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Performance Evaluation and Viability Studies of Photovoltaic Power Plants in North Cyprus

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Abstract- Generation of electric power by photovoltaic system largely depends on multiple factors such as weather condition, panel orientation, panel efficiency, inverter efficiency, etc. These factors directly affect the magnitude of PV output power. The first grid-tied photovoltaic power plant in Northern Cyprus is the Kib-Tek solar panel station located in Serhatkoy with a capacity of 1.275 MW. The aim of this paper is to comprehensively investigate Kib-Tek solar panel station considering investment made, plant efficiency, performance ratio, capacity factor and also determine the potential impact on levels of output power when a single-axis solar tracking system is incorporated into the plant design. Kib-Tek solar panel station is at a fixed tilt angle of 24.84^0. Furthermore, selected locations such as Famagusta, Girne and Lefkosa are investigated by simulation to determine their viability/suitability for the construction of similar photovoltaic power plants. Simulations are conducted in PVsyst software using technical parameters of Kib-Tek solar panel station as a model. The result of this investigation shows that Kib-Tek solar panel station operates at optimal capacity, the average PR and CF values are 85.77% and 17.71% respectively. The magnitude of PV output power increased by 27.88% when a single-axis tracking system was added to the plant design. Finally, computed average payback period of the simulated PV plants is 9.62 years which approximately equals to 9 years for Kib-Tek solar panel station. The average payback period was reduced to 7.4 years when a single-axis tracking system was added to the plant design. The average grid injected energy for the selected regions are 2158.16MWh and 2831.93MWh for fixed-tilt angle and single-axis tracking respectively, this represent a 31.22% increase in grid injected energy.

Keywords Capacity Factor, Payback Period, Photovoltaic Power Plant, Single-Axis Tracking System.

1. Introduction

Continuous reliance on fossil fuel for electric power generation has become questionable due to the release of CO_2 gases into the atmosphere causing rapid depletion of the ozone layer, constant price fluctuation of crude oil and geopolitical issues such the current Russia-Ukraine war. Global warming is another negative effect of fossil fuel which endangers or threatens the quality of life of all species on earth [1]. Renewable energy sources (solar, wind, tidal, hydro etc.) have proven over the years to be reliable, economical and environmentally-friendly. Solar energy compared to other forms of renewable energy with respect to electric power generation, offers the best trade-off between investment and revenue generation. There are various methods of using solar energy to generate electric power. Photovoltaic system, solar thermal energy, concentrated solar power and concentrated PV system are some examples [2]. Investment and research work into solar energy technologies most especially photovoltaic systems have increased over the past few years.

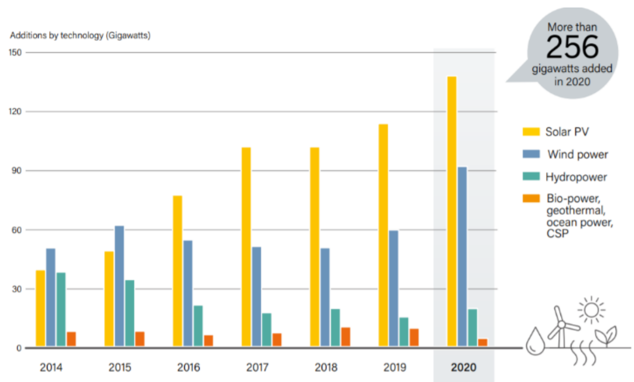


Fig. 1. Generations based on renewable energy sources [3]

Figure 1 shows the quantity of electric power added to the various national grids around the world by renewable energy sources. As at the end of 2020, more than 256 Gigawatts of electric power generated from renewable energy sources have been added to various grids. As shown in Fig. 1, solar PV systems added more gigawatts of electric power to the various grids compared to other renewable energy sources [3].

Most developed countries have increased investments into electric power generations based on renewable energy sources. China continues to take the lead in investments and capacity additions for solar, hydro and wind resources as the end of 2020. Particularly in terms of PV installations, the quantum of investments and capacity addition is enormous. This is evident from the graph of Fig. 2. This graph shows the cumulative installed PV systems from 2010 to 2019 [4]. The total capacity of installed PV systems in China in the last three years of 2017, 2018 and 2019 surpasses the entire installed capacity in the European Union. The rest of the world especially Africa and the Middle East have the best weather conditions for PV system installations but are yet to make significant investments. Countries such as India, China, and the US will increase the capacity of installed plants between the years 2020 and 2022. It's estimated that the installed capacity of PV plants in the world will reach 2TW of power by 2025 [5].

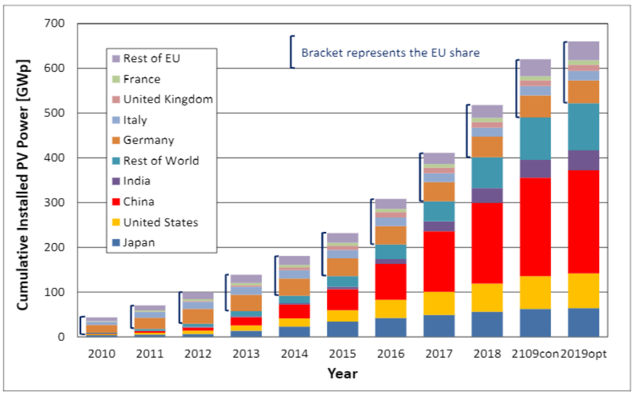


Fig. 2. Cumulative installed PV systems [4]

1.1. Electric Power and PV Potential in Northern Cyprus

Cyprus is an island located by the southern border of Turkey and the north-eastern side of the Mediterranean Sea. Cyprus is a member of EU as a de facto divided island [6] but the whole of Cyprus is an EU territory. Northern Cyprus has a population of 326,000 and area of 3354 km^2. Research has shown that Cyprus is a perfect location for installing PV power plants, this makes it one of the best places for solar PV energy-related applications in Europe. The duration of sunshine in Cyprus for winter 5.5 hours and that of summer is 12 hours. The average daily solar radiation varies between 2.3 kWh/m^2 and 7.2 kWh/m^2 for cloudiest and clear skies respectively [7-8]. The yearly global horizontal radiation varies between 1800 kWh/m^2 and 2000 kWh/m^2.

