DETERMINATION OF THE OPTIMAL SOLAR PANEL TILT ANGLE FOR BAKU AND NAKHCHIVAN

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Abstract - Solar energy, which is the most widely used of renewable resources, is more preferred due to its affordable cost and easy installation. In order to obtain the optimum amount of electricity from solar energy, it is very important to place the PV panels at an optimum angle to the sun. In addition, other factors such as avoiding shade, suitable and high quality equipment, avoiding dust and pollution also affect the optimum energy from the sun.

In this study for two different regions in Azerbaijan, the determination of the optimum solar panel tilt angle for the selected regions, the maximum radiation values that can be obtained, the amount of energy produced from PV panels and their comparison were analysed. When the obtained values are analysed, the difference between 4.25% (Baku) and 5.6% (Nakhchivan) occurs in PV systems with variable tilt angle 12 times a year (every month) compared to fixed angle systems. In addition, when the PV systems with variable adjustment every month are compared, it is seen that the PV system installed in Nakhchivan is 33.4% more than the PV system installed in Baku. When the PV panel inclination angle is constant throughout the year for both regions, it is concluded that 422.7 MWh/year (or 30%) more electrical energy is obtained from the PV system installed in Nakhchivan than the PV system installed in Baku. According to the results of the study carried out in two different simulation tools for both regions, the positioning of PV systems at varying angles every month is more suitable for system efficiency and performance.

Keywords: Solar energy, PV systems, Solar Panel, Optimal Tilt Angle

1.INTRODUCTION

Energy is the most fundamental element that makes life sustainable and provides technological and economic development at the same time. For this reason, it is of great environmental and socioeconomic importance to use this energy both effectively and correctly. Since heat and electricity are the two types of energy used and most needed in the world, the energies produced from different energy sources are converted into electricity or heat energy. The energy sources used in the world are fossil fuel-based energies and renewable energy sources. The energy obtained from all these energy sources has positive and negative effects on economic, health and environmental factors [1].

The most widely used renewable energy source is solar energy. Solar energy is the least environmentally damaging energy source compared to both traditional energy sources and other types of renewable energy sources. During the use of this energy, none of the gases that will cause global warming such as carbon dioxide and methane gas are released into the atmosphere.

There are 2 types of solar radiation: direct, direct, i.e. direct and diffuse, i.e. indirect radiation according to the angle of arrival of solar radiation into the atmosphere. Direct radiation can be defined as the radiation coming from the sun to a certain point or surface, and diffuse radiation can be defined as the radiation that is absorbed by certain molecules in the atmosphere and reflected at the same time, resulting in dispersion and reflection on the earth's surface.

In order to make maximum use of solar radiation, it is necessary to carefully adjust the orientation, azimuth and tilt angle of the solar panels. These parameters vary according to the location where the system will be installed, the type of system, the shape of the land or roof. In land-type applications, the direction of the panels should be adjusted to face towards the south in the Northern Hemisphere and towards the north in the Southern Hemisphere. However, depending on the condition of the terrain, it is also possible that the direction of the solar panels is not adjusted exactly to the south or north. The direction and slope of the PV systems installed on the roofs may vary according to the roof shape and shading situation.

Table 1. Total irradiance and diffuse irradiance ratios for different sky conditions [2]

Weather Conditions	Total Radiation (W/m^2)	Diffuse radiation (W/m^2),%
Cloudless Weather (Clear Sky)	600- 1000	%10-20
Partly Cloudy Weather	200- 400	%20-80
Cloudy Weather (Overcast Skies)	50-150	%80- 100

