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PERFORMANCE INVESTIGATION OF BIFACIAL PHOTOVOLTAIC PANELS AT DIFFERENT GROUND CONDITIONS

[1]Muharrem Hilmi AKSOY , [2]Murat Kubilay ÇALIK

[1]*Konya Technical University, Engineering and Natural Sciences Faculty, Mechanical Engineering Department, Konya, TÜRKİYE*
[1] mhaksoy@ktun.edu.tr, [2] muratkubilaycalik@gmail.com

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ABSTRACT: Photovoltaic (PV) panels are generally used for monofacial applications due to the back surface coating materials. When the coating material is transparent, it is defined as bi-facial PV. In this study, the variable albedo effects on bi-facial PVs in different ground conditions were examined. The results were compared with monofacial PV panels in the same conditions for the Konya region. Bifacial PV panels were analyzed under white, sand, and asphalt ground conditions. Simulations were made by the PVsyst program, and the results were compared by global radiation value, the performance ratio (PR), and the produced energy results. An installed capacity of 54,6 kWp bifacial and monofacial PV panels with a horizontal angle of 35°, azimuth angle of 0°, and 6m intervals for roof installation is considered. It has been observed that the yearly total solar radiation value of 1969 kWh/m² occurs on the monofacial PV, which is higher as 6,4% for the white ground, 2,4% for the sand ground, and 0,8% for the asphalt ground conditions. The annual energy generated in the Konya region is calculated as 91,197 MWh, 94,404 MWh, and 97,730 MWh for asphalt, sand, and white ground conditions. It was only 105,690 MWh for monofacial PV panels. It has been determined that the performance ratio of the system in June, which is one of the months of the highest radiation occurred, 7,0% higher than the sand ground conditions, 10,4% compared to the asphalt ground, and 14,5% higher than the monofacial photovoltaic system. It was evaluated that the ground conditions of the bi-facial panels contributed significantly to the panel efficiency and performance ratio and could be applied with a small investment cost compared to the project's total cost.

Keywords: *Albedo, Bifacial photovoltaic panel, Photovoltaic panel, PVsyst, Performance ratio*

Çift Yüzlü Fotovoltaik Panellerin Farklı Zemin Koşullarında Performansının İncelenmesi

ÖZ: Fotovoltaik paneller genellikle arka yüzey kaplama malzemelerinden dolayı tek yüzlü olarak kullanılmakta olup, kaplama malzemesi şeffaf olarak kullanıldığında çift yüzlü panel olarak tanımlanmaktadır. Bu çalışmada, Konya bölgesinde çift yüzlü panellerin farklı zemin koşullarında oluşan albedo etkilerinde incelenerek sonuçlar aynı koşullardaki tek yüzlü fotovoltaik paneller ile karşılaştırılmıştır. Çift yüzlü paneller beyaz, kum ve asfalt zemin koşullarında incelenmiştir. Simülasyonlar PVsyst programı ile yapılarak yüzeye gelen ışınım değeri, performans oranı ve üretilen elektrik değerleri karşılaştırılmıştır. Çalışmada 54,6 kWp kapasite için yatayla açısı 35° azimut 0° ve 6m aralıklı olarak Konya bölgesinde çatı kurulumu için değerlendirilmiştir. Tek yüzlü panele gelen yıllık toplam 1969 kWh/m² olan ışınım değerinin beyaz zemin için %6,4, kum zemin için %2,4 ve asfalt zeminin için %0,8 fazla olduğu görülmüştür. Konya bölgesinin yıllık şebekeye aktarılan enerji değerleri karşılaştırıldığında tek yüzlü panellerde 91,197 MWh iken asfalt, kum ve beyaz zemin koşullarında sırasıyla 94,404 MWh, 97,730 ve 105,690 MWh olduğu görülmüştür. Performans oranı ışınımın en fazla olduğu aylardan olan haziran ayında, beyaz zemin koşullarındaki sistemin kum zemine göre %7,0 asfalt zemine göre %10,4 tek yüzlü panel sistemine göre ise %14,5 fazla olduğu tespit edilmiştir. Çalışmada çift yüzlü panellerin farklı zemin koşullarının panel verimine ve performans oranına önemli katkı sağladığı ve proje toplam maliyetine göre az bir yatırımla uygulanabilir olduğu değerlendirilmiştir.

Anahtar Kelimeler: *Albedo, Çift yüzlü fotovoltaik panel, Fotovoltaik panel, PVsyst, Performans oranı*

1. INTRODUCTION

With the rapid development of science and technology in the world and Turkey, the energy demand is increasing. It has become inevitable for countries to seek alternatives to meet their energy needs, follow technological developments and monitor the energy sector's development. As a result of the environmental and economic effects of fossil fuels such as oil, coal, and natural gas, the energy diversity topic has focused on renewable energy sources (Allouhi et al., 2019; Çiftçi et al., 2020; Bilčík et al., 2020).

The green deal, approved in 2020, is a set of policy initiatives by the European Commission to minimize the global climate crisis and switch to net zero emissions by 2050. For this reason, using renewable energy, energy management, and efficiency increases in energy systems have gained even more importance. Solar energy systems, which have become very common today, draw attention as the fastest growing renewable source of renewable energy (Yaniktepe et al., 2017; El-houari et al., 2021). Many investments are made in solar energy systems in Turkey, especially in the Central Anatolia region. In the PV sector, which is dependent on a few manufacturers in the world, studies for the increase in efficiency in the systems are critical (Haon et al., 2019, Güven and Mete, 2021).

Only 50% of the solar radiation reaches the earth's surface by passing through the atmosphere. It is essential to use the radiation coming to the earth's surface effectively to obtain maximum efficiency from photovoltaic systems. By the way, bifacial PV panels can produce solar power from both sides of the panel.

The solar energy potential of the Europe and Turkey region is shown in Figure 1 (Bükün, 2017). It is seen that the annual radiation of 1100 kWh/m^2 in Central Europe is considerably below the value of 1700 kWh/m^2 in Turkey which means a strong advantage (Kaya et al. 2017; Bulut et al. 2018; Çetinkaya, 2017).

