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Solar Energy Technology for Northern Cyprus: Assessment, Statistical Analysis, and Feasibility Study

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Abstract: Solar power is the fastest-growing energy source in the world. New technologies can help to generate more power from solar energy. The present paper aims to encourage people and the government to develop solar energy-based power projects to achieve sustainable energy infrastructures, especially in developing countries. In addition, this paper presents a solar energy road map to attract investors to invest in clean energy technology to help reduce the effect of global warming and enhance sustainable technological development. Therefore, the first objective of the paper is to analyze and compare the monthly global solar radiation for five different locations in Northern Cyprus using the measured data collected from the Meteorological Department and estimated values collected from the satellite imagery database. In addition, the mean hourly meteorological parameters including global solar radiation, air temperature, sunshine, and relative humidity are analyzed statistically and the type of distribution functions are selected based on skewness and kurtosis values. Accordingly, estimating global solar radiation improves solar power generation planning and reduces the cost of measuring. Therefore, models of a surface were analyzed by means of polynomial adjustments considering the values of *R-squared*. Finally, this study provides a comprehensive and integrated feasibility analysis of a 100 MW grid-connected solar plant project as an economic project in the selected region to reduce electricity tariffs and greenhouse gas (GHG) emissions. RETScreen Expert software was used to conduct the feasibility analysis in terms of energy production, GHG emissions, and financial parameters for the best location for the installation of a 100 MW grid-connected photovoltaic (PV) plant. Finally, the results concluded that the proposed solar system could be used for power generation in Northern Cyprus.

Keywords: distribution function; global solar radiation; meteorological parameters; Northern Cyprus; 100 MW grid-connected; solar plant project

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1. Introduction

Global warming is a serious environmental phenomenon that threatens the quality of life on the Earth's surface [1]. This phenomenon has been observed since the mid-twentieth century and serious efforts are now being made to find appropriate solutions to eliminate it and minimize its negative impacts [1]. Continuous environmental changes are likely to lead to global warming, while the depletion of strategic oil reserves and the ongoing threats of reduced access to electricity have recently led to an increased focus on alternative energies, including wind and solar energy [2,3]. In addition, increasing demand and scarcity of conventional sources have led scientists to pay attention to and develop research in the field of renewable energy, especially solar energy [4]. Solar energy is considered an alternative solution for reducing energy demand, the energy crisis, and environmental pollution. Solar energy is becoming more attractive particularly with the constant fluctuations in the supply of grid electricity. The solar photovoltaic (PV) system is based on converting sunlight into electricity directly using PV panels. Solar PV system generation utilizes solar modules consisting of several solar cells containing PV material. Grid-connected PV systems and stand-alone PV systems are the most widely used configurations among all types of PV systems. Various studies have evaluated the solar energy potential in many countries worldwide. For instance, Bhakta and Mukherjee [5] evaluated the solar potential and analyzed the performance of a 10 kW PV system without battery storage for four islands in India. The results showed that the annual mean capacity factor and performance ratio were within the range 15.51%–16.09% and 64.22%–65.83%, respectively. Syafawati et al. [6] utilized solar radiation data to analyze the solar energy potential in UluPauh, Perlis, Malaysia. The results indicated that UluPauh is a potential area to harvest solar energy. Nassar and Alsadi [7] assessed the solar potential of five cities in the Gaza Strip, Palestine based on the temporal and spatial analysis of meteorological parameters. The authors concluded that the Gaza Strip has significant potential for generating electricity from solar power plants. Almarshoud [8] investigated the performance of the PV system in 32 sites across Saudi Arabia based on real solar irradiance data. The results showed that the highest and lowest generated solar energies were found in the Najran and Qunfudhah sites, respectively. Nematollahi and Kim [9] investigated the feasibility of utilizing solar energy in 24 stations in South Korea. The results indicated that Daejeon, Jinju, Andong, Daegu, and Busan have the highest solar radiation in most months compared to other stations. Lau et al. [10] investigated the potential of solar energy in Dares Salaam, Tanzania by utilizing numerical modeling of solar irradiance. The results suggested that solar energy would provide solutions to reduce the energy demand, thus improving living quality in urban areas.

1.1. Related Works in Northern Cyprus and Research Gaps

Northern Cyprus has to make a big decision about its energy infrastructure in the coming years, especially in the power sector. Oil products are currently imported from different countries and Northern Cyprus is attempting to reduce this dependency on imported oil through the development of domestic energy resources. It has a tremendous scope for generating solar energy. The reason for this is its geographical location and the fact that it receives solar radiation almost throughout the year, receiving from 2700 to 3500h of sunshine annually. Thus, Cyprus has a high solar energy potential. Figures S1–S6 in the Supplementary Material show the long-term averages of solar resources generated by a global solar atlas map including global horizontal irradiation, the optimum angle of the PV module, global tilted irradiation at an optimum angle, direct normal irradiation, air temperature, and PV electricity output. It is found that the annual average of global horizontal irradiation of Northern Cyprus varies from 1900 kWh/m^2 to 2100 kWh/m^2 (see Figure S1 in the Supplementary Material). The highest global horizontal irradiation is in the northwestern part of Northern Cyprus, which ranged from 2000 to 2100 kWh/m^2. These results indicate the northern part of Cyprus receives a huge amount of solar energy that can be used to generate electricity. The second most significant climate variable to determine the performance of the solar system is air temperature. It is noticed that the air temperature is within the range 20–24 °C, as shown in Figure S4 in the Supplementary Material. Moreover, it is observed that the optimum angle of the PV module is within a range from 30 to 40°, as shown in Figure S5 of the Supplementary Material. The global solar atlas map is the most reliable source of data and can be used to estimate the solar potential in the specific region.

At present, electrical energy production in Northern Cyprus is provided almost entirely by petroleum, with the renewable energy sources in the country not playing an effective role. Currently, the electricity energy needs in Northern Cyprus are mainly generated from four power plants; namely, Kalecik Diesel (43.67%), Teknecik Diesel (34.83%), Teknecik Steam Unit No. 2 (12.27%), and Teknecik Steam Unit No. 1 (9.12%), the rest (0.11%) is generated from the solar PV system at Serhatköy [11], as is illustrated in Figure 1.

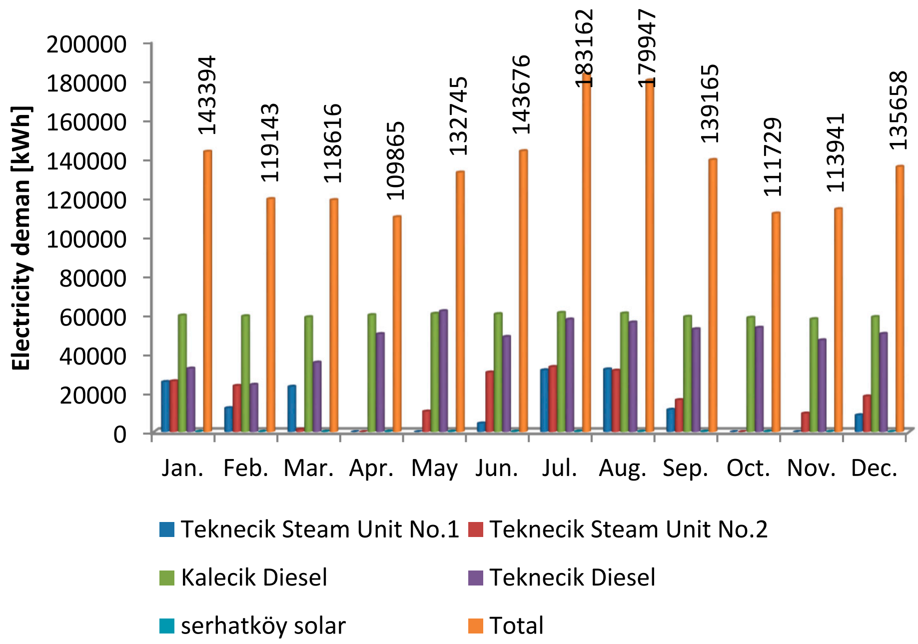

Figure 1. Histogram of monthly electricity demand in Northern Cyprus for the year of 2018 [11].

On the basis the statistics of annual electricity generation and maximum demand for Northern Cyprus, the average annual increase has been about 5.63% during the past 15 years, i.e., the total electricity demand between 2004 and 2018 increased from 883.869 MWh to 1631.041 MWh, as shown in Figure 2. This may be due to the fast growth of the population, as well as increased levels of construction and so on in Northern Cyprus. Several studies have examined the effect of economic variables on electricity consumption in Northern Cyprus. For example, Egelioglu et al. [12] investigated the impact of economic variables including per capita income, population, and the number of tourists on the annual electricity consumption in Northern Cyprus during 1988–1997. The results showed that these variables were significantly associated with electricity consumption. Furthermore, the relationship between electricity consumption and economic growth mainly in the education sector has also attracted attention and been investigated. Katircioğlu [13] estimated higher education-induced energy consumption in Northern Cyprus. The results demonstrated that higher education development in Northern Cyprus exerts a positive and significant growth impact not only on electricity consumption, but also on overall oil consumption.

In the following, we present a summary of the main points from an interview by the Anadolu Agency with the Minister of Economy and Energy of Northern Cyprus [14,15]:

- Northern Cyprus depends on the use of fuel oil in the production of electricity that accounts for a 98% share of the total power generation;
- The annual fuel oil consumption on the island is 200 tons, at a current cost of up to $100 million; it should be noted that the cost of damaging the environment due to the resulting gases is about 40 $/m^3 of oil;
- Northern Cyprus made an agreement with Turkey regarding a project to connect electricity to the northern part of the island by sea. This will be the second project of its kind after the delivery of water to the island in the same way;
- Current electricity consumption in Northern Cyprus is estimated to be 1.5 billion kilowatt-hours per hour and is still supplied from oil-powered plants, but new estimates indicate a need for twice as much to meet the electricity demand in Northern Cyprus.

