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RESEARCH ARTICLE

A Comparison Between Fixed Solar Panel and Dual-Axis Solar Tracking System in Menderes District

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HIGHLIGHTS

> The electricity generation from solar energy was found to have increased by approximately 40% with proper implementation of solar tracking systems.

> In İzmir-Menderes district, the electricity needs of approximately 50 houses can be shown to be able to be met with a 38m x 125m solar field with the dual-axis solar tracking system.

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ABSTRACT

Solar energy has great importance among renewable energy sources. Electricity generation from solar energy has become a priority for all countries of the world in recent years. The sun's rays do not come at the same angles to the earth at all times of the day. Therefore, ways to make maximum use of solar energy are being researched. One of them is solar tracking systems. The use of horizontal and vertical two-axis solar tracking systems provides approximately 40% more electricity to be produced. In this study, a land for electricity generation from solar energy, which is a renewable energy source, was selected in the Menderes district of İzmir, and a comparison was made in terms of energy production using the fixed and 2-axis solar tracking system. Results It has been seen that in the case of using the 2-axis solar tracking system, an electricity production that can meet the annual electricity production of approximately 50 houses. For this reason, it is much more advantageous to use different forms of solar tracking systems instead of being in a fixed position when designing solar energy fields.

Contents

1. Introduction 33
2. Solar Energy and Solar Panels 33
   2.1. Electromagnetic Waves 33
      2.1.1. Ultraviolet-A (UV-A) Rays 33
      2.1.2. Ultraviolet-B (UV-B) Rays 34
      2.1.3. Ultraviolet-C (UV-C) Rays 34
   2.2. Solar Panel Types 34
      2.2.1. Monocrystalline Panels 34
      2.2.2. Polycrystalline Panels 34
      2.2.3. Thin-film Panels 34
3. Solar Energy Production 34
   3.1. Solar Energy in Turkey 35
4. Material and Method 35
   4.1. Solar Tracking System 35
   4.2. Solar Panel Angle 35
3. Conclusion 38

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Declaration of Conflict of Interest 38
References 38

1. Introduction

The need for energy on Earth is increasing dramatically day by day. This situation is of course due to the high energy consumption by people (more people mean more energy demand). So far, humanity has preferred to meet this need by using fossil fuels [1, 2]. According to the information given about the world energy consumption in 2016, fossil fuels met %80 of the required energy needs, whereas this rate is only %5 for renewable energy [3]. However, it is clearly known that fossil fuels are going to run out in a few decades (probably in 2060) and have a lot of bad effects not only on environment but also on people's lives [4].

Some of the main disadvantages of using fossil fuels can be listed as follows [5].

- Threatening the atmosphere
- Global warming
- Acid rains
- Climate change
- Air pollution
- Smog

For these types of reasons, many people around the world get serious illnesses, such as cancer and asthma and even die because of the air pollution created by fossil fuels. Because fossil fuels tend to generate different emissions of SO_2, CO_2, NO_x, Particular Materials (PM) when they are burned [6].

The first and most logical alternative that comes to people's minds at this point is "Renewable Energy Sources" for different kinds of reasons. The first reason why people have started generating energy by using renewable energy sources is that renewable energy sources are clean, so they reduce air pollution and don't damage the environment. Thus, it is very easy to say that there will be fewer threats to clean nature and people's safety. Another reason is that, unlike fossil fuels, renewable energy sources don't run out over time, so there will always be some clean energy for people to use to carry out their daily tasks.

Renewable energy sources are sometimes produced directly by the sun (such as solar energy) and sometimes indirectly by the sun (such as hydropower, wind) [7]. Overall, the renewable energy sources are Hydro Energy, Solar Energy, Wind Energy, Geothermal Energy and Biomass Energy. Since these types of energy are renewable, it is easy to regenerate them because they are derived from natural sources which don't run out [8].