PV systems installed on the land can be positioned at a fixed angle, or it is possible to position them at variable angles throughout the year according to climatic conditions, weather conditions, intended use and other different purposes (Table 1). PV system design and simulation tools are needed to obtain preliminary information such as how much energy the installed system can produce, how efficient it will be, which losses will occur, how long it can amortise itself and installation cost. PV simulation software tools also calculate the effect of different orientations and tilt angles on system performance and global variables such as shadow losses. In addition, the ability to report the cost and payback period of residential and commercial projects is a critical feature of such software tools. Within the scope of the study, PVGIS and PVsyst design and simulation programs were used to calculate the maximum amount of radiation on the panels, the optimum tilt angle and the amount of energy produced. There are similar studies in the literature in accordance with the research carried out; In the study carried out by Belmahdi and Bouardi with PVsyst program, the amount of energy transferred to the grid for a system with a power of 1 MW at fixed angle and seasonally adjusted tilt angles installed in four different cities was compared. As a result of the simulation, it was observed that fixed angle systems produced more energy than seasonally adjusted systems [3]. Demiryürek study is on the comparative analysis of the Lebit Solar Power Plant with a power of 200 kWp in Siirt province through PVsyst software. As a result of the study, it was calculated that there was a deviation of 0.56% between the production values of the real PV energy system and the values obtained from the PVsyst program [4]. In a study conducted by Bakirci, monthly average daily global solar radiation amounts on inclined surfaces at 0-90° were calculated in order to determine the monthly optimum collector tilt angles for Erzurum province [5]. As a result of the study conducted by Kallioğlu et al. for Gaziantep province, it was revealed that the panel tilt angle varies between 55°-0° for January-June and between 0°-57° for July-December. The annual optimum panel tilt angle is calculated to be 30° on average, and when the panel tilt angle is adjusted monthly, it is seen that the annual energy efficiency increases by approximately 14 per cent compared to the horizontal plane [6]. In a study conducted by Li et al. in five different cities with different climatic zones in China, it was found that panels with optimum tilt angles that change every month are more advantageous than panels with optimum tilt angles with annual fixed angles [7]. In a study conducted by Morcos for the Assiut region of Egypt, it was found that adjusting the PV panel tilt angle to be changed 8 times a year is close to the optimum value and that this system increases the amount of solar radiation to the inclined surface by approximately 6.85% compared to the system with a fixed angle (27º). In addition, it was stated that changing the inclination angle six times a year and the azimuth value twelve times a day increased the amount of solar radiation to the inclined surface by 29.18% [8]. Two researchers named Jafarkazemi and Saadabadi conducted a study on determining the tilt angle for Abu Dhabi. As a result of the study, considering the amount of energy to be produced when the inclination angle is set as monthly changing, it is recommended to change the inclination angle of the value closest to this value at least twice a year [9]. As a result of an experimental study conducted by Kaldellis and Zafirakis in Athens, Greece, the optimum tilt angle for summer months was accepted to be 15º (±2.5º) [10]. In a study conducted by Lubitz, it was found that if the panel tilt angle is adjusted to vary every month, the amount of solar radiation will increase by an average of 5% per year compared to PV systems with a constant tilt angle [11]. In a study conducted by Khatib et al. for five different regions of Malaysia, it was found that the efficiency increased by 6.13% when the PV panels were adjusted at the optimum tilt angle on a monthly basis and by 5.85% when the PV panels were adjusted at the optimum tilt angle on a seasonal basis [12]. In the study of Koçer et al. on the determination of the optimum tilt angle in Ankara and its districts, it was determined that when the tilt angle is changed twice a year, there will be approximately 5% efficiency increase compared to the systems with fixed tilt angle, and when the tilt angle is adjusted as changing every month, this rate will increase up to approximately 8% [13]. In a study conducted by H.M.S. Hussein et al. in Cairo, it was stated that the maximum amount of solar radiation will come to the PV panel surface when the solar panel is set to face south and the panel tilt angle is set to vary seasonally. In addition, in this study, it was also stated that panels placed towards the west produce more energy than panels placed towards the east [14]. As a result of a study conducted by Benghanem for the city of Medina in Saudi Arabia, it was revealed that the optimum panel tilt angle is approximately equal to the latitude value of the city. It was also determined that monthly adjustment of the optimum tilt angle for Medina would benefit 8% more energy than the system with a fixed angle [15]. In a study conducted by Koray Ülgen for Izmir province, it was stated that the optimum tilt angle for PV solar panels varies between 0-61˚ throughout the year. In addition, for systems with fixed tilt angle, it was stated in the study that the annual average tilt angle was 30.3˚ [16]. According to the results of a study conducted by Dal, it was revealed that compared to the solar panel placed at a fixed (29.5°) annual tilt angle, the efficiency of the panel tilt angles that changed every month, twice and four times a year increased by 4.11%, 2.99% and 3.25% annually, respectively [17]. Abdullah et al. calculated the annual, monthly, semi-annual and seasonally changing tilt angles for Palestine by means of PV GIS and PV Watts simulation program. As a result of the study, it was determined that the adjustment of solar panels in Palestinian cities at varying angles every month can produce approximately 17% more solar energy than panels with fixed tilt angles [18].

