Simulation and performance analysis of 110 KWP grid-connected photovoltaic (PV) system for residential building in Northern Cyprus

Hüseyin Gökçekuş, Youssef Kassem, Shilan Abdi

Abstract*: *The rises in the populations and energy demand have encouraged the scientific researchers to investigate the renewable energies potential practically solar energy in the world. The solar rooftop Photovoltaic system is considered an alternative energy source for generating electricity for small households. Therefore, the main aim of this article is to research the possibility of using grid-connected PV system in Northern Cyprus with different urban locations. This study is focused on the use of PVGIS as simulation tool to analyze the performance of 110kW PV system also the comparison between various Photovoltaic technologies based on performance ratio. The result showed that the annual average performance ratio was varied from 75% to 80%. within the three types of PV technologies considered here, Cadmium telluride (CdTe) Photovoltaic system has the higher performance ratio except in Girne (35.337, 33.319) and Dipkarpaz (35.595, 34.379).

Index Terms*: *Grid-connected; photovoltaic; Northern Cyprus; PV technologies; simulation tool.

I. INTRODUCTION

Solar energy is clean fuel energy and it is considered as significant renewable source to reduce the fuel consumptions. A key advantage of solar energy is that they avoid carbon dioxide emissions [1]. Solar system is based on converting sunlight into electrical energy directly using photovoltaic (PV). Solar PV system is used extensively for meeting the electricity demand in many countries particularly with the constant fluctuating in supply of grid electricity [2]. The process of harvesting solar energy by PV is accomplished using solar modules consist of a number of solar cells made of photovoltaic materials. The grid-connected PV systems and stand-alone PV systems are the most widely formations of PV system used [3].

Various studies have been investigated the PV system performance. Dondariya et al., [4] examined the feasibility of grid-connected rooftop PV system for small household building in India using four-simulation software. Charfi et al., [5] studied experimentally the performance of PV system with different inclination angles. Shukla et al. [6] investigated the feasibility of grid-connected rooftop PV system for residential Hostel building at MANIT using Solargis PV Planner software. Kumar et al. [7] analyzed the feasibility of developing a solar PV plant at two different campuses of University Malaysia Pahang (UMP) using PVGIS and PV Watts simulation tools. The global energy demand is rapidly increased because the growth of the population, consumption of fossil fuel [8]. Therefore, the increases of populations and energy demand have increased in recent years the significance of renewable energy as alternative source especially solar energy for electricity generating in Northern Cyprus to reduce greenhouse gas emissions (GHG). Numerous studies have been conducted the solar potential in Northern Cyprus. Kassem et al. [9] evaluated the economic feasibility of 12MW grid-connected wind farms and PV plants for producing electricity at Girne and Lefkoşa in Northern Cyprus. The authors concluded that PV plants are the most economical option compared to wind farms for generating electricity in the selected studied. Kassem and Gökçekuş [10] conducted a techno-economic assessment of a proposed 1MW grid-connected PV power plant in the town of Lefke. The analysis results showed that a PV plant could be used as a viable alternative for reducing the GHG emissions in Northern Cyprus and generating electricity from environmentally friendly sources. In this regard, the current paper aims to describe the solar potential at 25 locations across the Northern Cyprus. PVGIS simulation software is tool to evaluate the performance of 110kW grid-connected rooftop PV system for given location. In addition, three different PV technologies (crystalline silicon PV modules, Copper Indium Selenide (CIS) PV modules and Cadmium telluride (CdTe) PV modules) are compared in order to select the best PV technologies for area based on the simulation results. Moreover, the effect of inclination angles on the performance of PV systems has been discussed.

II. MATERIAL AND METHOD

A. Location details

Cyprus is the third largest island in the Mediterranean Sea, and the climate of Cyprus is considered as subtropical climate, Mediterranean and semi-arid (in the TRNC) which is classified as Csa

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and BSh according to Köppen-Geiger climate classification [11]. Cyprus location make it hard to have an electrical network connection with surrounding countries. hence, the demands of energy in the Northern part of Cyprus need to be fulfilled by a local power generator mostly by fossil fuel.

Locations considered in this study are the major cities and towns of Northern Cyprus. Figure 1 shows the location of the towns considered in this study on map. The description of the explored areas in terms of longitude, latitude, and elevation is tabulated in Table 1.

