Transfer Model (RTM), as was explained in Section 2. The losses due to AOD include the aerosol effect, in addition, the CMF losses only include the effects of clouds. In general, the effect of aerosols is much more stable than the effect of clouds, during a year similarly to studies in other regions [44]. Hence, the losses associated with AOD are relatively constant during the year compared to losses due to clouds, which show very large variations. Especially, the percentage attenuations due to CMF are smallest during summer months, which are related to its upper limits of CMF and GHI or DNI in each case. The other two curves show the same configuration for these months but to a much lesser degree. All of this information helped in order to make radiation balances and from there the subsequent energy planning scenarios in the following Section 3.2.

3.2. Energy Planning Scenarios

The energy planning scenarios were based on the hypothesis that we need to fulfill the energy requirements of the island for the most months of the year, so we calculated the required nominal power, always considering the new energy needs after the start of operation of the European Climate Change Observatory (ECCO). For the whole island without the ECCO consideration, we estimated the energy needs to be close to 271 MWh per year as referred by the Greek Independent Power Transmission Operator (IPTO). For the energy requirements of the ECCO, an estimated amount of 540 MWh annually was incorporated (a stable amount of almost 45 MWh per month). The total annual energy requirements are 811 MWh, which is the energy target that must be fulfilled. The energy planning strategy designed, as well as the individual scenarios developed in the following, are built on the basis of these energy requirements that were previously mentioned. The scenarios that will be presented and analyzed including both PV and CSP solutions and combinations are for: 200 KW PV system for the current island energy needs (scenario 0), 500 KW PV with the ECCO included in a fully operational form (scenario 1), 500 KW PV with the ECCO included operating with minimum activity during the period from November to February (scenario 2) and 700 KW, including the 500 KW PV and additionally a 200 KW CSP (scenario 3).

Many studies have estimated the optimum tilt angle for maximum solar energy production levels for the PV installations, and the common conclusion was that the difference between latitude and optimal tilt angle is larger under cloudy conditions on a climatological basis. On the other hand, under more cloudless conditions, the tilt angles differences between the optimal and the latitude are significantly smaller, promoting the selection of the latitude based tilts [45]. The latitude of Antikythera is 35.855° North, so regarding the tilt of the panels, 36° with a southern orientation is considered taking into account that climatologically the island is characterized as a cloudless region.

Figure 4 presents the solar irradiation that reaches the PV systems with horizontal panels and with optimal south-faced inclined panels at 36 degrees, PV with a 2-axis tracker which follows the sun, and finally for CSP installations. Based on the above climatological calculations it appears that the most balanced PV installation solution in order to exploit efficiently the solar yield is the inclined planes at 36 degrees. This is because, whilst the 2-axis tracker PV can increase the energy potential by 23.7 and 15.4% as compared to the horizontal and tilted PV, respectively, this solution is able also to significantly increase the total installation cost and needs demanding maintenance and support because of the moving parts [46]. At the same time, the tilted PV panels provide a larger energy production potential during the winter months as compared to the horizontal panels, where the solar irradiation levels cannot cover the average energy consumption. So, the energy scenarios 0, 1 and 2 for the solar plant in Antikythera are based on the 36 degrees PV installations and in conjunction with the CSP in scenario 4. As a result, the total mean monthly energy input of Figure 4 indicates that the available energy potential for the horizontal PV is 1845 kWh/m^2; for the PV at 36° degrees, it is 1978 kWh/m^2; for the sun tracker based PV, the energy rises to 2283 kWh/m^2; and finally, for the CSP technologies the input energy is 1312 kWh/m^2 since its exploit the DNI.

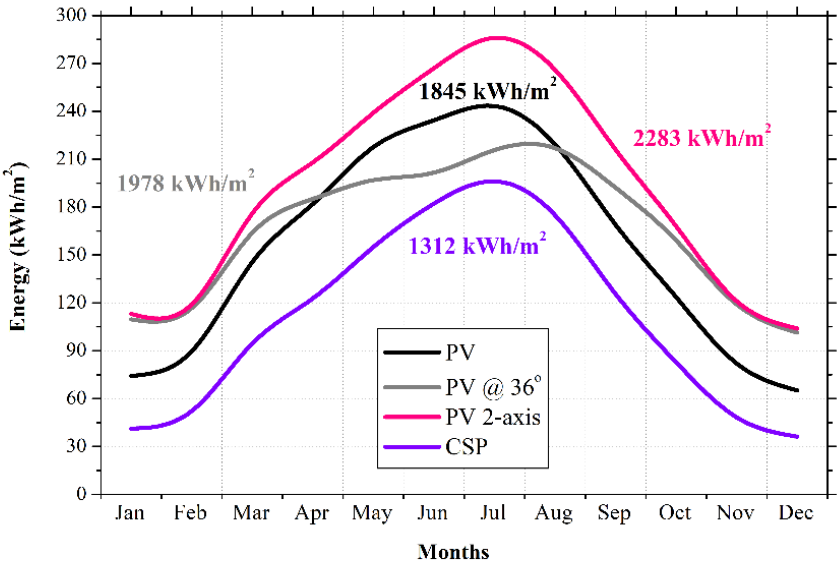

Figure 4. Mean solar energy input to the PV and CSP systems in a monthly time horizon (in kWh/m^2). The inset values represent the annual total energy.

The most balanced PV solution in terms of energy production levels during the whole year period is that with inclined panels at 36 degrees. As a result, for the selected energy planning scenarios, the energy output was simulated for the Crystalline Silicon (CS) panels material, which presents combined losses of the order of 29%, and the Cadmium Telluride (CdTe) with average losses of almost 20%. Concerning the CSP technology, the Parabolic Trough (PT) and the Solar Tower (ST) were used in this study, which present more efficiency as compared to the PV alternatives in terms of collectors/mirrors surface and energy storage but much less efficiency per total land surface coverage [46,47].

The energy output per square meter for the PV CS is 102.97 kWh/m^2 and for the PV CdTe, it is 115.44 kWh/m^2 (Table 1). For the CSP PT and ST the energy outputs per square meter of mirrors are 204.77 and 292.51 kWh/m^2 (scenario 3), respectively, (indicating the better collectors' efficiency), while the energy outputs per square meter of total land surface (mirrors + facilities) are 68.26 kWh/m^2 for the PT and 53.77 kWh/m^2 for the ST (indicating the less land surface efficiency). The required area for each scenario and technology in m^2 was also calculated providing useful information for the solar plants planning and installation part.