When the studies in the literature are examined, it is seen that there is no study that deals with the determination of the tilt angle of a PV system to be installed in Azerbaijan and the amount of radiation on the panel and there is no calculation related to this. Therefore, this study aims to determine the optimum tilt angle of a PV system to be installed in Azerbaijan and the amount of radiation on the panel.

Azerbaijan is known as a country located between 38°-25 north latitude and 44°-50 east longitude, and the total length of its border exceeds 3600 kilometres. Azerbaijan ranks among the countries with high potential in terms of renewable energy resources [19]. The estimated technical potential of renewable energy resources in the country is 135 GW on land and 157 GW at sea. The economically usable potential of these resources is estimated to be 23,040 MW of solar energy, 3,000 MW of wind energy, 380 98 MW of bioenergy and 520 MW of mountain river potential (hydropower), totalling 26,940 GW [20, 21].

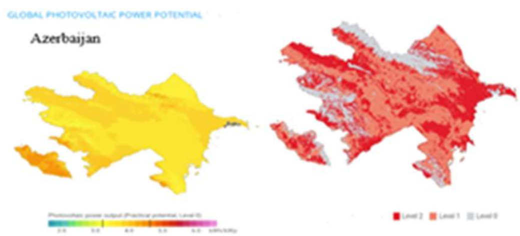

Fig 1. PV power potential map for Azerbaijan [22]

Fig 1 shows the PV power potential map for Azerbaijan [22, 23]. As can be seen from the Fig, the Nakhchivan region located in the south-west of the country has the highest solar energy potential. However, since Baku is the most populous city with the highest population and therefore the most electricity demand, this study covers the comparative analysis of the PV system to be installed in Nakhchivan and Baku.

2. MATERIAL AND METHOD

In order to obtain optimum energy from the sun, it is necessary to position the solar panels at the optimum angle. Panels positioned at the optimum angle can obtain more electrical energy with the maximum amount of radiation coming on them. The total radiation falling on an inclined surface consists of 3 different radiation. These are; Direct or direct radiation, diffuse or diffuse radiation and reflected radiation. Total radiation incident on an inclined surface (solar panels);

$$I_{et} = R_d\,(I_t - I_y) + (I_y)\,[1 + \cos(s)/2] + (I_t) \times \times \rho\,[1 - \cos(s)/2] \qquad (2.1)$$

is calculated by equation 2.1. In this equation, $Rd\ (It$ - $Iy)$ represents the direct radiation value falling on the inclined surface,

$$R_d = I_{ed}/I_d = \cos(\varphi - s)\, \cos\delta \cos\omega + \sin\delta \sin(\varphi - s) / /\cos\varphi \cos\delta \cos\omega + \sin\delta \sin \qquad (2.2)$$

is calculated by equation 2.2. In this equation, δ is the declination angle, φ is the latitude angle, ω is the hour angle and Id is the direct radiation. Diffuse radiation incident on the inclined surface:

$$I_{ey} = I_y\,[1 + \cos(s)/2] \qquad (2.3)$$

is calculated by equation 2.3. In Equation 2.3, $I_y$is the instantaneous average diffuse radiation. Reflected radiation incident on the inclined surface;

$$I_{ya} = I_t \times \rho\,[1 - \cos(s)/2] \qquad (2.4)$$

is calculated by equation 2.4. In Equation 2.4, I_t is the total radiation, ρ is the reflection oefficient of the ground and s is the tilt angle [24].

In this study, it is planned to calculate the optimum tilt angles of the panels in order to maximise the benefit from the radiation coming on the solar panels, which are an inclined plane. This calculation was performed with two different solar simulation tools in order to obtain better results, minimise the deviation value and contribute to the literature. These are; PVGIS and PVsyst simulation tools.