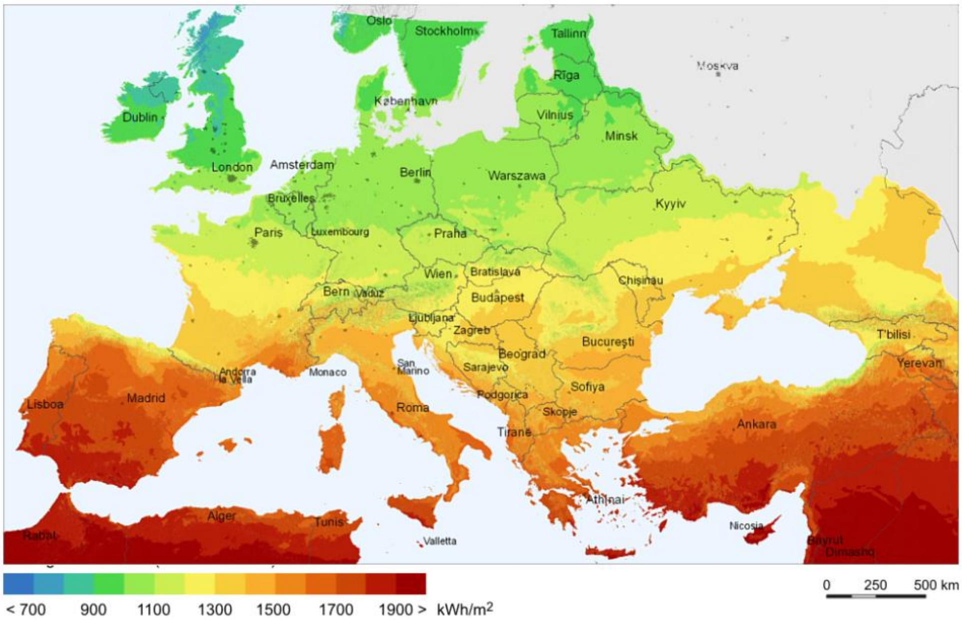


Figure 1. Annual solar radiation map of Europe (Anonymous, 2022a)

Turkey's solar energy potential is shown in Figure 2. Turkey's total daily average radiation value is 3.6 kWh/m², and the sunshine duration is 7.2 hours. (Kose et al., 2019; Vekil, and Özyiğit, 2020, Sancar and Altınkaynak, 2021). The Turkish grid operator TEIAS has reported that around 992 MW of new PV systems were connected to the grid in Turkey in the first ten months of 2021 and increased the country's cumulative installed solar power capacity to 7,658.6 MW.

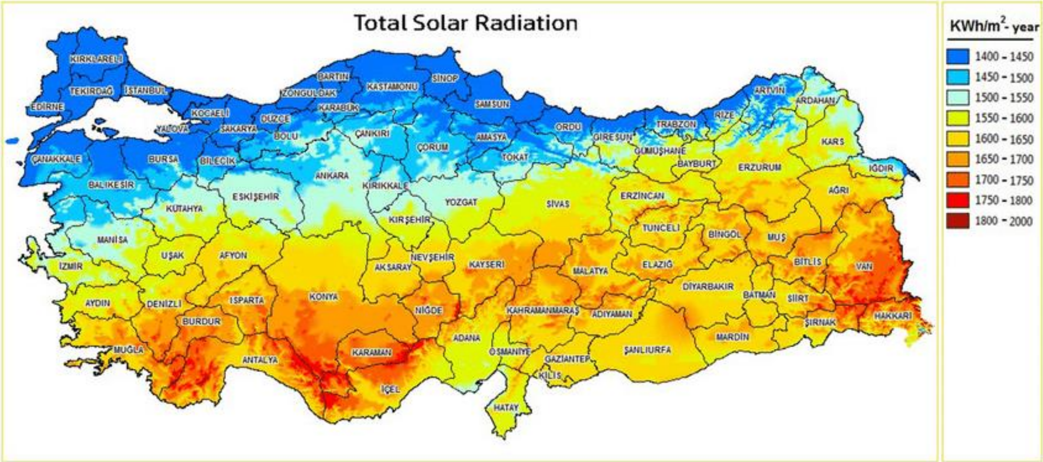


Figure 2. Turkey's annual solar energy potential map (Yılmaz et al., 2019)

The total daily average radiation duration of the Konya region is 7.94 hours, and the radiation value is 4.41 kWh/m². These values are well above Turkey's average daily radiation duration of 7.2 hours and radiation value of 3.6 kWh/m² given in Figure 3 (Solmaz et al. 2014). For this reason, Konya attracts attention as a suitable region for many roof and field PV applications (Aksoy, 2011). With the solar potential, Konya is home to the Karapınar YEKA-1 Solar power plant, Turkey's largest solar energy field with an installed area of 20 million m². When this power plant is installed, it will be one of the largest solar energy regions in the world, with a total installed power of 3,300 MW. When the project is completed, a 1-week energy need of a settlement with a population of 50 thousand will be produced in just 1 hour. In other words, it will meet the annual electrical energy needs of approximately 2 million people. In addition, 1.5 million tons of fossil waste and carbon emissions will be prevented annually.

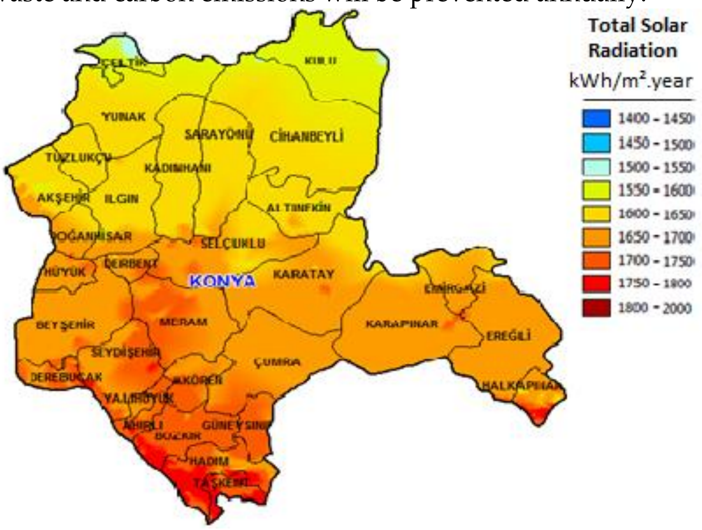


Figure 3. The solar energy potential map of the Konya region (Anonymous, 2022c)

While the solar radiation of the Konya region is 1.98 kWh/m² in January, it reaches 6.81 kWh/m² in the summer months when the electricity demand increases. It is imperative in terms of a large amount of land not suitable for agricultural use and the fact that the region is close to most electricity consumption regions (Özcan, 2019; Sadıkoğlu, 2018).

In a bifacial panel, lost and reflected light has a chance to be reabsorbed by the PV. In this application, where the light passes right through and collides with a highly reflective surface, this then bounces back towards the panels to be converted into solar energy. The additional power generation from the transparent back surface in bifacial PV panels is mainly dependent on the ground albedo effect, the module tilt angle, and the shadow effect from the structures holding the panels and the environment. In addition, more power generation reduces the system balance costs (Lorenzo, 2021). The radiation received by the bifacial solar panels from the sun and the surfaces and a sample series are shown in Figure 4 (Mamizadeh and Aslan 2019).