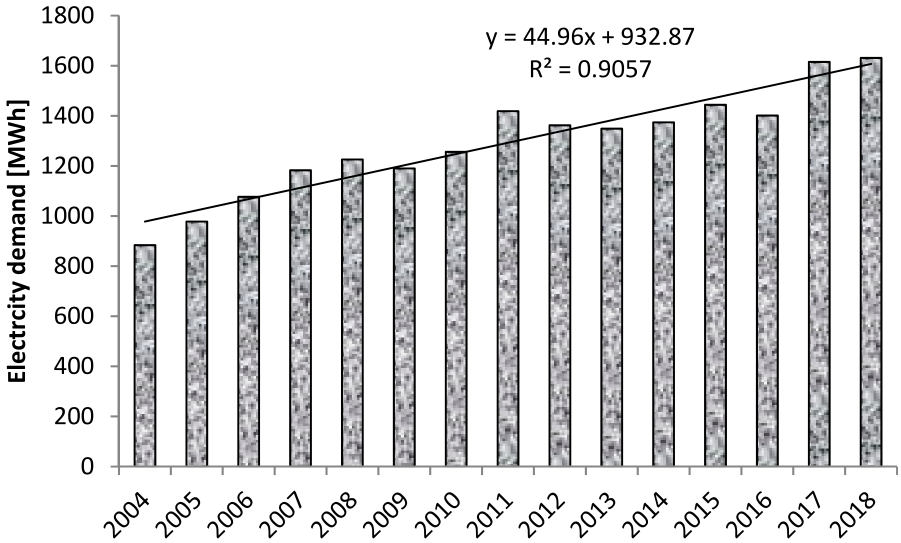

Figure 2. Annual electricity production (2004–2018) [11].

Numerous studies on the potential of renewable energy in terms of solar energy and wind energy have been investigated in Northern Cyprus. For example, Okoye and Atikol [16] investigated the feasibility of installing a solar chimney power plant in Northern Cyprus. The results indicated that this technology can be made economically feasible by utilizing the greenhouse effect produced by the collector for agricultural purposes, such as drying of coffee grains, tomatoes, and bananas. Radmehr et al. [17] explored people's preferences for a Built-In Photovoltaic (BIPV) renewable energy system to be integrated into housing construction. The results demonstrated that the capital cost of the PV system is not instrumental in choice, and a lower feed-in tariff could be acceptable. Ilkan et al. [18] made an economic analysis for small-sized solar and wind systems in Northern Cyprus that could be utilized to reduce the level of peak demand. The results indicated that the internal rate of return for the solar system is lower than the wind system and the availability of solar potential is boundless in all parts of Northern Cyprus. Kassem et al. [19] investigated the feasibility of a 12 MW grid-connected renewable energy project in Northern Cyprus. The results showed that Northern Cyprus has a greater potential for solar power compared to wind energy. Kassem and Gökçekuş [20] conducted a techno-economic evaluation of a proposed 1 MW on-grid PV power plant in the town of Lefke. The authors concluded that the PV system could be used as an alternative solution to reduce greenhouse gas (GHG) emissions and electricity consumption in Northern Cyprus. Kassem et al. [21] investigated the performance of a 6.4 kW grid-connected PV system for household buildings in three urban regions in Northern Cyprus. They found that the PV system has significant potential in reducing electricity consumption. Kassem et al. [22] developed and compared the PV technologies of a 30 kW grid-connected PV system on the available roof and front of the Near East University (NEU) grand library building. The results indicated that the freestanding mounting position system performs better than BIPV, and technology-wise Cadmium Telluride (CdTe) performs better than Copper Indium Selenide (CIS) and crystalline systems. Kassem et al. [23] evaluated the techno-economics of a 45 kW grid-connected in the Lefke region in Northern Cyprus. The results indicated that Lefke town has a very good solar potential, i.e., the mean daily solar radiation-horizontal is 5.96 kWh/m^2/day. Ouria and Sevinc [24] investigated the utilization of solar energy in Famagusta in Cyprus. They found that the rate of solar energy depends on the city's climatic and geographic features, as well as other factors. Ogbeba and Hoskara [25] proposed the PV system as a shading device to reduce the heating problem in Northern Cyprus. They concluded that this system could generate nearly 2800 W, which can provide up to 50% of the electricity demand of a house. Moreover, according to the deputy prime minister and ministry foreign affairs of Northern Cyprus [26], International Cyprus University completed an important PV project for generating electricity in the university building. They found that the system met 80% of the electricity demand of the university during the daytime. Yenen et al. [27] evaluated and compared two solar thermal energy systems over Northern Cyprus. The results demonstrated that the highest solar irradiation absorption and lowest GHG emissions and cost for the northern part of Cyprus were obtained from the Fresnel system. Maltini and Minder [28] designed and built a 1.275 MW grid-connected PV plant at the Serhatköy site in Northern Cyprus. Ozerdem et al. [29] evaluated the performance ratio and the capacity factor of the Serhatköy PV plant in Northern Cyprus.

In summary, most of the studies have investigated the potential of solar or wind in some parts of Northern Cyprus. It was found that solar energy has huge potential compared to wind energy in Northern Cyprus and solar systems helped to reduce carbon dioxide emissions and electricity consumption in Northern Cyprus. However, none of these papers analyzed the global solar potential to examine the best location for the future installation of the PV system in Northern Cyprus. Furthermore, none of these papers assessed the sustainability of large-scale PV systems in the relation to a suitable location using RETScreen software, which is a vital tool in project decision making, wherein the uncertainty of a project is analyzed by predicting the future return of the renewable energy project in terms of sustainability.

1.2. Scope of Present Work

Regarding the literature review, it reveals a clear lack of evaluation of global solar radiation in terms of examining the best locations to install a PV system in Northern Cyprus. Furthermore, there is a clear lack of exploring the potential of large-scale grid-connected PV system generation in Northern Cyprus. Therefore, this paper is aimed at analyzing the global solar radiation for five different locations in Northern Cyprus based on measurements on the surface by the Meteorology Department and satellite imagery results from the Photovoltaic Geographical Information System (PVGIS) and RETScreen database. Furthermore, after determining the best location to install the PV system, mean hourly meteorological parameters including global solar radiation, air temperature, sunshine, and relative humidity are analyzed statistically, and the type of distribution functions are selected based on skewness and kurtosis values. The data, which covered January 2014–December 2016, are presented. With the values of hourly global solar radiation as a function of temperature, sunshine, and relative humidity, a study of the influence of these variables was carried out and a model of the surface was proposed to adjust the obtained curves. Moreover, this study provides the technical, environmental, and economic aspects of a large-scale PV system (100 MW grid-connected solar plant project) in the region selected as being best suited in Northern Cyprus; this has the potential to reduce the electricity consumption generated by diesel fuel by 33%. The technical, financial, economic, and environmental analyses of PV power plant developments were performed by RETScreen Expert software. The flowchart in Figure 3 illustrates the analysis procedure of this study.

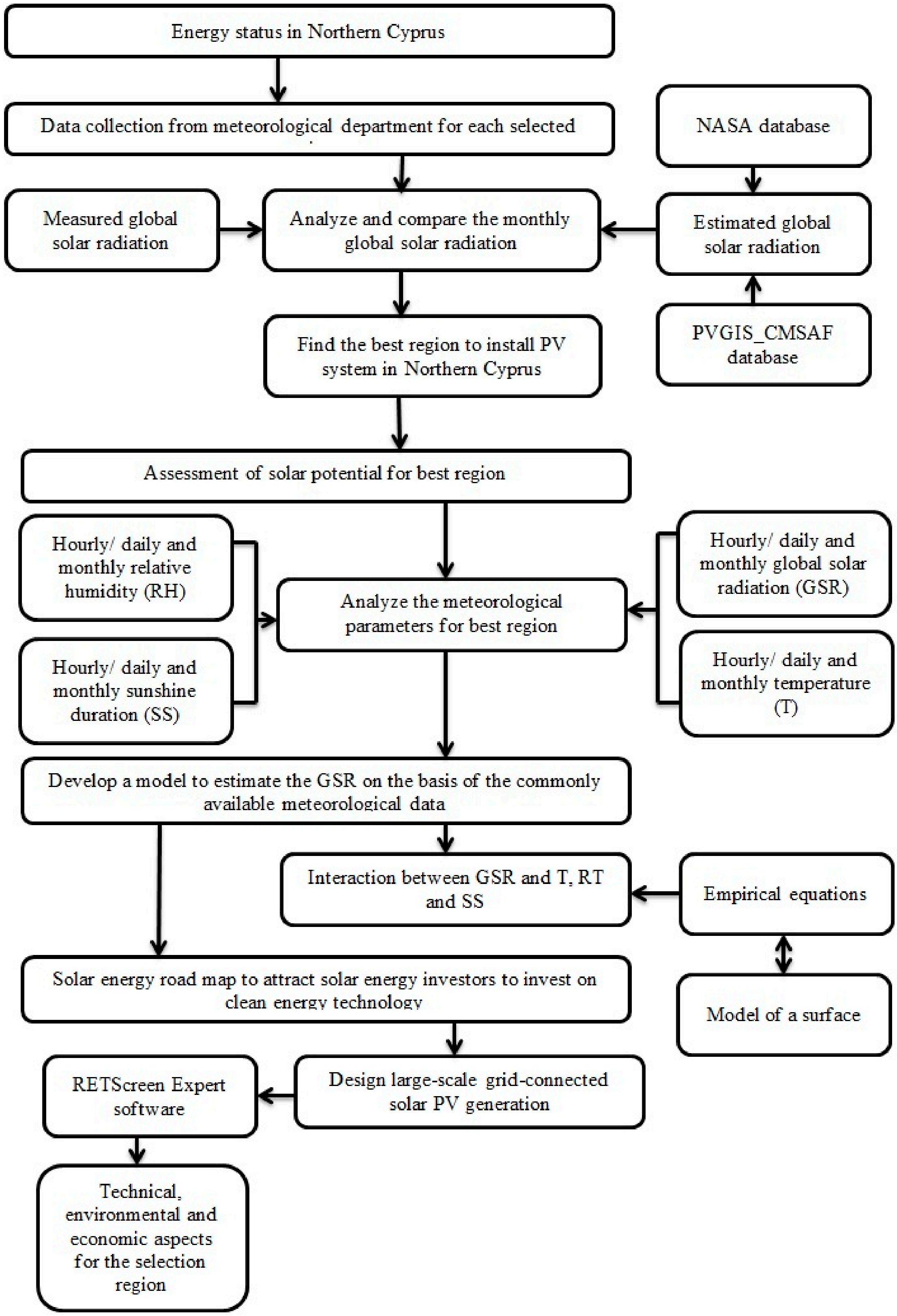

Figure 3. Flowchart of the analysis procedure of the present study.