Table 1. Summary table of scenario zero on average energy output, required installation area, energy production, energy consumption and energy coverage (the deficits were highlighted in red) per month.

Scenario 0	Output (kWh/m^2)	Output (MWh)	Area (m^2)
PV CS 200 KW	102.97	416.47	4044.58
PV CdTe 200 KW	115.44	416.47	3607.67
Months	**Output PV (MWh)**	**Consumption (MWh)**	**Energy Coverage Percentage %**
Jan	23.08	23.00	100.35
Feb	24.57	21.00	117.01
Mar	34.50	22.00	156.81
Apr	38.97	20.75	187.79
May	41.45	21.00	197.38
Jun	42.44	22.00	192.91
Jul	45.42	26.25	173.02
Aug	45.67	29.00	157.47
Sept	40.46	24.25	166.83
Oct	33.50	20.75	161.47
Nov	25.07	19.50	128.56
Dec	21.34	21.50	99.28

3.2.1. Current Energy Needs of the Island

This scenario (called zero) describes a total 200 KW PV system, which consists of two different options based on the PV material, i.e., Crystalline Silicon (CS) of 200 KW or Cadmium Telluride (CdTe) of 200 KW. The purpose of this scenario is to cover the existing energy needs of the island. It is reminded that for the whole island the estimated energy needs are approximately close to 271 MWh per year. Specifically, in August the consumption of the island reaches 29 MWh, while the lowest value is observed in November at 19.5 MWh. In order to understand if this scenario is suitable for 100% coverage of the energy needs, Figure 5 presents the production and consumption energy for each month based on energy planning scenario 0 and a summary table on average energy production, energy consumption and energy coverage per month is presented in Table 1. Based on the results obtained, we noticed that the energy production from the photovoltaics is quite adequate each month and the surplus electrical energy gives the opportunity to distribute electricity to the rest of the grid with which the island is not connected to this today. The only month that is not 100% covered is December, reaching 99.28% and indicating the need for a small supply support from the existing PPC thermal units.

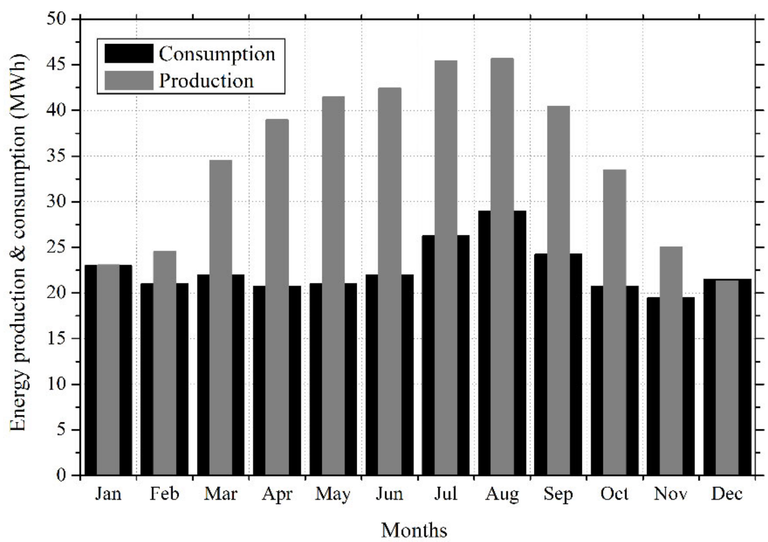

Figure 5. Monthly average production and consumption for scenario zero.

3.2.2. Energy Need after the ECCO Establishment

Scenario 1

This scenario is a total 500 KW PV that consists of a CS of 500 KW oran option for a CdTe of 500 MW. The purpose of this scenario is to cover the energy needs of the island and of the ECCO under its full operational phase (i.e., 45 MWh/month). The numerical calculations for the 1st scenario were based on the average monthly tilted GHI input and the average monthly energy consumption (after ECCO construction), which was assumed to be close to 811 MWh. This design was tested in terms of performance for each month and hence Figure 6 depicts the production and consumption energy for each month and Table 2 analyzes the average energy production, energy consumption and energy coverage per month.

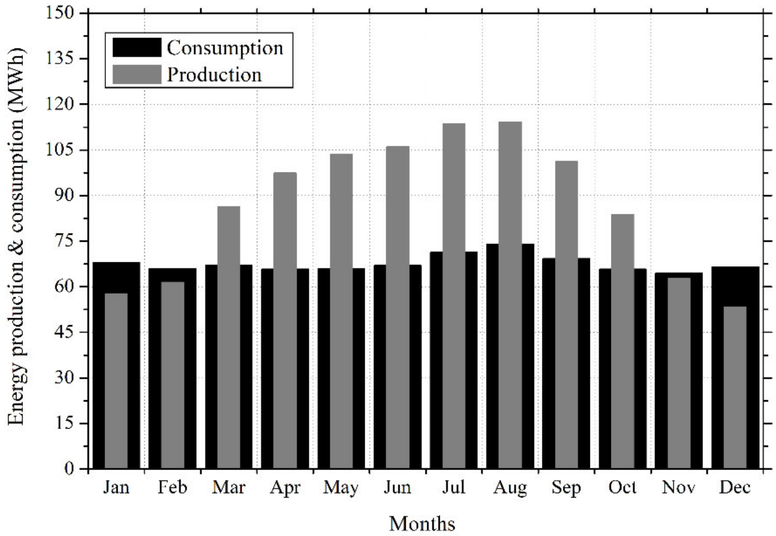

Figure 6. Monthly average energy production and consumption based on scenario 1.

Table 2. Summary table of scenario 1 on average energy output, required area, energy production, energy consumption and energy coverage (the deficits were highlighted in red) per month.

