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Bir Binanın Çatısında Güneş Enerjisinden Yararlanmak İçin Çeşitli Eğim Açıları Üzerine Bir Fizibilite Çalışması

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Amaç

Güneşten elektrik enerji eldesi fotovoltaik paneller sayesinde günümüzde yaygın olarak kullanılmaktadır. Ancak çatıya panel yerleşimi yapılırken hangi açı ile kurulması gerektiği önemlidir. Bunun için güneş takip sistemleri olduğu gibi sabit bir açıyla sistemin kurulduğu panel kurulumu da mümkündür. Sabit açılı sistemlerde en ideal açının belirlenmesi üretilecek enerji miktarını etkilemektedir. Bu çalışmada iki farklı eğim açısı için hesaplamalar yapılarak karşılaştırma yapılmış ve en uygun açı belirlenmiştir.

Materyal ve Metot

Panel yerleşimi ile ilgili olarak piyasada birçok yazılım kullanılmaktadır. Bu çalışma kapsamında da buna benzer bir yazılım kullanılmıştır. 30° ve 13° eğim açıları için iki farklı hesaplama PVSOL programı kullanılarak belirlenmiştir. Çıkan sonuçlar karşılaştırılarak ideal uygulama tespit edilmiştir.

Araştırma Bulguları

Sistem kurulumunda eğim açısının enerji üretimi üzerindeki etkisi ve panel kurulumunda bu hususa dikkat edilmesi gerektiği belirlenmiştir.

Sonuçlar

Bursa'da bir işletme çatısında kurulacak olan PV sistemi için ideal eğim açısının 30° olduğu tespit edilmiştir. 13°'ye göre 30° eğim açısı için 42.168 kWh daha fazla enerji üretimi ve 199.197 kWh daha az toplam kayıp hesaplanmıştır. 25 yıllık proje ömrü boyunca 30° eğim açısı için karbondioksit emisyon azaltımı 495 ton daha fazladır.

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A Feasibility Study on Various Tilt Angles to Exploit Solar Energy on a Building Rooftop

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Highlights

- Installation of photovoltaic (PV) systems
- The importance of tilt angel of a PV panel
- Determination of an optimum tilt angel for a rooftop PV installation

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Abstract
Energy is the basic need in our daily life. It is also important how we produce energy. Fossil fuels are non-renewable and have some environmental problems. Renewables especially solar energy is the key to a cleaner future. Luckily, Turkey has a very rich solar energy potential to use sun in generating energy. Along with the solar thermal collectors to supply hot water, photovoltaic panels have been growing a lot in recent years in Turkey. They are used to produce electricity on rooftops of the buildings. This paper focuses on tilt angle; one of the main parameters to install panels on a roof area to get the optimum energy yield. The installed capacity, potential electricity generation, financial aspects are calculated and assessed for two different tilt angles. A software is used to compare 30° and 13° tilt angles. The results reveal 42.168 kWh more energy production and 199.197 kWh less total loss for 30° tilt angle. While the carbon dioxide emission reduction is 495 tons more for 30° tilt angle throughout the 25 year project lifetime, the payback periods of the two angle are almost same.

Keywords: Renewable Energy, Energy for Buildings, Rooftop Solar System, Tilt Angle

1. Introduction

Population growth and technological developments result in the average per person electricity consumption increase. To meet this growing energy demand, fossil fuels, natural gas, and coal are used. However fossil fuels cause carbon dioxide emissions, and there are some environmental problems occurred like climate change, Global warming, Earth's temperature increase, and etc. The renewable energy plants are replacing fossil fuels to lower carbon dioxide emissions. Renewables cause less or none emissions that will harm the environment so they are preferable than fossil fuels. As a result of this tendency, the renewable energy plant amount increased by 12%. It is predicted that the renewables is expected to increase by 50% by 2024. Photovoltaic (PV) systems have a huge support in this increase in 2020 [1].