The PVGIS simulation tool is an online simulation tool funded by the European Commission and developed by the Joint Research Centre in Italy. PVGIS is used to calculate the predicted performance of grid-connected (on grid) or off grid PV systems. A map-based user interface allows users to select the desired location. It is possible to select any location by clicking on the map, zooming in or out, and entering the latitude and longitude coordinates in the specified field [25].

The PVsyst simulation tool helps to design the configuration of the system and also allows the calculation of the amount of energy produced. The results are based on the simulation of the sizing system, which mainly depends on the geographical location of the PV system. The results can include many simulation variables that can be displayed as monthly, daily or hourly values. Through the PVsyst program, inter-table shading effects can be calculated depending on the PV array parameters, the location of the system and the orientation of the solar panels. It is possible to simultaneously model PV systems consisting of multiple inverters of different sizes and types, and PV systems of two different tilt and azimuth angles connected to a single inverter. One of the most powerful features of PVsyst is the addition of a different design module and library for pumping systems used in agricultural PV systems [26,27].

Within the scope of the study, the latest version PVGIS 5.2 was used and PVGIS-SARAH2 dataset was used in PVGIS 5.2 simulation. SARAH2 provides solar datasets for global and direct solar radiation and effective cloud albedo based on satellite measurements. PVsyst generates hourly synthesised datasets using monthly measured data (global and diffuse radiation, wind speed and temperature) from Meteonorm 8. The monthly solar radiation datasets are averages of measurements from 1986-2000. The diffuse radiation calculations in PVsyst 7.2.21 are based on the Perez model (1987,1988) [27].

This study aims to determine the optimum tilt angle for the photovoltaic system to be installed in 2 different economic regions of the Republic of Azerbaijan by selecting the annual, 6-month, seasonal and monthly changing solar panel tilt angle parameter and to calculate the monthly, seasonal, semi-annual, annual maximum solar radiation on the PV panel by means of two different simulation programs. The geographical coordinates of these regions are given below. Baku (40.3953; 49.8822), Nakhchivan (39.2083; 45.4122).

3. MEASUREMENTS IN THE SIMULATION PROGRAM

The optimum angle values and irradiation amounts for Nakhchivan and Baku provinces were first calculated by PVGIS simulation program. Then the same calculations were calculated through PVsyst simulation program. For this calculation, firstly, the latitude and longitude information of both cities were entered into the program separately and monthly, semi-annual, seasonal and annual optimum angle and maximum solar radiation values were obtained and shown in the Tables below. In this study, tilt angles between 0-90° are entered into PVGIS and PVsyst simulation programs as tenths and calculations are made separately, the angle values with maximum solar radiation amount are determined and monthly, seasonal, semi-annual and annual optimum angle values are found and tabulated.

Table 2 shows the irradiance values obtained from PVGIS and PVsyst simulation programs.

Table 2. Difference between maximum irradiance values calculated in PVGIS and PVsyst programs

CITIES	Baku			Nakhchivan		
	PV GIS Max. Amount of Radiation kWh/m²	PVSyst Max. Amount of Radiation kWh/m²	Radiation Amount Difference kWh/m²	PV GIS Max. Amount of Radiation kWh/m²	PVSyst Max. Amount of Radiation kWh/m²	Radiation Amount Difference kWh/m²
January	80,91	108,6	27,69	101,02	156,5	55,48
February	84,2	91,8	7,6	115,65	140,3	24,65
March	127,23	134,5	7,27	156,3	177,4	21,1
April	153,43	146,2	-7,23	167,53	183,8	16,27
May	194,99	185,7	-9,29	194,84	203,8	8,96
June	209,39	200,3	-9,09	222,75	234,7	11,95
July	206,87	193	-13,87	231,96	230,4	-1,56
August	195,17	176,3	-18,87	220,97	229,7	8,73
September	160,82	143,4	-17,42	198,46	211,4	12,94
October	120,42	109,5	-10,92	161,12	178,9	17,78
November	86,42	99,2	12,78	137,07	158,2	21,13
December	77,99	102,3	24,31	101,77	150,9	49,13
Annual (12 Months) Total	1697,84	1690,8	-7,04	2009,44	2256	246,56
Winter	242,34	301,2	58,86	317,52	446,4	122,88
Spring	471,31	461,3	-10,01	511,63	555,7	44,07
Summer	609,39	567,8	-41,59	672,87	690,6	17,73
Autumn	364,65	347,6	-17,05	491,07	541,6	50,53
Seasonal Total	1687,69	1677,9	-9,79	1993,09	2234,3	241,21
March-August	1077,82	1025,3	-52,52	1179,74	1238,8	59,06
September-February	604,57	645	40,43	805,97	982,9	176,93
Months+6 Months	1682,39	1670,3	-12,09	1985,71	2221,7	235,99
Annual Constant Angle	1642,94	1621,8	-21,24	1925,59	2136,2	210,61

