JOURNAL OF ENERGY SYSTEMS

2024, 8(1)

2602-2052

DOI: 10.30521/jes.1345912

Research Article

Efficiency analysis of fixed and axis tracking options of photovoltaic systems to be installed in a marina

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Submitted: 18.08.2023
Accepted: 27.12.2023
Published: 31.03.2024

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Abstract: Electricity consumption is an important cost in businesses operating in the service sector such as marinas. Although the use of solar power for electricity has become widespread in various fields in Türkiye, marinas have yet to fully utilize this technology. The aim of this study is to examine the feasibility of supplying the electricity needs of a marina with a photovoltaic (PV) system. For this purpose, a marina in Muğla (Bodrum) was selected, and monthly/yearly electricity needs were determined. In this study, the PV installed capacity needed to meet the marina's electricity demand was selected. Simulations were performed for three different options using the Photovoltaic Geographical Information System (PVGIS). According to the calculations, a 2012 kW single-axis tracking PV system generated 4,469,618 kWh/year of electricity, which is sufficient to meet the annual electricity demand. It has been determined that the installation cost payback period is 3.91 years for the single-axis tracking PV system. In addition, it was observed that both the dual-axis tracking and single-axis tracking PV systems were more efficient than the fixed options.

Keywords: *PVGIS, Solar energy, Solar radiation, Tracked photovoltaics*

Cite this paper as: Dal, A.R., Nasraldeen, H.N., & Şahin, H.M. Efficiency analysis of fixed and axis tracking options of photovoltaic systems to be installed in a marina. *Journal of Energy Systems 2024; 8*(1): 40-52, DOI: 10.30521/jes.1345912

1. INTRODUCTION

Electricity is one of the most important indispensable parts of life. Electricity, which has a very high consumption in the field of industry in the world, is also consumed in the service sector. Today, producing and using electricity at the cheapest cost in a way that does not pose a danger to the environment and human health forms the basis of the development of countries. In parallel with the developments in the world, investments in renewable energy sources are increasing day by day. Environmental pollution and high costs during the production of electricity from fossil fuels necessitate the use of renewable energy sources and environmentally friendly technologies in electricity production. Solar energy finds more uses than other renewable energy sources. The effective use of solar energy is important for our country's economy as it is all over the world. Today, solar energy is used in different areas such as heating, drying, hot water, and electricity production.

According to the International Renewable Energy Agency (IRENA), renewable energy installed capacity in 2022 is 3,372 GW in the world and 56 GW in Turkiye. While the solar energy installed power was 1053 GW in the world, it increased to 9.42 GW in Türkiye [1]. According to the report published by IRENA [2] It is stated that by 2050, 25% of the global electricity worldwide will be met by solar energy. It is stated that with the rapid use of PV technology alone, 4.9 GT (Gigaton) Carbon Dioxide (CO_2) emissions will decrease in 2050 and solar energy will continue to be a rapidly developing industry in parallel with the developments in the industry. Among the renewable energy sources, solar energy is an energy source compatible with the environment both in terms of production technologies and fuel and operating costs. If long-term financing is provided to the energy production system by utilizing the sun, solar energy will be utilized to the maximum extent in our country [3].

Yacht tourism is a sector that allows people to travel on the seas. It contributes to the promotion of the country, especially in countries with a coastline. Marinas, on the other hand, are coastal structures built for the safe accommodation of yachts. These ports constitute an important source of income for the country's economies. In our country, marinas are densely located in the Mediterranean and Aegean regions. There are 61 marinas on the Turkish coast with a total mooring capacity of 24,728 yachts. There are 4 marinas with a total mooring capacity of 2,425 yachts in Bodrum alone [4]. 9.8% of the total yacht mooring capacity in Türkiye is located within the borders of Bodrum district. In addition to the administrative and social buildings in the marinas, hot water, and electrical energy are needed in the services provided to the yachts in the harbor. Marinas meet their electricity needs from the city grid. It is important that the electricity used in marinas is obtained by utilizing solar energy. Although the opportunity to benefit from solar energy varies according to geographical conditions and seasons, the convenience of solar energy in the Mediterranean makes it advantageous for marinas to benefit from solar energy. In addition, electricity generation from solar energy has started to be implemented by installing PV panels on the roofs of the warehouses and sea surfaces of many passenger and cargo handling ports in the world. Although the use of electricity based on solar energy has become widespread in many sectors in Türkiye, this technology is not yet utilized in marinas.