In addition to this, it is known that China is the country with the most renewable energy, with a capacity of around 895 GW (gigawatts). The United States of America takes the 2nd place after China, its capacity is around 292 GW. Yet, they're not the only countries trying to produce as much energy as possible through natural sources. An increasing number of countries on the planet will start paying attention to renewable energy sources more and more as time goes on. For instance, there is a huge potential for the use of wind energy in Turkey because of the high wind speeds especially in the western regions of the country. That's why the Turkish government has started contributing more money to the companies dealing with this subject.

Since I will create an imaginary solar panel field in this article, I will be focusing on Solar Energy rather than the other types of energy. Solar energy is basically any kind of energy that is produced by the sun. It is one of the main renewable energy sources and has been used for many years for taking a shower or a bath, water heating, and drying crops [9]. On the other hand, there are a lot of different advantages that solar energy has. The main advantages of the use of solar energy can be listed as follows.

- Renewable energy source
- Economical
- Less dependence on fossil fuels
- Technology development
- Low cost of maintenance
- No carbon emission

2. Solar Energy and Solar Panels

2.1. Electromagnetic Waves

Ultraviolet rays are basically the rays coming from the sun. There are mainly 3 different types of sunlight (visible light, ultraviolet light, infrared radiation). Electromagnetic waves are a type of energy that spreads very quickly in a vacuum (vacuum). More physical events that we experience daily, such as the rise of sunlight, the microwave cooking our meals, and the operation of radios and televisions due to the electromagnetic field, are situations that make us feel the presence of electromagnetic waves. X-rays, ultraviolet (ultraviolet) rays, microwaves and radio waves can be considered as the main electromagnetic waves. Radio waves, TV waves, and microwaves are types of electromagnetic waves. As seen in Figure 1, they are separated from each other only by their wavelengths.

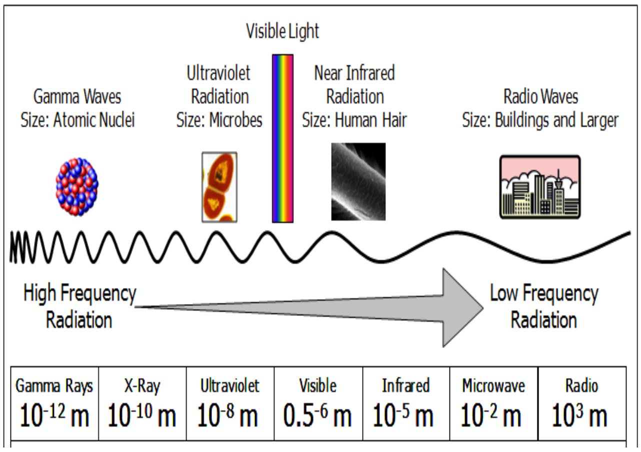

Figure 1 Wavelengths of electromagnetic radiation in meters [12]

2.1.1. Ultraviolet-A (UV-A) Rays

The wavelength is between 320-400 nm. UV-A rays are the rays with the longest wavelength and the least energy among UV rays. UV-A rays coming from the sun are not retained by the atmosphere, so people can feel them every single day.

It can penetrate into the inner skin known as the dermis. Therefore, it causes premature aging, wrinkles on the skin and the progression of skin cancer.

2.1.2. Ultraviolet-B (UV-B) Rays

They are rays with wavelengths between 280-320 nm and are in the middle of the UV band in terms of both energy and wavelength. It is about 1000 times stronger than UV-A rays. UV-B rays are absorbed not only by the Ozone layer but also by the clouds. The most dangerous impact of these rays on the human body is to weaken people's immunity system. Another major impact is skin cancer.

2.1.3. Ultraviolet-C (UV-C) Rays

They are the rays with the shortest wavelength and the highest energy in the UV band between 200-280 nm wavelength. It causes cancer as a result of contact with the skin and eyes. No exposure to UV-C radiation should be made without taking protective measures. These rays are observed by the Ozone layer [10].