PV systems does not release carbon and its source is unlimited. Turkey has a very tempting solar energy potential as it is located in the northern hemisphere between 36 and 42° north latitude and 26–45° east longitude. The geographical position gives a benefit to Turkey because the mean annual solar radiation of Turkey is 1.527 kWh/m^2-year. Turkey has a better potential while comparing with Germany, France and Italy with potentials of 1.014 kWh/m^2-year, 1.248 kWh/m^2-year and 1.448 kWh/m^2- year, respectively [2].
At the end of 2021, Turkey had almost 100 GW of installed electricity generation capacity and solar photovoltaic (PV) accounted for 7,816 MW. This means an annual increase of 1,148 MW compared to 2020, which allowed solar PV to reach 7.8% of all Turkish generation capacity. This increase in solar energy investments has naturally led to the production of PV modules. In 2021, 22 companies were producing PV modules for a total annual production of 6,500 MW, while around 800 MW of cells are domestically manufactured [3]. PV systems are environmentally friendly as they have no moving parts. SEPs convert sunlight into energy so it gives energy independency to its user especially in rural areas. It also creates an opportunity to reduce dependency on imported energy. This alternative way of producing electricity becomes cheaper because of the latest technological developments and locally produced PV panels. Due to latest developments, the initial cost of PV systems is decreasing. Costs were 350 USD/MWh in 2009 where it was 50 USD/MWh in 2020 [4]. Photovoltaic (PV) systems can be grid-connected (on-grid) and off-grid systems. A PV system can be built on land or on rooftop. On-grid system can give the extra electrical energy to the grid and receive income from the network. However, the off-grid systems are designed to generate what is needed. Usually, this is favorable where the grid access is difficult. The off-grid systems is designed to produce the needed amount of energy so it is not possible to make an income from energy [5]. The investment cost for rooftop PV system is less as there is no land cost. The main purpose of these systems is to meet internal consumption of a building. The surplus energy can be sold to the grid to make some additional earnings. The continual increase in electricity prices also push consumers to invest in PV systems.

The cost of electricity, geographical potential, roof orientation, and investment cost are factors affecting the idea of installing rooftop solar PV systems on both residential and industrial buildings.

This paper deals only with roof orientation parameter out of these factors. The objective of this study is to calculate and compare performance of PV systems at different tilt angles (the slope/inclination/tilt angle) on the same roof. In the present work, a 1.369 kWp rooftop PV system is considered for 30° and 13° tilt angles. With this PV installation, the CO_2 emission reduction was also calculated for a 25-year project lifetime due to its contribution to global warming.

2. PV Market in Turkey

PV system is one of the renewable energy technologies. PV system can be integrated to the buildings for two purposes. It can either solar thermal collector or photovoltaic (PV) systems. The solar thermal collectors supply hot water where PV produce electricity. The installed capacity of solar thermal application in Turkey was 826.000 TOE by 2019 [6].

Based on statistics from 2019, it is anticipated that Turkey's rooftop PV system technical potential is 14.9 gigawatts (GW). These systems can supply 17% of Turkey's total building electrical needs, including those for cooling, lighting, ventilation, partial space heating, and hot water. Rooftop PV systems can cut Turkey's buildings' primary energy demand by 11%, assuming that all electricity is used for self-consumption [7].

By 2021, the installed capacity of rooftop was 458 MW. In addition to this, there were 9.284 roof with a capacity of 3.564 MW at the stage of installation (waiting for application approval) in Turkey [6]. Lastly, the technical potential of roof top was estimated to be 14,9 GW in Turkish solar market. To utilize this potential, the upper limit to benefit from the national tariff for 7 million kWh/year was changed to 3 million kWh/year at the “Final Source Consumer Tariff” on October 23, 2021. This change is expected to increase the demand for unlicensed roof top solar projects for self-consumption and to make roof applications more widespread [8].

There are two types of PV system on a land application; fixed tilt panels, (cannot change their positions or angles) and sun-tracking system (fixed, vertical one-axis, inclined one-axis and two axis tracking system). The tracking systems; presented in Figure 1, allow the PV modules to follow the position of the sun, means increased solar radiation and energy production. Hence, tracking systems are more complicated in construction, requires more investment, labor and maintenance cost while comparing with fixed tilt ones [9].

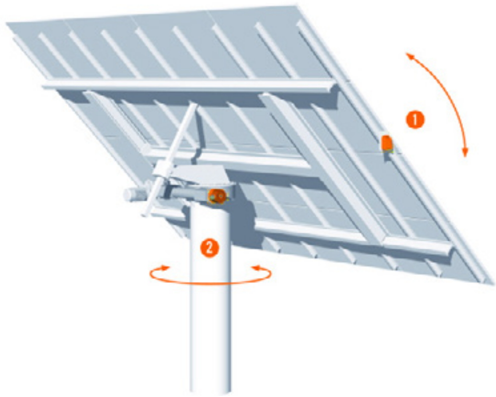

Figure 1 Sun-tracking system movement [10]

Although it is costly, it was found that the tracking system gives a 40% more energy production than the fixed system [11]. The PV installation on the roof might have different tilt angle depending on the roof geometry. The tilt angle is presented in Figure 2. The PV modules' tilt angle and the structure's roof slope could differ if the roof is flat [12].