Irrespectively of the favorable weather conditions, electric power generation in Northern Cyprus is heavily dependent on fossil fuel [9-10]. More than 94% of generated electric power comes from fossil fuel. There are four thermal power plants responsible for generating majority of the required electric power. One of the major disadvantages of relying on fossil fuel is the long period of power rationing experienced in the early and mid-parts of 2022.

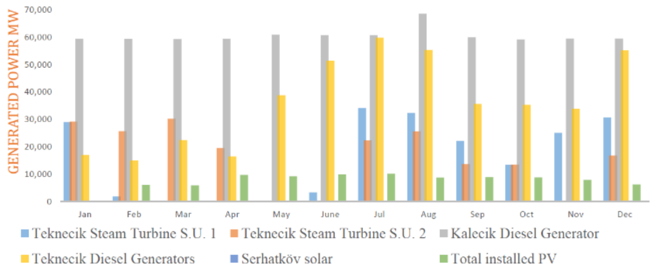


Fig. 3. Detailed generation mix in Northern Cyprus (2021)

This was mainly caused fuel scarcity and therefore could not to power the thermal plants. As at the end of 2021, only 5.58% of the total generated electric power was from PV systems. Table 1 shows the electric power generation mix in 2021 for Northern Cyprus. Figure 3 shows the bar-chart representation of the 2021 generation mix in Northern Cyprus. Apart from Kib-Tek solar panel station (Serhatkoy solar), there are other large-scale and small-scale PV installations in Northern Cyprus. Some of these PV systems are 1.3MW PV system installed in 2016 at Cyprus International University campus, 1MW PV system installed in 2015 at Middle East Technical University [11], 120kW PV system installed in 2018 at Levent college and 50kW PV system installed in 2017 in the main building of KKTCell [11-12].

Table 1. Generation mix in Northern Cyprus (2021)

Generating Unit	Output Power (MW)	Production Percentage (%)
Teknecik Steam Turb. S.U. 1	191,765	11.67
Teknecik Steam Turb. S.U. 1	196,278	11.95
Kalecik Diesel Generator	725,541	44.17
Teknecik Diesel Generator	435,794	26.53
Serhatköy Solar	1,686	0.10
Total installed PV (MW)	91,673	5.58
TRNC Total Production	1,642,737	100

The following are some selected published literature on photovoltaic systems applications in Northern Cyprus. In [13], the authors investigated a PV-Wind hybrid system in Nicosia, the aim was to provide an efficient power supply at an affordable cost. The authors in [14] investigated a cost-effective off-grid PV system for a rural community in Famagusta. In [15], the author investigated the feasibility of having 1MW PV systems in various cities in Northern Cyprus. The performance of 1.27MW PV system was evaluated in [2] considering the payback period, capacity factor and performance ratio. In [16], a 6kW hybrid Wind-PV system was investigated and it proved to be more economical compared to grid power. Also, a Wind-PV hybrid system sizing was presented by the authors in [17].

The aim of this paper is to comprehensively investigate the performance of Kıb-Tek solar panel station using selected performance indexes such as specific yield, performance ratio, capacity factor and nominal plant output power. Also, simulations are conducted for three selected regions to determine their suitability for PV power plant installations. Theoretical computation of the payback period of the simulated plants and Kib-Tek solar panel station are provided. The rest of this paper is segmented as follows: section 2 reviews Kib-Tek solar panel station (Serhatkoy PV plant) and examines some selected performance indexes. Section 3 compares the PV plant output power for Kib-Tek solar panel station and the simulated PV plants. Also, simulations are conducted for the selected regions of Lefkosa, Girne and Famagusta. Discussion of the result and conclusion are provided in sections 4 and 5 accordingly.

2. Serhatkoy PV Power Plant

The first grid-connected solar photovoltaic power plant in Northern Cyprus is a 1275.5kWp plant called Kib-Tek solar panel station (Serhatkoy PV plant). It is located in Guzelyurt with geographical coordinates: latitude 35.2^0N and longitude 33.1^0E at an altitude of 110m. Figure 4 shows the solar irradiation map of Cyprus and the location of Kib-Tek solar panel station. The region or site of the plant has the highest solar irradiation hence very suitable for PV systems. The cost of the plant installation was borne by the European Union at the cost of three million, seven hundred thousand euros (3.700.000 Euros). Technical details of the plant are shown in Table 2. Produced energy and generated revenue by Serhatkoy PV plant from 2011 to 2019 are given in Table 5. The plant started production in May 2011. There was a three-month production deficit from January to April, this shortfall adversely affects produced energy, capacity factor and performance ratio computation in 2011. To determine the generated revenue, produced energy is multiplied by the cost of 1kWh of electric power. Previous investigation of the plant's performance for a four-year production period (2011 – 2014) shows optimal production by Serhatkoy photovoltaic plant [2]. Figure 5 shows part of the panel arrangement of Serhatkoy PV power plant.

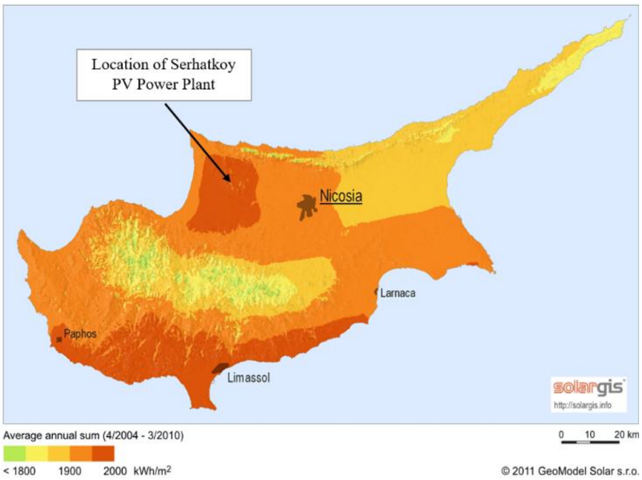


Fig. 4. Solar irradiation map of Cyprus [18]