2. Materials and Methods

2.1. Measurements, Data, and Statistical Analysis

2.1.1. Measurements Data

In this study, global solar radiation and other meteorological parameters including average temperature, sunshine duration, relative humidity, and wind speed for the selected regions were collected from the Meteorology Department located in Lefkoşa. The data were measured at various heights (i.e., global solar radiation, temperature, sunshine duration, and relative humidity were measured at a height of 2m, the wind speed was measured at a height of 10m), as shown in Table 1. In the present work, five regions located in different parts in Northern Cyprus were selected as case studies. Table 1 presents the geographical characteristics, surface area, and meteorological parameters of the selected locations. Furthermore, Figure 4 shows the location of the selected regions.

Table 1. Characteristic of the selected regions used in this study.

Region	Latitude [°]	Longitude [°]	Elevation [m]	Surface Area [km^2]	Investigation Period
Girne	35.337	33.319	29	10.5	2008–2016
Lefkoşa	35.180	33.374	139	502	2008–2016
YeniBoğaziçi	35.315	33.951	15	16.9	2012–2016
Salamis	35.186	33.903	7	14.5	2009–2016
Güzelyurt	35.199	32.993	48	55.5	2008–2016

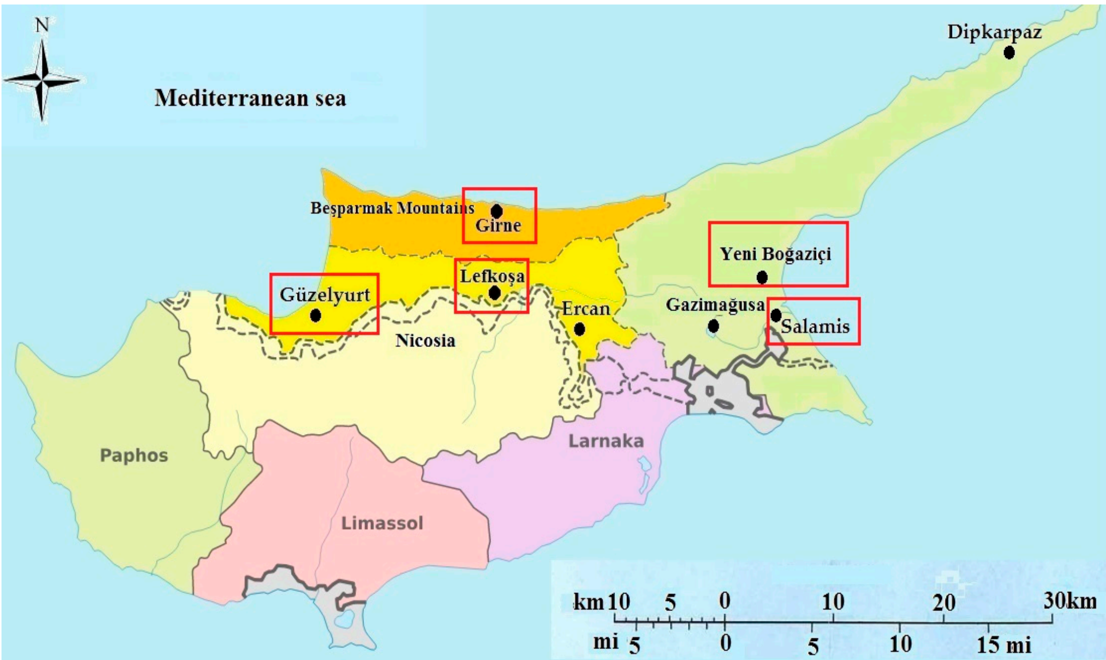

Figure 4. Map of Cyprus.

2.1.2. Statistical Analysis

In the literature, various distribution functions were used to analyze the global solar irradiation, surface temperature, and relative humidity characteristics at a specific region. Thus, to select the best distribution function, the definition of the frequency distribution type as a function of the range of the skewness and kurtosis values was used, as shown in Table 2.

Table 2. Distribution curve selections [30].

Distribution Type Number	Distribution Curve	Skewness (S) Range	Kurtosis (K) Range
I	Normal	−0.4 < S < 0.4	−0.8 < K < 0.8
II	Almost normal with positive tail	S ≥ 0.4	−0.8 < K < 0.8
III	Narrow peak with positive tail	S ≥ 0.4	K ≤ −0.8 K ≥ 0.8
IV	Almost normal with negative tail	S ≤ −0.4	−0.8 < K < 0.8
V	Narrow peak with negative tail	S ≤ −0.4	K ≥ 0.8
VI	Bimodal, symmetrical with flat peak	−0.4 < S < 0.4	K ≤ −0.8

2.2. Design Large-Scale Grid-connected PV Plant

2.2.1. Reviews of Solar PV Technology with Simulation Tools

Many scientific researchers have worked on solar PV using various simulation tools, such as PVWatts, RETScreen, Homer, PV*SOL, Solargis PV Planner software, and so on, to assess solar potential in the specific region. For instance, Shukla et al. [31] evaluated the 10 kW grid-connected PV system at Manit, Bhopal, India using Solargis PV Planner software. Dondariya et al. [32] examined the performance of a 6.4 kW grid-connected rooftop of the PV system using four simulation tools (PV*SOL, PVGIS, SolarGIS, and SISIFO) in the holy city of Ujjain, India. Nassar and Alsadi [7] investigated the potential of solar energy in the Gaza Strip, Palestine using SAM software. Mohammadi et al. [33] used RETScreen software to investigate the potential of 5 MW grid-connected PV systems in different cities on the southern coast of Iran. Obeng et al. [34] utilized RETScreen software to investigate the feasibility of a 50 MW grid-tied solar photovoltaic plant at UENR Nsoatre Campus. Pavlovic et al. [35] assessed the performance of a 1 kW fixed-on-grid PV system in Belgrade, Negotin, and Zlatibor using the HOMER software simulation. Enongene et al. [36] investigated the potential of the PV system in residential buildings in Lagos Metropolitan Area, Nigeria using HOMER Pro. Shahzad et al. [37] estimated the cost of generated electricity of the hybrid system (PV/Biomass) for an agricultural farm and a residential community in Pakistan using the HOMER software. Bocca et al. [38] evaluated the performance of the PV system for generating electricity in Italy using actual and PVGIS simulation data. Chang and Starcher [39] used the PVWatts simulation tool to evaluate the energy production of the 45 kW PV system at various slope angles in different locations in Texas. Psomopoulos et al. [40] investigated the performance accuracy of the PVGIS, PVWatts, and RETScreen simulation tools for estimating the potential of roof-integrated PV systems in Greece. Hassaine and Mraoui [41] designed a grid-connected PV system in Algeria based on a database collected from PVGIS. Belkilani et al. [42] assessed the global solar radiation to examine the best locations to install a PV system in Tunisia based on actual data and database collected from PVGIS. Chakraborty et al. [43] estimated the potential of a 1 MW PV system for an energy-efficient building in Bangladesh based on the PVsyst simulation software and RETScreen simulation software. Ohijeagbon and Ajayi [44] investigated the feasibility of hybrid systems for an off-grid rural community in Sokoto in north-west Nigeria by using the HOMER and RETScreen software. Assamidanov et al. [45] evaluated the techno-economic feasibility of implementing a residential PV system in South Kazakhstan based on the RETScreen software. Kumar et al. [46] investigated the potential of a 1 MW grid-connected PV system at Universiti Malaysia Pahang by using various simulation tools (PVWatts and PVGIS). Owolabietal [47] investigated the feasibility of a 6 MW installation in six regions in Nigeria based on the RETScreen Experts software. Rashwan et al. [48] studied the economic and environmental feasibility of a grid-connected PV system on a small building located in Saudi Arabia using the RETScreen software. Rehman et al. [49] investigated the potential of 10 MW grid-connected PV plants in Saudi Arabia utilizing the RETScreen software.

On the basis of the above information, it can be concluded that simulation software is necessary to investigate the feasibility of a solar PV system at a given location. Therefore, the present study used the RETScreen and PVGIS software to evaluate the feasibility of a grid-connected PV system in five locations in Northern Cyprus. In this study, optimal panel inclination is estimated based on the PVGIS software and the energy production, greenhouse gas (GHG) emissions, and financial parameters of the grid-connected PV plant are analyzed using RETScreen software.

2.2.2. Grid-connected PV System

The grid-connected PV system is a solar system that generates electricity only when connected to the national grid system. The proposed grid-connected PV system includes all the components needed to build the grid-connected solar system in the absence of a storage system. The grid-connected PV system consists of solar panels that absorb sunlight and produce direct current (DC) electricity, the inverter which converts the DC from the solar modules to alternating current (AC), the electricity meter through which the solar electricity flows to the national grid, the AC breaker panel and fuses, the safety switches and cabling, the electricity grid, and the household sockets. Furthermore, in the case of a surplus of electricity, it is exported and sold to the grid. In the case of insufficient electrical energy produced from the solar cells, the shortage of the main power grid is immediately met. The grid-connected PV system configuration is shown in Figure 5.