Scenario 1	Output (kWh/m^2)	Output (MWh)	Area (m^2)
PV CS 500 KW	102.97	1041.16	10,111.29
PV CdTe 500 KW	115.44	1041.16	9019.06
Months	**Output PV (MWh)**	**Consumption (MWh)**	**Energy Coverage Percentage %**
Jan	57.70	68.00	84.85
Feb	61.43	66.00	93.07
Mar	86.24	67.00	128.72
Apr	97.42	65.75	148.16
May	103.62	66.00	157.00
Jun	106.10	67.00	158.36
Jul	113.55	71.25	159.36
Aug	114.17	74.00	154.28
Sept	101.14	69.25	146.05
Oct	83.76	65.75	127.39
Nov	62.67	64.50	97.17
Dec	53.36	66.50	80.24

According to the initial conditions that were mentioned in terms of steady monthly average energy consumption of ECCO, the results from Figure 6 and Table 2, show that this scenario provides 100% energy adequacy for the months from March to October, 93.07–97.17% energy coverage for February and November and the rest of the months 80.24–84.85% percentage coverage (i.e., December and January). As a result, this scenario cannot be acceptable in the current form since it does not provide a 100% energy coverage in 4 out of the 12 months. Consequently, fuel oil and diesel at the Autonomous Power Station (APS) will be needed to cover the energy consumption. However, a supplemental energy supply from the existing infrastructure can be taken into account on a transitional basis.

Scenario 2

This scenario is a total 500 KW PV scenario that consists of two different options based on the PV material, similar to scenario 1. The first option is CS 500 KW and the second option CdTe 500 KW. The qualitative difference has to do with the energy consumption levels of ECCO for which a minimum activity was assumed from November to February. To this end, during these months the average energy needs were reduced to 30 MWh per month from the initial 45 MWh, while the corresponding island needs remained at the same levels (19.5–29 MWh). The main purpose of this scenario is to cover 100% of the energy needs of the island and of the ECCO under the aforementioned operating conditions. Figure 7 and Table 3 indicate the achievement of this objective with a coverage percentage of more than 100% during all months, from 103.62 in December up to 159.36% in July. The required area for the PV installation of this scenario is of the order of 9019.06–10,111.29 m^2 for the CdTe and CS, respectively. The results of scenario 2 provide the opportunity for Antikythera to become an energy autonomous island with a slight adjustment of the ECCO energy consumption from November to February. This means that a lower activity plan has to be considered and the winter scientific campaigns limited in order to reduce the hosting, maintenance and operation energy requirements. The surplus electrical energy from March to October, sets the ground for a sustainable tourism development and similar to the previous scenarios, it enables the energy incorporation to the mainland electrical grid once the island of Antikythera is electrically interconnected.

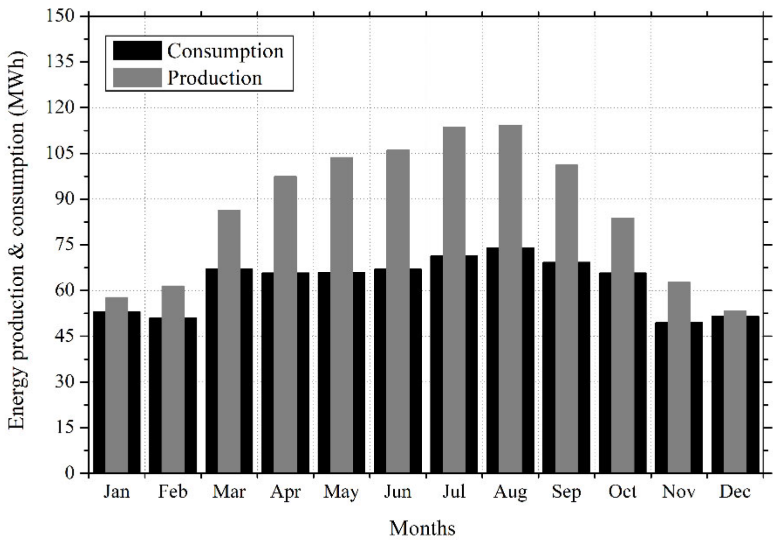

Figure 7. Column bars of monthly production and consumption based on scenario 2.

Table 3. Summary table of scenario 2 on average energy output, energy production, energy consumption and energy coverage per month.

Scenario 2	Output (kWh/m^2)	Output (MWh)	Area (m^2)
PV CS 500 KW	102.97	1041.16	10,111.29
PV CdTe 500 KW	115.44	1041.16	9019.06
Months	**Output PV (MWh)**	**Consumption (MWh)**	**Energy Coverage Percentage %**
Jan	57.70	53.00	108.87
Feb	61.43	51.00	120.45
Mar	86.24	67.00	128.72
Apr	97.42	65.75	148.16
May	103.62	66.00	157.00
Jun	106.10	67.00	158.36
Jul	113.55	71.25	159.36
Aug	114.17	74.00	154.28
Sept	101.14	69.25	146.05
Oct	83.76	65.75	127.39
Nov	62.67	49.50	126.61
Dec	53.36	51.50	103.62

Scenario 3

In this last scenario 3, a hybrid system was tested consisting of 500 KW PV (Crystalline Silicon or CdTe) and 200 KW CSP (Parabolic Trough or Solar Tower) technologies in order to utilize both forms of radiation and technology and reach a maximum supply of 700 KW in total. Figure 8 depicts the production and consumption of energy for each month, while a summary Table 4 reports on average output energy, energy production, energy consumption and energy coverage per month. It has to be noted that in scenario 3 the ECCO energy consumption was assumed to be 45 MWh per month indicating its fully operational form (similar to scenario 1). The results from Figure 8 and Table 4, show that the final energy coverage percentage for December that this scenario provides is 97.48%, requiring minimum energy supply to support the thermal units. During the other months, there are adequate percentages of production in relation to future energy needs, which are from 104.11 in January up to 246.75% in summer months. The required area of scenario 3 is 9019.06–10,111.29 m^2 for the PV and 6101.2325–7745.40 for the CSP plant, following the corresponding material (CS and CdTe) and technological (PT and ST) options.