Fig. 5. Serhatkoy PV power plant [19]

Table 2. Plant details [2]

ITEM	DETAILS	DESCRIPTION
Number of panels	6192	206Wp(Pmpp), $Umpp_{[V]}$=25.98V, $Impp_{[A]}$= 7.93V, $Uoc_{[v]}$ = 32.57V, $Isc_{[A]}$ = 8.44A. 13.71% Efficiency Manufacturers: KIOTO Solar
Number of inverters	86 groups	DC power of 13kW Maximum DC power 14.3kWp Input voltage 200–850Vdc (580V nominal) 98% Efficiency Grid connection 3ph, 400Vac, 50Hz Manufacturers: Powerone
Area of panels (Generating area of plant)	8,412m^2	With aluminum frame: 1507 mm x 992 mm x 33 mm (+/-2 mm) Laminate: 1500 mm x 985 mm x 4.5mm Height of connection-box 22.5mm Weight: 16.50 kg Glass specification: Solarglas ESG 3.2 mm

2.1. Performance Indicators

Selected performance indexes such as specific yield, performance ratio, capacity factor and nominal output power are utilized in determining the overall performance of Serhatkoy PV plant. This section provides explanations of theoretical computation of these performance indicators. Table 3 shows the computed values of capacity factor and performance ratio. Table 5 shows the monthly produced energy and its corresponding revenue.

2.1.1. Specific Yield

Specific yield is a performance index that is used to compare or determine the performance of PV systems with respect to location, type of design and finally the health of the

PV system. The total amount of energy produced (kWh) divided by panel capacity (kWp) for a period of time in a year is referred to as specific yield [20].

$$\text{Specific Yield} = \frac{\text{Produced energy (kWh)}}{\text{Panel capacity (kWh)}} \qquad (1)$$

2.1.2. Capacity Factor (CF)

Capacity factor of a photovoltaic power plant gives the relationship between annual produced energy and the name-plate capacity. It's ideal to calculate the CF using AC voltage. The capacity factor of solar photovoltaic power plants ranges between 10% to 25%. However, there are modules/panels with CF values beyond this range, they are not yet commercially available. Calculated CF values for Serhatkoy PV plant from 2011 to 2019 are shown in Table 3. 2011 and 2019 have the least CF values because there was a three-month production deficit in each year. Nonetheless, the other CF values are within the acceptable range of 10% to 25%.

$$\text{Capacity Factor} = \frac{\text{Generated power}}{365 * 24 * \text{Nominal power}} * 100\% \qquad (2)$$

2.1.3. Performance Ratio (PR)

There are several methods proposed by industry players to calculate or find the performance ratio of a photovoltaic power plant. National Renewable Energy Laboratories of United States of America (NREL) proposed the method being used below to calculate the PR of Serhatkoy PV power plant. Nominal plant output equals to extrapolated value multiplied by module efficiency. Extrapolated value equals to solar irradiation multiplied by plant area. Calculated PR for Serhatkoy PV plant from 2011 to 2019 are shown in Table 3. 2011 and 2019 have the least PR values because there was a three-month production deficit in each year. Nonetheless, almost all the other PR values are above 76%.

$$\text{Performance Ratio} = \frac{\text{Produced power (kWh)}}{\text{Nominal plant output (kWh)}} * 100\% \qquad (3)$$

2.1.4. Nominal Output Power

The nominal output power of a PV system is determined by the formula below:

$$\text{Nominal Output Power} = \frac{\text{Incident irradiation on PV panels}}{\text{Panel efficiency} * \text{area} * \text{irradiance}} \qquad (4)$$

Table 3. Calculated CF and PR Values

YEAR	PRODUCED ENERGY (kWh)	CAPACITY FACTOR (%)	PERFORMANCE RATIO (%)
2011	909955.72	8.14	39.45
2012	1985214.9	17.76	86.07
2013	2152368.97	19.26	93.31
2014	1856647.8	16.62	80.49
2015	2007600	17.97	87.04
2016	1889671.6	16.91	81.93
2017	1770240	15.84	76.75
2018	1736931.84	15.55	75.30
2019	497342.484	9.89	47.92

3. Simulation Results

In this section, comparative analysis of electric power produced by the real Serhatkoy PV plant and modelled PVsyst simulation results are investigated. Simulations are conducted for PV systems having fixed-tilt angle and single-axis tracking systems. Also, simulation results for some selected regions (Famagusta, Girne and Lefkosa) using the model of Serhatkoy PV plant are produced. PVsyst software is used for the simulation. PVsyst was designed by two engineers at the University of Geneva in Switzerland for photovoltaic system simulations and studies.

3.1. Simulation Results for Serhatkoy

This section provides simulation result for Serhatkoy region using Serhatkoy PV power plant as a model (1.27MW). The average solar radiation data of Table 4 provided by NASA (National Aeronautics and Space Administration) is used as the input data for the simulation. The solar radiation data was recorded over a period of 15 years (1990 to 2005). Figure 6 represents the normalized production results of the plant after simulation. Each bar is composed of three variables; collection loss, system loss and produced useful energy. Useful energy produced is 4.75kWh/kWp/day, while collection and system losses are 0.98 kWh/kWp/day and 0.14kWh/kWp/day respectively.