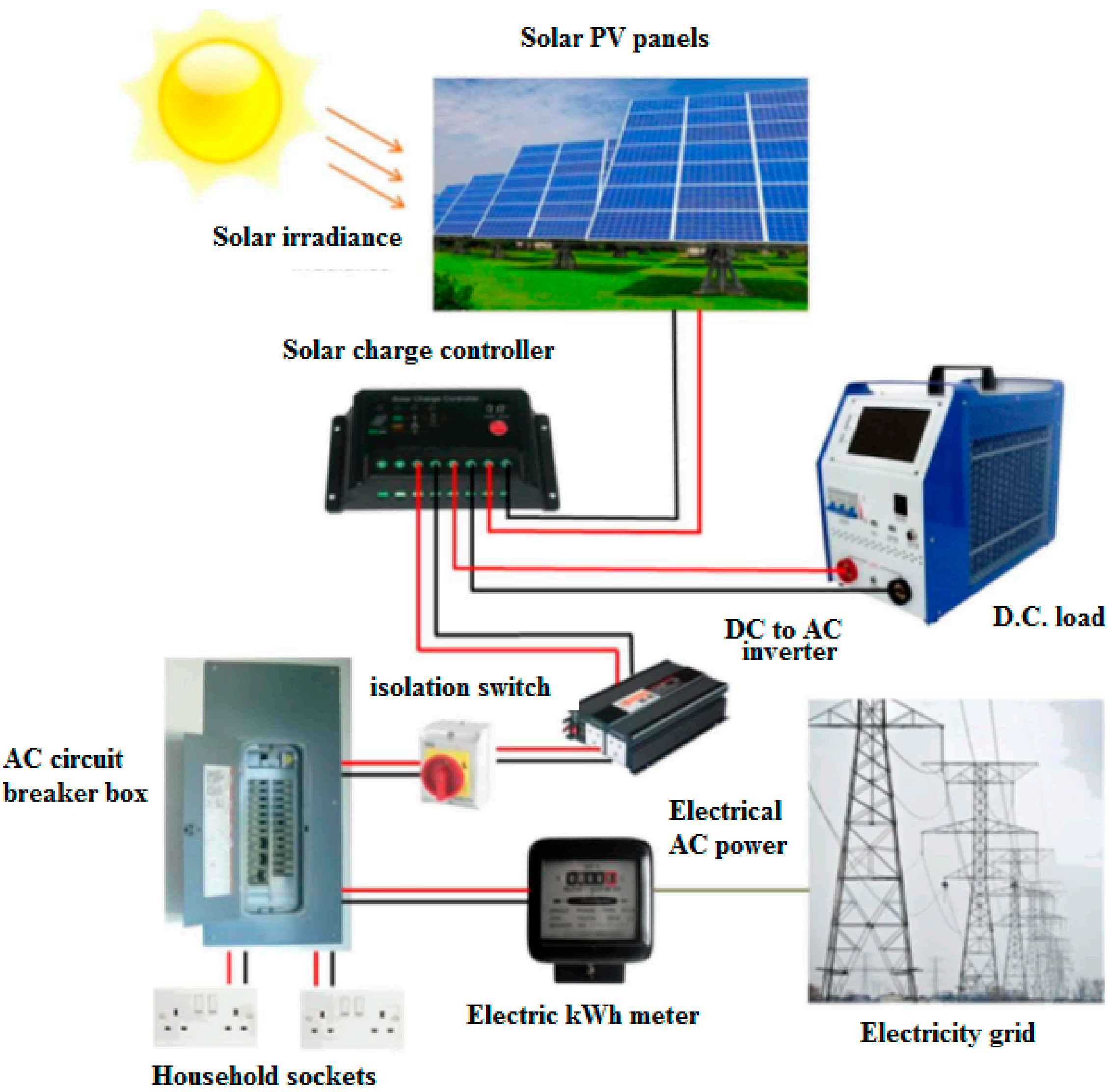

Figure 5. Components of the grid-connected photovoltaic (PV) system.

In this section, the technical specifications of the solar PV system, design methodology, and the parameters that are considered for a solar PV project in Northern Cyprus are discussed below.

Power generating factor (PGF)

PGF is an essential factor considered in the sizing of solar photovoltaic technology based on the total Watt peak rating of the system. The PGF is calculated using the equation below:

$$\mathrm{PGE} = \frac{\mathrm{Solarirradiance} \times \mathrm{Sunshinehours}}{\mathrm{Standardtestconditionirradiance}} \tag{1}$$

Energy demand

The total power and energy consumption of all loads that need to be supplied are important factors for designing a PV system [47,50].

Solar PV energy required

The total energy in Wh/day needed from the PV modules can be calculated by using the following equation:

$$\text{Total energy } = \text{peak energy requirement} \times \text{Energy lost in the system} \tag{2}$$

- Peak energy requirement = 100 MW;
- The energy lost in the system = 1.3 [51];
- Energy required from PV modules = 100 × 1.3 = 130 MWh/day.

PV module sizing

To calculate the size of the photovoltaic modules that are required, the first thing to estimate is the total Watt-peak rating needed for the PV modules; this can be estimated using the formula below:

$$\mathrm{TotalWattpeakrating} = \frac{\mathrm{SolarPVenergyrequired}}{\mathrm{Panelgenerationfactor}} \tag{3}$$

$$\mathrm{PVmodulesize} = \frac{\mathrm{TotalWattpeakrating}}{\mathrm{PVoutputpowerrating}} \tag{4}$$

Inverter sizing

The size of the inverter used for any solar photovoltaic project is a function of the total wattage of the energy consumed and the factor of safety [52], and it is calculated as shown below:

- Peak energy requirement = 100 MW;
- Factor of safety = 1.3 [51];
- Inverter size = 100 × 1.3 = 130 MW.

2.2.3. PV-module Selection

For proposed solar projects, various types of PV modules with various characteristics are available in Turkey, and two criteria applied to find the suitable PV-module type are given below [49]:

$$\mathrm{BestsuitablePVmodule} \ = \frac{\mathrm{Modulecapacity}}{\mathrm{Moduleprice} \times \mathrm{Modulearea}} \tag{5}$$

$$\mathrm{panelsselection} = \frac{\mathrm{Maximummodulecapacity} \times \mathrm{Moduleefficiency}}{\mathrm{Moduleprice} \times \mathrm{Modulearea}} \tag{6}$$

The specifications of the best PV cells available in Turkey are shown in Table 2. On the basis of the abovementioned selection criterion, the AS-P60-290W was chosen (see Table 3). The Electrical characteristics of the selected PV module are shown in Table 4.

Table 3. Specifications of best PV modules from the Ankara Solar company [53].

Material	Model/Maximum Power	Efficiency	Module Area	Price	Selection Criterion	Number of Modules for 2 MW	Number of Modules for 10 MW
Polycrystalline Solar Panels	**AS-P60-290W**	**17.83%**	**1.63 m^2**	**371TL**	**0.479**	**6897 Modules**	**34483 Modules**
	AS-P72-345W	17.78%	1.94 m^2	442TL	0.402	5797 Modules	28986 Modules
Monocrystalline Solar Panels	AS-M60-310W	19.00%	1.63 m^2	434TL	0.438	6452 Modules	32258 Modules
Bifacial Solar Panels	AS-B60 -320W	21.00%	1.61 m^2	669TL	0.295	6250 Modules	31250 Modules

Table 4. Electrical characteristics of the selected PV module.

Nominal Power (Pmax)	290W
Open circuit voltage (Voc)	39.2V
Short circuit current (Isc)	9.59A
Voltage at nominal power (Vmp)	32.0V
Current at nominal power (Imp)	9.07A
Model efficiency	17.83
Operating temperature	−40 °C to +85 °C
Maximum system voltage	1000 V DC
Maximum series fuse rating	15A

2.3. Economic Analysis

Different simulation tools have been used by researchers, engineers, and scientists for estimating the annual and monthly energy production and the capacity factor of an installed wind turbine and photovoltaic systems [54]. To evaluate the technical, economic, and environmental effects of the renewable energy projects, RETScreen software was used in this study. RETScreen software is a useful tool for analyzing and evaluating the feasibility of a grid-connected renewable power system [54]. On the basis of the input data, RETScreen software is capable of estimating annual and monthly energy production, and the capacity factor of an installed wind turbine. In this study, the important economic measures, such as net present value (*NPV*), internal rate of return (*IRR*), levelized cost of energy (*LCOE*), payback period (PB), annual life cycle savings (*ALCS*), and benefit-cost ratio (*B-C*), were calculated using the RETScreen software.

Net present value (NPV):

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} \tag{7}$$

Levelized cost of energy (LCOE):

$$LCOE = \frac{sum\ of\ cost\ over\ lifetime}{s\ of\ electricity\ generated\ over\ the\ lifetime} \tag{8}$$

The internal rate of return (IRR):

$$O = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n} \tag{9}$$

Simple payback (SP):

$$SP = \frac{C - IG}{\left(C_{ener} + C_{capa} + C_{RE} + C_{GHG}\right) - \left(C_{o\&M} + C_{fuel}\right)} \tag{10}$$

Equity payback (EP):

$$EP = \sum_{n=0}^{N} C_n \tag{11}$$

Annual life cycle savings (ALCS):

$$ALCS = \frac{NPV}{\frac{1}{r}\left(1 - \frac{1}{(1+r)^N}\right)} \tag{12}$$

GHG emission reduction cost (GRC):

$$GRC = \frac{ALCS}{\Delta_{GHG}} \tag{13}$$

Benefit-cost ratio (B-C):

$$B - C = \frac{NPV + (1 - f_d)C}{(1 - f_d)C} \tag{14}$$

where N is the project life in years; C_n is the after-tax cash flow in year n; r is the discount rate; C is the total initial cost of the project; f_d is the debt ratio; B is the total benefit of the project; IG is the incentives and grants; C_{ener} is the annual energy savings or income; C_{capa} is the annual capacity savings or income; C_{RE} is the annual renewable energy (RE) production credit income; C_{GHG} is the GHG reduction income; $C_{o\&M}$ is the yearly operation and maintenance costs incurred by the clean energy project; C_{fuel} is the annual cost of fuel, which is zero for renewable projects; and Δ_{GHG} is the annual GHG emission reduction.

3. Results and Discussions

3.1. Selecting the Best Locations to Install a PV System

3.1.1. Measurement Data

The mean monthly values of solar radiation for the selected regions are provided in Figure S7 in the Supplementary Material. The maximum global solar radiation of 248.9 kWh/m^2 and 248.4 kWh/m^2 were found in Salamis and Girne, respectively. These values were obtained in July 2009 for Salamis and June 2009 for Girne. In addition, the minimum global solar radiation was recorded in December 2009 with a value of 53.7 kWh/m^2 at Salamis; this was followed by Girne, with a minimum value of 57.5 kWh/m^2, which was recorded in December 2009. Moreover, the average monthly solar radiation during the investigation period is illustrated in Figure 6a. It was found that the maximum and minimum solar radiations were obtained in July and December, with values of 242.15 kWh/m^2 at Lefkoşa and 65.75 kWh/m^2 at Salamis, respectively. On the basis of the mean annual global solar radiation value (see Figure 6b), Lefkoşa had the highest global solar radiation with a value of 160.78 kWh/m^2, followed by YeniBoğaziçi with a value of 160.33 kWh/m^2. Moreover, the monthly mean sunshine duration hours for the five regions in Northern Cyprus are shown in Figure 7. It is observed that the minimum sunshine duration of 4.47h/day was recorded in December at Girne, while a maximum of 11.63 h/day was obtained in August at Lefkoşa. In addition, it is found that the average solar radiation was about 7.81h/day for Girne, 8.56h/day for Lefkoşa, 8.30h/day for YeniBoğaziçi, 7.99h/day for Salamis, and 8.07h/day for Güzelyurt.