These values are the maximum radiation values on the PV panel at the optimum tilt angle. In both programs, conditions such as climatic conditions, weather conditions, clear or cloudy skies of the location where the analysis is carried out are calculated by taking into account the climatic data between certain years. As can be seen from Table 2, the values obtained differ in both programs. This difference is calculated in the direction of how much higher or lower the irradiance amount obtained from the PVsyst program is than the irradiance amount calculated in PVGIS. Table 2 indicates that the PVsyst value is less than the PVGIS value.

The irradiance differences between the two programs for Baku city vary between 7.04 and 58.86 (kWh/m^2). The maximum value of the amount of radiation on the PV panel is obtained when the panel tilt angle is set to vary every month. Although this value varies in both programs, the maximum value is obtained from PVGIS simulation tool with a difference of 7.04 kWh/m^2. When the PV system installed in the angle setting that changes every month is compared with the annual fixed angle systems, a difference of 54.9 - 69 (kWh/m2) or 3.34 - 4.25% occurs. When the irradiance differences between both programs are calculated for Nakhchivan city, this value varies between 1.56 - 246.56 (kWh/m2). In Nakhchivan city, the maximum value of the amount of radiation on the PV panel is obtained when the panel tilt angle is set to vary every month.

Table 3. Difference between the optimum tilt angle values calculated in PVGIS and PVsyst programs

CITIES	Baku			Nakhchivan		
	PV GIS Optimum Tilt Angle°	PVSyst Optimum Tilt Angle°	Slope angles difference°	PV GİS Optimum Tilt Angle°	PVSyst Optimum Tilt Angle°	Slope angles difference°
January	59.7	61,6	1.9	60.3	64	3.7
February	50.3	49	-1.3	52.3	54.6	2.3
March	39.4	39,5	0.1	41	42	1
Apri	27.2	25,6	-1.6	26.7	26.7	0
May	15.2	15,4	-0.8	14.4	13	-1.4
June	9.3	9,3	0	8.7	7,2	-1.5
July	13.8	11,5	-2.3	13	9.7	-3.3
August	24	21,9	-2.1	22.9	23	0.1
September	37	34,1	-2.9	37.6	38.2	0.6
October	48.4	45,5	-2.9	50.2	51.5	1.3
November	57.7	59,4	1.7	60.4	61.9	1.5
December	62.3	64,2	1.9	63.4	66.2	2.8
Annual Constant Angle	31.6	32.1	0.5	33.7	36.3	2.6
Winter	57	59.3	2.3	58.8	61.6	2.8
Spring	26.1	25.6	-0.5	26.7	27.4	0.7
Summer	16	13.9	-2.1	14.6	13.2	-1.4
Autumn	45.5	44.6	-0.9	48	49.5	1.5
March-August	20.5	19	-1.5	20.1	19.8	-0.3
September-February	50.3	51.3	1	52.2	56	3.8

Although this value varies in both programs, the maximum value is obtained from PVsyst simulation tool with a difference of 245.56 kWh/m^2. When the PV system installed in the angle setting that changes every month is compared with the annual fixed angle systems, a difference of 83.85-119.8 (kWh/m^2) or 4.35 - 5.6% occurs.

When the Table 3 is examined, it is seen that the optimum tilt angle values obtained from both programs are different in both provinces. This is because the databases used by these tools are different. Only in April in Nakhchivan and in June in Baku, the same values were obtained in both programs. The deviation value between the two systems, a difference of 83.85 - 119.8 (kWh/m^2) or 4.35 - 5.6% occurs.