Table 4. Solar radiation (kWh/m^2/day) [21]

MONTH	Jan	Feb	Mar	April	May	June
22-YEAR AVERAGE	2.49	3.44	4.83	5.98	7.24	8.11
MONTH	July	Aug	Sept	Oct	Nov	Dec
22-YEAR AVERAGE	7.93	7.08	5.88	4.26	2.87	2.20

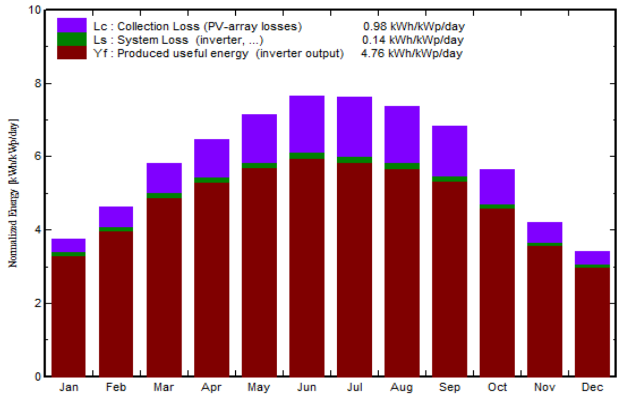


Fig. 6. Results of normalized production

3.2. Performance Ratio

The performance ratio of a PV power plant as defined by PVsyst is the ratio of energy produced in a year (final yield) divided by the expected amount of energy to be produced (reference yield).

The performance ratio obtained after the simulation is 0.819 which is approximately 80.19%. Figure 7 shows the monthly PR for Serhatkoy PV power plant. The months June, July and August were the least-performing months in terms of PR and this can be attributed to high temperature during this period of the year.

Table 5. Monthly Produced Energy and Generated Revenue

Month	**2011 Energy [kWh]**	**Generated Revenue (TRY) 2011**	**2012 Energy [kWh]**	**Generated Revenue (TRY) 2012**	**2013 Energy [kWh]**	**Generated Revenue (TRY) 2013**
Jan	0	0	106560.07	47952.0315	130011.56	58505.202
Feb	0	0	146883.96	66097.782	146467.19	65910.2355
Mar	0	0	197472.06	88862.427	192874.67	86793.6015
April	0	0	126191.35	56786.1075	219072.76	98582.742
May	16216.43	7297.3935	215443.92	96949.764	220037.4	99016.83
June	191982.22	86391.999	200002.26	90001.017	213484.9	96068.205
July	1190.34	535.653	222038.77	99917.4465	229208.31	103143.74
Aug	100696.07	45313.232	227272.13	102272.459	209777.13	94399.7085
Sept	139209.88	62644.446	210647.36	94791.312	185991.55	83696.1975
Oct	184920.91	83214.41	139499.04	62774.568	164084.66	73838.097
Nov	140991.97	63446.387	106770.18	48046.581	125461.83	56457.8235
Dec	134747.9	60636.555	86433.81	38895.2145	115897.01	52153.6545
Total	909955.72	409480.07	1985214.9	893346.71	2152368.97	968566.037
Month	**2014 Energy [kWh]**	**Generated Revenue (TRY) 2014**	**2015 Energy [kWh]**	**Generated Revenue (TRY) 2015**	**2016 Energy [kWh]**	**Revenue (TRY) 2016**
Jan	120804.6	54362.07	104160	46872	104160	46872
Feb	160531.6	72239.22	127680	57456	153120	68904
Mar	182007.6	81903.42	163680	73656	178560	80352
April	172284.3	77527.935	201600	90720	208800	93960
May	172153.6	77469.12	178560	80352	188460	84807
June	188277.6	84724.92	216000	97200	215010	96754.5
July	174905.0	78707.25	215760	97092	225761	101592.45
Aug.	110359.7	49661.865	208320	93744	172900	77805
Sept	185277.6	83374.92	187200	84240	150580	67761
Oct	155013.7	69756.17	148800	66960	121566.72	54705.024
Nov	130011.2	58505.04	136800	61560	94512.96	42530.832
Dec	105021.3	47259.59	119040	53568	76240.96	34308.432
Total	1856647.8	835491.52	2007600	903420	1889671.6	850352.22
Month	**2017 Energy [kWh]**	**Generated Revenue (TRY) 2017**	**2018 Energy [kWh]**	**Generated Revenue (TRY) 2018**	**2019 Energy [kWh]**	**Generated Revenue (TRY) 2019**
Jan	111840	50328	108248.88	48711.996	76552.56	34448.652
Feb	127200	57240	110666.4	49799.88	93953.04	42278.868
Mar	155280	69876	165492.24	74471.508	127667.52	57450.384
April	144480	65016	198893.76	89502.192	129769.2	58396.14
May	177840	80028	174475.44	78513.948	138080.64	62136.288
June	160800	72360	176022.72	79210.224	132946.8	59826.06
July	176160	79272	183005.76	82352.592	179304	80686.8
Aug.	172800	77760	167651.76	75443.292	146363.28	65863.476
Sept	150480	67716	160854.24	72384.408	80568.48	36255.816
Oct	172800	77760	121566.72	54705.024	-	-
Nov	130080	58536	94812.96	42665.832	-	-
Dec	90480	40716	75240.96	33858.432	-	-
Total	1770240	796608	1736931.84	781619.32	1105205.52	497342.484

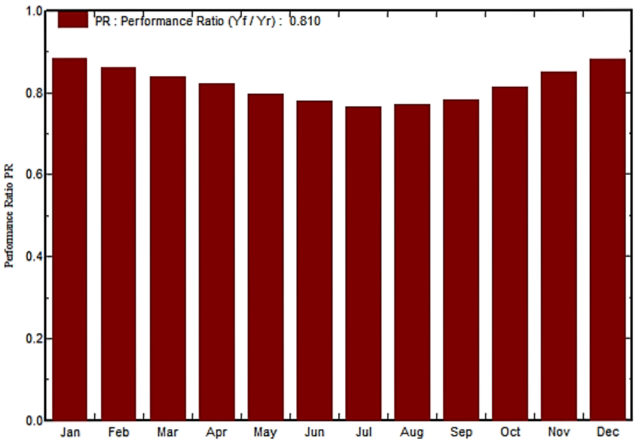


Fig. 7. Performance ratio

3.3. Balances and Main Results

The balances and main result table for Serhatkoy at fixed-tilt angle and single-axis tracking are represented by Table 6. The table is made up of the following parameters; global horizontal insolation (GlobHor kWh/m^2), ambient temperature (T Amb ^{0}C) energy produced at the array output (Earray MWh) and energy injected into the grid (E_Grid MWh). The percentage increase in energy injected into the grid between fixed-tilt angle (2089.7MWh) and a single-axis tracking system (2672.3MWh) is 582.6MWh which is a 27.88% increase. Normalized production results for Serhatkoy between fixed-tilt angle and single-axis tracking system is shown in Table 7. The useful energy produced per day by the single-axis tracking system is 18.21% better than fixed-tilt angle.