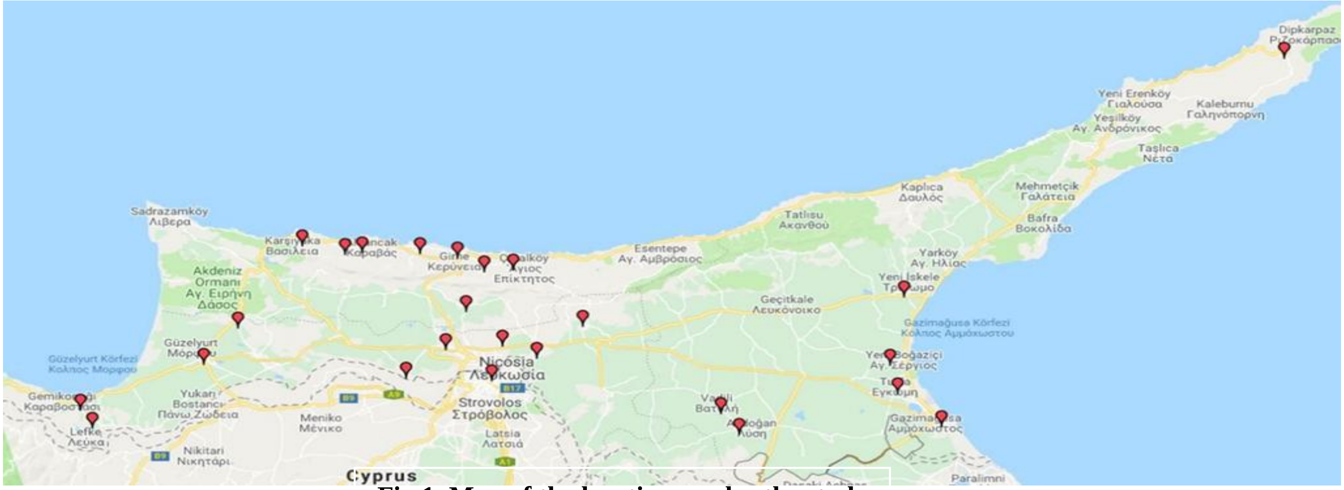

Fig.1. Map of the locations under the study in Northern Cyprus

Table 1. Information of the studied towns

Location	Latitude (°N)	Longitude (°E)	Elevation
Akdogan	35.107	33.68	60
Lefke	35.116	32.85	107
Gazimagusa	35.118	33.94	16
Vadili	35.134	33.656	55
Gemikonagi	35.139	32.835	13
Tuzla	35.161	33.883	4
Lefkosa	35.177	33.363	146
Alaykoy	35.181	33.253	172
Yenibogazici	35.197	33.874	11
Guzelyurt	35.198	32.993	49
Haspolat	35.206	33.42	109
Gonyeli	35.218	33.303	148
Hamitkoy	35.222	33.377	148
Kalkanli	35.245	33.037	134
Degirmenlik	35.248	33.479	154
Asagi dikmen	35.267	33.33	254
Iskele	35.286	33.892	26
Ozankoy	35.319	33.354	76
Catalkoy	35.321	33.39	82
Girne	35.337	33.319	23
Lapta	35.341	33.175	60
Karaoğlanoğlu	35.342	33.271	20
Alsancak	35.343	33.196	57
Karsiyaka	35.352	33.12	52
Dipkarpaz	35.595	34.379	126

B. System description

Table 2 shows the description of 110kW rooftop system used. The system is of fixed stand type and can appropriately power a building. The components of the grid-connected solar PV plants are shown in Figure 2.

Table 2. Description of a 110kW rooftop system

Installed power	110kW
Type of modules	CIS, Crystalline silicon, CdTe
Mounting system	Fixed mounting, free standing
Optimum Azimuth/slope	Variable
Availability	95%
System loss:	14 %
Availability	95.0%
DC/AC losses	5.0%/2.0%

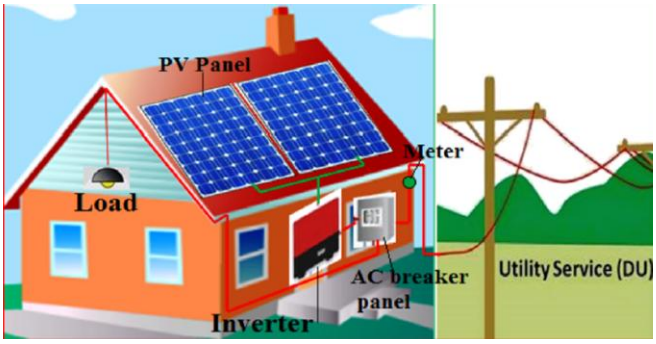

Fig. 2. Grid-connected PV system components

C. Energy harvest and performance ratio

Energy yield and performance ratio of the system are the most important parameters to estimate the performance of the PV system, which depends on two factors: solar radiation and energy production under the operating conditions. They are expressed as below.

$$Energy\ Yield = \frac{E_{PV,AC}}{P_{max,G,STC}} \quad (1)$$

$$Performance\ ratio = \frac{E_{AC}}{E_{DC} \times Irradiation} \quad (2)$$

where E_{AC} is energy output, E_{DC} is the nameplate D.C power obtained in (stc) standard test condition.

III. RESULT AND DISCUSSION

A. Solar irradiation

The data of irradiation obtained from PVGIS are tabulated in Table 3. The in-plane normal irradiation data are varied from 112 to 240 kWh/m2. Generally, the maximum in-plane solar irradiation is obtained in July and August, while the minimum in-plane irradiation is recorded in December and January. The yearly irradiation according to the location varies from kWh/m2 2341 to 2240 kWh/m2.