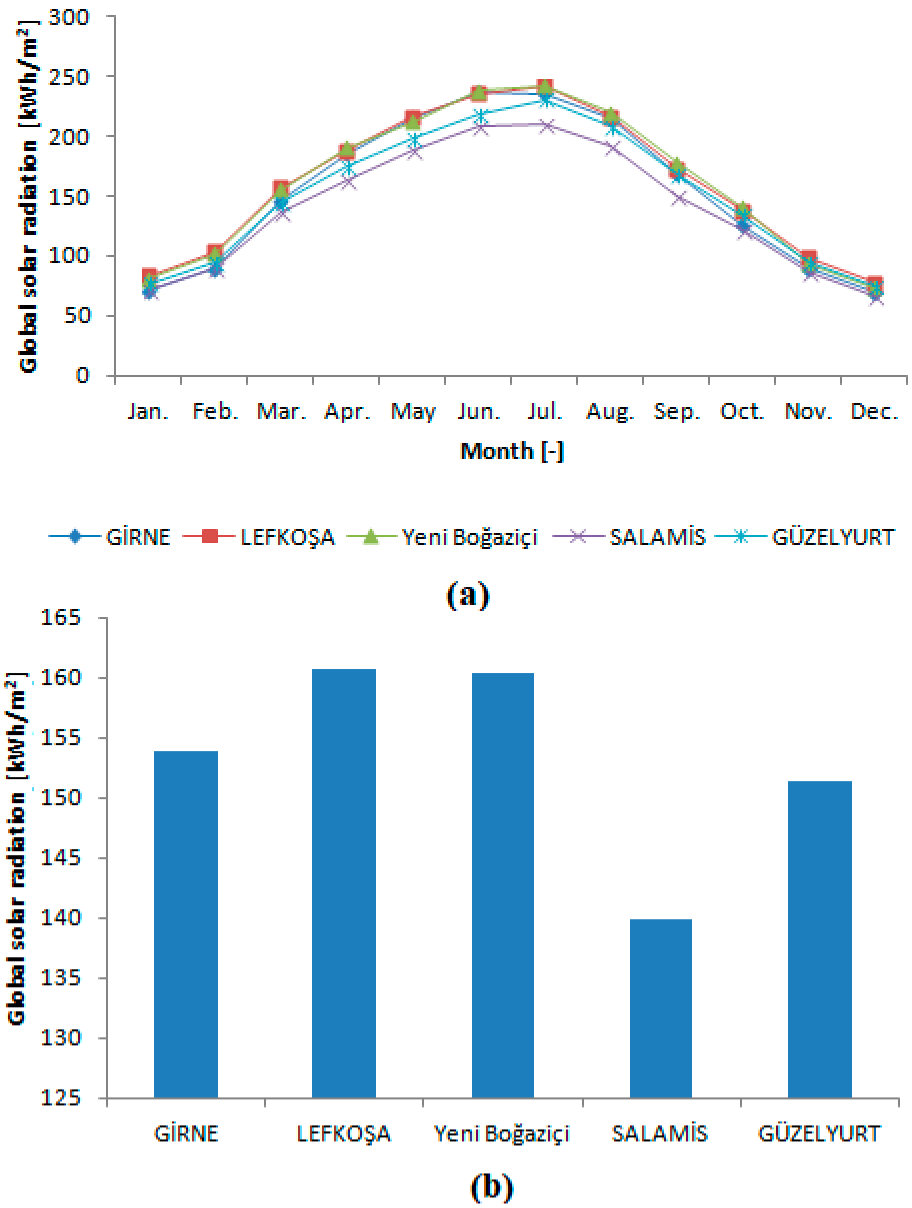

Figure 6. Global solar radiation: **(a)** mean monthly data and **(b)** annual data for whole years.

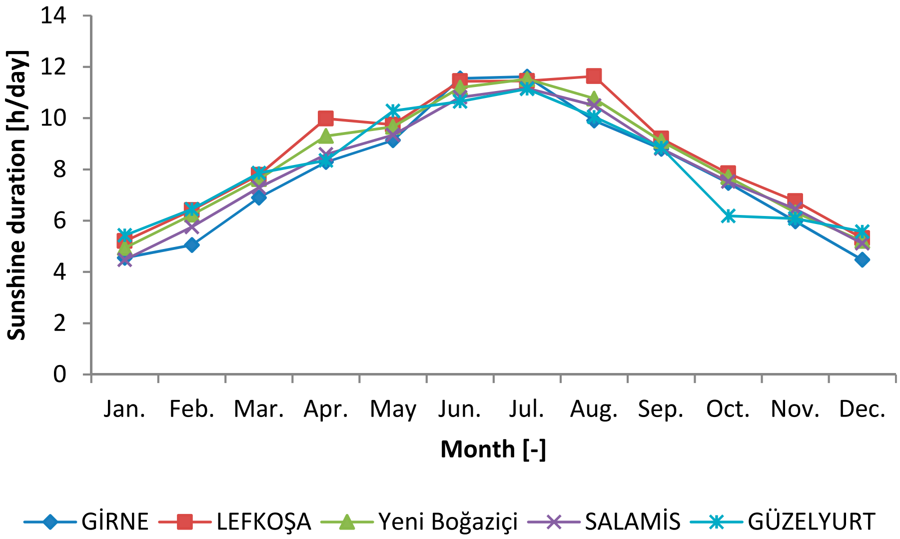

Figure 7. Mean monthly sunshine duration for all chosen regions.

3.1.2. Performance Evaluation of satellite data and NASA

In reality, the accuracy of the satellite data is not enough to design a solar PV system [55–57]. Therefore, to ensure the accuracy of the performance of the PV solar system, the solar radiation values collected from satellite imagery based on the PVGIS and RETScreen databases are compared with the actual measurement data. Therefore, this section aims to investigate the global solar radiation using actual solar radiation and solar radiation estimates from satellite PVGIS_CMSAF (Photovoltaic Geographical Information System_Climate Monitoring Satellite Application Facility) and NASA databases. It is observed that the actual annual solar radiation was 1929 kWh/m^2 for Lefkoşa and 1924 kWh/m^2 for Yeni Boğaziçi, as shown in Figure 8. In addition, it is noticed that the actual value and estimated value of solar radiation are almost equal for the Lefkoşa region. Moreover, the mean monthly global solar radiation values for the five selected regions using the measured data and satellite imagery database are compared, as shown in Figure S8 in the Supplementary Material and listed in Table S1 in the Supplementary Material. It is noticed that there is a good correlation between the measured and estimated data for the global solar radiation. In addition, the accuracy of the estimated values obtained from PVGIS and NASA are examined by calculating the R^2 and absolute error in percent, as shown in Table S1 in the Supplementary Material. It is found that the absolute error values were in the range 0.49%–26.9%. Additionally, the results showed that the two databases gave good estimations according to the value of R^2, which is approximately 1.0. The difference between the measured and estimated values is mainly explained by the uncertainties and errors in the underlying data of radiation and temperature from the station.

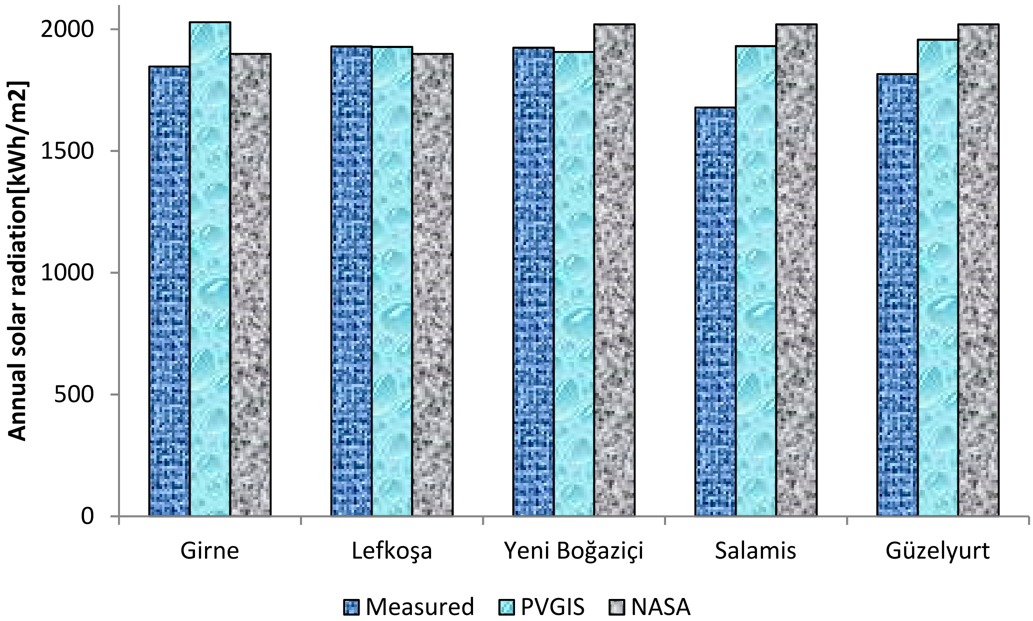

Figure 8. Annual solar radiation for all selected locations.

3.1.3. Summary

The output power from the PV system depends on the global solar radiation (GSR) and sunshine duration (SSD). Table 5 summarizes the mean annual global solar radiation and sunshine duration, the average temperature and relative humidity for all chosen locations in this study. It is found that Lefkoşa has the highest GSR, SSD, and air temperature (AT) and lowest relative humidity (RH) compared to the other locations. The availability of global weather data, such as GSR, SSD, AT, and RH, have enabled scientific researchers to determine the PV potential in the specific location. Power output from the PV model highly depends on the amount of solar radiation that reaches the solar cells [58]. Additionally, according to Tyagi et al. [59], during the low sunshine duration, the output power from the PV system decreases compared to the high sunshine duration. In addition, according to Sağlam [60], Kazem et al. [61], and Dubey et al. [62], RH and AT influence the performance of the PV system, which depends on the PV technology. It can be concluded that Lefkoşa is the most promising location for the future installation of a PV system in Northern Cyprus.

Table 5. Summary for all chosen locations in Northern Cyprus.

Location	GSR [kWh/m^2]	SSD [h/day]	AT °C	RH [%]
Girne	153.89	7.81	21	65.8
Lefkoşa	160.78	8.56	19.6	62.7
YeniBoğaziçi	160.33	8.30	18.6	62.8
Salamis	139.88	7.99	13.5	67.8
Güzelyurt	151.34	8.07	18.9	67.9

3.2. Meteorological Parameters for the Best Location

3.2.1. Statistical Analysis of Meteorological Parameters

As mentioned previously, Lefkoşa has the highest annual global solar radiation compared to the other regions. Thus, the hourly and daily meteorological parameters for Lefkoşa were analyzed.