Table 6. Balances and Main Results for Serhatkoy

		Fixed Tilt Angle		Single Axis	
Month	GlobHor kWh/m^2	EArray MWh	E_Grid MWh	EArray MWh	E_Grid MWh
Jan	79.2	128.5	125.0	152.7	148.5
Feb	93.2	137.4	133.6	169.4	164.9
Mar	143.5	183.5	178.5	225.4	219.2
Apr	173.4	197.3	191.9	249.9	243.1
May	206.5	210.6	204.6	282.6	274.8
Jun	218.3	213.4	207.4	289.8	282.0
Jul	217.4	212.3	206.3	289.3	281.4
Aug	220.0	228.5	222.1	300.9	292.7
Sept	162.4	190.7	185.4	244.0	237.4
Oct	128.3	173.8	169.1	217.8	211.9
Nov	91.5	142.7	138.9	169.4	164.9
Dec	76.0	130.5	126.9	155.8	151.7
Total	1809.7	2149.1	2089.7	2746.9	2672.3

Table 7. Normalized Production Results for Serhatkoy

Parameter	Fixed Tilt	Single Axis
Useful energy produced kWh/kWp/day	4.76	5.82
Collection loss kWh/kWp/day	0.98	1.23
System loss kWh/kWp/day	0.14	0.16
Performance Ratio	0.819	0.806

3.4. Payback Period for Serhatkoy PV Plant

The payback period of a power plant is the duration required by the plant to pay for the initial cost of installation as well as maintenance cost from generated revenue. Power plants become profitable if the pay-back period of the plant is less than the life-span of the plant. To determine the payback period of a photovoltaic power plant, the following parameters should be determined: cost of plant installation, amount of energy produced in a time frame (minimum of three years) and price of one kilowatt-hour (1kWh) of power. For Serhatkoy photovoltaic power plant, the above parameters are determined below. The cost and exchange rates are the average values in 2019. Cost of plant installation in 2010: 3.7 million Euros (8.14 million Lira). Amount of energy produced in 3 years (2012-2014): 5994231.67 kWh. Price of one kilowatt-hour of power: 0.45TRY.

Revenue generated within the same time frame: 0.45 * 5994231.67 = 2,697,404.252TRY (5)

The average annual revenue generated within three years = 899134.7507TRY (6)

$$\text{Payback Period} = \frac{8140000}{899134.7507} = 9 \text{ years} \tag{7}$$

3.5. Validating PVsyst Software

In order to validate simulation results, comparative analysis of the annual electric power produced by Serhatkoy photovoltaic power plant and PVsyst modelled simulation are investigated. Firstly, we calculate the possible maximum and minimum error so as to determine an acceptable range of magnitude for yearly energy production using actual produced energy from Serhatkoy photovoltaic power plant.

$$\textit{Change in produced energy } \Delta E = \frac{E_{max} - E_{min}}{2} \tag{8}$$

$$\Delta E = \frac{2152.37 - 1736.93}{2} = 207.73MWh \tag{9}$$

$$\textit{Average energy produced } E_{AV} = \frac{\sum E}{\#E} \tag{10}$$

$$E_{AV} = \frac{13398.65}{7} = 1914.096MWh \tag{11}$$

Acceptable range of magnitude for annual energy production = 1914.096 ± 207.73(MWh) (12)

From Table 6, the average annual electric power produced by PVsyst for fixed-tilt angle and single-axis tracking system are 2089.7MWh and 2672.3 MWh respectively. Based on equation (12), the simulation result magnitudes are within the acceptable range of 1914.096 ± 207.73 MWh. Using the technical details of Serhatkoy photovoltaic power plant as a model, simulations are conducted for the following locations; Famagusta, Girne and Lefkosa.

3.6. Simulation Result for Famagusta

Famagusta is a coastal city located east of Northern Cyprus, it is also the capital city of Gazimağusa district. The normalized production results for Famagusta with geographical coordinates; Latitude: 35°7.5′N Longitude: 33°57′ E is represented by Fig. 8.

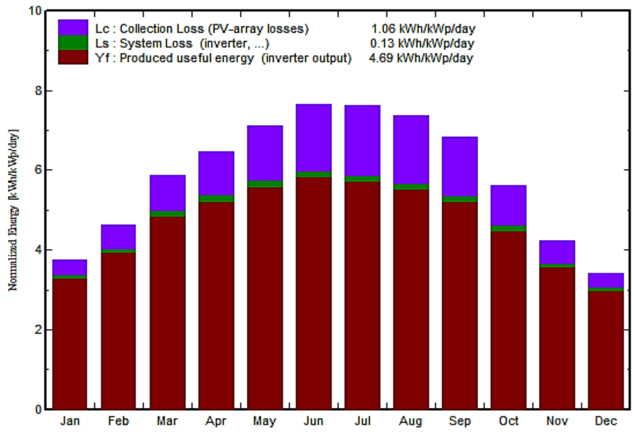


Fig. 8. Results of normalized production for Famagusta

Table 8. Balances and main results for Famagusta

		Fixed Tilt Angle		Single Axis	
Month	GlobHor kWh/m²	EArray MWh	E_Grid MWh	EArray MWh	E_Grid MWh
Jan	77.2	129.3	125.7	161.2	156.8
Feb	96.3	139.7	135.8	173.7	168.9
Mar	149.7	190.8	185.5	242.2	235.4
Apr	179.4	198.8	193.3	267.0	259.7
May	224.4	219.9	213.8	305.8	297.4
Jun	243.6	221.7	215.5	309.1	300.6
Jul	245.8	224.8	218.5	313.8	305.3
Aug	219.5	217.2	211.2	294.4	286.3
Sept	176.4	198.7	193.3	263.6	256.3
Oct	132.1	176.7	171.9	228.5	222.3
Nov	86.1	136.1	132.3	168.7	164.0
Dec	68.2	117.1	113.8	143.5	139.6
Total	1898.7	2170.6	2110.7	2871.5	2792.7

The balances and main result for fixed-tilt angle and single-axis tracking system are shown in Table 8. For fixed-tilt angle, energy produced at the array output is 2170.6 MWh and energy injected into the grid is 2110.7MWh. For single-axis tracking system, energy produced at the array output is 2871.5 MWh and energy injected into the grid is 2792.7MWh. This represents 28.66% increase in produced energy when single-axis tracking system is incorporated into the plant design. Normalized production results between fixed-tilt angle and single-axis tracking system are shown in Table 9. The useful energy produced with the tracking system is higher than that of the fixed-tilt angle, the percentage difference is 18.21%. However, the performance ratio of the fixed-tilt system is 1.59% better than that of the single-axis tracking system.