B. Estimated energy production for different PV technologies

Generally, the global solar irradiation does not depend on the PV technologies. Unlike the energy output from the PV panel. the monthly energy output with optimum slope angle and azimuth angle at different test location presented in Figure 3 to Figure 10 and tabulated in Table 4. It is observed that the maximum electricity generated in July. In addition, it is noticed that the monthly electricity production by CdTe PV modules is higher compared to crystalline silicon and CIS PV modules at the optimum slope angle and azimuth angle in all location except Girne (35.337, 33.319) and Dipkarpaz (35.595, 34.379).

Table 3. Monthly solar in-plane normal irradiation [kWh/m^2] with fixed-angle in test locations

Location	January	February	March	April	May	June	July	August	September	October	November	December	Yearly
Akdogan	130	139	186	198	214	226	238	237	214	190	157	130	2259
Lefke	128	143	199	210	216	226	238	237	216	192	161	132	2298
Gazimagusa	138	150	199	206	220	227	236	237	218	194	162	135	2322
Vadili	128	140	187	197	210	225	237	236	213	188	156	129	2246
Gemikonagi	125	139	194	206	213	224	236	234	213	188	156	127	2255
Tuzla	137	148	196	204	217	226	236	236	216	193	161	134	2304
Lefkosa	128	139	188	201	210	222	234	233	211	190	160	130	2246
Alaykoy	135	148	198	207	213	225	235	235	215	192	163	135	2301
Yenibogazici	139	150	197	204	217	226	237	237	217	196	166	138	2324
Guzelyurt	133	147	200	212	219	230	239	239	221	196	164	136	2336
Haspolat	128	141	190	201	208	221	234	233	211	190	160	129	2246
Gonyeli	132	144	194	204	212	224	235	235	214	192	162	132	2280
Hamitkoy	129	141	189	202	210	222	235	233	212	192	161	131	2257
Kalkanli	131	146	200	215	220	230	239	240	222	196	163	134	2336
Degirmenlik	129	143	191	200	207	221	234	233	211	187	157	128	2241
Asagi dikmen	131	144	195	205	212	223	235	235	214	192	162	131	2279

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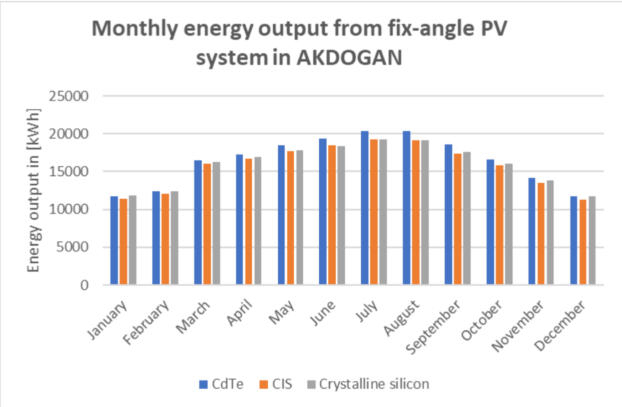
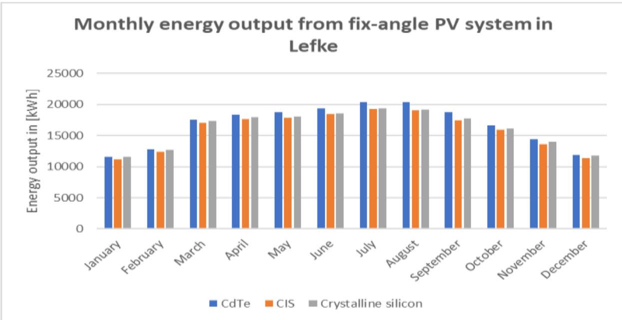
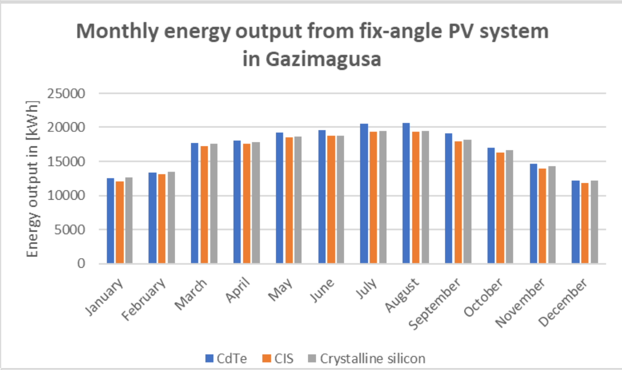
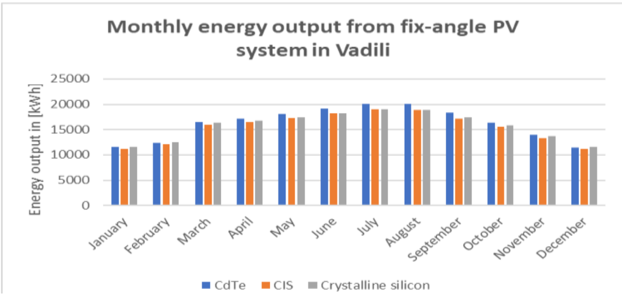
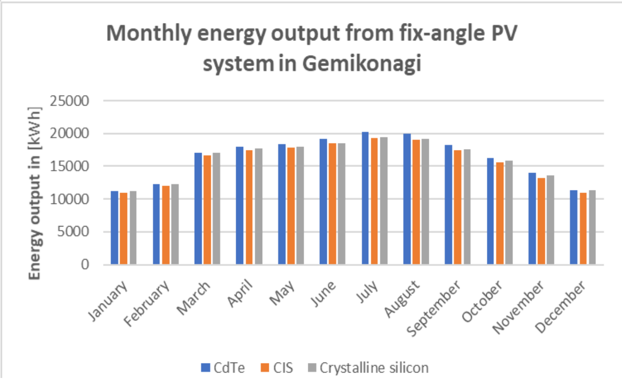
Iskele	137	149	198	205	215	225	237	237	216	194	165	135	2313
Ozankoy	123	138	194	206	212	224	236	235	215	189	150	118	2240
Catalkoy	126	140	195	207	213	225	236	236	216	192	154	122	2262
Girne	124	138	197	210	217	228	238	238	219	193	155	121	2278
Lapta	118	135	195	211	218	230	239	238	218	190	146	112	2250
Karaoğlanoğlu	125	138	197	211	218	228	238	238	218	194	158	122	2285
Alsancak	122	138	198	213	219	230	240	239	219	193	152	122	2285
Karsiyaka	132	143	203	217	223	230	239	239	222	201	162	130	2341
Dipkarpaz	128	146	196	205	217	225	234	235	213	190	157	124	2270
Maximum	139	150	203	217	223	230	240	240	222	201	166	138	2341
Minimum	118	135	186	197	207	221	234	233	211	187	146	112	2240