According to previous scientific studies, the performance of PV system depends on the weather parameters. In general, the module efficiency of solar PV panel depends on air temperature and relative humidity. Furthermore, several studies have investigated the most influential input parameters to affect the estimation of global solar radiation. For instance, Meenal and Selvakumar [63] found that sunshine hours, maximum temperature, and relative humidity are the most important parameters that affect the estimation of global solar radiation. Yadav et al. [64] concluded that the most relevant input variables for predicting solar radiation are temperature, altitude above mean sea level, and sunshine hours. Mohammadi et al. [65] found that sunshine hours, water vapor pressure, and ambient temperature are the important parameters that influenced the solar radiation characteristics. Rao et al. [66] concluded that temperature has the most significant effect on the availability of solar radiation at that location.

In line with the abovementioned studies, meteorological parameters including mean hourly global solar radiation, sunshine, relative humidity, and temperature were analyzed statistically. The data were taken as 1h average values for the three years between January 2014 and December 2016.

The statistical characteristics of mean hourly global solar radiation (GSR), sunshine (SS), relative humidity (RH), and temperature (T) data for Lefkoşa are summarized in Table 6. The tables show the following statistical parameters: arithmetic mean (Mean), standard deviation (SD), coefficient of variation in percent (CV), minimum (Min.), the first and third quartiles (Q1 and Q3), median, maximum (Max.), skewness (S), kurtosis (K), and the type of distribution (DT) (see Table 2).

It is found that the median values of GSR, T, and SSD are mainly lower than the mean, while the median value of RH is higher than the mean. The maximum SD occurred in July. In addition, it was noticed that the CV values of GSR show the lowest value in the summer months, which means higher stability is observed in these months. Furthermore, it is found that the GSR values varied between –0.1cal/cm^2 and 82.1cal/cm^2 with an average of 19.04 cal/cm^2 during the investigation period. The maximum GSR value was recorded in July. Type II frequency distributions curves, i.e., almost normal with positive tail, characterize the mean hourly GSR for January, February, October, November, and December. The most frequent distribution at Lefkoşa was Type III, which is narrow peak with positive tail (spring months, summer months, and September).

Moreover, the maximum and minimum temperature values were recorded in July and January with values of 36.533 °C and 6.2 °C, respectively. The maximum mean and SD values occurred in August and July, respectively. In addition, the most frequent distribution was Type VI, bimodal, symmetrical with flat peak, which was recorded in February, March, April, May, June, July, August, September, November, and October. Type II frequency distribution curves, i.e., almost normal with positive tail, characterize the mean hourly T for January and December.

Furthermore, it is found that the mean SS values varied from 12.79 min to 28.78 min. The highest and lowest mean SS values were recorded in January and July, respectively. The maximum hourly SS value is 59.87 min followed by 59.33 min, which were recorded in July and August, respectively. Type III was recorded in January, February, October, November, and December. Spring months, summer months, and September are of Type VI, i.e., bimodal, symmetrical with flat peak.

Additionally, it is observed that Type VI is recorded in all months for mean hourly RH data. Furthermore, the lowest (24.2%) and the highest (84.23%) mean hourly RH occurred in January and August, respectively.

Table 6. Statistical estimators of the mean hourly meteorological parameters for the period 2014–2016.

Parameter	Month	Mean	SD	CV	Min.	Q1	Median	Q3	Max.	S	K	DT
GSR [cal/cm^2]	Jan.	9.63	14.4	149.54	−0.1	−0.1	−0.1	19.99	38.67	1.14	−0.35	II
	Feb.	13.8	19.26	139.54	−0.1	−0.1	0.08	30.22	51.23	0.99	−0.7	II
	Mar.	18.35	23.77	129.5	−0.1	−0.1	1.37	41.67	60.3	0.83	−1.05	III
	Apr.	23.11	27.96	120.98	−0.1	−0.1	5.42	51.78	71.6	0.71	−1.23	III
	May	24.73	28.07	113.47	−0.1	−0.1	10.2	56.33	70.67	0.56	−1.47	III
	Jun.	28.12	31.6	112.36	−0.1	−0.1	13.08	61.82	80.53	0.58	−1.4	III
	Jul.	28.15	32.25	114.55	−0.1	−0.1	11.08	61.24	82.1	0.6	−1.38	III
	Aug.	25.3	30.38	120.07	−0.1	−0.1	6.58	56.1	78.57	0.69	−1.25	III
	Sep.	20.71	26.4	127.48	−0.1	−0.1	2.77	48.47	68.73	0.82	−1.04	III
	Oct.	15.67	21.54	137.45	−0.1	−0.1	0.68	35.35	57.7	0.99	−0.67	II
	Nov.	11.92	17.34	145.48	−0.1	−0.1	0	28.3	46.33	1.08	−0.52	II
	Dec.	8.98	13.42	149.54	−0.1	−0.1	−0.1	20.34	35.87	1.11	−0.49	II
T [°C]	Jan.	9.983	3.313	33.18	6.2	6.833	9.15	13.7	15.1	0.41	−1.5	III
	Feb.	11.468	3.989	34.78	6.7	7.725	10.283	15.98	17.333	0.31	−1.6	VI
	Mar.	14.001	3.97	28.35	8.833	10.183	13.2	18.18	19.867	0.22	−1.57	VI
	Apr.	17.704	4.733	26.73	11.233	13.25	17.267	22.68	24.6	0.15	−1.57	VI
	May	21.451	4.324	20.16	15.433	17.158	20.933	25.98	27.233	0.07	−1.61	VI
	Jun.	26.189	4.404	16.82	20	21.975	25.517	30.79	32.4	0.09	−1.59	VI
	Jul.	29.112	4.753	16.32	22.567	24.667	28.35	34.16	36.133	0.19	−1.53	VI
	Aug.	29.425	4.636	15.76	23.067	25.333	28.533	34.31	36.533	0.24	−1.44	VI
	Sep.	26.172	4.058	15.51	20.533	22.783	25.517	30.29	32.467	0.24	−1.39	VI
	Oct.	21.699	4.044	18.64	16.333	17.875	20.783	25.83	27.933	0.27	−1.47	VI
	Nov.	15.465	4.228	27.34	10.233	11.442	14.117	20.03	21.833	0.34	−1.54	VI
	Dec.	11.337	3.308	29.17	7.533	8.417	10.283	14.99	16.533	0.43	−1.45	III

Table 6. *Cont.*

Parameter	Month	Mean	SD	CV	Min.	Q1	Median	Q3	Max.	S	K	DT
SS [min]	Jan.	12.79	17.58	137.52	0	0	0	35.17	41.67	0.78	−1.34	III
	Feb.	16.85	21.29	126.36	0	0	0	43.18	48.43	0.57	−1.74	III
	Mar.	20	22.92	114.6	0	0	0.87	46.75	50.67	0.36	−1.91	VI
	Apr.	23.46	24.58	104.81	0	0	10.17	49.98	52.83	0.16	−2.09	VI
	May	24.12	23.68	98.18	0	0	24.62	45.82	54.07	0.03	−2.06	VI
	Jun.	27.77	26.81	96.53	0	0	33.25	54.05	59.07	−0.01	−2.06	VI
	Jul.	28.78	28.35	98.48	0	0	27.07	57.78	59.87	0.02	−2.08	VI
	Aug.	26.66	28.12	105.51	0	0	9.98	57.27	59.33	0.17	−2.09	VI
	Sep.	22.54	25.64	113.78	0	0	1.97	49.19	58.27	0.35	−1.91	VI
	Oct.	19.11	23.59	123.44	0	0	0.28	46.72	53.47	0.53	−1.7	III
	Nov.	16.9	22.68	134.17	0	0	0	46.37	50.5	0.72	−1.53	III
	Dec.	13.18	18.38	139.5	0	0	0	38.22	41.37	0.79	−1.39	III
RH [%]	Jan.	72.9	11.96	16.41	52.33	60.23	77.83	83.28	84.23	−0.67	−1.23	VI
	Feb.	68.65	14.68	21.39	45.27	52.33	74.9	81.94	83.6	−0.53	−1.45	VI
	Mar.	62.71	15.6	24.87	38.47	46.35	67.7	77.56	79.93	−0.38	−1.59	VI
	Apr.	55.93	18.59	33.24	29.53	36.08	58.65	75.02	77.73	−0.21	−1.72	VI
	May	56.32	17.93	31.84	32.57	36.27	58.77	74.28	78.23	−0.09	−1.78	VI
	Jun.	48.15	17.04	35.39	25.57	29.62	50.23	65.63	68.97	−0.09	−1.79	VI
	Jul.	49.43	19.17	38.79	22.83	29.63	52	68.24	72.13	−0.16	−1.75	VI
	Aug.	53.43	19.09	35.73	24.2	33.42	58.32	72.33	75.1	−0.32	−1.64	VI
	Sep.	54.34	16.33	30.05	29	37.15	59.78	69.72	72.9	−0.38	−1.56	VI
	Oct.	59.98	16.38	27.3	33.57	42.9	65.37	75.04	77.53	−0.5	−1.45	VI
	Nov.	58.85	13.67	23.23	36.57	44.46	64.2	71.18	74.5	−0.49	−1.41	VI
	Dec.	71.24	11.88	16.67	51.13	59.21	76.13	81.79	83.33	−0.61	−1.27	VI

3.2.2. Mean Hourly and Monthly of Meteorological Parameters

The mean hourly meteorological parameters for an average day of each month are illustrated in Figure 9. The graphs reveal that maximum GRS, T, and SS occur between 10 a.m. and 12 p.m. In contrast, the minimum value of RH occurs at 11 a.m.