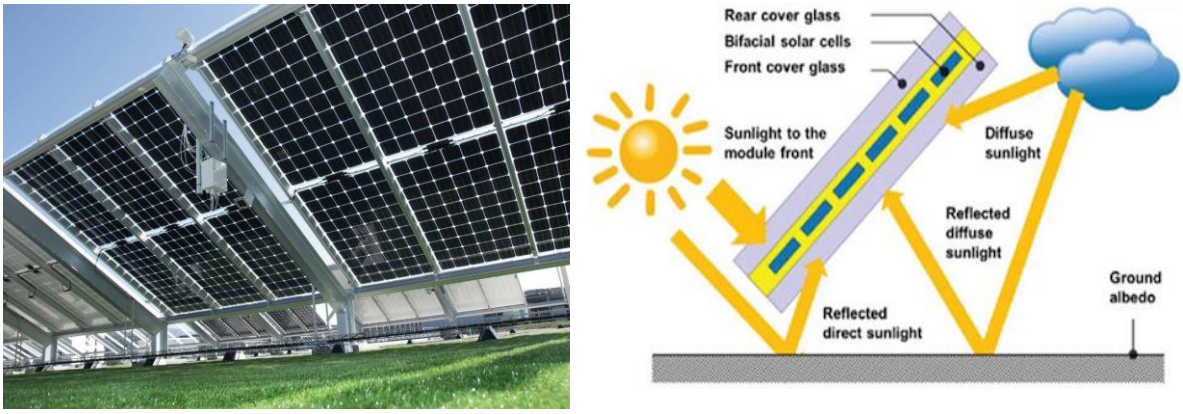


Figure 4. Bifacial PV panels (left) (Anonymous, 2022d) and representation of reflected radiation on panel surfaces (right) (Jinkosolar, 2022)

In recent years, there has been an increasing interest in bifacial PV technology as it promises a higher performance rate and lower energy cost than conventional monofacial PV applications. However, the studies are limited due to the difficulty of PV system modeling tools. Understanding the effect of different parameters, such as height, tilt angle, the reflectivity of the floor, and array size of panels, on bifacial PV system performance can help determine installation parameters for the system and provide an accurate estimation of energy efficiency (Chen et al. 2021). Some studies on the subject are given below.

Lopez-Garcia et al. (2019) examined the factors affecting the radiation reflected on the back surface of the panels in their study. He investigated the electrical performance of monofacial and bifacial PV modules under different indoor mounting configurations. They found that additional backlighting increases the electricity produced by up to 20% with current and voltage measurement in IEC TS 60904-1-2:2019 standards.

Matúš et al. (2020) investigated the effects of 25° and 90° inclination angles of monofacial and bifacial PV panels on the power balance at the Faculty of Education of Masaryk University, Czech Republic. It was stated that the annual average performance of the PV module measured with a 90° tilt angle is 30% higher than the values measured with a 25° tilt angle. In using bifacial PV panels, an efficiency increase of 7.6% was investigated.

Asgharzadeh et al. (2018) examined the effect of installation parameters and system configuration on the performance of bifacial PV arrays. They used simulation programs and laboratory measurement results with tilt angles of 5°, 35°, and 65°. Three different ground materials were used: soil, beige, and snow-covered white ground. It has been found that the optimum tilt angle for large-scale, south-facing bifacial systems is higher than monofacial systems and can increase up to 20°. In addition, with a floor albedo of 21%, the single application of PV panels was 7% higher than array efficiency.

Backside light distributions of bifacial PV modules were investigated according to the view factor models by Wang et al. (2019). The albedo gains of bifacial PV modules with an inclination angle of 30 degrees were measured as 10.50% for meadow, 22.73% for cement ground, and 38.88% for snow ground.

Eremkere et al. (2020) conducted technical, economic, and environmental analyses of bifacial PV panels. As a result of the research, the annual solar energy potential was determined as 1543 kWh/m^2 by taking the module angle as 20° and the azimuth 0°. The power ratios of single-crystalline silicon, polycrystalline silicon, and amorphous silicon were calculated as 85.15% - 84.39% - 80.40%, respectively, and annual electricity production was calculated as 1219 kWh/year, 1280 kWh/year, and 1291 kWh/year, respectively.

It is seen in the literature that the studies examined in different ground conditions for bifacial PV panels are limited. In this study, bifacial PV panels on different grounds were compared with conventional monofacial PV panels in the Konya region. Solar radiation reflected on the panels, the energy production of the system, and the performance rates are presented.

2. MATERIAL AND METHOD

Simulation programs such as PVsyst, PVSOL Expert, RETScreen, Homer, and PVGIS can be used to analyze PV systems. In this study, The PVsyst, a program developed by the University of Geneva, Switzerland, to study solar systems such as grid-connected or off-grid solar systems and solar irrigation systems (Akcan et al., 2020), and also makes transferring the losses of the PV systems to the system in detail, shading with 3D drawing feature, and economic analysis possible (Bolat et al. 2020, Çınaroğlu et al. 2021), is opted because the losses can be detected, the assumed selection conditions are compatible with the literature, consistent results can be obtained between the real results.

In the study, the PV system installed on the roof of Konya Technical University Engineering and Natural Science Faculty is evaluated. The satellite view of the region and its location in the PVsyst program are shown in Figure 5. The geographical coordinates of the region are between latitude 38°1'35'' and longitude 32° 30'39'' and the altitude is 1134 meters.

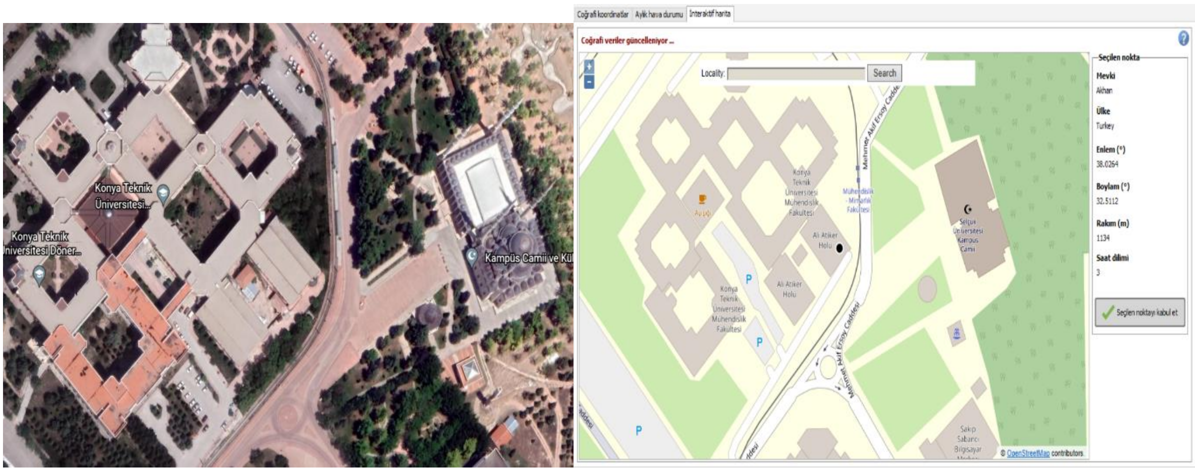


Figure 5. Satellite view of the evaluated region and its position in the PVsyst program

The rate at which the surface reflects the striking light is called as albedo effect. The albedo values of various surfaces may vary depending on the surface, color, material structure, and texture of these objects. Generally, a white object has a high albedo and reflects most of the light it hits. In contrast, a black object absorbs most of the incident radiation.