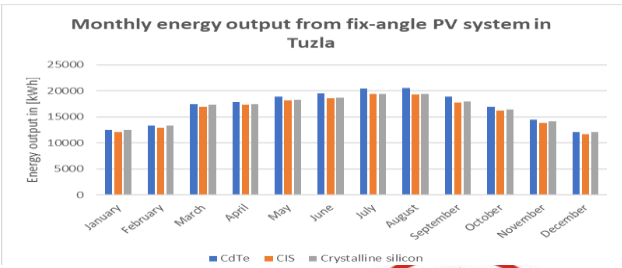












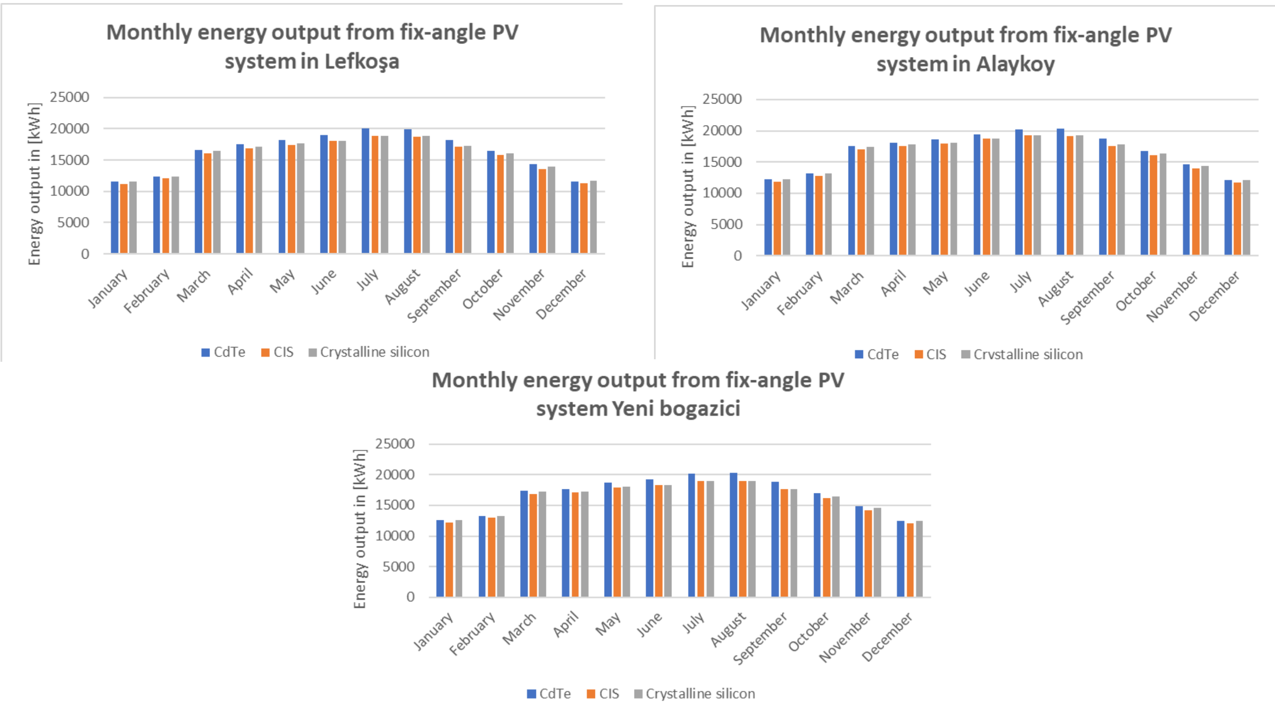
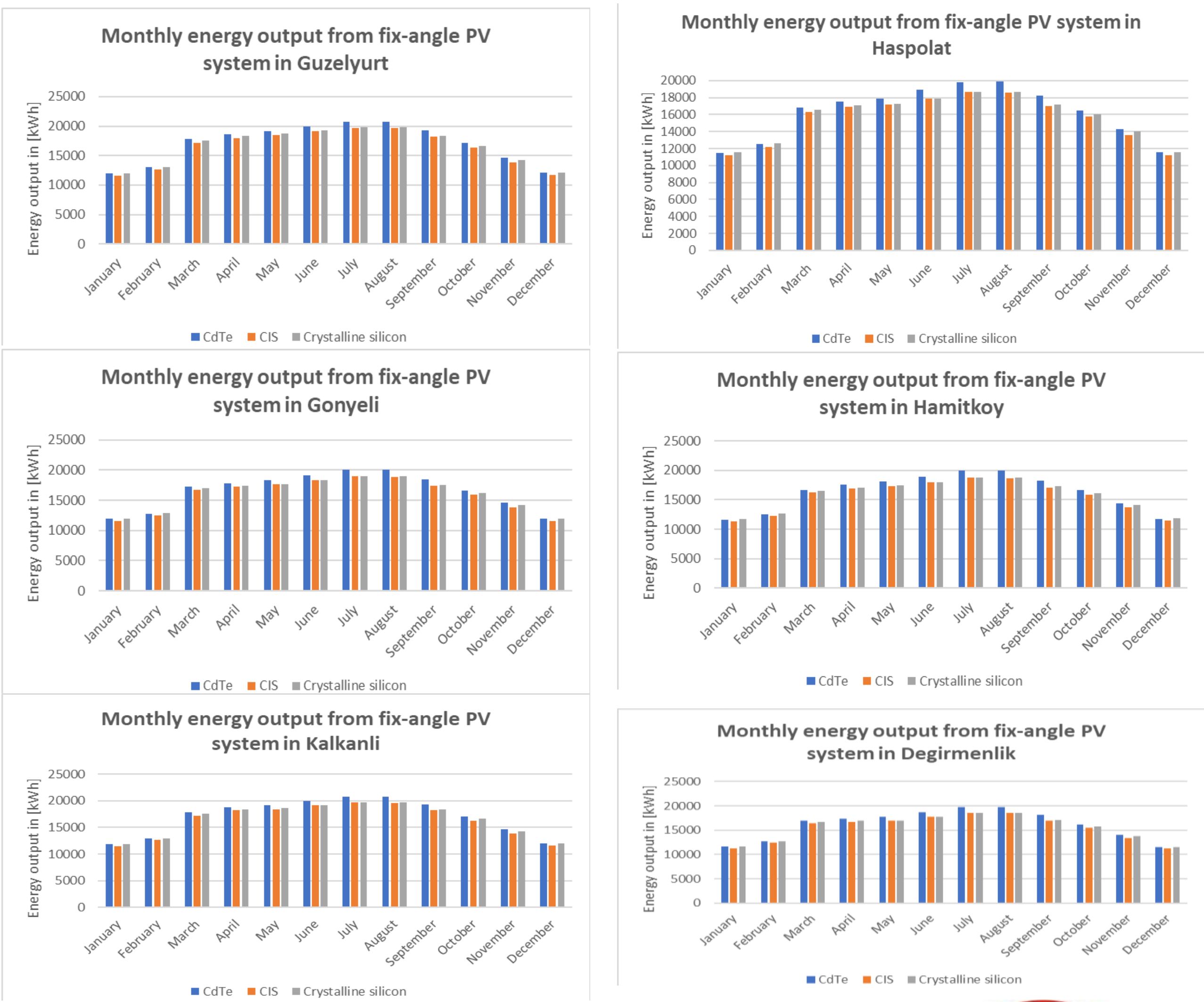


Fig. 3. Monthly electricity production for different PV technologies at nine locations (Akdogan, Lefke, Gazimagusa, Vadili, Gemikonagi, Tuzla, Lefkosa, Alaykoy,