Our country is at the forefront of the world regarding solar energy potential due to its location. In terms of solar energy potential, all regions except the Black Sea Region are investment grade [5]. When the Solar Energy Potential Atlas (GEPA) [6] and the Global Solar Atlas (KGA) [7] prepared by the Ministry of Energy and Natural Resources (MENR) are examined It is understood that the south of the Aegean Region, the Mediterranean Region, the Central Anatolian Region and the Southeastern Anatolia Regions are advantageous regions in terms of solar energy potential. Bodrum, located in the Aegean Region of Türkiye, is one of the districts that receives more solar radiation. The solar radiation distribution of Bodrum district of Muğla is seen in Fig. 1.

Figure 1. Solar radiation distribution of Muğla / Bodrum district [7].

PV devices produce electrical energy directly from sunlight [8]. At the same time, PV systems that convert sunlight into electrical energy have high investment costs and low operating costs [9]. PV systems are of two types, with storage and grid connection. Storage systems store the electricity produced by the solar panel in batteries and use electricity if needed. In grid-connected systems (on-grid), the PV system meets the electricity need, while the excess electricity produced is given to the grid. While the electricity produced by the PV system is in use, uninterrupted energy is provided by the activation of the mains electricity in the absence of the sun. Considering that electricity consumption reaches its peak usage values during the day, the widespread use of grid-connected systems will both reduce the load on the grid electricity and relieve the distribution of grid electricity by giving the excess electricity produced to the grid [10].

Türkiye's solar energy potential and PV technology investments are increasing day by day [11]. When solar energy is examined in terms of usage area, it is more preferred in settlements and agricultural areas where there are no electricity networks far from the city and transportation problems. The advantage of grid-connected systems is that excess electricity produced by businesses is sold to the grid. In cases where solar energy is insufficient, the required amount of electrical energy is purchased from the grid. In this case, since the battery is not needed, the installation cost of the system decreases. To benefit from the sun at the highest level at any time of the day, designs that will follow the sun in PV panels have been started to be developed. There are two types of solar tracking systems for PV panels: single-axis moving and double-axis moving. When the literature is examined, many studies have been performed on solar tracking systems to measure solar energy potential and to achieve maximum efficiency in the world and in our country. Single-axis moving solar tracking system increases energy efficiency by 31% compared to fixed system, and double-axis moving solar tracking systems increase energy efficiency by 34-37% compared to fixed systems [12]. In the study conducted by Eke and Şentürk at Muğla University, they found that the dual-axis solar tracking system is 30.79% more efficient than the inclined fixed system [13]. The study by Chang found that the single-axis tracking system is 18.7% more efficient than the fixed panel [14]. In the study by Abdallah and Nijmeh It was stated that the two-axis movable system showed an efficiency increase of up to 41.34% in total energy compared to the fixed system [15]. It is suggested that PV panels should be adjusted to the optimum inclination angle of that month once a month with the help of a simple and economical mechanism, instead of being placed with constant tilt angles throughout the year or season [16]. In the use of PVs in the vertical shell of the building, it is imperative to take formal measures to provide the necessary inclination and orbital movement [17]. Huang et al., in their experimental study, stated that the power produced in a single-axis 3-position solar tracker solar PV system in a region with high solar radiation would be 37.5% higher than the fixed PV system [18].

In solar panel system measurements with programmable tracking control by Sungur reported that the tracking-controlled solar panel system produced 42.6% more energy compared to the fixed system [19]. In the study conducted by Yılmaz, it was stated that the efficiency of the dual-axis movable system is 31.67% more annually than the fixed system, and this efficiency is measured as 70% in the winter months and 11% in the summer months [20]. In order to reveal the real energy production potential in Greece, power and efficiency comparisons of 42 single-axis movable and 82 double-axis movable PV systems were made compared to the fixed system. According to these data, it was found that the single-axis movable system was 25.2% more efficient than the fixed system, and the double-axis movable system was 34.5% more efficient than the fixed system [21]. In another study, a fixed PV system with a panel power of 142.4 Wp and a uniaxial moving PV system were compared, and the system had an efficiency increase of 12% to 20% compared to the fixed axis system [22]. Maximum efficiency is obtained when the angle between the sun and the panel surface is steep. In order to achieve this, the PV panels must move so that the rays are perpendicular from sunrise to sunset.