Table 1. Albedo values of different surfaces (Anonymous, 2022b).

Surfaces	Albedo Value
Sea (by angle)	0,05-0,25
Forest	0,10
City	0,15
Meadow	0,20
Desert	0,30
Cloudy	0,60-0,90
Clean Snow	0,80-0,90

2.1. Features of Simulation in PVsyst

The solar azimuth angle is defined as the angle between the projection of the sun's center onto the horizontal plane and the due south direction. The distance between the panels or the feasible most extended shadow length is calculated as follows (Çikla, 2020).

$$L = a\,x\left[\frac{sin(\beta_{opt})}{tan(23°)} + cos(\beta_{opt})\right] \quad (1)$$

In Eq (1), L is the distance between panels or the most extended possible shadow length (m), a is the panel length to be used (m), and β_{opt} is the optimum panel tilt angle (°). GTC Solar Turkey, GG1H-300 bifacial PERC 60 cells PV module was used in the analysis. The characteristic curve of the bifacial PV module is shown in Figure 6. The panel has a characteristic of approximately 30.7 V and 9.1 A at an irradiance value of 1000 W/m^2.

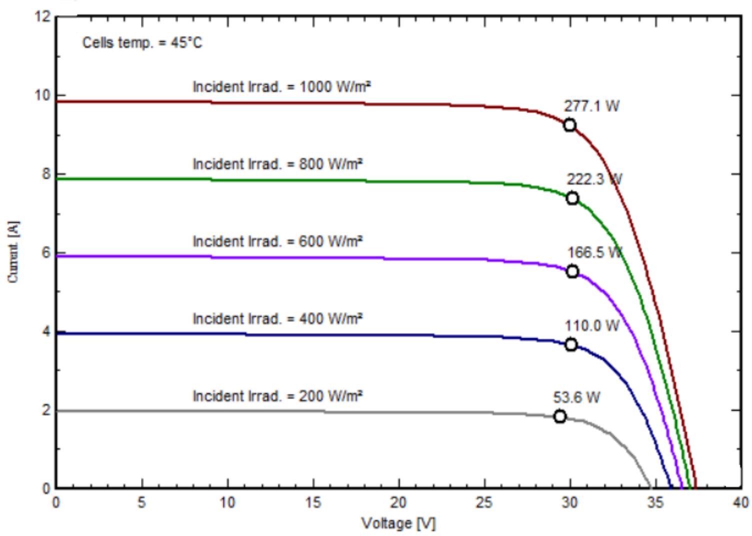


Figure 6. Bifacial PV module characteristic curve

In any grid-connected system, an inverter is required to convert direct current to alternating current. The inverter efficiency curve selected in the PVsyst program is shown in Figure 7. In the PVsyst program, the installed power is calculated as 54.6 kWp for 300 m^2. The number of modules is set to 180, serial modules to 30, and the power ratio to 1.08.

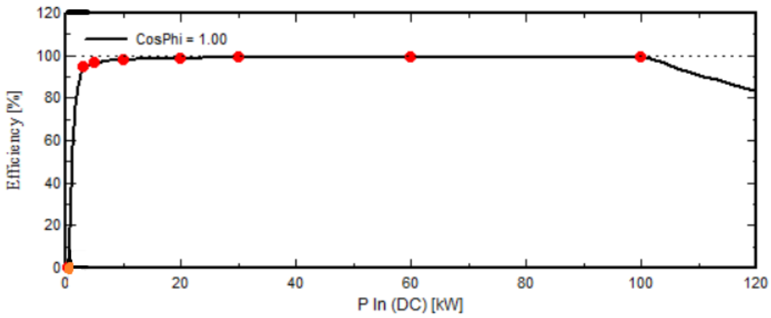


Figure 7. Inverter efficiency curve

The ground reflection is calculated as the sum of the reflection from the shaded area and the reflection from the unshaded area. The radiation in the unshaded area is modeled with global horizontal radiation (*GHI*). The radiation in the shaded area is modeled with diffuse horizontal radiation (*DHI*) and calculated as follows:

$$G_1 = \frac{\rho_g * DHI * A_1}{A_n} F_1 + \frac{\rho_g * GHI * A_2}{A_n} F_2 \quad (2)$$

Here ρ_g is the reflectivity of the floor, A_1 is the shaded area of the floor, A_2 is the unshaded area of the floor, A_n is the area of the modeled PV, F_1 is the visibility factor from the shaded area of the floor to the rear surface of the modules; F_2 is the visibility factor from the unshaded area of the floor to the rear surface of the module. The diffuse radiation is calculated with the anisotropic model;

$$G_2 = DHI * \frac{1-\cos\beta}{2} \quad (3)$$

Where β is the installation slope angle of the PV module. The reflectivity of the PV modules in the back row makes a minor contribution due to the low reflectivity of the PV modules can be calculated as:

$$G_3 = \frac{\rho_m * G_m * A_m}{A_n} F_3 \quad (4)$$

Where A_m is the area of the rear PV module, ρ_m is the reflectivity of the rear PV modules, and G_m is the incident radiation in the plane of the PV module, F_3 is the visibility factor from the rear PV module to the rear surface of the module. Therefore, the total radiation received by the back surface of bifacial PV modules can be calculated as follows: (Wang et al., 2019).

$$G_{rear} = G_1 + G_2 + G_3 \quad (5)$$

The Performance Ratio (PR) is the ratio of the energy effectively produced with respect to the energy produced if the system was continuously working at its nominal STC efficiency, defined in the norm IEC EN 61724. In the Grid-connected systems, the available energy is defined as E_{Grid}. The energy potentially produced at STC conditions is equal to multiplication of $Glob_{Inc}$ and P_{nomPV}, where P_{nomPV} is the STC installed power. Therefore for a grid-connected system, the *PR* can be calculated as below.

$$PR = E_{Grid} / (Glob_{Inc} * P_{nomPV}) \quad (6)$$

For bifacial PV Systems, the bifacial contribution from the rear side of the PV modules will become a gain, increasing the *PR*. The revised IEC 61724 -1 standard introduces the concept of a bifacial *PR*. The basic idea is that the additional irradiance contribution on the rear side of the PV modules is added to the Global incident irradiance. In PVsyst, to calculate the bifacial PR, the rear side irradiance is approximated as the difference between $Glob_{Bak}$ and $Back_{Shd}$, where $Glob_{Bak}$ is the effective irradiance on the rear side of the PV modules, and $Back_{Shd}$ are the losses induced by the 'Structure shading factor' in the bifacial model definitions. The bifacial PR_{bf} becomes;

$$PR_{bf} = PR / (1 + (Glob_{Bak} - Back_{Shd})/(Glob_{Inc})) \quad (7)$$

The following processes are used to simulate in PVsyst. A flowchart of the PVsyst simulation of the suggested grid-connected project is shown in Figure 8.