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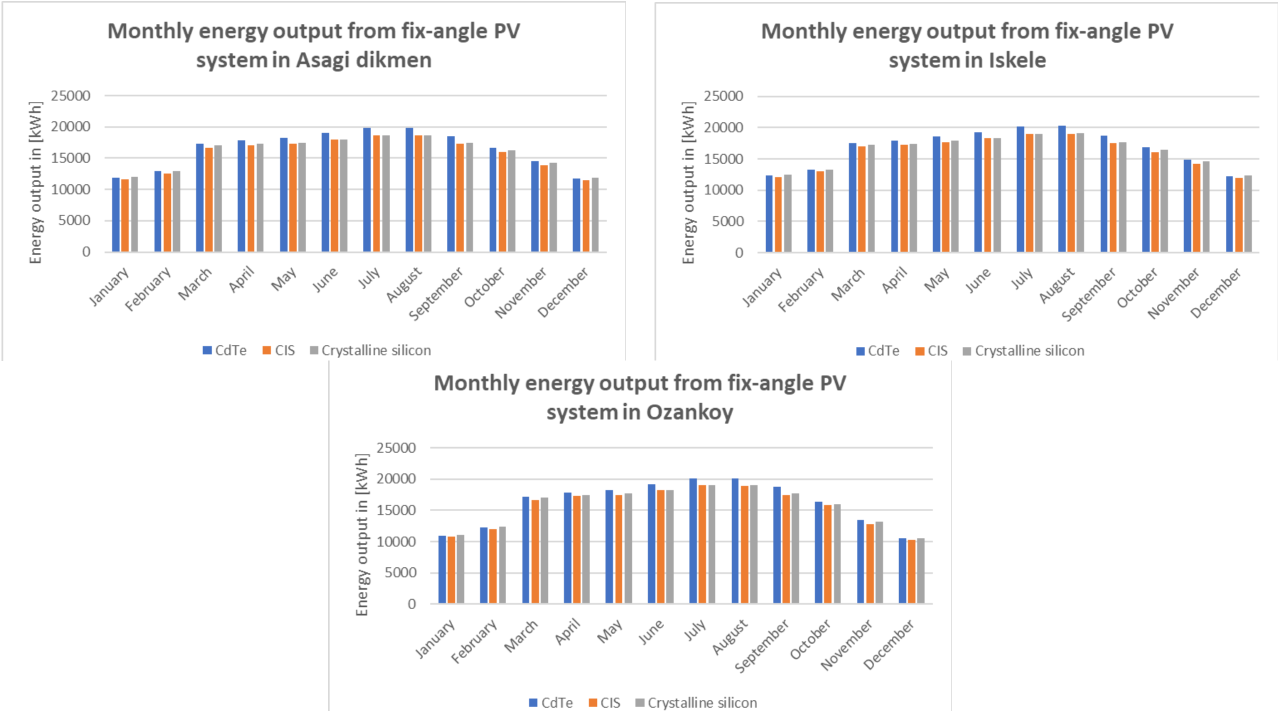
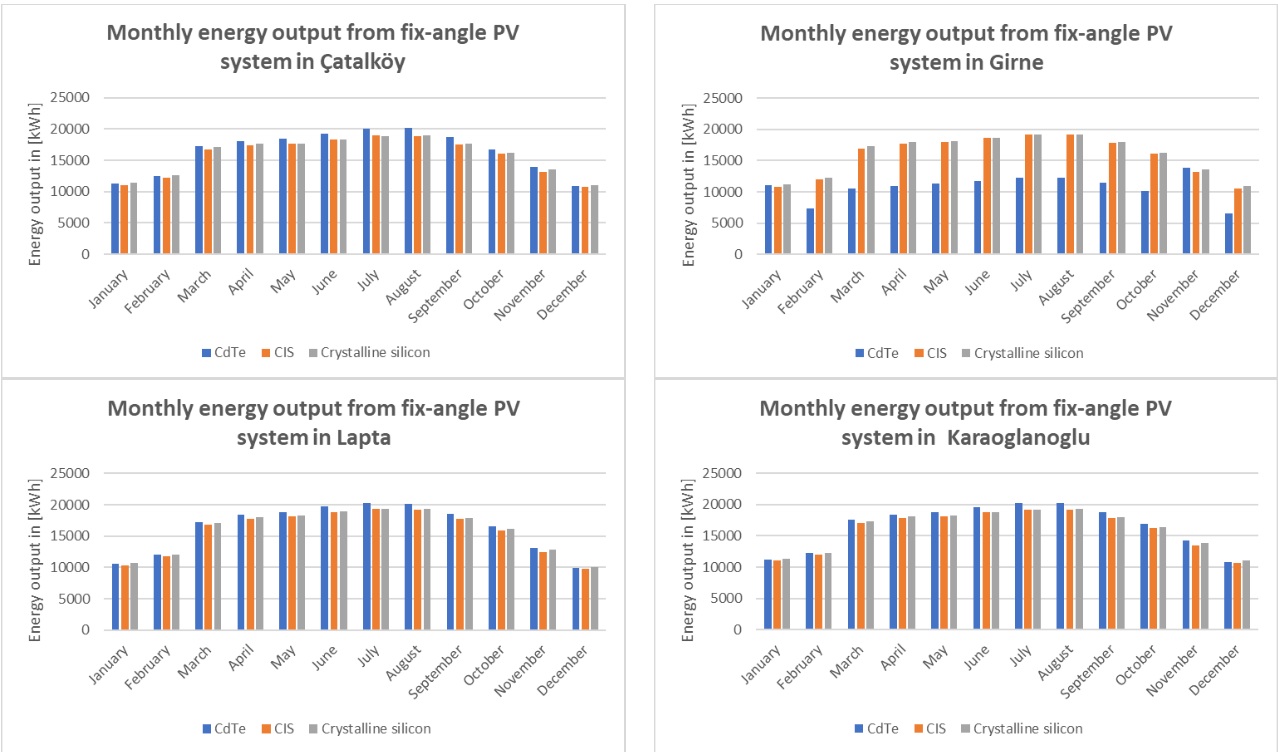