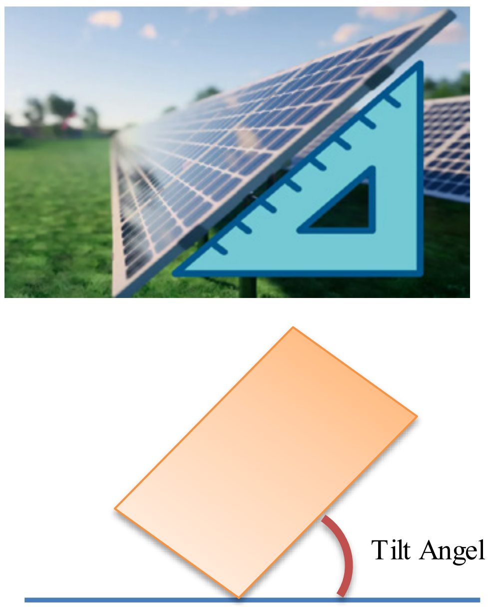

Figure 2 Tilt angle of a PV panel

There are some aspects must be kept in mind during a PV system installation [12]:

(i) Aesthetic factor
(ii) Available roof area factor
(iii) Shading factor
(iv) *PV* modules separation factor
(v) Service area factor
(vi) Dust deposition factor

In order to consider these parameters, a simulation software is mostly used before on site project installation. As mentioned, one of the most important parameter is shading. Shading depends on both the height of the panels and panel tilt angle [13]. Generally, the optimal tilt angle is calculated for a given location. The result is only suitable for this specific location [14]. Therefore, the PV installers require a simple tilt angle-latitude relationships that they can be applied. To achieve this, several models offer estimation of the optimum tilt angles in a PV installation project. On the evaluation of the energy received by PV systems for any orientation and all tilt angles that diverge from the ideal ones, there is, however, little information available. For instance, in a study, it was shown that a significant range of installation angles for PV systems results in very little annual energy loss [15]. In another study a model is used to calculate the ideal angel [16].

To determine the annual solar irradiation that reaches a tilted surface, researchers study angles in one-degree stages between 0° and 90°. Additionally, they found that minor variations from the ideal tilt angle do not result in significant energy losses [17].

The energy losses and the distribution of the PV modules on rooftop were analysed [12]. They found that 5% energy losses with deviations of the tilt angle between 21° and 23°, 10% energy losses with deviations of the tilt angle between 31° and 33°, 15% energy losses with deviations of the tilt angle between 37° and 40° and 20% energy losses with deviations of the tilt angle between 43° and 47°. In Turkey, a tilt angle of 30° is ideal for PV panel installation. Depending on the module type, different placement orientations and angles result in different performance deterioration in PV panels. The annual performance difference between 10° and 30° tilt angles will not exceed 15% in Turkish conditions [18]. In another study, mathematically, the annual optimum tilt angle value for the Yuregir Plain is calculated as 34° [19]. Photovoltaic panels are placed at an optimum angle. It is predicted that a 6% production loss will occur in the case of ± 15° deviation from the optimum angle. South is the best direction for solar panels to mount. To avoid low performance, panels are assembled in South-East and South-West directions. According to the summer and winter conditions in Turkey panels' tilt angle is 30° [20]. The monthly, seasonal and the annual optimum fixed tilt angles of PV panels depending on solar angles are calculated for Bilecik city. In the experimental study, optimum fixed tilt angles for May, June, July and August are determined by PV panels placed at 10º, 20º, 30º, 40º, 50º and 60º tilt angles [21]. However, it was found that when the tilt angle increased, the energy output of the PV system decreased [22]. They determined that 5° of the examined region was the ideal tilt angle. As presented, there are various studies completed on tilt angle within the literature. This study assesses the results of two different tilt angle on a roof in Bursa.