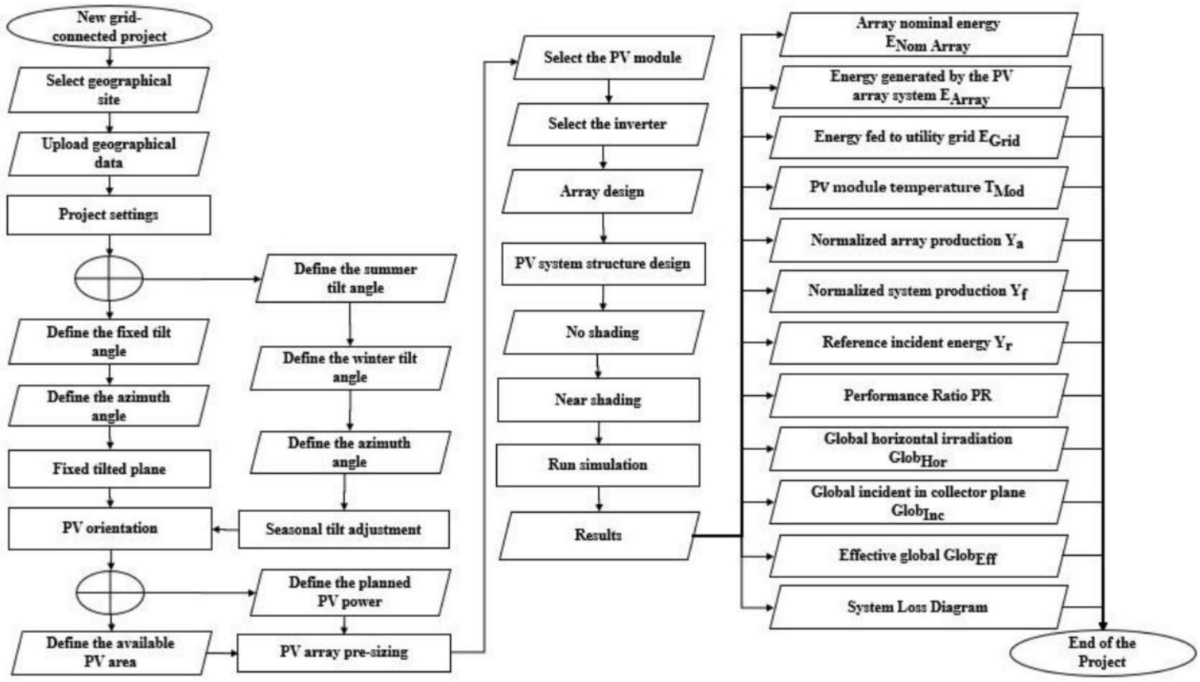


Figure 8. A flowchart of the PVsyst simulation of the proposed grid-connected system (Abagy et al., 2021)

In this study an installed capacity of 54,6 kWp bifacial and monofacial PV panels with a horizontal angle of 35°, azimuth angle of 0°, and 6m intervals for roof installation is considered (PVsyst, 2020). GTC Solar Turkey, GG1H-300 bifacial PERC 60 cells PV module was used in the analysis. Albedo values of the grounds of white sand and asphalt grounds are taken as 80%, 30% and, 10%.

3. RESULT AND DISCUSSION

The monthly variation of the global horizontal irradiation and horizontal diffuse irradiation values for the Konya region are given in Table 2. Climatic conditions and radiation values are considered the same for all analyzes. The annual total radiation value for the region is calculated as 1754.7 kWh/m². It is seen that the 594.3 kWh/m² of the total radiation is the diffuse radiation. The Linke turbidity factor, an indicator of the number of clean, dry atmospheres that would be necessary to attenuate the extraterrestrial radiation produced by the atmosphere (Chabane et al., 2021), is also calculated and given in Table 2.

Table 2. Solar radiation and climate conditions of the Konya region

	Glob. Hor. irradiation (kWh/m^2)	Hor. Diff. irradiation (kWh/ m^2)	Temp. (°C)	Wind speed (m/s)	Linke turbidity [-]	Relative humidity (%)
January	69,2	28,60	-0,20	3,0	2,62	80,6
February	87,3	36,6	1,80	3,39	2,93	74,3
March	131,0	47,8	6,80	3,80	3,41	60,3
April	166,1	69,8	11,10	3,69	3,91	54,3
May	210,6	73,7	16,20	3,50	3,55	52,3
June	223,3	62,9	20,70	4,10	3,17	44,3
July	229,2	68,0	24,70	4,60	3,13	35,2
August	208,4	56,8	24,40	4,40	3,09	35,1
September	169,6	47,5	19,30	3,60	2,92	41,5
October	119,2	41,3	13,40	3,21	2,99	56,1
November	78,4	31,0	6,60	2,70	2,74	68,7
December	62,4	30,30	1,50	2,69	2,60	80,3
Year	1754,7	594,3	12,20	3,60	3,09	56,9

Table 3. Monthly values obtained on asphalt ground for Bifacial PV Panels and monofacial panels in the Konya region

	Bifacial on Asphalt Ground					Monofacial PV				
Months	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
1	111,9	106,9	5,72	5,648	0,935	111,2	106,7	5,579	5,508	0,917
2	124,2	119,6	6,34	6,268	0,935	123,4	119,3	6,159	6,088	0,914
3	162,4	157,1	8,061	7,964	0,908	161,2	156,6	7,808	7,714	0,886
4	176,4	168,9	8,626	8,526	0,895	174,9	168,3	8,317	8,221	0,87
5	198,3	189,8	9,509	9,397	0,878	196,4	188,9	9,122	9,013	0,85
6	198,2	189,7	9,327	9,22	0,862	196,1	188,7	8,905	8,799	0,831
7	207,8	198,6	9,58	9,469	0,844	205,7	197,7	9,156	9,047	0,814
8	213,6	205,7	9,764	9,647	0,836	211,7	204,9	9,432	9,318	0,815
9	200,6	193,9	9,364	9,257	0,854	199,1	193,3	9,084	8,981	0,835
10	164,8	159,9	7,992	7,898	0,887	163,8	159,5	7,766	7,674	0,868
11	124,4	118,8	6,129	6,057	0,902	123,7	118,5	5,978	5,908	0,885
12	102,2	95,6	5,115	5,052	0,915	101,7	95,4	4,987	4,926	0,897
Total	1984,9	1904,2	95,527	94,404	0,881	1969	1897,9	92,294	91,197	0,858