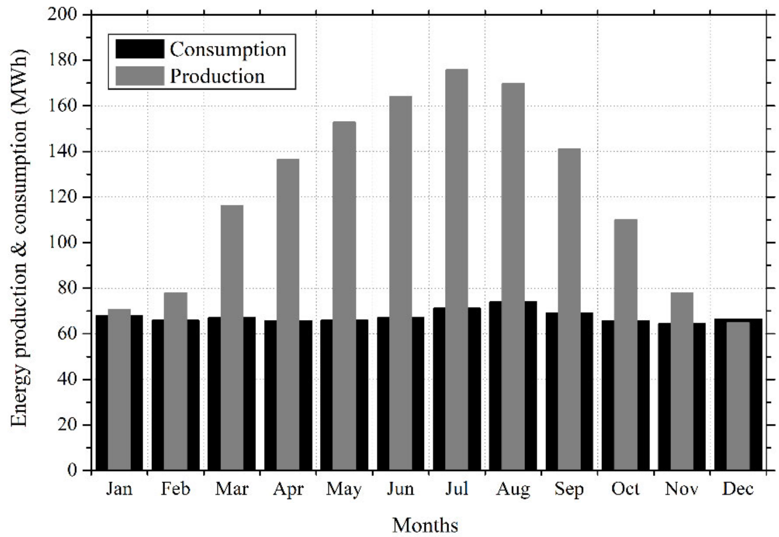

Figure 8. Column bars of monthly production and consumption based on scenario 3.

Table 4. Summary table of scenario 3 on average energy output in terms of actual exploited area and mirror based for PV and CSP technologies, respectively, required area, energy production, consumption and percentage coverage (the deficits were highlighted in red) per month.

Scenario 3	Output (kWh/m^2)	Output Mirrors (kWh/m^2)	Output (MWh)	Area (m^2)	Mirrors (m^2)
CSP PT 200 KW	68.26	204.77	416.47	6101.23	2033.84
CSP ST 200 KW	53.77	292.51	416.47	7745.40	1423.78
PV CS 500 KW	102.97	102.97	1041.16	10,111.29	10,111.29
PV CdTe 500 KW	115.44	115.44	1041.16	9019.06	9019.06
Months	**Output 500 + 200 KW (MWh)**		**Total Consumption (MWh)**	**Energy Coverage Percentage %**	
Jan	70.79		68.00	104.11	
Feb	78.02		66.00	118.21	
Mar	116.26		67.00	173.52	
Apr	136.40		65.75	207.45	
May	152.82		66.00	231.54	
Jun	163.95		67.00	244.70	
Jul	175.81		71.25	246.75	
Aug	169.70		74.00	229.33	
Sep	140.99		69.25	203.60	
Oct	110.05		65.75	167.37	
Nov	78.00		64.50	120.92	
Dec	64.82		66.50	97.48	

The advantage of scenario 3 as compared to the previous scenarios is the ability to store by default a large amount of energy since PV technology requires a storage system in the form of batteries in order to be able to supply energy during night time or during storms. The CSP plant technologies first convert the direct solar irradiation into thermal energy in the form of molten salt or oil, before conversion to electrical energy becomes possible (via steam turbines). This fact indicates that the CSPs can store, by their nature, energy in thermal form during the intermediate step. On the other hand, the PVs generate electrical energy directly from the total solar irradiation, and this can only be stored in battery systems or converted into hydrogen, which are rather expensive and the feasibility in practice of operating such large storage systems and technologies is questionable [46]. In this direction, a 2800–3000 kWh lithium battery for the 500 KW PV system part is able to support the overall energy flow and electricity stability in the intraday operations.

4. Discussion

Figure 9 presents a time series of simulated solar energy production in Antikythera, in the form of contour plots during the years 2005–2020, highlighting the maximum values during summer months and near the local noon time window (i.e., 10:30 UTC). The contour plots show the hourly energy production for each time of the day throughout the year, indicating the changes in production during winter months and near sunrise and sunset. The hours that appeared to be the peak of energy production are approximately 8:00–11:00. This could motivate future work to use a 2-axis tracker, which increases the energy potential [46] compared to the option of the horizontal panel and that with tilted panels. Of course, such an option greatly increases the financial cost, so it is proposed as safer (for both energy efficiency and cost) and an initial solution, "the mature technology" with inclined panels. It also has to be noted that the contour plot of scenario 3 (Figure 9c) indicates the advantage of the CSP storage solution contribution to the overall hybrid system usefulness (i.e., 500 KW and 200 KW CSP) which enables the high energy production lengthening within the course of the day in order to achieve an effective energy adequacy.

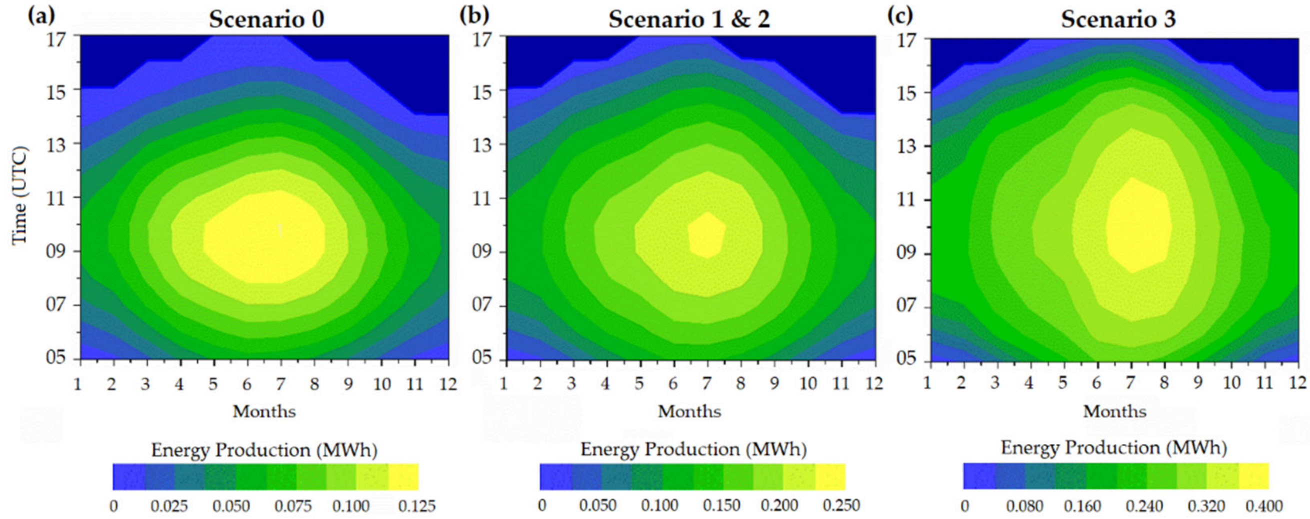

Figure 9. Contour plots of hourly energy production for each day of the year (**a**) scenario 0 of 200 KW PV (**b**) scenarios 1 and 2 of 500 KW PV and (**c**) scenario 3 of 500 KW PV and 200 KW CSP.