Bodrum district is an important settlement for the application of PV system in terms of marinas. However, as in our country, there is no electricity generation application from the PV system in the marinas in Bodrum district. In this study, it is aimed to provide electricity consumption with the PV system to be installed at the facility without paying the electricity fee of the marina by using the minimum installed power in a model marina in Bodrum district. With the PV system to be installed in the marina, the process of meeting the consumption, selling the surplus electricity to the grid and purchasing electricity from the grid in case of need has been calculated. Calculations Efficiency analysis was made by simulating electricity generation in case of fixed axis, single axis tracking (SAT) and double axis tracking (DAT) options of PV systems.

2. MATERIAL AND METOD

In the study, PVGIS computer program was used to calculate the power, radiation, monthly and annual electricity production amounts of PV panels. This program receives meteorological data from satellite and calculates solar radiation accordingly. Data can also be entered into the program by the user. In addition, data on the monthly electricity consumption amount of 2018 for a marina have been obtained, as seen in Table 1.

Table 1. Monthly electricity consumption of a marina in 2020.

Months	Electricity Consumption (kWh)
January	304.325
February	261.245
March	297.753
April	325.306
May	343.273
June	424.545
July	512.790
August	526.595
September	400.712
October	287.882
November	248.646
December	349.159
Total	4.282.231

The solar radiation was calculated based on the inclination angle, azimuth angle, system efficiency, panel material used, and the coordinates of the ground, which must be entered in the program. In the PVGIS program, monthly/annual [kWh] amounts of electrical energy to be produced by the PV system were calculated depending on the marina PV installed power. In the study, the distribution of electricity consumed in the marina by months was examined. Based on the electricity consumed, the minimum value of the PV installed power (kW) sufficient for itself, excluding the PV installation cost and the PV system that is foreseen to be established in the marina, has been calculated. The amount of electricity to be produced based on this power is simulated separately in the PVGIS simulation program on a monthly/annual basis in fixed option, SAT, and DAT (three different) options. In addition, a formulation has been developed in the Microsoft Excel program between the amount of electricity produced monthly (kWh) and the amount of electricity consumed, depending on the power determined in PVGIS. The amount of electricity that will meet the marina's need has been calculated separately for three different options over the electricity purchase/sale values of the Republic of Turkiye Energy Market Regulatory Authority (EMRA). Then, the yacht harbor efficiency analysis was made, and the most suitable option was selected.

In the study, the changing of electricity consumed in the marina according to the months was examined. Based on the consumed electricity, the minimum value of the PV installed power (kW) sufficient for itself, and except for the PV installation cost has been calculated. The amount of electricity to be produced depending on this power is simulated separately in the PVGIS simulation program in the fixed option, SAT, and DAT (three different) options on a monthly/annual basis. In addition, a formulation has been developed in the Microsoft Excel program between the amount of electricity produced monthly (kWh) and the amount of electricity consumed, depending on the power determined in PVGIS. The amount of electricity to meet the marina's need has been calculated separately for three different options over the electricity purchase/sale values of EPDK. Then, the yacht marina efficiency analysis was made, and the most suitable option was selected.

2.1. PVGIS Computer Program

PVGIS, a free-to-use computer program, calculates the power obtained from solar radiation [23]. Depending on the geographical location, the average daily, monthly, and annual irradiance values and the capacity power of the PV system can be calculated in different options according to the desired panel angular value from the PVGIS database. The problem can be solved without the need for a panel area of the PVGIS program. In the PVGIS simulation program, the total solar radiation incident on inclined surfaces is calculated by the equations given below, depending on the azimuth angle γ_s, sun elevation angle α_s and inclination angle β [24].

$$G_T = G_{bT} + G_{dT} + G_{rT} \qquad (1)$$

Given in Eq 1, G_T is radiation incident on an inclined surface, G_{bT}, G_{dT} and G_{rT} are direct, diffuse and reflected radiation [W/m^2], respectively.

$$G_{bT} = G_b \frac{cos\xi}{cos\sigma_z} \qquad (2)$$

Given in Eq. 2, the position of the sun G_{bT} varies according to inclined surface and azimuth angle. Here G_b is the solar radiation incident on the horizontal plane, ξ is the incidence angle of direct radiation [°], σ_z is the solar zenith angle [°].