2.2. Solar Panel Types

It is very important to choose the right solar panel when it comes to producing electricity through sunlight. If the selected solar panel is not suitable for the system, there may be many different disadvantages such as money loss, energy wastage. In Figure 2, there are basically 3 main types of solar panels (monocrystalline, polycrystalline, and thin-film solar panels). The choice of the solar panels depends on the main goal. If the goal is to produce as much energy as possible, then choosing a monocrystalline solar panel will be more logical. But if the designer wishes to see a nice shape, then thin-film solar panels are going to fit the system better. The necessary type of solar panel for the system in this article will be chosen depending on these factors.

2.2.1. Monocrystalline Panels

Monocrystalline panels are ideal for long-term investments, as their efficiency is between 15-18%. This yield reached up to 20% in the laboratory environment. Considering the solar situation in our country, the depreciation periods of the power plants to be built with monocrystalline panels will vary between 5-7 years. At the end of a 20-year period, there is a yield loss of less than 10%. Costs are high due to its pure crystal structure.

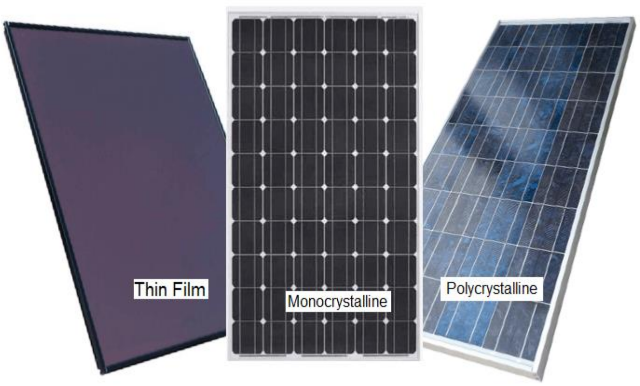

Figure 2 Solar panel types [11, 12]

2.2.2. Polycrystalline Panels

Polycrystalline panels are cheaper than monocrystalline panels (around 20%) due to their efficiencies of 12-15% and the inhomogeneity of their crystal structures. Yields reached up to 17% in the laboratory environment. Considering the solar situation in our country, the depreciation periods of the power plants to be built with polycrystalline panels will vary between 5-7 years.

2.2.3. Thin-film Panels

Although it has a high absorption rate of sun rays, it has a low share in the sector because its efficiency is between 7-12%. The biggest disadvantage of thin-film panels is that they need a lot of installation space [11].

Table 1 shows that the features of solar panel types.

Table 1 Advantages and disadvantages of solar panel types

Solar panel type	Advantages	Disadvantages
Monocrystalline	- Highest efficiency as it is made of high-grade silicon - Longest life, 25 years warranty	-The most expensive panels.
Polycrystalline	-The manufacturing process is simpler and cheaper.	-Not as efficient as Monocrystalline panels.
Thin-film	- More aesthetic	- Needs a lot of space

3. Solar Energy Production

Even though the COVID-19 pandemic temporarily slowed down the markets around the world, the latest data shows that the Photo-Voltaic (PV) market again rose rapidly. Currently, the use of solar energy is rising sharply in almost every country on the planet. Countries have already started contributing more to this sector as it will be even more critical soon. Logically, more developed countries such as China, European Union (EU), United States are the best countries in this field. Figure 3 shows that the countries which produce the most solar energy [13].