Figure 10 presents the financial analysis from January to December under different energy production scenarios for the island's needs (scenario zero in Figure 10a) and including the ECCO energy consumption (scenarios 1, 2 and 3 in Figure 10b,c). The energy production is seen to be at maximum in the summer months from May to July in all scenarios. Figure 10a shows the 200 KW PV energy production plant (scenario zero) with a total production of 416 MWh and a total revenue generation of 33,408 EUR. The losses incurred from aerosols is found to be mostly within 70–200 EUR per month with a peak during spring mainly due to dust transport from northern Africa. The corresponding losses from clouds were found to vary from 200 to 550 EUR with a minimum in July and August [48]. The total energy and financial loss from aerosols was found to be 18.3 MWh and 1460 EUR, respectively, and that from clouds was 60.7 MWh and 4858 EUR.

The financial analysis of scenarios 1 and 2 (500 KW PV) is presented in Figure 10b, which shows a total production of 1041 MWh and a total revenue generation of 83,519 EUR. The energy production is seen to be at maximum in the summer months of May to July, similar to Figure 10a, while the losses incurring from aerosols is found to reach 480 EUR in April and May and while the losses from clouds were found to vary from 500 to 1400 EUR with a minimum in July and August. The total energy and financial loss from aerosols was found to be 45.6 MWh and 3650 EUR, respectively, and that from clouds was 151.8 MWh and 12,144 EUR.

A combination of energy production from PV and CSP systems is presented in Figure 10c with scenario 3 (500 KW PV and 200 KW CSP). The total production of 1041 and 416 MWh for each technology (1457 MWh in total for the 700 KW hybrid outcome) is followed by a total revenue of 116,927 EUR totally. The losses incurred from aerosols is found to reach 400 and 450 EUR for CSP and PV parts, respectively, and that from clouds is found to vary from 200 to 800 EUR and 500 to 1400 EUR, respectively, from the CSP and PV plants. The total energy and financial loss from aerosols was found to be 91.4 MWh and 7269 EUR and 240.4 MWh and 18,364 EUR from clouds. It has to be noted that the aerosol and cloud attenuation for the CSP is relatively larger (per MWh of production) compared to the PV because of the DNI exploitation, which is more sensitive to the atmospheric parameters direct and indirect effects as compared to the GHI.

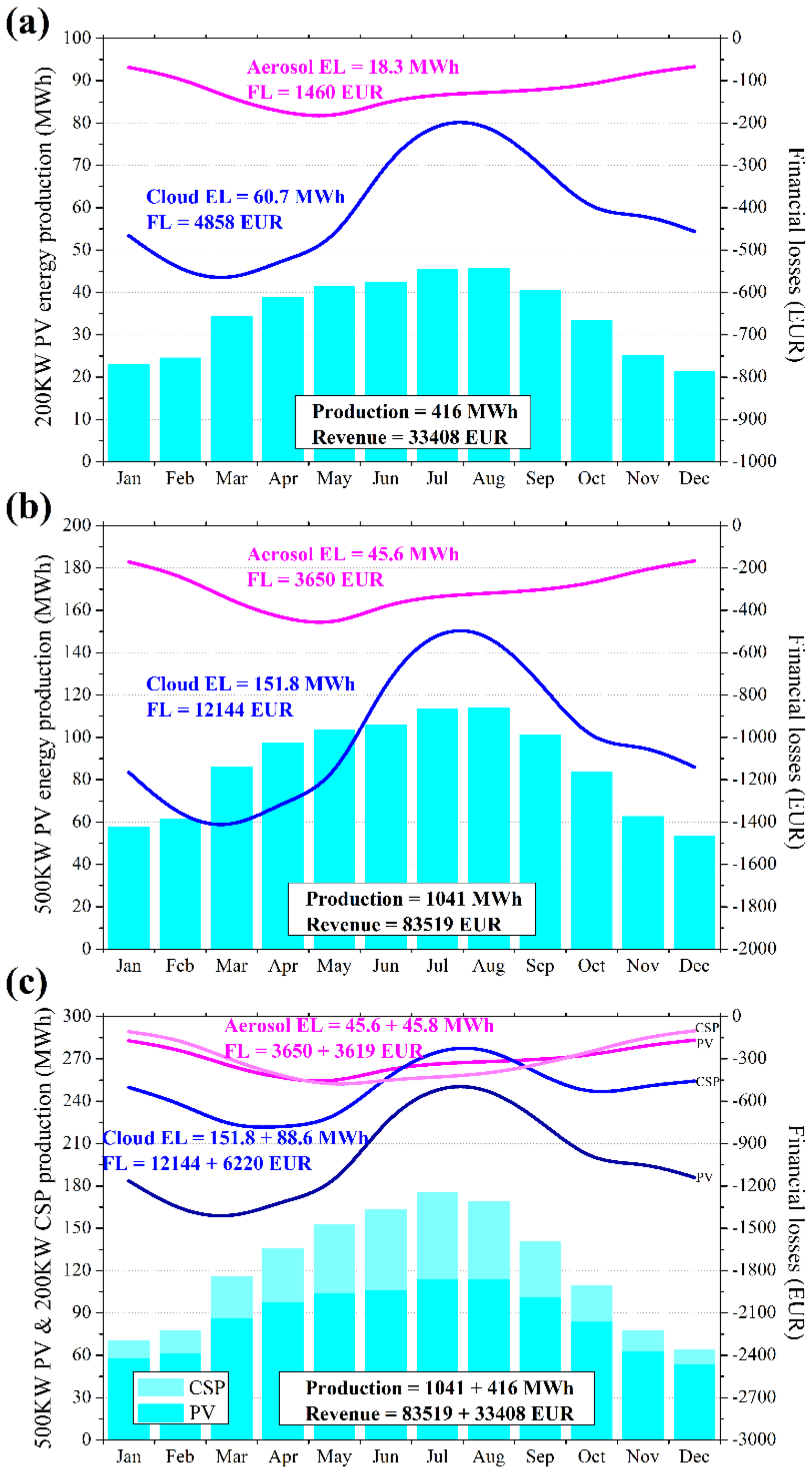

Figure 10. Annual financial analysis for PV and CSP plants with (**a**) 200 KW PV, (**b**) 500 KW PV and (**c**) 500 KW PV combined with 200 KW CSP energy production depicted in different colors. The corresponding energy and financial losses due to aerosol and cloud presence was included.