Fig. 4. Monthly electricity production for different PV technologies at nine locations (Guzelyurt, Haspolat, Gonyeli, Hamitkoy, Kalkanli, Degirmenlik, Asagi dikmen, Iskele, Ozankoy)



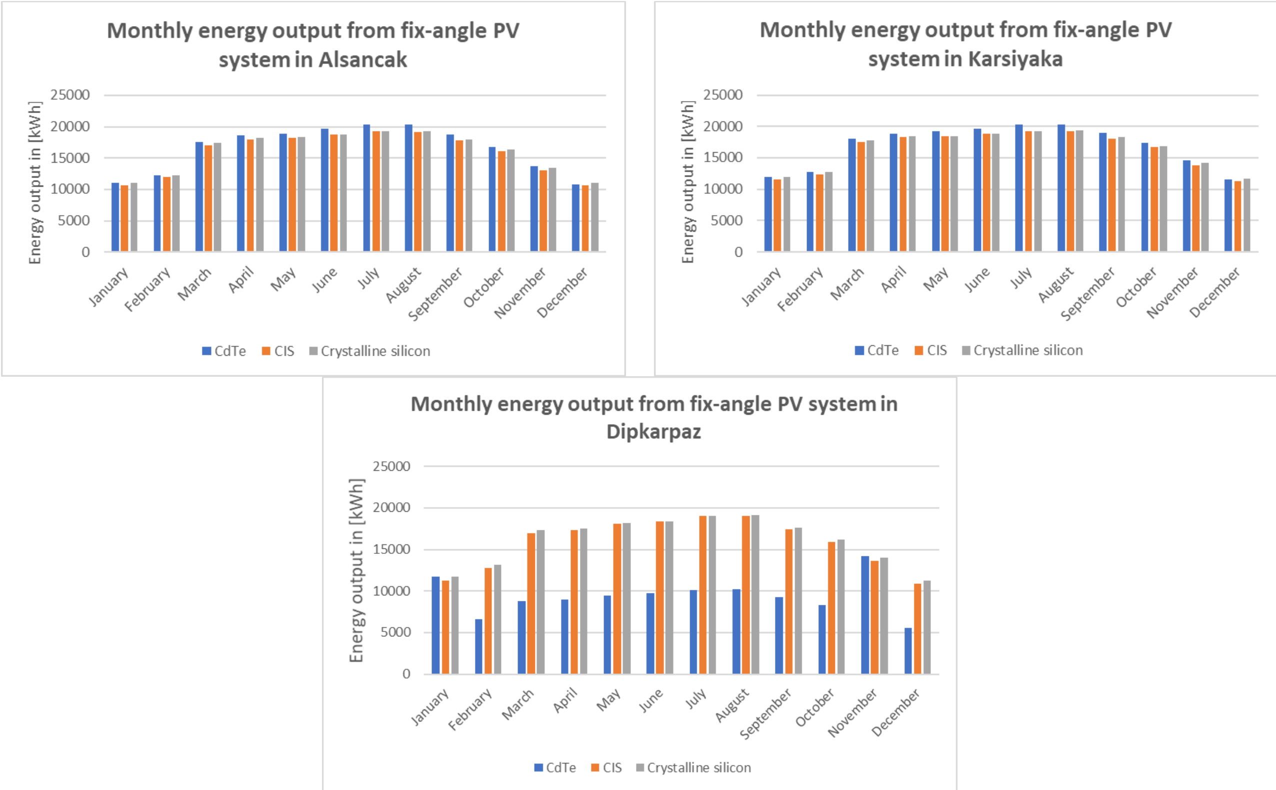


Fig. 5. Monthly electricity production for different PV technologies at seven locations (Catalkoy, Girne, Lapta, Karaoğlanoğlu, Alsancak, Karsiyaka, Dipkarpaz)

Table 4. Annual and average energy output from fix-angle PV system at optimum tilt angle (31°) in test locations with different PV technologies