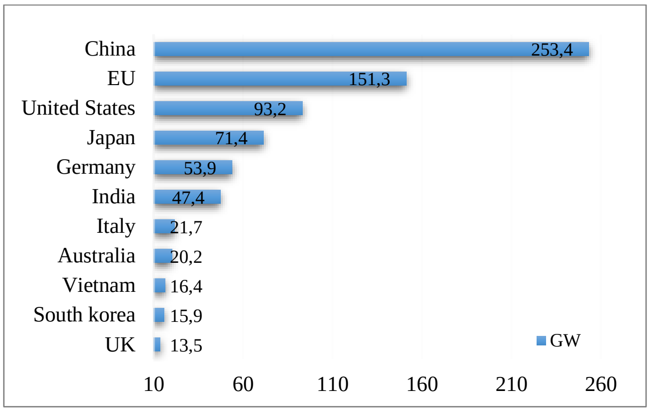

Figure 3 Top 10 countries with their total installed capacities in 2020

According to “Snapshot of Global PV Markets 2021” 760.4 GW were installed all over the world by the end of 2020. As it can be seen in Figure 3, China is the world’s number 1 PV market. 20 countries installed at least 1 GW of PV in 2020. In addition, 14 countries have installed at least 10 GW of cumulative capacity at the end of 2020. It is also important to know which country consumes the most solar energy. Australia consumes the most energy produced by the sun with 1764 kWh per capita. Since the solar panel field will be designed in a particular region in Turkey, it is also necessary to give some information about the solar market in Turkey [13].

3.1. Solar Energy in Turkey

A few countries which produced a considerable amount of solar energy in the previous years have left the top 10 because of the capacities they install annually, and Turkey is one of them since it experienced a major decline in 2019. These countries still witnessed significant developments, but not enough to be able to stay in the top 10. Figure 4 shows the installed PV capacity in Turkey in different years.

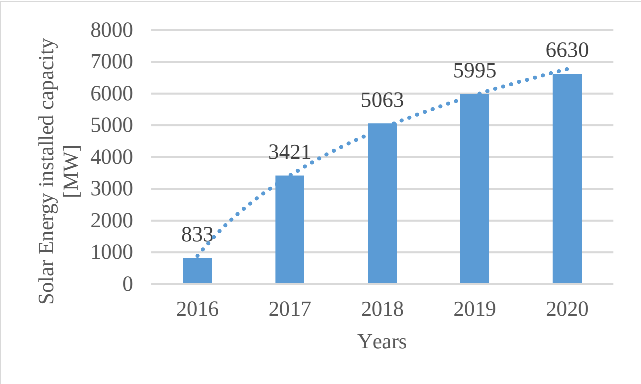

Figure 4 The PV capacity of Turkey between the years 2016-2020 [14]

Turkey currently has the solar capacity to meet about 5.9% of its electricity needs and it has increased its total PV capacity recently. Figure 5 shows the geographical distribution of the solar energy potential in Turkey.

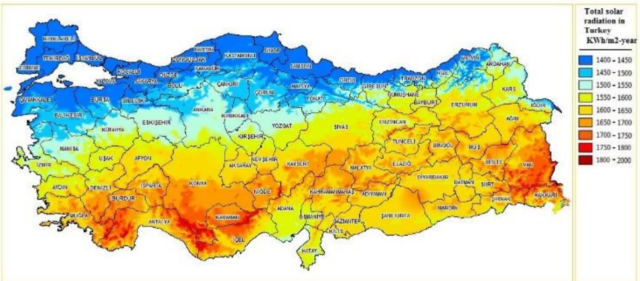

Figure 5 Solar energy potential in Turkey [16]

4. Material and Method

4.1. Solar Tracking System

The solar panel must be at the right angle to harness the solar energy. However, it is a known fact that the position of the sun during the day is not fixed. It keeps moving at different times. This is the biggest disadvantage that fixed solar panels have because they cannot change their direction when the sun starts moving. And this situation causes the energy amount to decrease. To be able to get the maximum efficiency from the sun, there are some steps to take. Firstly, there is a type of solar panel called “One-axis sun tracking system”. This system basically makes the panel move either in a horizontal or vertical way so that the amount of energy produced by the sun can increase. Another type is the Dual-axis solar tracking system which can alter the panel's position vertically and horizontally. These panels can generate more energy than the other solar panel types [17]. A detailed illustration of solar tracking systems is shown in Figure 6.