Reflected solar radiation incident on an inclined surface is expressed as;

$$G_{rT} = G\ \rho\ \frac{(1 - cos\beta)}{2} \qquad (3)$$

Defined as in Eq 3, G is total radiation incident on the horizontal plane [W/m^2], G_d is solar radiation incident on the horizontal plane [W/m^2] and G_b is direct solar radiation [W/m^2]. Also, ρ represents the surface reflectivity and β represents the inclination angle of the horizontal panel surface [°]. Diffuse radiation is a result of the scattering of solar radiation by the components of the atmosphere, and there is no homogeneous distribution in the sky. There are two approaches, the isotropic and anisotropic model. The model implemented in PVGIS has been developed by Muneer [25] and classified in the category of anisotropic models. This model estimates G_{dT} by choosing between clear or cloudy, sunny or shady skies [24]. Equivalent (Eq 4.) for shaded surfaces or overcast situations:

$$G_{dT} = G_d \, G_{dT} = G_d \left[\left(\frac{1+cos\beta}{2} \right) + 0.25227 \left(sin\beta - \beta \; cos\beta - \pi \left(sin\frac{\beta}{2} \right)^2 \right) \right] \quad (4)$$

For sunlit surfaces under non-overcast sky conditions (Eq 5):

$$G_{dT} = G_d \left[\left(\left(\frac{1+cos\beta}{2} \right) + \left(sin\beta - \beta \, cos\beta - \pi \left(sin\frac{\beta}{2} \right)^2 \right) \left(0.00263 - 0.712 \frac{G_b}{G_o} - 0.6883 \left(\frac{G_b}{G_o} \right)^2 \right) \right) \left(1 - \frac{G_b}{G_o} \right) + \left(\frac{G_b}{G_o} \frac{cos\xi}{cos\sigma_z} \right) \right] \quad (5)$$

has been given with, where G_o is the total of solar radiation outside the atmosphere [W/m^2]. Under these circumstances, a correction has to be applied when the solar elevation angle, αs, is low. Therefore, if $\alpha_s < 0.1$ [rad], G_{dT} is calculated following Eq. 6:

$$G_{dT} = G_d \left[\left(\left(\frac{1+cos\beta}{2} \right) + \left(sin\beta - \beta \; cos\beta - \pi \left(sin\frac{\beta}{2} \right)^2 \right) \left(0.00263 - 0.712 \frac{G_b}{G_o} - 0.6883 \left(\frac{G_b}{G_o} \right)^2 \right) \right) \left(1 - \frac{G_b}{G_o} \right) + \left(\frac{G_b}{G_o} \frac{sin\beta . cos\,(\gamma_T - \gamma_s)}{0{,}1 - 0.008 . \alpha_s} \right) \right] \quad (6)$$

The PVGIS simulation program calculates using the effects of solar radiation and panel temperature. Power P [W] is determined in Eq.7 depending on solar radiation and panel temperature [23, 26].

$$P(G_T{}', T') = G_T{}'(P_{STC,m} + k_1 In(G_T{}') + k_2 In(G_T{}')^2 + k_3 T' + k_4 T' In(G_T{}') + k_5 \, T' In(G_T{}')^2 + k_6 \, T'^2) \quad (7)$$

Here, $G_T{}'$is the total solar irradiance, and T' is the normalized panel temperature. The coefficients. k_1' to k_6'are values based on data measured by the European Solar Test Establishment (ESTI) specific to the PV panel type. $P_{STC,m}$ refers to the maximum power [W] under standard test conditions [23].

$$G_T{}' \equiv G_T / G_{STC} \quad (8)$$

$$T' \equiv T_{mod} - T_{STC} \quad (9)$$

$$\eta_{rel}(G_T{}', T') \equiv {P(G_T{}', T')} \big/ {P_{STC,m} G_T{}'} \quad (10)$$

In Eq. (8-10), T_{mod} panel temperature [ºC] and in STC (standard test conditions) $G_{STC} = 1000$ [W/m^2], $T_{STC} = 25$ [ºC] and η_{rel} means efficiency [23].