Table 9. Normalized production results for Famagusta

Parameter	Fixed Tilt	Single Axis
Useful energy produced kWh/kWp/day	4.69	6.21
Collection loss kWh/kWp/day	1.06	1.56
System loss kWh/kWp/day	0.13	0.18
Performance Ratio	0.797	0.782

3.7. Simulation Result for Girne

Girne is also a coastal city with many historical buildings like the famous castle (Kyrenia Castle) and harbour. Girne is also known as Kyrenia. The geographical location of Girne is at a latitude of 35.34° North and a longitude of 33.32° East. The normalized energy production results obtained from simulation is represented by Fig. 9. The balance and main results for Girne with fixed-tilt angle system is presented in Table 10. Produced energy at the array output is 2173.3MWh and energy injected into the grid is 2113.3MWh. This represents 97.23% inverter efficiency. Similarly, Table 10 shows the balances and main results when a single-axis tracking system (N-S) is added to the plant design and simulation done to determine the amount of energy produced. Array output energy and grid injected energy are 2875.8MWh and 2796.9MWh respectively, this shows an increase of 32.34% in energy production between fixed-tilt angle and single-axis tracking systems. Table 11 is made up of the following parameters; useful energy produced, collection loss, system loss and performance ratio for fixed-tilt angle and single-axis tracking systems. It's evident that the useful energy produced per day is higher for single-axis tracking system. Nevertheless, it also has high losses. However, performance ratio is approximately equal for both systems.

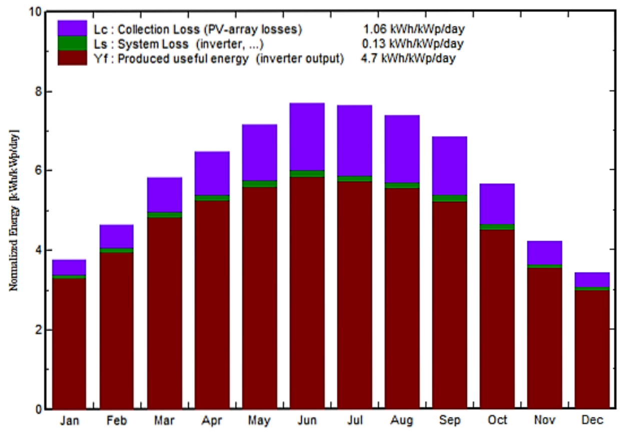


Fig. 9. Normalized simulation results for Girne

Table 10. Balances and main results for Girne

		Fixed Tilt Angle	Single Axis

Month	GlobHor kWh/m²	EArray MWh	E_Grid MWh	EArray MWh	E_Grid MWh
Jan	77.2	129.7	126.1	161.9	157.5
Feb	96.3	140.5	136.6	176.3	171.4
Mar	149.7	190.0	184.8	245.4	238.7
Apr	179.4	199.2	193.7	268.6	261.3
May	224.4	220.0	213.9	302.3	293.9
Jun	243.6	222.6	216.3	311.2	302.7
Jul	245.8	224.8	218.5	313.0	304.5
Aug	219.5	217.9	211.9	295.0	286.9
Sept	176.4	198.8	193.4	263.2	256.0
Oct	132.1	177.7	172.8	228.7	222.5
Nov	86.1	134.7	131.0	164.9	160.4
Dec	68.2	117.5	114.2	145.2	141.3
Total	1898.7	2173.3	2113.2	2875.8	2796.9

Table 11. Normalized production results for Girne

Parameter	Fixed Tilt	Single Axis
Useful energy produced kWh/kWp/day	4.7	6.21
Collection loss kWh/kWp/day	1.06	1.56
System loss kWh/kWp/day	0.13	0.18
Performance Ratio	0.797	0.782

3.8. Simulation Result for Lefkosa

As seen from simulation results for Serhatkoy, Famagusta and Girne, the balances and main results for Lefkosa without tracking system is shown in Table 12. The global horizontal radiation is 1898.7kWh/m^2 which produces 2250.5MWh and 2188.1MWh of energy at the array output and grid injected energy respectively. When a single-axis tracking system is incorporated into the design, the simulation result is represented in Table 12. The total energy produced at the array output is 2988.4MWh and energy injected into the grid is 2906.2MWh. This shows a 32.82% increase in energy production between fixed-tilt angle and single-axis tracking systems.