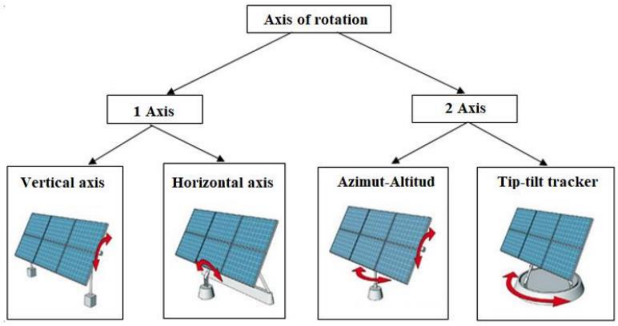

Figure 6 Solar tracking systems [17]

Since this article aims to produce as much energy as possible and meet the energy needs of many people, a dual-axis tracker system was chosen. It is known that a panel that is moved by a dual-axis solar tracker system can produce about 40% more energy than fixed solar panels [18]. This information will be used in the next parts of this article. The first step is to choose a suitable solar panel field. There are some requirements and conditions when it comes to choosing a solar panel field. For instance, there should be no plants in this field and the distance between the field and transformer center must be a maximum of 20 km [12]. The longer the distance, the higher the price. The field chosen for a solar panel is in Figure 7.

Figure 7 Top view of the selected field [12].

It is necessary to choose a city which has a huge solar energy potential. The field (38 m x 125 m) will be created in Menderes District in Izmir which is the 3rd biggest Turkish city. The choice of solar panels is also an important factor to produce a decent amount of energy. The market is very competitive, and many countries have their own solar panel brands. For instance, SunPower, which is an American company which specializes in solar energy production, has not only efficient but also very expensive panels. That’s why choosing these panels is a considerable debate [12]. On the other hand, a famous Korean brand Q Cells produces both efficient and affordable panels. In addition to this, a Monocrystalline panel will be used in this field since its efficiency is more than the other solar panel types.

4.2. Solar Panel Angle

Solar panels are placed at an angle where they can achieve high efficiency. If the solar panel is not placed at a right angle, the expected performance from the system will not be achieved. Therefore, calculating the right angle is quite crucial for energy production. In countries located in the Northern hemisphere such as Turkey, it is seen that the panel is oriented towards the south. With the same logic, it is seen that the panels are oriented towards the north in the countries located in the southern hemisphere [11, 12]. The most important angles in this regard are 2, one is the azimuth angle (the direction angle), and the other is the inclination angle (in Figure 8). For the fixed panels to achieve maximum efficiency, their direction must be turned to the Earth's equator line. It is used to indicate the angular distance of any object to the south, so it is 0° for south and 90° for west. If the azimuth angle is 0° and faces exactly south, it means that the system achieves maximum efficiency.

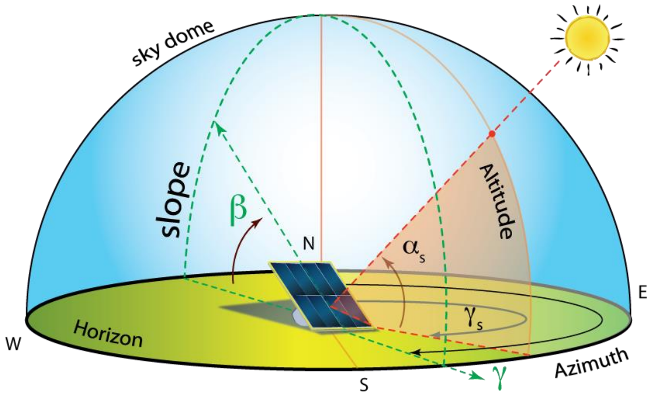

Figure 8 Azimuth and tilt angle with ground [11, 12].

It is also necessary to calculate the tilt angle between the panel and the ground. The annual average tilt angle (β) for the city of Izmir was taken as 32.8 degrees [19].