3. Methodology

The optimal tilt depends on weather conditions, including cloud cover and the altitude above sea level and latitude [13]. There is no simple calculations to determine tilt angle. Some software are utilized to define best suitable tilt angle. They simulate solar PV installation to calculate the highest electricity production by the panels. There are many software such as HOMER, TRNSYS PVWATSS, PVSYST, HELIOS 3D, PVSOL, PVMAPPER, and PVGIS that can model PV systems [11].

In this paper study, a feasibility study of a PV system on rooftop is investigated in detail. Both technical and financial aspects of the project are included into the feasibility study. PVSOL software is used for this purposes. The PV system has a 25 years lifetime. PVSOL offers a configuration and analysis for PV systems. The software gives solar output, panel sizing and economic forecasting for a planned PV project. A 1.369 kWp PV system is studied to install on the rooftop of a factory building in Bursa, Turkey at latitude 40° 12' 19'' N, longitude 29° 17' 25'' E 40. The system consists of 2.512 monocrystalline solar modules with 545 Wp each. The total surface area of the factory building is 6.421 m^2. Panels generates direct current (DC) and there will be 11 inverters to convert DC to alternating current (AC) electricity. This conversion enables electricity to be connected to the national grid. The factory consumes 4.260.000 kWh/year electricity and it comes from national grid. It is determined that the building roof is suitable for PV panels. It is investigated whether the tilt angle makes any difference in terms of energy generation, payback, and CO_2 emissions. While preparing detailed feasibility study, both 30° and 13° panel installations are studied and results are compared within this study explicitly. The differences between two tilt angles are provided.

a. Performance Analysis

PV panels can be installed in two various tilt angles. In this section, the differences are presented for these two options. The tilt angle 30° is named as VA (Version A) and the 13° tilt angle one is named as VB (Version B). The data is presented in Table 1. The PV panels can produce 1.759.832 kWh annually in VA where VB panels can produce 1.717.664 kWh/year. In terms of production amount, VA panels can generate 42.168 kWh/year more electricity (it means 42.168 kWh less energy from the grid in VA scenario). As a result of a better production performance, the percentage self-consumption of solar PV system for this factory is 41,31% in VA where it is 40,32% in VB. Another difference appears in the amount of electricity that comes from the grid.

The tilt angle defines the amount of global radiation at the PV modules. In this case, while VA receives 1.468,68 kWh/m^2, VB can receive 1.431,09 kWh/m^2. The roof area is 6.421 m^2 but the difference in PV radiation is 241.365 kWh (Information shown in Table 2). The PV panels cannot produce that amount of electricity because they have a Standard Test Conditions (STC) efficiency ratio of 21,32%. Standard Test Conditions (STC) refers to the fixed set of laboratory conditions under which every solar module is tested. Additionally, there are some losses such as; low-light performance, deviation from the nominal module temperature, input voltage deviates from rated voltage, DC/AC conversion, standby consumption (Inverter, and total cable losses.

Table 1 The production rate for two tilt angle

PV System	30° Tilt Angle (VA)	13° Tilt Angle (VB)	Difference	Unit
PV Generator Energy (AC grid)	1.759.832	1.717.664	42.168,00	kWh/Year
Electricity consumption	4.260.000	4.260.000	0,00	kWh/Year
Energy from grid	2.500.168	2.542.336	-42.168,00	kWh
Solar Fraction	41,31	40,32	0,99	%

Table 2 Global radiation variance in VA and VB

Specification	VA	VB	Difference	Unit
Global Radiation at the Module	1.468,68	1.431,09	37,59	kWh/m²
Roof Area	6.421	6.421	0	m²
Global PV Radiation*	9.430.394	9.189.029	241.365	kWh
STC Conversion (Rated Efficiency of Module 21,32 %)	7.419.834	7.229.928	189.906	kWh
Other losses	250.728	241.437	9.291	kWh
Total Amount of Losses	7.670.562	7.471.365	199.197	kWh
PV Generator Energy (AC grid)	1.759.832	1.717.664	42.168	kWh

*(It equals to multiplying global radiation at the module with roof area)

b. Economic Analysis

The project financial evaluation is calculated and outputs are given in Table 3. Assuming that the project will start on 31st July 2022 with a lifetime of 25 years. The interest rate is taken as 1%. According to these figures, VA gains $ 487.181 more earnings than VA at the end of the lifespan of the project. The payback times are almost same but the first year earnings is $ 5.955 more in favor of VA.