	Average energy output for a month [kWh]			Annual energy output [kWh]		
Location	**CdTe**	**CIS**	**Crystalline silicon**	**CdTe**	**CIS**	**Crystalline silicon**
Akdogan	16475	15733.3	15933.3	197700	188800	191200
Lefke	16758.3	15958.3	16225	201100	191500	194700
Gazimagusa	17041.7	16333.3	16600	204500	196000	199200
Vadili	16266.7	15541.7	15766.7	195200	186500	189200
Gemikonagi	16350	15733.3	15975	196200	188800	191700
Tuzla	16900	16183.3	16425	202800	194200	197100
Lefkosa	16308.3	15600	15825	195700	187200	189900
Alaykoy	16816.7	16141.7	16383.3	201800	193700	196600
Yenibogazici	16875	16116.7	16325	202500	193400	195900
Guzelyurt	17116.7	16400	16658.3	205400	196800	199900
Haspolat	16283.3	15550	15775	195400	186600	189300
Gonyeli	16566.7	15866.7	16083.3	198800	190400	193000
Hamitkoy	16350	15616.7	15833.3	196200	187400	190000
Kalkanli	17058.3	16358.3	16591.7	204700	196300	199100
Degirmenlik	16200	15475	15650	194400	185700	187800
Asagi dikmen	16200	15475	15650	194400	185700	187800
Iskele	16833.3	16083.3	16316.7	202000	193000	195800
Ozankoy	16266.7	15575	15791.7	195200	186900	189500
Catalkoy	16200	15475	15650	194400	185700	187800
Girne	10774.2	15833.3	16058.3	129290	190000	192700
Lapta	16284.2	15664.2	15883.3	195410	187970	190600
Karaoğlanoğlu	16550	15933.3	16133.3	198600	191200	193600
Alsancak	16541.7	15891.7	16116.7	198500	190700	193400
Karsiyaka	16966.7	16308.3	16500	203600	195700	198000
Dipkarpaz	9411.7	15891.7	16125	112940	190700	193500
Average	**16055.8**	**15869.6**	**16091.0**	**192669.6**	**190434.8**	**193092**

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C. Performance ratio

The yearly average performance ratio for the three PV technologies are listed in Table 5. Also, the performance ratio is within the range of 75.9-80.3%. Moreover, CdTe PV technologies in most locations shows higher performance in terms of annual energy production compared to other PV technologies. This may be caused by lower temperature coefficient and capture losses of these technologies. But, in Girne (35.337, 33.319) and Dipkarpaz (35.595, 34.379) CdTe PV performed very poorly

Table 5. Annual average performance ratio at optimum tilt angle (31°) in test locations with different PV technologies

Location	PR_CdTe	PR_CIS	PR_Cry_Si
Akdogan	79.90%	76.40%	77.60%
Lefke	79.80%	76.10%	77.50%
Gazimagusa	80.30%	77.10%	78.50%
Vadili	79.30%	76.00%	77.30%
Gemikonagi	79.40%	76.40%	77.70%
Tuzla	80.30%	77.00%	78.30%
Lefkosa	79.50%	76.20%	77.50%
Alaykoy	80.00%	76.80%	78.10%
Yenibogazici	79.50%	76.10%	77.20%
Guzelyurt	80.10%	76.80%	78.20%
Haspolat	79.40%	76.00%	77.30%
Gonyeli	79.60%	76.30%	77.50%
Hamitkoy	79.30%	76.00%	77.20%
Kalkanli	79.90%	76.70%	78.10%
Degirmenlik	79.20%	75.90%	76.90%
Asagi dikmen	79.50%	76.10%	77.20%
Iskele	79.70%	76.40%	77.60%
Ozankoy	79.50%	76.30%	77.60%
Catalkoy	79.60%	76.30%	77.50%
Girne	53.20%	76.30%	77.60%
Lapta	79.30%	76.40%	77.70%
Karaoğlanoğlu	79.30%	76.50%	77.70%
Alsancak	79.30%	76.30%	77.70%
Karsiyaka	79.40%	76.40%	77.50%
Dipkarpaz	47.10%	76.90%	78.20%
Average	**77.3**	**76.4**	**77.6**

IV. CONCLUSIONS

The current study described herein had two goals. The first goal was to evaluate and describe the solar energy harvesting potential in the Northern Cyprus. To achieve this, PVGIS simulation tool was used in terms of collecting and analyzing data. The result demonstrated that the maximum and minimum solar radiation potential at the selected locations is achieved in July and January, respectively. The second goal of this study was to determine the most suitable PV technologies for area based on the simulation results. At this stage of the analysis, energy yield and performance ratio were calculated for each system. The result showed that the annual performance ratio was varied from 75.9 to 80.3%. and their energy yields were ranged from 112940 to 205400 kWh annually. Among the three types of PV systems considered here, CdTe PV system has the higher performance ratio except in two locations where Crystalline silicon type outperformed this need further study to explain the causes of this situation. From the annual energy output of the PV systems, it is concluded that all the three technology achieve satisfactory performance under the subtropical and Mediterranean weather conditions. The electrical power delivered by PV systems can be used to power many applications in houses, residences or public loads like street lightings.

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