The azimuth angle indicates the southward orientation of the PV panels, and the azimuth angle is 0° for south oriented panels, -90° for east and 90° for west [27]. Commercially available polycrystalline silicon solar energy conversion efficiencies range from about 14−19% [28]. They stated that the actual values of the off-grid power system located in Gökçeada are compatible with the PVGIS radiation data. During the monitoring period of the system, they calculated that the average total irradiance measurement results were 5.15 [kWh/(m^2 d)] and 5.35 [kWh/(m^2 d)] in the PVGIS database. Likewise, they stated that the PVGIS estimates are consistent with the real-time temperature measurements obtained from the General Directorate of Meteorology of the Republic of Türkiye. In this context, they confirmed the consistency of the PVGIS database [29]. Energy analysis of a solar power plant in Isparta was carried out by Ceylan and Taşdelen with different simulation programs of PV*SOL, Helioscope, Polysun and PVGIS. It is stated that Isparta solar power plant is a PVGIS simulation program with a deviation rate of 1.3% according to the total energy production value [30].

In the study, the location of the coordinates of the marina was selected from the PVGIS map base. Crystal silicon material technology was chosen as the PV panel for all three options, and the system efficiency was accepted as 14%. Since there is no snowfall in the Mediterranean Region, this loss has not been considered. In the fixed option, assuming that the panel is oriented to the south, its slope is selected by calculating the optimum with PVGIS and the azimuth angle is taken as 0°. In addition, there is no problem in terms of the arrangement of the PV panels on the ground and the panel installation area, where the marina is on the seafront and surrounded by unused jetties and quays. There is a generator and transformer system of sufficient power, since the system will operate connected to the mains, and the marina is outside the residential area.

3. RESULTS AND DISCUSSIONS

3.1. Solar Radiation Amount of the Marina Region

In PV systems, the intensity of radiation coming to the panel surface is a factor that determines the power of the panel [31]. As can be seen in Table 2, solar radiation values at the location of the marina operation were calculated in three different options with the PVGIS program. When the fixed option is compared, it is seen that the highest solar radiation is 36.2% for the SAT option and 32.1% for the DAT option.

Table 2. Annual solar radiation values under three different options in the marina region [23]

	Fixed option	**DET option**	**TET option**
Solar irradiance [W/m^2]	2111.95	2875.47	2788.91
Solar radiation increase rate	1.000	1.362	1.321

3.2. Monthly Comparison of Three Different Options of PV System

Three different options were simulated by selecting the PV installed power for sufficient electricity generation in a marina operation. The simulation results were calculated in Microsoft Excel, considering the electricity purchase/sales values of EMRA. In these calculations, optimum values were found between the amount of electricity to be produced monthly by the PV system and the marina consumption for each option. These values have been calculated by considering the marina does not pay the electricity price for the network buying and selling transactions. The monthly distributions of the marina consumption with the three calculated options are given in Table 3 and Fig. 2.

When Table 3 and Fig. 2 are examined, it is seen that the electricity consumption amount of the marina and the increase and decrease in the monthly distribution of the electricity to be produced in the three different options of the PV system overlap with each other.

Table 3. Monthly distribution of the electricity production amount obtained under optimum conditions in the marina region [23].

Month	Electricity generation on fixed option (kWh)	Electricity generation on SAT option (kWh)	Electricity generation on DAT option (kWh)	Electricity generation in the marina (kWh)
January	234,317	207,069	214,047	304,325
February	256,727	234,356	233,288	261,245
March	365,635	348,441	339,203	297,753
April	417,994	417,177	407,615	325,306
May	449,194	463,732	463,770	343,273
June	460,019	502,964	512,489	424,545
July	488,215	541,451	546,799	512,790
August	481,641	516,254	507,623	526,595
September	431,787	434,470	422,186	400,712
October	363,295	345,131	341,210	287,882
November	277,611	252,127	258,780	248,646
December	232,224	206,446	217,186	349,159
Total	4,458,661	4,469,618	4,464,196	4,282,231

In all options, the highest electricity generation occurs in July, while the lowest electricity generation occurs in January and December. However, from the point of view of the monthly electricity produced to meet the consumption, the electricity produced in January, February, August, and December is not sufficient for the consumption in all three different options. In the case of three options, it was observed that production was higher than consumption and electricity was sold to the grid in March, April, May, June, September, October, and November. Moreover, in July, it was observed that only the fixed option generation did not meet the consumption and purchased electricity from the grid, while the other two options produced excess and sold the surplus to the grid. As can be seen in Table 3 and Fig. 2, the fact that there is a parallelism between the monthly electricity consumption at the marina and the amount of electricity expected to be produced in three different options in the PV system, except for January and December, means less solar panels and equipment use. This will reduce the initial investment cost of the PV system and positively affect the efficient use of the system. With the PV system that is foreseen to be established, it will be possible to benefit at the maximum level both in the tourism season and in other months. The optimum amount of power required in the PV system installation required for the electricity need by performing the purchase and sale transactions of the marina without paying any electricity consumption fee was calculated with PVGIS among three options and is given in Table 4. The optimum PV system installed power required for the marina has been determined as 1952.77 kW for the option with DAT (double axis tracking), 2012.31 kW for the option with SAT (single axis tracking) and 2671.41 kW for the fixed option. In case a PV system is established with these installed powers, the marina management will have the opportunity to generate sufficient electricity for itself by buying / selling from the grid without paying any electricity consumption fee.