The solar panel selected will be placed as many as it can fit in the selected field. However, there are naturally various conditions when placing the panels. For example, the horizontal-vertical distance between the panels [17]. Figure 9 shows some parameters.

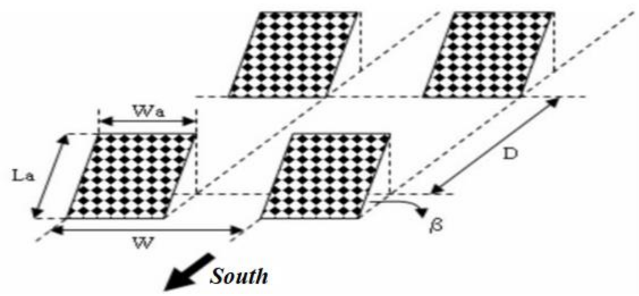

Figure 9 Necessary parameters for the solar panel field [11, 12].

"L_a" in Figure 9 is the height of the solar panel, "W_a" the width of the panel, "ß" the angle of the panel with the ground, "W" represents the horizontal distance between the panels, and "D" the vertical distance between the panels. However, in this project, more panels will be placed in the field, so W distance will not be taken to obtain more efficiency, the panels will be placed next to each other [11, 12]. Wa value is Wa=1007 mm and La value is 1984 mm in the panel selected.

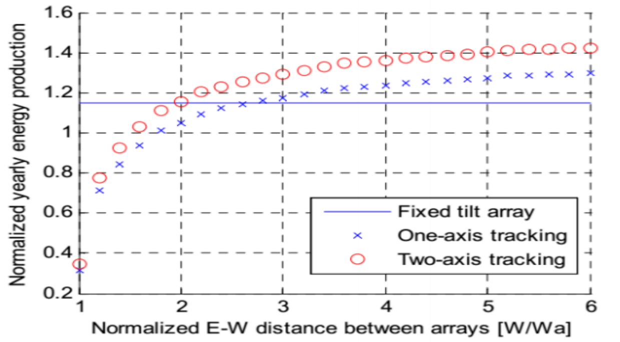

Figure 10 Effect of horizontal spacing between panels [11, 12].

As seen in Figure 10, the maximum energy production for the dual tracking system was obtained when the [W/W_a] value was 5. W is calculated as;

$$W = Wa\ x\ 5 = \ 1007\ mm\ x\ 5 = 5035\ mm \quad (1)$$

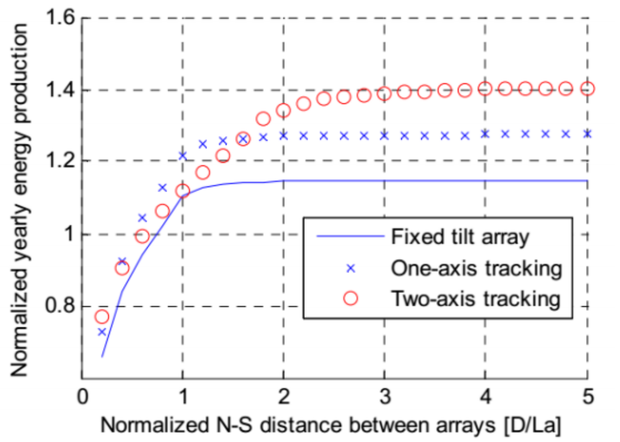

Figure 11 Effect of vertical spacing between panels [11, 12].