The energy and financial results of this study are comparable with similar studies performed in regions such as India, Cyprus, and Egypt and a large number of European and North African cities [17,28,37,45]. Particularly, a solar plant in the Himalayan region with a nominal power of 1 MW receives almost 2769 and 2308 kWh/m^2 annually for PV and CSP, respectively, with financial losses close to 11.5 K and 30 K EUR due to aerosol and cloud presence [17]. Similarly, on the island of Cyprus, which is located in the eastern Mediterranean, a 500 KW system has increased energy production by almost 4% with a tilt equal to the latitude of the region as compared to the horizontal panels [28]. Such a system in Cyprus faces energy production reduction, mainly because of the dust transport from northern Africa, with direct combined economic losses in the order of 11–16 K EUR (30% due to dust). In Egypt, a 10 MW system is able to have an annual revenue more than 1 M EUR followed by aerosol losses close to 70 K and 180 K EUR for PV and CSP technologies, respectively [37]. Finally, for the majority of the European and North African cities, a 1 MW system can increase its productivity by almost 2.4% with an optimum tilt, while the revenue difference decreases as the cloud effect is lower [45].

According to the results, Antikythera is a typical example of a sustainable project (energy autonomy), which in combination with the special support of the European Union for electricity on the islands makes it an ideal opportunity for a clean energy transition [49]. The Greek IPTO which controls the electricity transmission operations needs to provide an interconnection between the islands and the mainland for energy security, while HEDNO is necessary to upgrade the grids into smart grids as to efficiently incorporate the distributed renewable energy production, and hence, to ensure an overall stability. Therefore, such energy planning studies will realistically be able to support the sustainable development of society through a holistic energy transition policy, which in Greece is handled by the Ministry for the Environment, Energy and Climate Change. At the same time, the global climate change crisis will be analytically studied through the research that will be carried out by the ECCO in a region that can be characterized by its negligible anthropogenic activity and is considered ideal for monitoring climatic parameters representative of the wider central and eastern Mediterranean region. Finally, the local economy will benefit since the energy production surplus during the summer months by the proposed scenarios will set the ground for a sustainable tourism development. The results of the monthly coverages rate, mainly in scenarios 2 and 3, show that during the summer and spring months there is overproduction which is an opportunity to expand to the rest of the island and/or the mainland grid. Finally, the existing thermal plant is useful to remain during the energy transition period, as a last resort safety solution with minimal operation and especially in case of extreme weather events and prolonged periods of high cloudiness or dust transport, in conjunction with possible technical and maintenance issues.

5. Conclusions

The island of Antikythera is one of the hundreds of small inhabited Greek islands that currently deal with extreme high energy production price levels in the EU. Energy transition to renewables is necessary as to be autonomous and to adequately host the planned ECCO infrastructure additional needs which will cause the island's total annual energy consumption to increase by almost 200%. To this end, a number of energy planning scenarios were tested and analyzed so as to identify the optimum solar plant solutions that are able to fulfill the current and the forthcoming electricity requirements. The main conclusions of the study are as follows:

- A 200 KW system more than covers the existing needs, while with the incorporation of the ECCO a system of 500–700 KW will be necessary in order to mostly cover the winter months where the solar energy potential is lower;
- Such a system will require an area of 9019–10,111 m^2 for the PV panels and can reach almost 17,856 m^2 with the inclusions of CSP plants mainly for thermal storage capabilities;
- A PV panel's tilt equal to the latitude of the region is able to provide an increase to the final annual produced energy up to 7.2% as compared to the horizontal installations. The aerosol and cloud effect on solar energy production was also quantified on a climatological basis, resulting an average 4–11% reduction from the aerosol presence and 14–22% due to clouds;

- The aforementioned findings were used in order to provide a financial analysis for the studied scenarios, indicating an overall revenue of the order of 83,000–117,000 euro for the proposed solar plants that will cover the energy needs of the island with the ECCO followed by estimated losses of 3650–7269 and 12,144–18,364 euro from aerosol and cloud levels, respectively;
- Concerning the excess energy during the summer months, an interconnection with the national electricity grid will be beneficial accompanied by potential storage solutions through batteries and/or conversions into hydrogen.

The limitation of the overall approach is related to the actual energy consumption that the ECCO will have under its fully operational phase, especially during massive scientific campaigns with numerous human resources and instruments running in parallel. A low energy consumption period could be proposed during the low solar energy potential levels, i.e., from November to February, to limit the required solar plant and the subsequent costs. The advantage of the solar plants is their technical ability for staggered expansion, so even if the selected installation scenario will not cover the future needs of the island with the ECCO, a gradual empowerment of the power unit with additional panels is totally feasible. Future research will include ground-based measurements of the ECCO for both solar irradiation and atmospheric parameters monitoring in order to precisely quantify their interactions and feedback mechanisms.

The Antikythera model for dealing with energy independence from fossil fuels could be an incentive for other similar islands in Europe and beyond, contributing to the fight against climate change and its effects. The energy plan supported by this study can support future development in the region by offering economic growth and at the same time protecting the environment. The analysis of energy planning scenarios and financial losses due to the direct and indirect effects of aerosols and clouds on the production of solar plants can help innovative electricity projects for energy autonomous islands to plan and schedule power generation, supply, security, and overall stability of power production. The findings of the present study will drastically increase awareness among decision makers regarding the opportunities to exploit solar plants for energy transition. In addition, this research will support the mitigation processes and policies for climate change and its direct and indirect impacts on sustainable development.

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References

1. Ioannidis, A.; Chalvatzis, K.J.; Li, X.; Notton, G.; Stephanides, P. The case for islands' energy vulnerability: Electricity supply diversity in 44 global islands. *Renew. Energy* **2019**, *143*, 440–452. [CrossRef]
2. Kaldellis, J.K.; Zafirakis, D. Present situation and future prospects of electricity generation in Aegean Archipelago islands. *Energy Policy* **2007**, *35*, 4623–4639. Available online: https://www.sciencedirect.com/science/article/pii/S0301421507001425 (accessed on 25 October 2022). [CrossRef]
3. HAS. *Greece in Numbers*; Hellenic Statistical Authority: Piraeus, Greece, 2018.
4. RAE Regulatory Authority for Energy-Non-Interconnected Islands—2022. Available online: https://www.rae.gr/non-interconnected-islands/?lang=en (accessed on 12 October 2022).