The global radiation coming to the collector, the energy transferred to the grid, and the performance ratios were calculated and compared for Bifacial PV panels on white, sand, asphalt ground conditions and monofacial PV panels in the same conditions for the Konya region and given in Table 3 and 4. The result of the transposition from horizontal radiation to tilted PV plane of the global Incident radiation (GlobInc) for monofacial panels was found to be 1969.0 kWh/m², while bifacial panels on asphalt, sand floors, and white grounds were found to be 1984.9 kWh/m², 2016.6 kWh/m² and 2095.9, respectively. The Effective global Radiation (GlobEff) on the panels is the GlobInc, affected by the optical losses like far and linear shadings, IAM, and soling losses. In this study, The Effective global Radiation (GlobEff) found 1897,9 kWh/m² for monofacial PV, 1904,2 kWh/m² for bifacial PV on asphalt, 1916,7 kWh/m² for bifacial PV on the sand, and 1948,1 kWh/m² for bifacial PV on white ground conditions. It has been observed that the irradiance values are highly dependent on the albedo of the ground. It is also found that the global radiation values reflected to the collector surface increase in the summer months. The maximum annual average PR was found as 0.934 for bifacial on the white ground, whereas the others were below 0.9.

Tablo 4. Monthly values obtained on the white and sand ground for Bifacial PV Panels in the Konya region

	Bifacial on White Ground					**Bifacial on Sand Ground**				
Months	**Glob Inc kWh/m²**	**Glob Eff kWh/m²**	**EArray MWh**	**E_Grid MWh**	**PR**	**GlobInc kWh/m²**	**GlobEff kWh/m²**	**EArray MWh**	**E_Grid MWh**	**PR**
1	116,2	108,2	6,05	5,98	0,952	113,1	107,2	5,82	5,74	0,94
2	129,7	121,4	6,88	6,8	0,97	125,8	120,1	6,5	6,42	0,946
3	170,7	160,1	8,87	8,77	0,951	164,7	157,9	8,31	8,21	0,922
4	187	173,1	9,71	9,6	0,951	179,4	170,1	8,95	8,85	0,913
5	211,6	195,6	11,03	10,9	0,954	202,1	191,4	9,96	9,84	0,902
6	212,3	196,1	11,04	10,92	0,952	202,2	191,5	9,83	9,72	0,89
7	222,3	205,1	11,27	11,14	0,928	211,9	200,5	10,07	9,96	0,87
8	226,8	211,1	11,1	10,97	0,895	217,4	207,2	10,16	10,03	0,855
9	211,4	197,9	10,35	10,23	0,897	203,7	195	9,66	9,55	0,868
10	172,4	162,5	8,71	8,6	0,924	167	160,6	8,21	8,11	0,899
11	129,4	120,3	6,52	6,44	0,922	125,8	119,2	6,24	6,17	0,908
12	106,2	96,7	5,39	5,33	0,93	103,4	95,9	5,19	5,13	0,919
Year	2095,9	1948,1	106,93	105,69	0,934	2016,6	1916,7	98,89	97,73	0,897

In the PVsyst simulations, the loss diagram of the bifacial PV panel on the white floor and monofacial PV panels installed in the Konya region are presented in Figure 9, and the losses in the bifacial PV panel on the Asphalt ground and sand ground are presented in Figure 10. All systems' annual total radiation value was calculated as 1755 kWh/m². The albedo of the white floor was taken as 80%, and the global radiation reflected on the floor was formed as 777 kWh/m² in 586 m². It is found that Array nominal Energy is 121.7 MWh for bifacial PV panels on the white ground and 102.5 MWh for monofacial PV panels. When the losses are subtracted, we see that the energy transferred to the grid is 105.7 MWh for the white ground, while it is 91.2 MWh for the monofacial PV panel. The temperature has a significant effect on PV efficiency with a value of 7%.

It is shown in Figure 10 that the albedo values of the sand and asphalt are 30% and 10%. It is seen that albedo has a significant effect on the reflectivity of the total global radiation of 777 kWh/m² to the back surface of the Bifacial PV (BF PV) and monofacial PV panels. Array nominal energy values were found to be 110.8 MWh for sand ground and 106.4 MWh for asphalt ground. After all losses, the energy transferred to the grid is 97.7 MWh for sand ground and 94.4 MWh for asphalt ground.