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When the irradiance differences between both programs are calculated for Nakhchivan city, this value varies between 1.56 - 246.56 (kWh/m^2). In Nakhchivan city, the maximum value of the amount of radiation on the PV panel is obtained when the panel tilt angle is set to vary every month. Although this value varies in both programs, the maximum value is obtained from PVsyst simulation tool with a difference of 245.56 kWh/m^2. When the PV system installed in the angle setting that changes every month is compared with the annual fixed angle systems, a difference of 83.85 - 119.8 (kWh/m^2) or 4.35 - 5.6% occurs.

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Table 4 shows the comparison of the values obtained from Nakhchivan and Baku provinces as a result of simulation. As can be seen from the Table, the PV system installed in Nakhchivan is 18.4% higher than the PV system installed in Baku at the angle setting that changes every month, where the maximum radiation value is obtained from PVGIS data. The value obtained from the PVsyst tool increases up to 33.4%.

Table 4. Total maximum solar radiation values and percentage increase rates obtained from PVGIS and PVsyst programs according to optimum angles

Cities/ PVGIS DATA	Total Maximum Solar Radiation Value Annually Varying Angle[kWh/m^2]	Total Maximum Solar Radiation Value at Seasonally Changing Angle[kWh/m^2]	Total Maximum solar radiation value at changing angle every 6 months [kWh/m^2]	Total Maximum Solar Radiation Value at Annual Fixed Angle [kWh/m^2]
Baku	1697.84	1687.69	1682.39	1642.94
Nakhchivan	2009.44	1993.09	1985.71	1925.59
Percentage Increase Rate (%)	18.4	18	18	14.7
Cities/ PVSyst DATA	Total Maximum Solar Radiation Value Annually Varying Angle[kWh/m^2]	Total Maximum Solar Radiation Value at Seasonally Changing Angle[kWh/m^2]	Total Maximum solar radiation value at changing angle every 6 months [kWh/m^2]	Total Maximum Solar Radiation Value at Annual Fixed Angle [kWh/m^2]
Baku	1690.8	1677.9	1670.3	1621.8
Nakhchivan	2256	2234.3	2221.7	2136.2
Percentage Increase Rate (%)	33.4	33.2	33	31.7

This difference between the two simulation tools is due to the fact that the data obtained from PVsyst takes into account multiple factors (such as global and diffuse radiation, wind speed and temperature). When all tilt angle settings are taken into account, a PV system installed in Nakhchivan can generate 14.7% to 33.4% more electrical energy than in Baku. Fig 2 shows the irradiation amounts obtained according to different tilt angles.

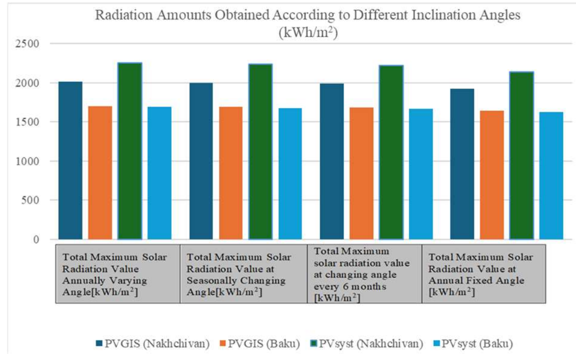

Fig 2. Radiation amounts obtained from PVGIS and PVsyst programs for different tilt angles

When the conversion of the irradiation amount obtained from the Pvsyst program into electrical energy is calculated, when the panel tilt angle is set at a constant value per year, the values obtained show that the amount of electrical energy produced from the PV system to be installed in Nakhchivan will be higher than in Baku city. The amount of AC energy injected into the grid for both cities is shown in Table. When the panel tilt angle in the PV system is set at a constant value throughout the year, the total AC electrical energy injected into the grid in Nakhchivan province is 1834.1 MWh/year and the total AC electrical energy injected into the grid in the capital city of Baku is 1411.4 MWh/year. When it is calculated how much more electrical energy When it is calculated how much more electrical energy it produces compared to Baku, it is concluded that it produces 422.7 MWh/year or (30%) more electrical energy and these results are given in Table 5.