In Figure 11, it is seen that the D/L_a ratio with the highest energy production according to the vertical distance between the panels is 3. D is calculated as;

$$\frac{D}{La} = 3\,, D = 1984\ mm\ x\ 3 = 5952\ mm \quad (2)$$

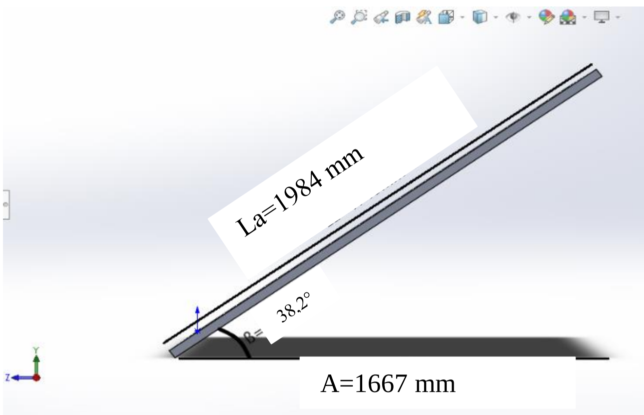

Figure 12 Size of the solar panel and the ß angle [14]

As seen in Figure 12, there is A value which is 1402 mm. Figure 12 shows the panel placement angle. The calculation is;

$$A = 1984\ mm\ x\ \cos(32{,}8°)\ 1667\ mm \quad (3)$$

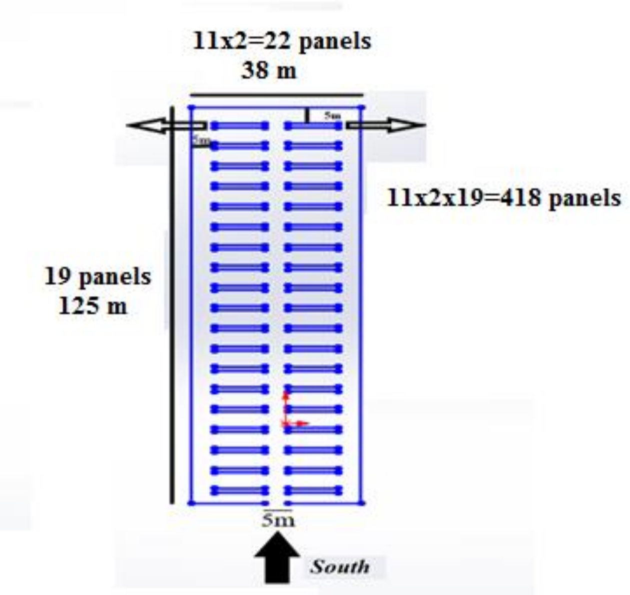

Figure 13 Design of the field [12]

According to the size of the field and calculations, as seen in Figure 13, there can be 418 solar panels in this field. Firstly, the amount of energy that can be produced by 418 fixed solar panels will be calculated and then the same thing will be done for panels with dual-axis tracking systems to make a comparison. There are some factors that play a key role in terms of energy production. For instance, the output of the solar panel and how long it absorbs sunlight during the day [10, 16].

Monocrystalline panels in Table 2 were selected for the solar energy facility. Each of these panels provides 400 W of power [20].

Table 2 Properties of monocrystalline panel.

Property	Value
Peak Power (Pmax)	400 W
Module Efficiency	20,06
Maximum Power Voltage (Vmp)	41,1
Maximum Power Current (Imp)	9,75
Open Circuit Voltage (Voc)	49,83
Cell Dimensions (mm)	158,75x158,75
Cells per Module (pcs)	72 (6X12)
Weight(kg)	22,5
Panel Dimensions (mm)	1984x1007x40
Short Circuit Current (Isc)	10,38

$$P_{total} = P_{panel}\ x\ n \quad (4)$$

$$P_{total} = 400\ W\ x\ 418 = 167200\ W$$

where P_{panel} is total energy production and n is the number of solar panels.

$$P_{daily} = P_{total}\ x\ t\ x\ 0{,}75 \quad (5)$$

whereP_{daily} is daily production and *t* is the sunshine duration in hours.

The rate shown as 75% is dirt, dust, or cloudy weather, etc. It is a standard calculated based on factors that can reduce the amount of power produced by the panel. To make this calculation, it is necessary to consider the sunshine durations of the Menderes district by month [12].