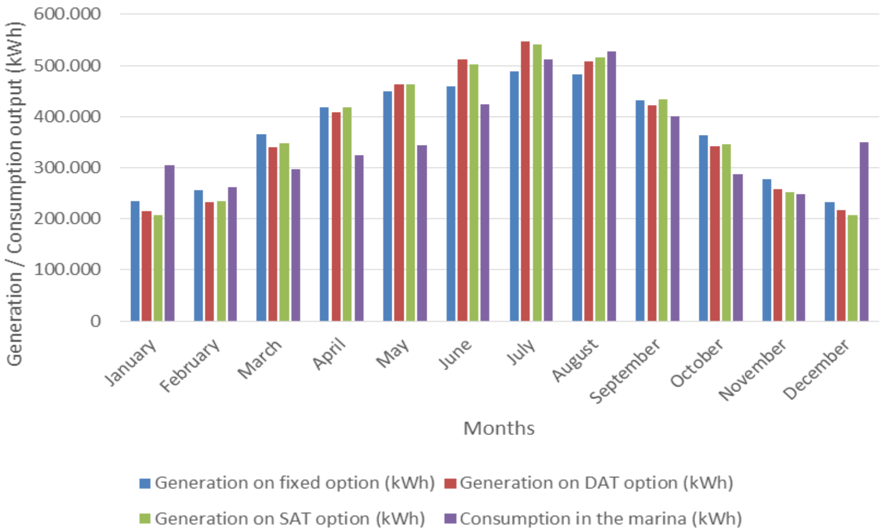

Figure 2. Comparison between yacht marina electricity consumption and electricity production in three different options of the PV system.

When the values are examined, it is seen that the same amount of electricity generation sufficient for the marina consumption is the option with DAT with the lowest installed power.

Table 4. Minimum PV installed power values for three different options [23].

	Fixed option	DAT option	SAT option
Maximum Power (kW)	2671.41	1952.77	2012.31
Power decrease rate	1.000	1.368	1.328

In Table 4, the PV installed power will be able to produce the same electricity with 36.8% less installed power requirement of the option with DAT compared to the fixed option. The electricity produced with a minimum installed power of 1952.77 kW will be able to meet the need of the marina. It means that the electricity to be produced with this power is sufficient for the marina, that the marina can both meet its consumption and continue its activities without any electricity costs from the enterprise by buying / selling with the tariffs determined by EPDK. Compared to the fixed option, the option with SAT will be able to meet the electricity required for the marina with 32.8% less power by making network purchases and sales transactions.

If the marina operator does not pay any electricity consumption fee, it has been determined that the minimum PV system installation is the option with DAT, with a power of 1952.77 kW, for electricity that will be sufficient for it.

In addition, Table 2 and Table 4 are compared, the difference between the rate of increase in solar radiation and the rate of decrease in installed power is given in Figure 2. As can be seen in Table 5, the difference between solar radiation and power is around 0.6% in the DAT option. The same situation shows that the marina need will be met with 0.7% less power in the SAT option. This means that in productions made with PV system in marinas, production with less power can be achieved in both options compared to the fixed option.

Table 5. Correlation between radiation and power for three different options in monthly solar radiation of Bodrum-marina

	Fixed option	DAT option	SAT option
Solar radiation increase rate	1.000	1.362	1.321
Power decrease rate	1.000	1.368	1.328
Difference	0.00	0.006	0.007

3.3. Initial Investment Cost of the PV System Installed in the Marina

The numbers of PV panels, inverters, and carrier systems to be used in the PV system are given in Table 6. In addition, market research and the average of the costs were accepted as the initial investment cost. The PV panel, inverter and copper energy cable, panel and consultancy services required for the installation of the PV system, which are required for the installation of the system, are purchased as a set and the costs are given in Table 7 [32].