The reason why the percentage ratios of the differences in the irradiation amounts in the calculated provinces and the percentage ratios of the differences in the amount of energy produced are not the same is due to the losses that occur during the conversion process of the DC energy produced in the PV panels to the grid as AC energy. These calculations were made for a 1 MWp field and in this calculation, a 335Wp monocrystalline solar panel with the brand TSM-335DD14A(II) produced by Trina Solar and a 125kW inverter with the brand SUN2000-125KTL-M0 produced by Huawei were used.

Table 5. Conversion of the amount of radiation obtained from PVsyst program at fixed angle into electrical energy

Cities	Total Maximum Solar Radiation Value at Annual Fixed Angle [Kwh/m^2]	Difference Between Total Radiation Amounts [Kwh/m^2]	Percentage Difference Between Total Radiation Amounts (%)	Total Amount of AC Energy Injected into the Grid [Mwh/Yıl]	Difference Between Total AC Energy Amounts Produced [Mwh/Yıl]	Percentage Difference Between Total AC Energy Amounts Produced (%)	Difference Due to Losses Fark (%)
Nakhchivan	2136,2	514,4	31,7	1834,1	422,7	30	1,7
Baku	1621,8			1411,4			

4. CONCLUSION

Since the demand for renewable energy is increasing day by day, the most preferred among these sources is solar energy due to its easy installation and maintenance. In order to make the use of solar energy more efficient, it is very important to establish a system that can receive the maximum amount of energy. Within the scope of this study, two different simulation programs were used to address the points related to the more efficient use of solar energy for Azerbaijan. As a result of the study, it has been concluded that the use of solar energy for Azerbaijan and increasing the projects for this purpose can play an important role in meeting the energy needs of the country. In addition, determining the optimum solar panel tilt angle for different selected cities of Azerbaijan draws a road map for SPP projects to be established in those places.

According to the PVGIS simulation results, it is seen that if the PV panel tilt angle is set at a constant angle per year, the highest amount of radiation on the PV panel is in Nakhchivan region. This result (1925,59 kWh/m^2) is obtained when the panel tilt angle is set to 33,7°. When the calculation is made in PVsyst simulation program, it is concluded that the highest amount of radiation on the panel is again in Nakhchivan region (2136,2 kWh/m^2). This value is observed when the panel tilt angle is set as 36.3° in the PVsyst program. When the tilt angle of the panel for Nakhchivan region is set at a constant annual angle, there is a difference of 2.6° in the tilt angle and a difference of 210.61 kWh/m^2 (or $\approx$ 11%) in the amount of radiation between the two programs. When both simulation programs are compared, the highest efficiency for Baku and Nakhchivan province is obtained when the tilt angle of the PV system is changed every month of the year (12 times a year). These values were obtained as 2009.44 kWh/m^2 in PVGIS program and 2256 kWh/m^2 in PVsyst program. Considering all tilt angle settings, the PV system installed in Nakhchivan is 14.7% to 33.4% higher than the PV system installed in Baku. In addition, it was concluded that the PV systems installed with the same characteristics produced 422.7 MWh/year or (30%) more electrical energy in Nakhchivan province than in Baku.

For the city of Baku, the irradiance differences between both programs range between 7.04 - 58.86 (kWh/m^2), and for the city of Nakhchivan, when the irradiance differences between both programs are calculated, this value varies between 1.56 - 246.56 (kWh/m^2). Considering the values obtained from PVGIS and PVsyst simulation tool, when the PV system installed in the angle setting that changes every month is compared with the annual fixed angle systems, a difference of 54.9 - 69 (kWh/m^2) or 3.34 - 4.25% occurs in Baku province. In Nakhchivan province, this value is higher with a difference of 83.85 - 119.8 (kWh/m^2) or 4.35 - 5.6%.

As a result of the calculation, it is seen that the optimum slope angle values obtained from both programs are different in both provinces. However, in April in Nakhchivan and in June in Baku, the same values were obtained in both programs. The deviation value between the two programs varies between 0.1- 2.9° in Baku and 0.1- 3.8° in Nakhchivan.

All calculations show that the solar energy potential in Nakhchivan province is more effective compared to other provinces. Based on this information, if a more detailed study is carried out, an optimum tilt angle map can be created throughout the country, so that all provinces of Azerbaijan can benefit from solar energy more efficiently.

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