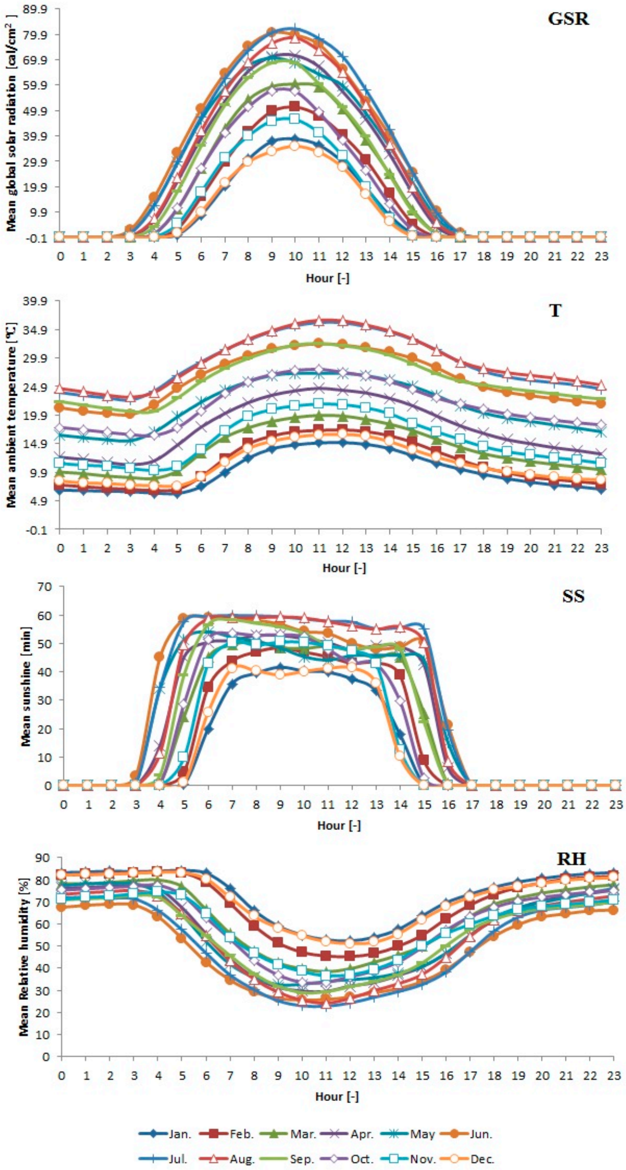

Figure 9. Mean hourly meteorological parameters for an average day for the period 2014–2016.

Moreover, Table 7 shows the monthly meteorological parameters in terms of mean, maximum, and minimum during the investigation period (2014–2016). It is found that the maximum monthly value of GSR was 750 cal/cm^2/day, which was recorded in June 2014, and the minimum monthly value of 44.3 cal/cm2/day was obtained in March 2015. In addition, it is observed that the monthly maximum temperature was found to be 38.2 °C, which was recorded in July 2016. The monthly minimum temperature occurred in January 2016 with a value of 3.2 °C. Furthermore, the mean monthly SS values are within the range 4.6–11.6 h/day and the mean monthly RH values varied from 44.0% to 78.0%, as shown in Table 7.

Table 7. Mean, maximum, and minimum monthly meteorological parameters.

Parameter	Year	Variable	Month											
			Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
GSR [cal/cm^2/day]	**2014**	Mean	242.8	352.2	438.5	540.6	572.1	667.3	674.8	586.9	484.9	377.3	271.8	203.7
		Max.	352.2	446.7	602.5	666.6	732.3	750.0	730.3	677.5	598.3	506.9	372.7	284.1
		Min.	69.7	160.9	157.0	228.6	83.0	437.0	575.6	494.7	317.1	230.7	85.6	70.0
	2015	Mean	216.8	300.3	423.7	550.7	606.6	645.9	668.6	605.8	487.7	346.8	291.4	230.4
		Max.	329.3	436.7	586.6	692.1	708.9	745.9	716.8	649.6	587.1	466.4	389.0	305.6
		Min.	52.5	128.3	44.3	220.8	368.4	269.7	565.1	513.5	297.8	148.8	139.1	71.0
	2016	Mean	235.3	339.2	452.5	551.3	598.6	691.5	674.5	622.8	513.1	400.8	296.5	203.0
		Max.	339.8	467.3	602.2	678.9	728.3	746.3	723.3	660.3	588.4	494.7	368.0	291.3
		Min.	49.6	107.2	257.6	313.9	321.8	574.8	481.4	564.4	427.0	287.6	65.1	49.2
T [°C]	2014	Mean	11.6	11.6	14.5	17.7	20.9	26.1	28.5	29.2	25.6	20.5	14.7	12.9
		Max.	17.9	19.0	21.6	25.9	28.1	33.4	36.7	37.7	32.4	27.8	21.5	19.2
		Min.	5.9	4.7	7.5	10.2	13.7	19.2	21.5	22.0	19.4	14.3	8.4	7.3
	2015	Mean	9.2	9.7	13.1	15.6	21.8	24.7	28.7	29.7	27.0	22.3	16.4	11.3
		Max.	15.0	15.7	19.7	23.3	30.0	32.3	37.2	37.8	35.7	29.5	23.9	18.3
		Min.	3.5	3.7	6.4	7.7	13.9	17.6	20.6	22.6	19.8	16.6	9.3	4.9
	2016	Mean	9.3	13.2	14.4	20.1	21.7	28.0	30.2	29.4	25.8	22.3	15.4	9.9
		Max.	15.1	20.7	21.5	29.0	29.3	35.7	38.2	38.0	33.4	30.2	22.6	14.9
		Min.	3.2	6.4	7.0	11.7	14.6	20.3	22.7	22.0	19.3	15.0	8.3	4.9

Table 7. *Cont.*

Parameter	Year	Variable	Month											
			Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
SS [h/day]	2014	Mean	5.5	7.3	8.1	9.2	9.1	10.9	11.6	10.1	8.6	7.6	6.3	4.9
		Max.	8.6	9.4	10.9	11.6	12.3	12.4	12.3	11.8	10.8	10.0	8.9	8.0
		Min.	0.0	1.0	0.8	2.1	0.0	5.7	9.8	6.7	3.1	4.2	0.4	0.3
	2015	Mean	4.6	5.9	7.6	9.2	10.1	10.6	11.3	10.8	9.0	6.7	6.9	5.8
		Max.	8.5	8.7	10.7	11.8	12.1	12.5	12.0	11.5	10.6	9.5	9.0	8.2
		Min.	0.0	0.2	0.0	2.0	5.1	6.3	9.0	9.6	4.6	0.7	0.5	0.0
	2016	Mean	5.2	6.9	8.1	9.3	9.6	11.6	11.4	10.9	9.3	8.5	6.9	4.6
		Max.	8.3	9.6	10.8	11.7	12.4	12.5	12.4	11.7	10.6	9.9	8.7	8.0
		Min.	0.0	0.0	3.0	3.8	4.2	8.4	5.8	9.4	6.9	5.7	0.0	0.0
RH [%]	2014	Mean	71.1	65.7	59.7	59.5	60.8	46.5	52.6	56.1	53.9	62.8	65.5	78.0
		Max.	93.0	95.0	94.0	95.0	96.0	92.0	91.0	91.0	88.0	92.0	92.0	94.0
		Min.	28.0	21.0	14.0	11.0	17.0	7.0	12.0	10.0	15.0	16.0	15.0	33.0
	2015	Mean	75.6	75.8	68.9	58.5	56.3	54.5	49.0	50.0	57.1	62.6	55.6	63.0
		Max.	94.0	95.0	104.0	94.0	94.0	92.0	92.0	89.0	93.0	93.0	94.0	94.0
		Min.	27.0	29.0	23.0	11.0	9.0	15.0	9.0	10.0	11.0	16.0	11.0	14.0
	2016	Mean	69.0	64.6	59.4	49.4	51.8	44.0	46.4	54.0	52.1	54.3	55.2	72.8
		Max.	94.0	96.0	94.0	93.0	94.0	84.0	85.0	86.0	90.0	87.0	91.0	94.0
		Min.	28.0	18.0	16.0	8.0	12.0	11.0	9.0	9.0	10.0	10.0	10.0	32.0

3.2.3. Empirical Modeling

A model with empirical correlations was proposed to relate the hourly data for meteorological parameters in terms of GSR, T, SS, and T using MATLAB R2015. Polynomial equations were utilized to verify the behavior of GSR as a function of SS, T, and RH. The correlations of the mixture models were expressed through Equations (13)–(15), which represent the dependence of the global solar radiation (GSR) with the temperature (T), with sunshine (SS), and with the relative humidity (RH).

$$\begin{gathered} GSR = 12.42 - 21.17 \cdot \mathrm{RH} - 4.77 \cdot \mathrm{T} + 8.152 \cdot RH^2 + 1.008 \cdot RH \cdot T - 0.7817 \cdot T^2 + 1.948 \cdot RH^3 \\ + 3.177 \cdot RH^2 \cdot T + 0.6659 \cdot RH \cdot T^2 \end{gathered} \tag{15}$$

$$\begin{gathered} GSR = 14.03 - 0.7242 \cdot \mathrm{RH} + 16.51 \cdot \mathrm{SS} + 0.09578 \cdot RH^2 - 4.984 \cdot RH \cdot SS - 0.258 \cdot SS^2 \\ -1.169 \cdot RH^3 - 0.8078 \cdot RH^2 \cdot SS - 3.088 \cdot RH \cdot SS^2 \end{gathered} \tag{16}$$

$$\begin{gathered} GSR = 13.53 + 0.825 \cdot \mathrm{T} + 18.96 \cdot \mathrm{SS} - 0.05722 \cdot T^2 + 2.394 \cdot T \cdot SS + 3.957 \cdot SS^2 + 0.5036 \cdot T^3 \\ -0.1744 \cdot T^2 \cdot SS + 0.6583 \cdot T \cdot SS^2 \end{gathered} \tag{17}$$

Moreover, Three-dimensional curve surfaces were plotted based on the predicted model equations to investigate the interactions among the variables (global solar radiation (GSR), sunshine (SS), relative humidity (RH), and temperature (T)). The effect of T, SS, and RH on the GSR is presented in Figure 10. Furthermore, the contour plots of the GSR indicate the interaction effects of the parameters. In each contour graph, the interaction effect of the three parameters was plotted. The contour areas help to explain how the GSR varies with changes in the weather conditions. These contour plots demonstrate that the interaction effects of all parameters were considerable.