Table 6. Number and characteristics of the equipment used.

Material list			
Material	Fixed option	Single option	Dual option
PV panel (Poly 275 W)	9.716	7.327	7.102
Inverter (40 kW)	66	51	49
Static system (Aluminum-tool set)	9.716	184	177

Table 7. Total initial investment cost of PV systems

Options	Fixed axis	Single axis	Dual axis
Initial investment cost (USD)	2,205,420	1,897,405	2,013,375

3.4. Calculation of Electricity Production Cost in PV Systems in Türkiye

The marina management's electricity purchase/sale price tariff, determined by EMRA, is given in Table 8 by converting it to USD. In the calculations, the price of excess electricity in the PV system to be installed and sold to the grid is 0.071834 USD/kWh. However, if the energy produced in the PV system is not sufficient for the marina requirement, the electricity price to be received from the grid is 0.120394 USD/kWh.

Table 8. Republic of Türkiye Energy Market Regulatory Authority (EMRA) Price Tariff (2020) [33].

	Unit price	**Unit**
Sale price	0.071834	USD/kWh
Distribution price	0.021599	USD/kWh
Taxes and funds	0.026961	USD/kWh
Total price	0.120394	USD/kWh

Table 9. Correlation between the installation of PV system options in the marina and the annual energy production / consumption (USD).

	Fixed axis	Single axis	Dual axis
The amount of consumption before the PV system is installed	4.282.231	4.282.231	4.282.231
The amount of energy from the grid after the PV system is installed	260.990	277.199	269.180
Annual direct electricity savings	4.021.241	4.005.034	4.013.050
The amount of energy sold to the grid after the PV system is installed	437.420	464.584	451.146
Total electricity production amount of the PV system	4.458.661	4.469.618	4.464.196
Annual total savings	515.557	515.557	515.557

The purchase/sale of the electricity produced by the PV system for the marina consumption to the grid was made according to the price tariff given in Table 8 and applied by EMRA. According to the marina need, electricity generation and consumption are calculated monthly in the Microsoft Excel program. In the calculation, with the optimum power to be installed in the marina operation, the total annual electricity generation of the PV system options is 4,458,661 kWh in the fixed option, 4,469,618 kWh in the SAT option and 4464.196 kWh in the DAT option. The electricity cost of the marina before the PV system is installed is 515,557 USD/year. This means that the total annual savings for all three options will be 515,557 USD. When Table 9 is examined, if a PV system is installed, the marina will directly use the electrical energy itself. In case of excess production, electricity will be sold to the grid, and in case of excessive consumption, electricity is purchased from the grid.

3.5. Calculation of the Payback Period of the PV System to be Installed at the Marina

The cash flow and payback period of the investment in the PV system installation at the marina are calculated separately in three options using the Net Present Value (NPV) method (Eq. 12) [34].

$$NPV = \sum_{t=1}^{m} \frac{I_t}{(1+k)^t} \quad (12)$$

Here t is the time period (i.e. year), I_t is the net cash flow in t years, m is the economic life of the investment (25 years), and k is the discount rate.

In this study, it is predicted that the power plant income will vary depending on the discount rate. In this context, the discount rate for July 2020 was taken as 0.25% by the United States [35]. In the study, it is predicted that the PV system installation will be completed and put into operation within one year. In addition, the payback period of the PV system installation at the marina with the NPV method is calculated for the three option cases and given in Table 10.

Table 10. The payback period for three options of PV system installation with NPV method (years).

	Fixed axis	Single axis	Dual axis
The payback period	4.58	3.91	4.16

In the calculations, the payback period of the initial investment cost of the PV system to be installed in the marina is calculated as 4.58 years for the fixed axis option, 4.31 years for DAT option, and 3.91 years for THE option.

When evaluated in terms of initial investment cost and payback period for all three option cases, it is seen that it will reach positive cash flow in less than 5 years. It has been determined that SAT option at the marina PV system is more advantageous than the other options, and it will be 8 months earlier than the fixed option and 3 months earlier than the DAT option. The calculated results agreed with similar studies [35,36]. When the results are compared with the results in Table 2, it is seen that the most solar radiation is in the DAT option, which means that the electrical energy will be produced the most but depending on the consumption in the marina and the network buying and selling process, the electricity generation in the SET option is more advantageous for the marinas. In addition, profit and loss status was calculated for all three options in the PV system installation and is given in Fig. 3.