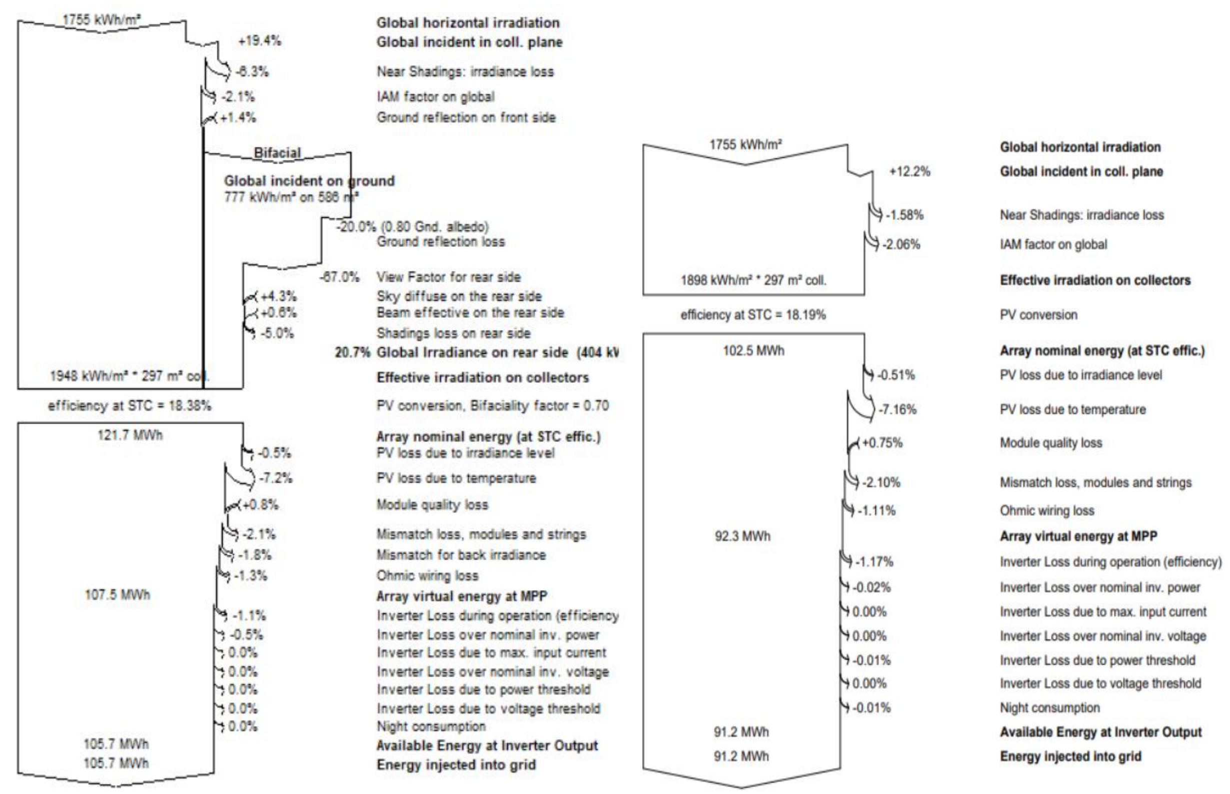
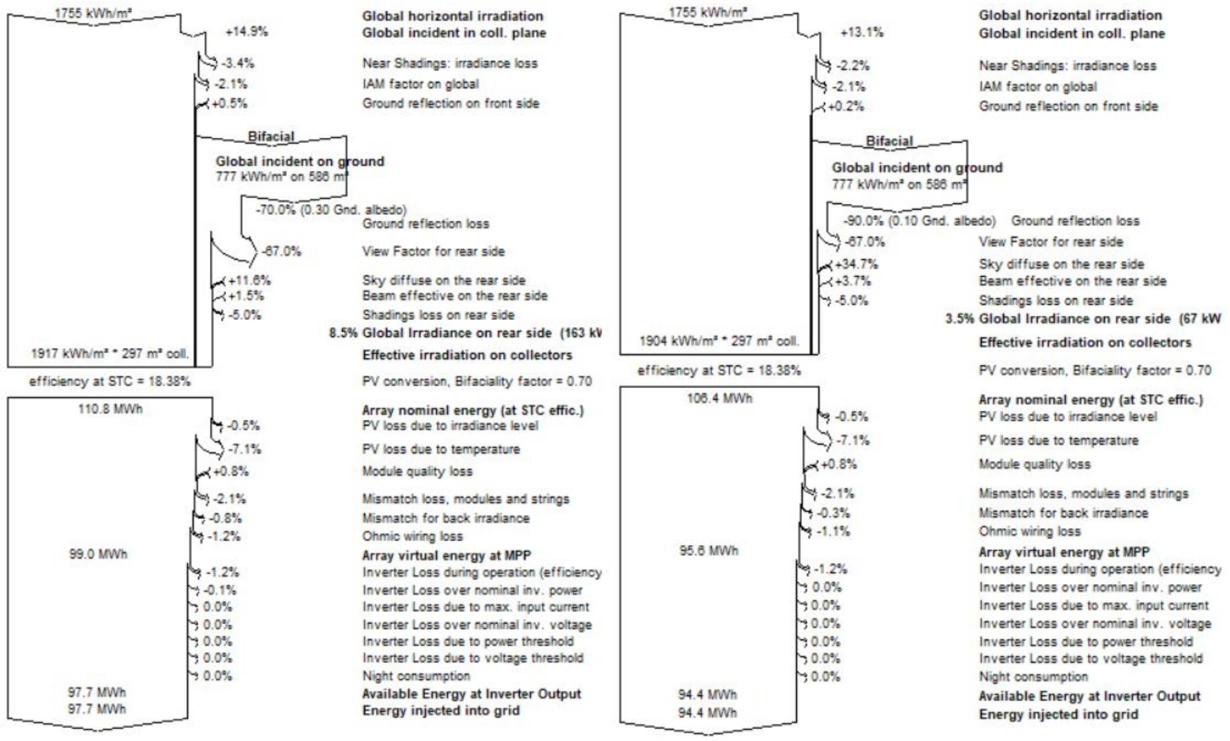


Figure 9. Loss Diagrams of Bifacial (left) PV installed on White Ground and monofacial (right) PV Panels



Şekil 10. Loss Diagrams of bifacial on sand (left) and bifacial on Asphalt Ground (right) PV Panels

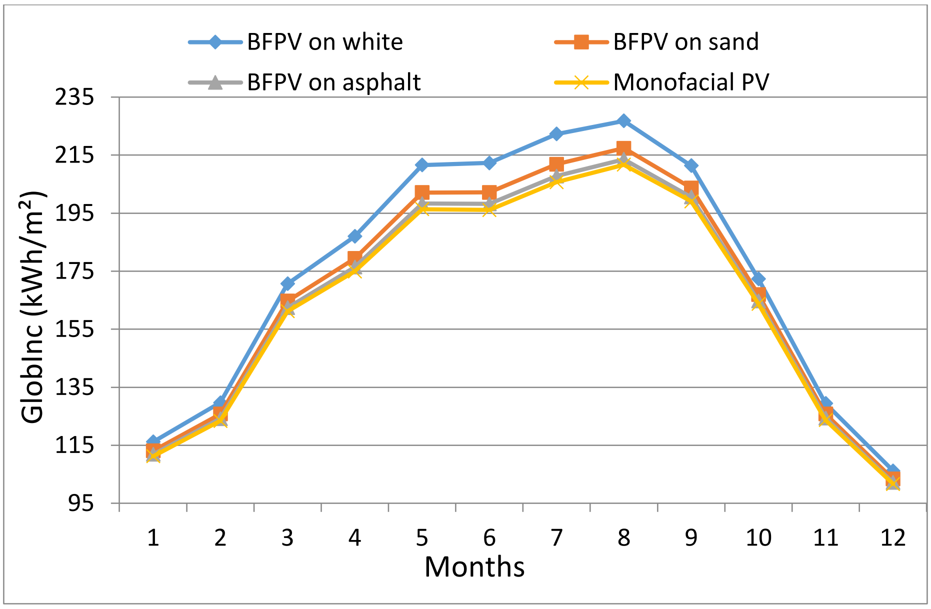


Figure 11. Monthly radiation reflected to PV surfaces

In Figure 11, the variation of global irradiance for bifacial PV panels and monofacial PV on different ground conditions (white, sand, asphalt) for the Konya region is given. Radiation values are low in winter and increase in summer. In August, which is one of the months with the highest radiation, 226.8 kWh/m^2 radiation value was obtained was 217.4 kWh/m^2 for the white, 213.6 kWh/m^2 for asphalt, and 211.7 kWh/m^2 for monofacial PV panels. The radiation obtained on the white background was 7.1% higher than the monofacial PV panel in August. It has been observed that different ground conditions are quite effective on the radiation formed on the back surfaces of the PV panels. The radiation incident on the monofacial panel is calculated by converting the horizontal radiation to the incident of the plane.