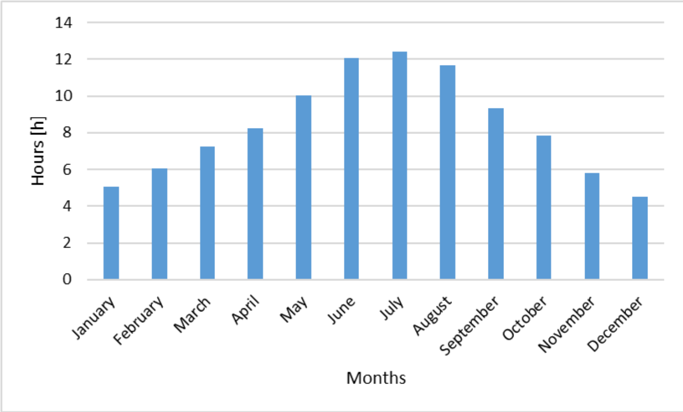

Figure 14 Exposure times to sunlight (Hour) [12].

As can be seen in Figure 14, Menderes district has different sunshine durations every month. Using these values, the amount of electrical energy that will be produced in a day in different months will be calculated [12].

For daily energy production in a month, say January, is;

$$167200\ W\ x\ 5.06\ x\ 0.75 = 634524\ W = 634.524\ kWh$$

With the same logic, the calculations for the rest of the months were done [12]. These calculations were only for one day in every month, the next step is of course to calculate the total energy production for every month.

$$P_{monthly} = P_{daily}\ x\ d \quad (6)$$

where $P_{monthly}$ is monthly production and d is the number of days.

The daily average and total production per month are given in Table 3.

Table 3 Total energy production in different months

Month	Production in a day (kWh)	Total production (MWh)
January	634.524	19.6
February	759.924	21.3
March	906.642	28.1
April	1033	30.99
May	1259	39.03
June	1513.5	45.4
July	1556.2	48.2
August	1462.1	45.3
September	1245.2	37.35
October	984.39	30.5
November	726.066	21.8
December	565.554	17.5
Total		345.77

All necessary calculations have been completed. But these calculations were for fixed solar panels. In the previous parts of this article, it was said that panels with a tracker system could produce more energy (about 40% more). So, the necessary calculation is as follows [12, 18].

$$P_{annual,tracker} = P_{annual,fixed} * improvement\ factor \quad (7)$$

$$P_{annual,tracker} = 345.77MWh + (345.77MWx0.40) \quad (8)$$

where P_{annual} denotes the annual energy production and is found to be $484.078MWh$ in the case of tracking.

Considering the calculations which have been made so far, it can be easily understood that panels that can move on a double axis can produce more electrical energy than fixed panels. In this part of the study, it will be investigated how many houses they can serve in Menderes district in a year, considering the amount of electricity produced by fixed panels and panels that can move in double axis. The average monthly electrical energy consumption of a house in Turkey is 230kWh and yearly is 2760 kWh. With fixed solar panels;

$$H = \frac{P_{annual,tracker}}{C_{avg}} \quad (9)$$

where C_{avg} is the average yearly electricity consumption and H is the number of homes.

By using the panels with a solar tracker system;

$$H = \frac{484078kWh}{2760kWh} = 175.3, \qquad hence\ 175\ homes$$

while fixed panels are sufficient for only 125 houses, tracking panels are sufficient for 175 houses.

3. Conclusion

In this study, calculations have been made on how much the energy production will increase in the case of using a fixed and solar tracking system of a solar energy field to be established in the Menderes district of İzmir. The results showed that the electricity needs of approximately 50 households can be met by using a solar tracking system. This is because fixed panels always stand at the same angle and are only exposed to sunlight for limited periods of time. However, panels with the same capacity can produce approximately 40% more electrical energy if they are designed to move 2-axis. Thus, taking this matter into consideration while making the initial investment will make the investment in electricity generation from solar energy more feasible.

Declaration of Conflict of Interest

The authors declare no conflict of interest.

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