c. Avoided CO_2 emission

It is about 475 g CO_2 eq/kWh carbon intensity of a 1 kWh electricity's life cycle [23]. The US-based National Renewable Energy Laboratory (NREL) valued that coal power plants produce around 700-1.000 g CO_2 eq/kWh. Natural gas generation is less polluting, with emissions above 400 g CO_2 eq/kWh, but still 10 times higher than the solar power [24]. The avoided CO_2 emission is one of the main contributors to global warming. It is worth emphasizing that the CO2 emissions during PV panel production does not included. The factory receives the electricity from the national grid, and it is not known whether this electricity comes from a coal power plant or a natural gas cycle power plant. Receiving electricity from PV panels reduce the amount of released CO_2 emissions. In the PVSOL software, the rate is taken as 470 g CO_2 eq/kWh. The data is given in Table 4. The total CO_2 emission reduction of this PV project for 25 years project lifetime was calculated as 20.676 tons for VA and 20.180 for VB. The difference is 495 tons in 25 years.

4. Results and Discussion

Technical and financial assessment of a PV project on a factory rooftop in Bursa is carried out with PVSOL software tool. The results are evaluated in terms of two tilt angles to identify best option. It can be stated that VA (30°) has shown better both technical and financial results. VA can produce 42.168 kWh more electricity with $ 487.181 better earnings at the end of project lifetime. One of the results obtained from this study is the tilt angle of a PV has an influence on energy production rate and energy losses. In the proposed tilt angle at VA, a 2,45% more total produced energy by the photovoltaic system. In addition, VA has higher energy loss than VB. The energy losses difference is 2,67% between two angles. In previous studies, the tilt angles 5°- 60° are calculated. The result obtained from this study; 30° tilt angle, stays within the mentioned range for tilt angle in Turkey.

5. Conclusion

Producing energy from photovoltaic (PV) systems to attract the attention of consumers, because these system need sunlight as raw material and they are environmentally friendly energy production way. Due to some regulations to make PV systems installation more attractive, there are many active PV projects in Turkish renewables market. In this study, a feasibility analysis is made for a rooftop PV installation. The tilt angle of the panels are critical parameter so the optimal tilt angles for solar panels are investigated. The study is based on two angles; 30° and 13°. Both calculations are made for same building roof to compare the tilt angle effect. This paper utilizes open source tool named PVSOL software. This study showed that a solar PV system can be installed on 30° tilt angle for rooftop in Bursa, Turkey for optimal solar PV energy generation. It is determined that the system would have a better energy generation with this angle. The factory building is suitable for installation of 1.369 kWp capacity of rooftop solar PV system. The results of the PVSOL showed an annual energy yield of 1.285,30 kWh/kWp in VA and 1.254,50 kWh/kWp in VB. The payback period is 3,4 years for VA and 3,5 years for VB.

6. Recommendations

PV panels are needed to be cleaned. The interval of this cleaning process depends on the surrounding. If there is a source of dirt such as dust, leaves and bird droppings, then the panels should be cleaned more regularly. The effect of dirt and cleaning panels should also be studied. A further study with sun-tracking system is also possible for PV installation. Lastly, although the PVSOL is a well know software, the validation and control of the results should be done. PVSOL software results can be compared with results obtained after the project installation on rooftop.

Table 3. Financial results of the project

Financial Analysis Overview	VA	VB	Unit
Investment cost	930.947	930.947	$
PV Generator Energy (AC grid)	1.759.832	1.717.664	kWh/Year
Start of Operation of the System	31.07.2022	31.07.2022	
Assessment Period	25	25	Years
Interest on Capital	1	1	%
Cumulative Cash Flow	19.433.046,76	18.945.865,40	$
Payback Period	3,4	3,5	Years
Electricity Production Costs	0,02	0,02	$/kWh
First year savings	248.863,47	242.908,20	$/Year
Energy Price	0,14	0,14	$/kWh
Inflation Rate for Energy Price	10	10	%/Year

Table 4. Carbon dioxide emission reduction of the project

CO_2 data	VA	VB	Difference	Unit
PV Generator Energy (AC grid)	1.759.832	1.717.664	42.168	kWh
CO_2 emission reduction	827.022	807.203	19.819	kg/year
CO_2 emission reduction (25 years)	20.676	20.180	495	ton

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