5. Katsoulakos, N.M. An Overview of the Greek Islands' Autonomous Electrical Systems: Proposals for a Sustainable Energy Future. *Smart Grid Renew. Energy* **2019**, *10*, 55–82. Available online: https://www.sciencedirect.com/science/article/pii/S0960148119306391 (accessed on 6 September 2022). [CrossRef]
6. Ali, S.; Jang, C.M. Optimum Design of Hybrid Renewable Energy System for Sustainable Energy Supply to a Remote Island. *Remote Sens.* **2020**, *12*, 1280. [CrossRef]
7. Khare, V.; Savita Nema, S.; Baredar, P. Solar–wind hybrid renewable energy system: A review. *Renew. Sustain. Energy Rev.* **2016**, *58*, 23–33. [CrossRef]
8. Notton, G.; Nivet, M.; Zafirakis, D.; Motte, F.; Voyant, C.; Fouilloy, A. Tilos, the first autonomous renewable green island in Mediterranean: A Horizon 2020 project. In Proceedings of the 2017 15th International Conference on Electrical Machines, Drives and Power Systems (ELMA), Sofia, Bulgaria, 1–3 June 2017; pp. 102–105.
9. Kaldellis, J.K.; Zafirakis, D. Prospects and challenges for clean energy in European Islands. The TILOS paradigm. *Renew. Energy* **2020**, *145*, 2489–2502. [CrossRef]
10. National Documentation Centre. Available online: https://www.ekt.gr/el/news/23667 (accessed on 2 August 2021).
11. Nikas, A.; Stavrakas, V.; Arsenopoulos, A.; Doukas, H.; Antosiewicz, M.; Witajewski-Baltviks, J.; Flamos, A. Barriers to and consequences of a solar-based energy transition in Greece. *Environ. Innov. Soc. Transit.* **2020**, *35*, 383–399. [CrossRef]
12. Solar Energy Application | Solea. Available online: http://solea.gr/ (accessed on 12 October 2022).
13. Kaldellis, J.K.; Doumouliakas, J.; Michalis, K. Chapter 416. Optimum Stand. Alone PV Solution, Including Financial Aspects. In Proceedings of the Renewables: The Energy for the 21st Century World Renewable Energy Congress VI, Brighton, UK, 1–7 July 2000; pp. 1966–1969. Available online: https://www.sciencedirect.com/science/article/abs/pii/B9780080438658504165 (accessed on 25 October 2022).
14. Kaldellis, J.K.; Simotas, M.; Zafirakis, D.; Kondili, E.E. Optimum autonomous photovoltaic solution for the Greek islands on the basis of energy pay-back analysis. *J. Clean. Prod.* **2009**, *17*, 1311–1323. Available online: https://www.sciencedirect.com/science/article/pii/S0959652609001528 (accessed on 25 October 2022). [CrossRef]
15. Giaconia, A.; Grena, R. A model of integration between PV and thermal CSP technologies. *Sol. Energy* **2021**, *224*, 149–159. Available online: https://www.sciencedirect.com/science/article/pii/S0038092X21004138 (accessed on 7 August 2022). [CrossRef]
16. Weisser, D. On the economics of electricity consumption in small island developing states: A role for renewable energy technologies. *Energy Policy* **2004**, *32*, 127–140. Available online: https://www.sciencedirect.com/science/article/pii/S0301421503000478 (accessed on 6 September 2022). [CrossRef]
17. Dumka, U.C.; Kosmopoulos, P.G.; Ningombam, S.S.; Masoom, A. Impact of Aerosol and Cloud on the Solar Energy Potential over the Central Gangetic Himalayan Region. *Remote Sens.* **2021**, *13*, 3248. [CrossRef]
18. Elian, A.W.; Facundo, O.; Jacobo, S. Study of UV cloud modification factors in Southern Patagonia. *AIP Conf. Proc.* **2017**, *1810*, 110012. [CrossRef]
19. Global Solar Atlas. Available online: https://globalsolaratlas.info/map (accessed on 25 October 2022).
20. Global Monitoring Laboratory—Earth System Laboratory. Available online: https://gml.noaa.gov/ (accessed on 12 October 2022).
21. Copernicus Atmosphere Monitoring Service (CAMS). Available online: https://atmosphere.copernicus.eu/global-forecast-plots (accessed on 7 August 2022).
22. Eskes, H.; Huijnen, V.; Arola, A.; Benedictow, A.; Blechschmidt, A.-M.; Botek, E.; Boucher, O.; Bouarar, I.; Chabrillat, S.; Cuevas, E.; et al. Validation of reactive gases and aerosols in the MACC global analysis and forecast system. *Geosci. Model Dev.* **2015**, *8*, 3523–3543. [CrossRef]
23. Dee, D.P.; Uppala, S. Variational bias correction of satellite radiance data in the ERA-Interim reanalysis. *Q. J. R. Meteorol. Soc.* **2009**, *135*, 1830–1841. [CrossRef]
24. Lorraine, A.R.; Richard, G.K.; Levy, R.C.; Kaufman, Y.J.; Tanré, D.; Mattoo, S.; Martins, J.V.; Ichoku, C.; Koren, I.; Yu, H.; et al. Global aerosol climatology from the MODIS satellite sensors. *J. Geophys. Res. Atmo.* **2008**, *113*. [CrossRef]
25. Remer, L.A.; Levy, R.C.; Mattoo, S.; Tanré, D.; Gupta, P.; Shi, Y.; Sawyer, V.; Munchak, L.A.; Zhou, Y.; Kim, M.; et al. The Dark Target Algorithm for Observing the Global Aerosol System: Past, Present, and Future. *Remote Sens.* **2020**, *12*, 2900. [CrossRef]
26. Hsu, N.C.; Jeong, M.-J.; Bettenhausen, C.; Sayer, A.M.; Hansell, R.; Seftor, C.S.; Huang, J.; Tsay, S.-C. Enhanced Deep Blue aerosol retrieval algorithm: The second generation. *J. Geophys. Res. Atm.* **2013**, *118*, 9296–9315. [CrossRef]
27. Filonchyk, M.; Yan, H.; Zhang, Z. Analysis of spatial and temporal variability of aerosol optical depth over China using MODIS combined Dark Target and Deep Blue product. *Theor. Appl. Climatol.* **2018**, *137*, 2271–2288. [CrossRef]
28. Fountalakis, I.; Kosmopoulos, P.; Papachristopoulou, K.; Raptis, I.P.; Mamouri, R.E.; Nisantzi, A.; Gkikas, A.; Witthuhn, J.; Bley, S.; Moustaka, A.; et al. Effects of Aerosols and Clouds on the Levels of Surface Solar Radiation and Solar Energy in Cyprus. *Remote Sens.* **2021**, 13. [CrossRef]
29. Papachristopoulou, K.; Fountalakis, I.; Gkikas, A.; Kosmopoulos, P.; Natsos, P.T.; Hatzaki, M.; Kazadzis, S. 15-Year Analysis of Direct Effects of Total and Dust Aerosols in Solar Radiation/Energy over the Mediterranean Basin. *Remote Sens.* **2022**, *14*, 1535. [CrossRef]
30. Derrien, M.; Le Gléau, H. SAFNWC/MSG Seviri Cloud Products, Météo-France/DP/Centre de Météorologie Spatiale. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.569.8731&rep=rep1&type=pdf (accessed on 25 October 2022).
31. Derrien, M.; Le Gléau, H. MSG/SEVIRI cloud mask and type from SAFNWC. *Int. J. Remote Sens.* **2005**, *26*, 4707–4732. [CrossRef]