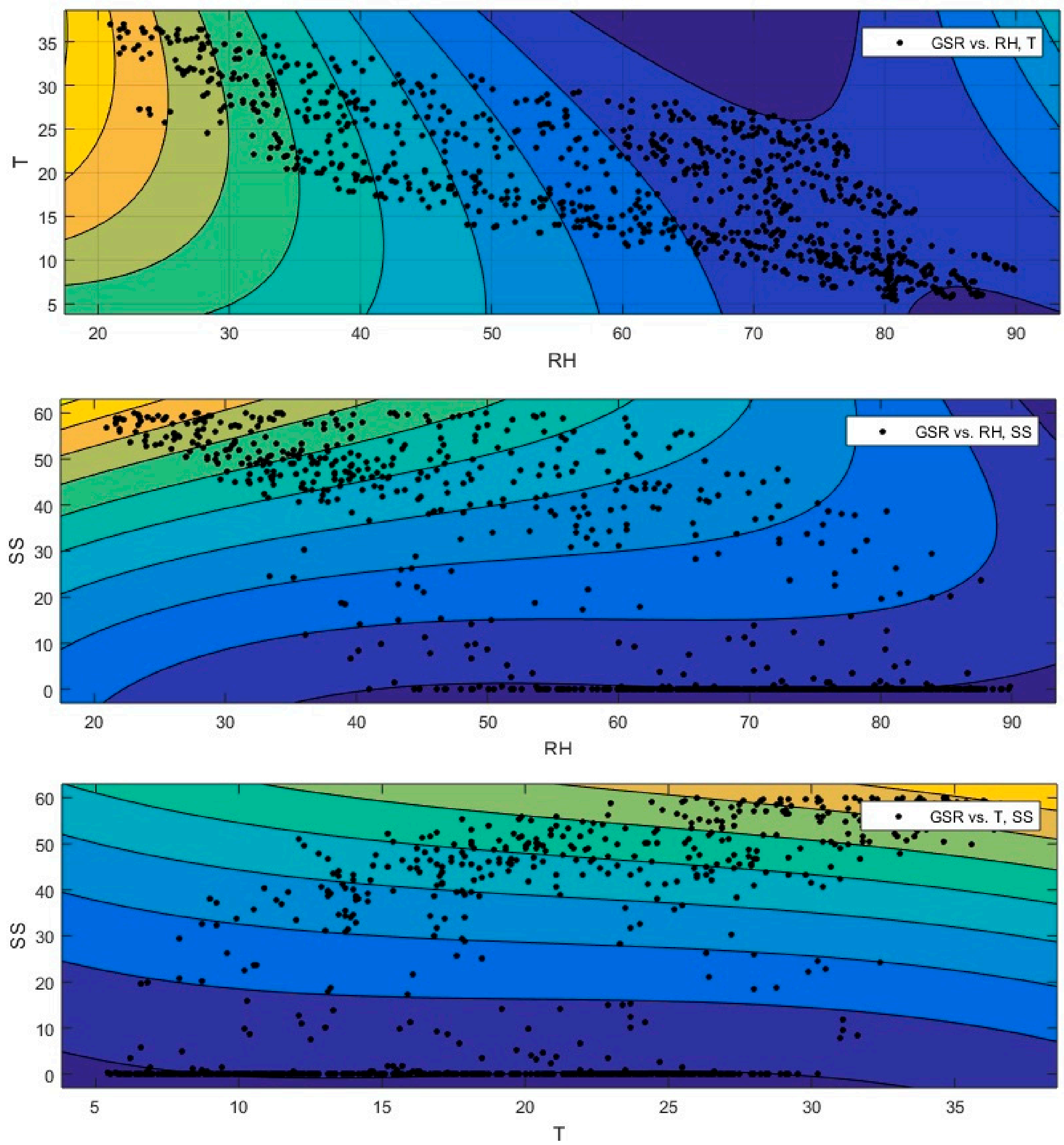

Figure 10. The response surface plot of global solar radiation (GSR).

3.3. Large-Scale Grid-Connected Solar PV System

As mentioned previously, the estimation of total energy consumption is considered the first step for designing a solar PV system. According to Mehr et al. [67], the total production capacity of the Turkish Electricity Authority in Lefkoşa is around 400 MW and is dependent on oil and fuel products. Thus, this study aims to reduce the electricity generated by diesel fuel by 33%. From the technical, economic, and environmental point of view, the evaluation of the feasibility of 100 MW grid-connected PV power in the Lefkoşa, Northern Cyprus was performed.

For a 100 MW installed capacity, a total area of 590,000 m^2 was considered for the PV power plant. In this analysis, a free-standing mode system with a fixed tilt is investigated. For the fixed tilt, the optimum slope and azimuth angles were selected based on the PVGIS simulation tool; they are 31° and -2°, respectively. To build the 1GWgrid-connected PV plant in the chosen location, 3000000 of the selected module are required. Moreover, 100 identical central inverters with an efficiency of 98.8% [68] are used to convert DC into AC and feed it directly to the grid with a capacity of 100 MW.

Thus, the initial cost of the PV project for the proposed 100 MW project for a fixed PV system would be 2700$/kW.

The RETScreen software was used to investigate the feasibility of the 100 MW installed capacity of the solar plant project in the selected region. Table 8 presents the monthly results for the electricity generation from the installed project and daily solar radiation-tilted. It is found that the highest electricity generation of 16.571GW was recorded in July. In addition, it was observed that daily solar radiation-tilted values varied from 3.3010 kWh/m^2/day to 7.2582 kWh/m^2/day. Moreover, the capacity factor of the solar PV project is found to be 18.1%.

Table 8. Daily solar radiation-tilted and electricity generation.

Month	Daily Solar Radiation-Tilted [kWh/m^2/day]	Electricity Exported to the Grid [MWh]
Jan.	3.6372	9174.8373
Feb.	4.5177	10,227.1483
Mar.	5.6236	13,860.4814
Apr.	6.1707	14,473.5296
May	6.8074	16,154.9994
Jun.	7.2826	16,349.2496
Jul.	7.2582	16,571.2942
Aug.	7.0468	16,073.6431
Sep.	6.6048	14,762.8562
Oct.	5.4820	13,001.2618
Nov.	4.1398	9824.1936
Dec.	3.3010	8297.6401

The financial parameters showing that the proposed system seems to be economically feasible are listed in Table 9. The overview of the cash flow over the project lifetime of solar plant projects for the selected region is shown in Figure 11. The cash flow indicates that the investor is expected to get positive cash flow from 7.8 years onwards from the solar plant project.

Table 9. Financial parameters.

Factor	Unit	Value
Inflation rate	%	8
Discount rate	%	6
Reinvestment rate	%	9
Project life	year	25
Debt ratio	%	70
Debt interest rate	%	0
Dept term	year	20
Electricity export escalation rate	%	5

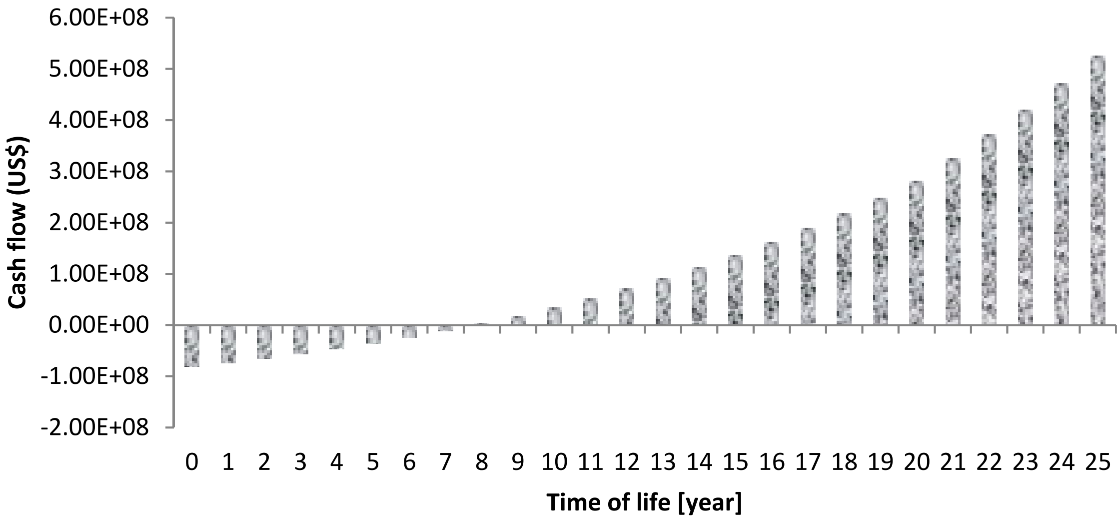

Figure 11. Cumulative cash flow for all projects.

Moreover, the economic performance of the 100 MW grid-connected PV system for the selected location is presented in Table 10. On the basis of the results of economic performance, the development of the proposed 100 MW PV project is very promising in the chosen region. Additionally, emissions of greenhouse gas (GHG) were estimated using the RETScreen software. The results demonstrate that using the PV project significantly reduced GHG emissions, as shown in Table 10.

Table 10. Economic performance and net annual reduction of greenhouse gas (GHG) emissions.

Economic performance							
NPV [$]	*EP* [year]	*SP* [year]	*LCOE* [$/kWh]	*B-C*	*ALCS* [$/year]	*IRR-assets* [%]	*IRR-equity* [%]
52,338,408.15	7.8	17	0.0933	3	12,699,318.65	5.2	16.3

Net annual reduction of GHG emissions			
Net annual GHG emission reduction [tCO_2]	**Car and light trucks not used**	**People reducing energy use by 20%**	**Hectares of forest absorbing carbon**
2,906,917	21,296.0944	116,276.6754	10,694.4321

4. Conclusions

Solar radiation is an essential meteorological parameter for the investigation of a PV project and the selection of the best location for installing the PV system. Additionally, it is important for assessing the potential of solar energy in a specific region. Therefore, the potential of exploring solar energy was investigated in five locations in Northern Cyprus based on real global solar radiation data, which was collected by the Meteorological Department. The results indicate that Lefkoşa has the highest global solar radiation with a value of 160.78 kWh/m^2 followed by YeniBoğaziçi with a value of 160.33 kWh/m^2. Additionally, mean monthly global solar radiation data were compared with the PVGIS_CMSAF and NASA databases to show the accuracy of the satellite data. The results indicate that the two databases gave good estimations according to the high R^2 value, which is approximately 1. In addition, it is found that the actual value and estimated value are almost equal for the Lefkoşa region. Among the locations, Lefkoşa is the most promising location for the future installation of a PV system due to the highest values for solar radiation and sunshine duration. Examining the feasibility of using solar energy in Northern Cyprus, as is done in this study, is a necessary first step for a PV project. Moreover, the meteorological parameters (global solar radiation, air temperature, sunshine duration, and relative humidity) of Lefkoşa location were analyzed. Additionally, statistical characteristics including skewness and kurtosis of hourly meteorological parameters were used to select the type of distribution function. The results demonstrated that the most frequent distribution at Lefkoşa is Type III, which is characterized by a narrow peak with positive tail for GSR, and Type VI, bimodal, symmetrical with flat peak for T, SS, and RH. Moreover, an analysis of the influence of meteorological parameters on GSR was carried out, and a model of a surface was proposed to adjust the curves that varied as a function of T, SS, and RH. Finally, this study provides a comprehensive and integrated feasibility analysis for 100 MW grid-connected wind farm or solar plant projects, which are two of the most economic projects in the selected region in terms of reducing the electricity demand and GHG emissions. The results show that the Levelized cost of electricity was 0.0933$/kWh for the selected region and more than 2906917 tCO_2 could be avoided annually. Thus, using a PV system would have environmental and socioeconomic benefits in Northern Cyprus.

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