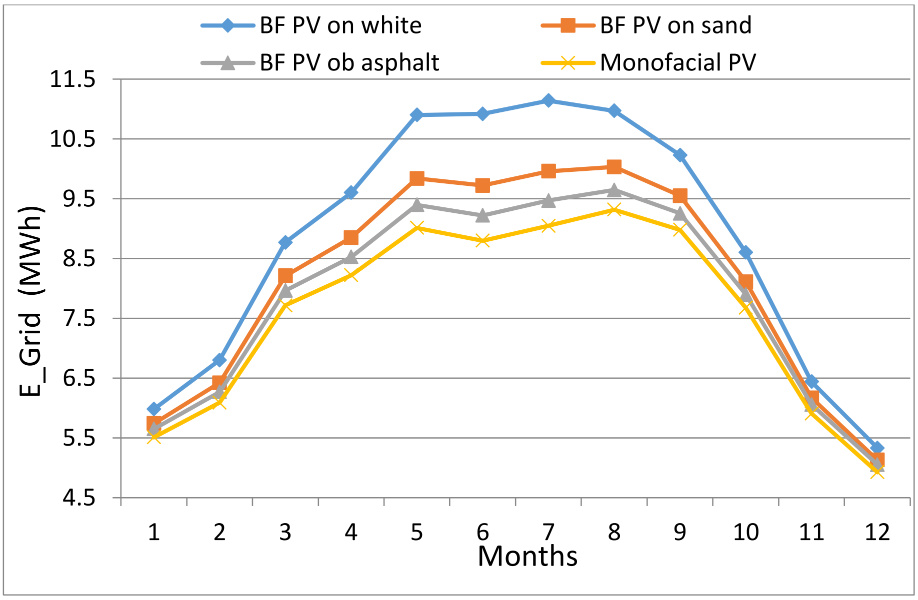


Figure 11. Energy Transferred to the Grid by Months for different PV panels and ground conditions

The monthly variation of electricity generation of bifacial and monofacial PV panels in different ground conditions for the Konya region according is given in Figure 12. It was observed that energy transferred to the grid by bifacial PV panels installed on the white floor in July is 23.1% more than the monofacial PV panels. While the annual energy transferred to the grid is 105.69 MWh by Bifacial PVs on white background, it is 91,197 MWh at monofacial panels. The annual energy transferred to the grid by the Bifacial PV system installed on the white ground is 15.9% higher than the monofacial PV systems. It is also seen that the energy production value of Bifacial PV panels installed on sand and asphalt surfaces is higher than monofacial panels. However, it is pretty low compared to the white ground.

The PR values of bifacial and monofacial PV panels installed in different ground conditions in the Konya region are given in Figure 13. According to the annual average values, the PR value of bifacial panels is 0.934 for the white floor, 0.897 for the sand floor, and 0.881 for the asphalt floor. Furthermore, the PR value for monofacial panels was calculated as 0.858. The performance ratio of bifacial PV panels installed on the white floor was 0.928 in July, which is 14% higher than 0.814 for monofacial panels. The most significant difference between the white floor and the monofacial PV panel occurred in June. When the annual average performances of bifacial on the white floor and monofacial PV panels are examined, it is seen that the PR value of the white floor is 8.8% higher.

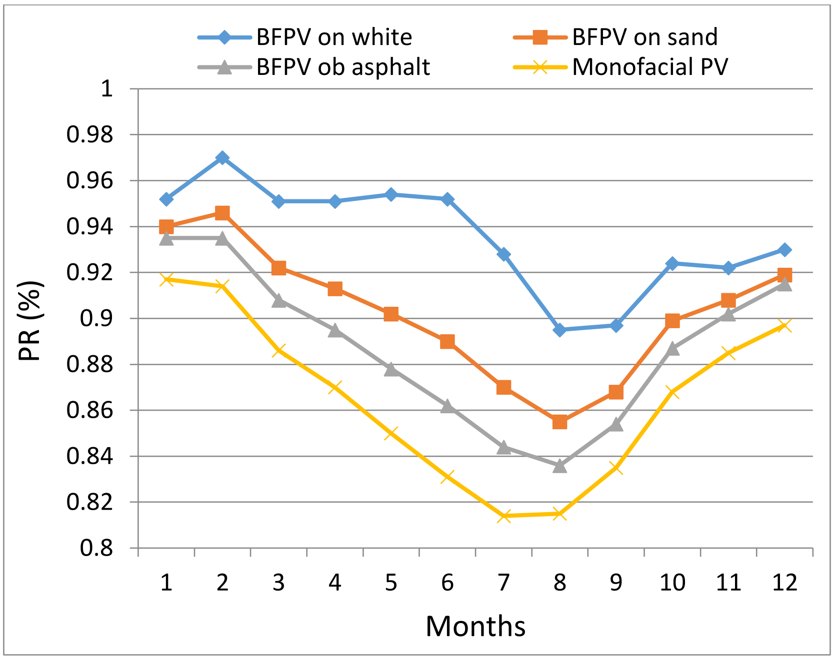


Figure 13. PR values for bifacial and monofacial PV panels

4. CONCLUSION

In this study, bifacial PV panel applications under different ground conditions were compared with monofacial PV panels in Konya region. Although there are many studies on modeling photovoltaic systems, studies modeling the comparison of monofacial and bifacial PV panels are very limited. Solar radiation reflected on the panels, energy production of the system, and the performance rates are presented.

- The annual total radiation value for the region is calculated as 1754.7 kWh/m^2. It is seen that the 594.3 kWh/m^2 of the total radiation is the diffuse radiation.
- The Bifacial system on white ground is the best choice compared to the sand and asphalt ground conditions with an 80% albedo effect.
- The yearly total energy production is 121.7 MWh for bifacial PV panels on the white ground and 102.5 MWh for monofacial PV panels.
- The energy transferred to the grid is 105.7 MWh for the white ground, while it is 91.2 MWh for the monofacial PV panel.
- The annual energy transferred to the grid by the Bifacial PV system installed on the white ground is 15.9% higher than the monofacial PV systems.

The performance of the models used in the PVsyst program can be compared by conducting the current study experimentally and comparing the results with the simulations. In addition, a techno-economic analysis can be done in future studies. In this study, the panel heights were assumed to be constant. The effect of the height of the PV panels on the efficiency can also be examined. The effects of the azimuth angle, another parameter, can also be evaluated. In addition, by modeling other variables with an optimization algorithm, optimum installation conditions can be determined in different regions and conditions. The study can also be repeated for different provinces, and the results can be compared in different coordinates.

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