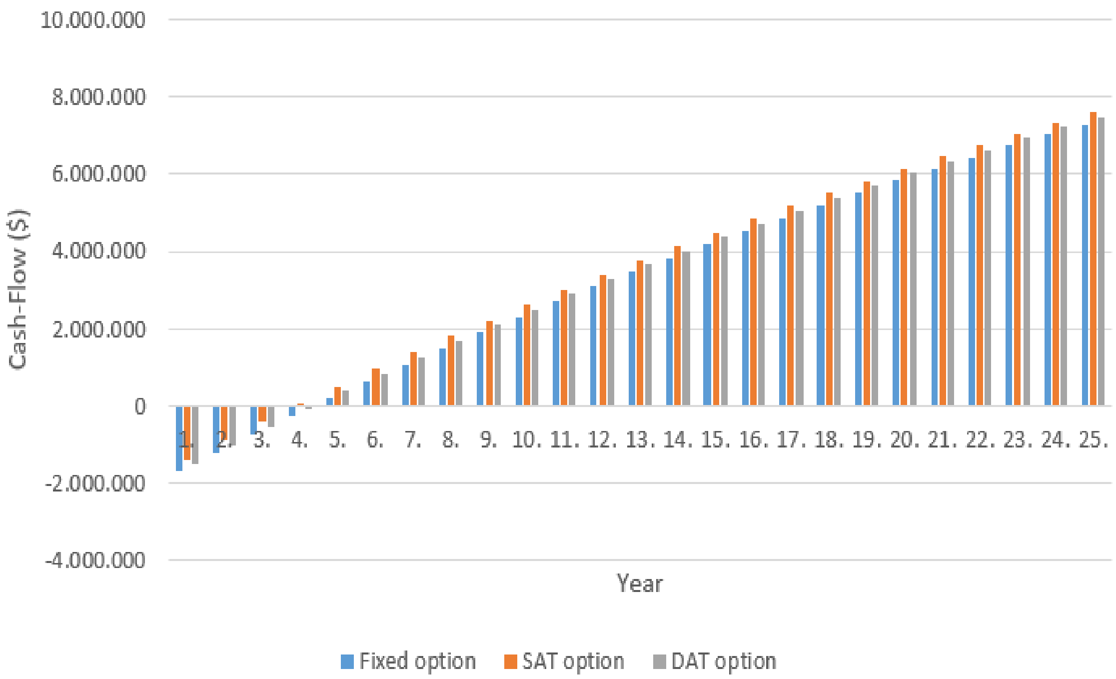

Figure 3. Profit and loss status for three options in PV system installation at the marina

4. CONCLUSION

In this study, the availability of solar energy for the electricity requirement of a marina was investigated for fixed axis, SAT (Single Axis Tracking) and DAT (Double Axis Tracking) options. The most important results are summarized below.

As a result of the calculations made, it will be possible to produce 4,469,618 kWh of electricity per year with the PV system with a minimum installed power of 2012.31 kW with SAT option. Similarly, a PV system with a minimum installed power of 1952.77 kW with DAT option will produce 4,464,196 kWh per year, and with a PV system with a minimum installed power of 2671.41 kW with fixed axis option, 4,458,661 kWh electricity will be produced annually. It has been determined that this production can be provided by the PV system without any electricity costs from the marina operation.

In the SET option, the difference between solar radiation and power is around 0.7%. This means that consumption will be met with less power installation in marinas compared to the fixed option.

The fact that the months when the marina consumes minimum and maximum electricity and the months when the PV system will generate minimum and maximum electricity are largely parallel makes it advantageous to install a PV system in marinas with both DAT and SAT options. Although the initial investment cost per unit kW is expensive in the DAT and SAT options, the shortening of the investment payback period makes mobile options advantageous.

This study has shown that choosing the other two options in the PV system to be installed in marina with the increase in electricity consumption will be more appropriate in terms of efficiency of the system compared to the fixed option. It has been observed that the electricity produced in January, February, August and December with the PV system planned to be installed in the marina does not meet the consumption. In the analyzes, the payback period of the initial investment cost of the PV system to be installed in the marina is calculated as 3.91 years for the most advantageous SAT option. It is predicted that the total annual savings of the marina management will be 515,557 USD.

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