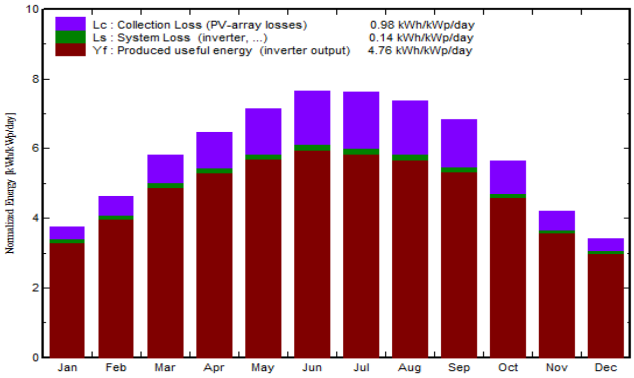


Fig. 10. Normalized simulation results for Lefkosa

Table 12. Balances and main results for Lefkosa

		Fixed Tilt Angle		Single Axis	
Month	GlobHor kWh/m²	EArray MWh	E_Grid MWh	EArray MWh	E_Grid MWh
Jan	77.2	132.8	129.2	165.9	161.4
Feb	96.3	144.3	140.4	181.5	176.5
Mar	149.7	195.9	190.4	253.6	246.6
Apr	179.4	205.8	200.1	278.5	270.9
May	224.4	228.2	221.8	314.8	306.1
Jun	243.6	231.6	225.1	325.3	316.4
Jul	245.8	234.5	227.9	328.1	319.1
Aug	219.5	227.4	221.1	309.1	300.6
Sept	176.4	207.0	201.3	275.2	267.5
Oct	132.1	184.0	179.0	237.5	231.0
Nov	86.1	138.7	134.8	170.1	165.3
Dec	68.2	120.3	116.9	148.8	144.7
Total	1898.7	2250.5	2188.1	2988.4	2906.2

Table 13. Normalized production results Lefkosa

Parameter	Fixed Tilt	Single Axis
Useful energy produced kWh/kWp/day	4.76	6.33
Collection loss kWh/kWp/day	0.98	1.43
System loss kWh/kWp/day	0.14	0.18
Performance Ratio	0.810	0.797

Table 14. Energy, revenue and payback period

FIXED-TILT ANGLE			
Location	Energy (KWh)	Revenue (TRY)	Payback (Years)
Serhatkoy	2089700	940365	9.8
Girne	2113200	950940	9.7
Lefkosa	2188100	984645	9.3
Famagusta	2110700	949815	9.7
SINGLE-AXIS TRACKING			
Serhatkoy	2672300	1202535	7.7
Girne	2796900	1258605	7.3
Lefkosa	2906200	1307790	7.1
Famagusta	2792700	1256715	7.4

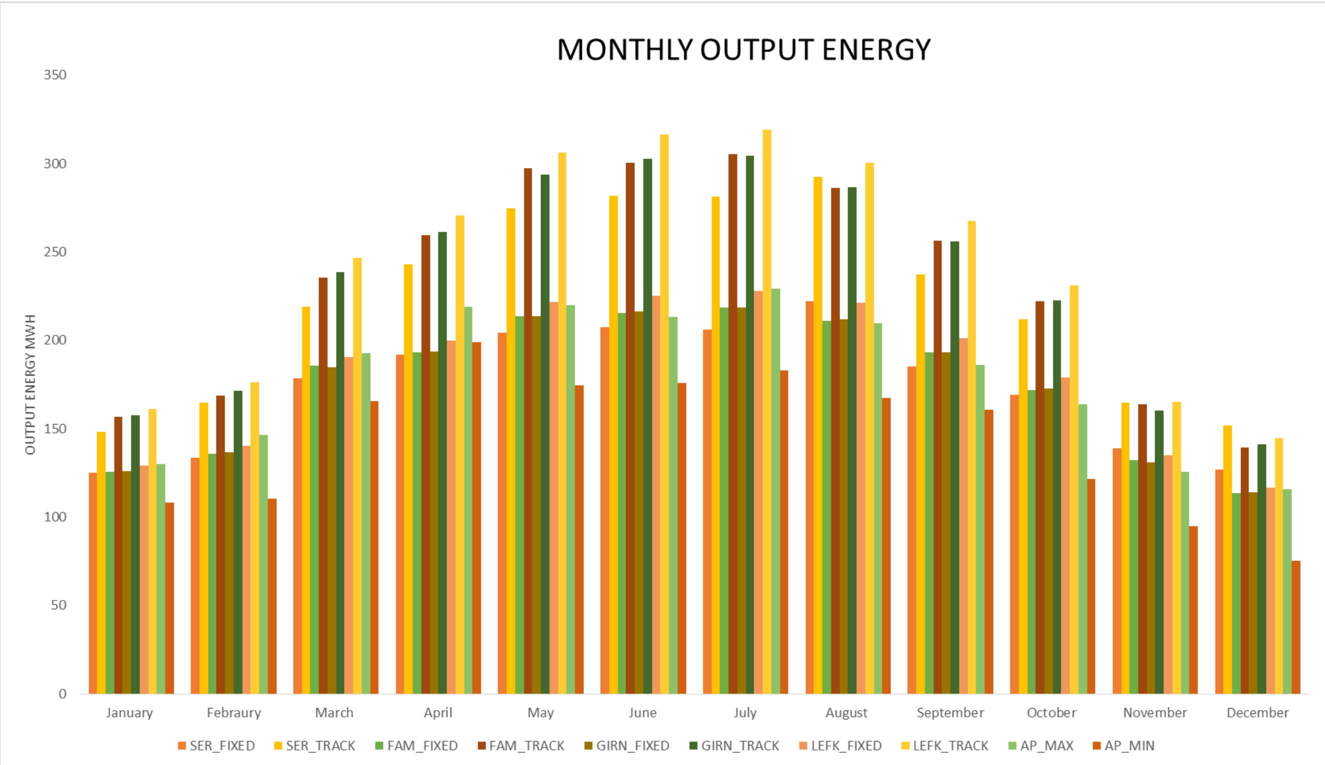
4. Discussion

This paper investigated the performance of Serhatkoy PV power plant and also explored the viability/suitability of Famagusta, Girne and Lefkosa regions for PV power plant installation using PVsyst software. Technical parameters such as number of models, type of models, type of inverters, number of inverters and field arrangement of Serhatkoy PV power plant are modelled and simulated in PVsyst software. The result of the investigation shows that Serhatkoy photovoltaic power plant is operating at optimal capacity. This is evident from the magnitude of produced energy and its corresponding high revenue shown in Table 5. Also, the results obtained from the capacity factor and performance ratio computation attest to the optimal operating conditions of the plant; except for the period of 2011 and 2019 which have some deficits. The average PR and CF values are 85.77% and

17.71 respectively. The generated revenue by a power plant has a direct correlation with the payback period of the plant. The payback period of the actual Serhatkoy PV plant and PVsyst simulated plant are between 7 years to 10 years. Computed average payback period of the simulated PV plants with fixed-tilt angle is 9.62 years. Also, the payback period of Serhatkoy PV power plant with fixed-tilt angle is 9 years. The average payback period for the simulated PV plants was reduced from 9.62 years to 7.4 years when a single-axis tracking system was included in the plant design. This shows that single-axis tracking systems have the least payback period. Therefore, single-axis tracking systems are more profitable compared to fixed-tilt angle systems.