32. Roebeling, R.A.; Fejit, A.J.; Stamnes, P. Cloud property retrievals for climate monitoring: Implications of differences between SEVIRI on METEOSAT-8 and AVHRR on NOAA-17. *J. Geophys. Res.* **2006**, *111*, 20210. [CrossRef]
33. Mayer, B.; Kylling, A. Technical note: The libRadtran software package for radiative transfer calculations—Description and examples of use. *Atmos. Chem. Phys.* **2005**, *5*, 1855–1877. [CrossRef]
34. Kosmopoulos, P.; Kazadzis, S.; Taylor, M.; Raptis, P.I.; Keramitsoglou, I.; Kiranoudis, C.; Bais, A.F. Assessment of surface solar irradiance derived from real-time modelling techniques and verification with ground-based measurements. *Atmos. Meas. Tech.* **2018**, *11*, 907–924. [CrossRef]
35. Photovoltaic Geographical Information System. Available online: https://re.jrc.ec.europa.eu/pvg_tools/en/ (accessed on 7 August 2022).
36. Kaldellis, J.K. Supporting the Clean Electrification for Remote Islands: The Case of the Greek Tilos Island. *Energies* **2021**, *14*, 1336. [CrossRef]
37. Kosmopoulos, P.G.; Kazadzis, S.; El-Askary, H.; Taylor, M.; Gkikas, A.; Proestakis, E.; Kontoes, C.; El-Khayat, M.M. Earth-Observation-Based Estimation and Forecasting of Particulate Matter Impact on Solar Energy in Egypt. *Remote Sens.* **2018**, *10*, 1870. Available online: https://www.mdpi.com/2072-4292/10/12/1870 (accessed on 12 October 2022). [CrossRef]
38. Masoom, A.; Kosmopoulos, P.; Kashyap, Y.; Kumar, S.; Bansal, A. Rooftop Photovoltaic Energy Production Management in India Using Earth-Observation Data and Modeling Techniques. *Remote Sens.* **2020**, *12*, 1921. Available online: https://www.mdpi.com/2072-4292/12/12/1921 (accessed on 12 October 2022). [CrossRef]
39. Hellenic Electricity Distribution Network Operator S.A. Available online: https://deddie.gr/en/ (accessed on 7 August 2022).
40. Monteiro, A.; Basart, S.; Kazadzis, S.; Votsis, A.; Gkikas, A.; Vandenbussche, S.; Tobias, A.; Gama, C.; García-Pando, C.P.; Terradellas, E.; et al. Multi-sectoral impact assessment of an extreme African dust episode in the Eastern Mediterranean in March 2018. *Sci. Total Environ.* **2022**, *843*, 156861. [CrossRef]
41. Anagnostopoulos, P.; Spyridaki, N.-A.; Flamos, A. A "New-Deal" for the Development of Photovoltaic Investments in Greece? A Parametric Techno-Economic Assessment. *Energies* **2017**, *10*, 1173. [CrossRef]
42. Fountoukis, C.; Figgis, B.; Ackermann, L.; Ayoub, M.A. Effects of atmospheric dust deposition on solar PV energy production in a desert environment. *Sol. Energy* **2018**, *164*, 94–100. Available online: https://www.sciencedirect.com/science/article/pii/S0038092X18301270 (accessed on 25 October 2022). [CrossRef]
43. Kawamoto, H.; Guo, B. Improvement of an electrostatic cleaning system for removal of dust from solar panels. *J. Electrost.* **2018**, *91*, 28–33. Available online: https://www.sciencedirect.com/science/article/pii/S0304388617303169 (accessed on 6 September 2022). [CrossRef]
44. Masoom, A.; Kosmopoulos, P.; Bansal, A.; Kazadzis, S. Solar Energy Estimations in India Using Remote Sensing Technologies and Validation with Sun Photometers in Urban Areas. *Remote Sens.* **2020**, *12*, 254. [CrossRef]
45. Raptis, P.I.; Moustaka, A.; Kosmopoulos, P.; Kazadzis, S. Selecting Surface Inclination for Maximum Solar Power. *Energies* **2022**, *15*, 4784. [CrossRef]
46. Evenflow SPRL. Business Plan for the Establishment, Operation and Exploitation of a Solar Farm: Aswan's Solar Plant Project, Report 2017. Available online: http://solea.gr/wp-content/uploads/2018/03/Aswan-Solar-Plant-Business-Plan.pdf (accessed on 11 November 2022).
47. Hofierka, J.; Kaňuk, J. Assessment of photovoltaic potential in urban areas using open-source solar radiation tools. *Renew. Energy* **2009**, *34*, 2206–2214. [CrossRef]
48. Ben-tayeb, A.; Diouri, M.; Meziane, R.; Steli, H. Solar radiation attenuation by aerosol: Application to solar farms. *Air Qual. Atmos. Health* **2020**, *13*, 259–269. [CrossRef]
49. International Energy Agency. World Energy Outlook 2022. Available online: https://www.iea.org/reports/world-energy-outlook-2022 (accessed on 25 October 2022).