The capacity factor and performance ratio values for both plants; actual and simulated, are within industry standards. Also, the performance ratio graph of Fig. 7 and the normalized production result graphs of Fig. 6, Fig. 8, Fig 9 and Fig. 10 shows the monthly output power of the simulated plants. It's evident that, high output power does not correspond to high performance ratio. Plant output power peaks in the months of June, July and August. However, the performance ratio values are slightly less in these months compared to the other months. Actually, performance ratio of the power plant peaks in the months of December and January and slightly reduces in summer season. In Cyprus, summer season is experienced in the months June, July, August and September; solar radiations and temperatures are high. High temperature affects power generation capabilities of the modules/panels and the conversion efficiency of inverters. Temperatures above standard test condition (S.T.C) affect efficiency of the modules/panels by decreasing energy production by 0.46%K for one-degree Celsius (1^oC) above the recommended maximum temperature value proposed by Kioto Photovoltaic (panel manufacturers). Similarly, produced energy is improved by the same value when the temperature is below the maximum S.T.C temperature value.

Selection of suitable modules with appropriate technical details for specific location is an important factor which affects the overall performance of a PV power plant. Based on the normalized production results of Table of 7, 9, 11 and 13; it's evident that the selected module and inverter are



NOTE: SER_FIXED represents the PV plant located in Serhatkoy with fixed orientation, SER_TRACK represents the PV plant located in Serhatkoy with single-axis tracking. FAM_FIXED represents the PV plant located in Famagusta with fixed orientation, FAM_TRACK represents the PV plant located in Famagusta with single-axis tracking. GIRN_FIXED represents the PV plant located in Girne with fixed orientation, GIRN_TRACK represents the PV plant located in Girne with single-axis tracking. LEFK_FIXED represents the PV plant located in Lefkosa with fixed orientation, LEFK_TRACK represents the PV plant located in Lefkosa with single-axis tracking. AP_FIXED represents the actual PV plant with fixed orientation, AP_TRACK represents the actual PV plant with single-axis tracking.

Fig. 11. Monthly output energy

efficient. This is because the system losses are less. For example, in Table 13, the useful PV power produced for fixed-tilt and single-axis tracking are 4.7kWh/kWp/day and 6.33kWh/kWp/day respectively, the collection losses for fixed-tilt and single-axis tracking are 0.98kWh/kWp/day and 1.43kWh/kWp/day respectively and the system losses for fixed-tilt and single-axis tracking are 0.14kWh/kWp/day and 0.18kWh/kWp/day accordingly. Efficiency of the system based on these values are 81.0% and 79.9% for fixed-tilt and single-axis tracking systems respectively. Collection losses are mainly caused by the module efficiency and system losses are caused by inverter efficiency plus other auxiliary components.

In other to validate simulation results for Famagusta, Girne and Lefkosa, technical parameters of Serhatkoy PV power plant are used as a model for simulation. Firstly, simulation is done for Serhatkoy region where the plant is located and the result is compared with actual energy produced by the plant. Based on the comparative analysis of simulated plant and the actual plant, the use of PVsyst software for simulation is validated because the simulation result (2089.7MWh) for Serhatkoy region falls within the acceptable range of produced energy (1914.096 ± 207.73MWh) by the actual Serhatkoy PV power plant. The yearly average energy produced (grid injected) for Famagusta, Girne and Lefkosa is a little more than that of Serhatkoy using the fixed-tilt angle. However, incorporating a single-axis tracking system into the design increased energy production by 27.88% for Serhatkoy, 32.33% for Famagusta, 32.35% for Girne and 32.82% for Lefkosa. This represents an average increase of 31.32%. Incorporating single-axis tracking into the plant design comes with power consumption from the motor drive and other accessories. However, they consume less power. Examples of single-axis tracking systems (photovoltaic power plant) that support the above analysis are referenced in [22-27]. Figure 11 shows the graph of monthly produced energy for the actual plant and simulated plant, it's obvious that integrating a single-axis tracking system into the power plant design maximizes energy production. Also, the modelled power plant in the selected regions produce more energy than the actual plant located in Serhatkoy.

5. Conclusion

This research is conducted in twofold. The first is to investigate the performance Serhatkoy PV plant, analyse the potential impact on energy levels when single-axis tracking system is incorporated into the design of Serhatkoy photovoltaic power plant. The second is to determine the viability/suitability of Famagusta, Lefkosa and Girne regions for the construction PV power plant. Based on the analysis and performance indexes computation, its conspicuous that the plant's functionality is efficient. Also, simulation results show that the selected regions are highly suitable for building PV power plants. There's an average of 31.32% increase in energy production when single-axis tracking system is integrated into the design of the PV plant. Economically, it's prudent to invest in PV power plants because they are able to quickly payback the cost of installation and are not susceptible to too much maintenance. To reduce total dependence on fossil fuel for electric power generation, better government policies should be put in place to reduce initial cost and also give incentives to private businesses for the construction of private (household) and commercial solar parks. This will significantly reduce the cost of electric power, provide stable electric power and boost socio-economic development in Northern Cyprus. The primary resource for electric power generation by solar photovoltaic system is solar irradiance, it's availability, duration and intensity determine the magnitude produced electric power. As mentioned in the introduction and validated by the efficient operation of Serhatkoy PV power plant, Cyprus has one of the best weather conditions in Europe for solar PV plant installation. One major disadvantage of solar photovoltaic power plants is the large acres of land they occupy. However, this is not a major problem in Northern Cyprus because of the vast acres of unoccupied land with little forest cover.

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