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Araştırma Makalesi - Research Article

Bilecik İli için Güneş Enerji Santrali Maliyet Analizi

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ÖZ

Fosil yakıt kullanımından kaynaklanan enerji talebinin ve çevresel kaygıların artması, elektrik üretiminde yenilenebilir enerji kaynaklarına (YEK) olan eğilimi arttırmıştır. YEK'lerden biri olan ve enerji üretiminde daha büyük bir paya sahip olan güneş enerjisi, enerji üretiminde önemli bir potansiyele sahiptir. Türkiye, enerji talebini karşılamak ve aynı zamanda ulusal enerji kaynaklarını korumak için fotovoltaik (PV) enerji üretim endüstrisine birçok yatırım yapmıştır. Özellikle şebekeye bağlı PV enerji santralleri gibi temiz enerji kaynakları ile enerji tüketimi politikasının bir kısmı değiştirilmiştir. Son yıllarda, yatırımcıları Türkiye'de güneş enerjisi sektörüne yatırım yapmaya ikna etmek için çeşitli teşvikler sağlanmıştır. Bu çalışmada, dünyada ve Türkiye'de güneş enerjisi potansiyeli incelenmiştir. Gelecekte güneş enerjisinin Türkiye'de kullanımına ilişkin tahminler ele alınmıştır. Güneş enerjisi ile ilgili teşvikler incelenmiş ve Bilecik ili için lisanssız 100 kW'lık bir güneş enerji santralinin maliyet analizi yapılmıştır. Ayrıca, sanayi, ticarethane, mesken ve tarımsal sulama gibi abone türlerine göre amortisman süreleri hesaplanmıştır. Hesaplamalara göre, ticarethane abonesi için en kısa amortisman süresi, mesken abonesi için ise en uzun amortisman süresi elde edilmiştir.

Anahtar Kelimeler- Güneş Enerji Santrali, Maliyet Analizi, Amortisman Süresi, Bilecik

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Cost Analysis of PV Power Plant for Bilecik City

ABSTRACT

Increasing energy demand and environmental concerns resulting from the use of fossil fuels have increased the tendency towards renewable energy sources (RESs) in electricity generation. Solar energy, which is one of the RESs and has a higher share in energy generation, has an important potential in energy generation. Turkey has invested in photovoltaic (PV) power generation industry to meet the energy demand as well as saving the national energy resources. The government has also substituted some of the energy consumption with clean energy sources, especially on grid connected PV power plants. In recent years, a number of incentives are provided to persuade investors to invest in solar energy sector in Turkey. In this study solar energy potential is examined in the world and in Turkey. Besides, the estimations of the use of solar energy in Turkey in the future are handled. Incentives related to solar energy are examined and cost analysis of an unlicensed 100 kW PV power plant installation for Bilecik city, Turkey was performed. Moreover, the depreciation time was calculated for subscriber types as industry, business firm, house and agricultural irrigation. Based on the calculations, the shortest depreciation time was obtained for business firms while the longest depreciation time was obtained for houses.

Keywords- PV Power Plant, Cost Analysis, Depreciation Time, Bilecik

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I. INTRODUCTION

Fossil fuels have played a significant role in the energy demand of the world. However, considering the fact that fossil fuels cannot meet the world's energy needs for a longer period due to their limited reserves, the need for renewable energy becomes more apparent [1]. In addition, electric power plants that use fossil fuels in order to obtain electrical energy have negative impacts on the environment in many respects. Since the reserves of some fossil fuels such as oil and natural gas are expected to run out after a certain period of time in the second half of this century, the efficient use of all energy resources is of great importance. Therefore, RESs which can be used instead of rapidly exhausting fossil fuels have been investigated. On the other hand, the efficient use of the available resources has become critically important and there have been varies initiatives with the aim of reducing energy consumption [2].

In addition to environmental concerns, independence in energy has a great importance for the developing countries such a Turkey where energy demand has mainly met by import. Turkey's economy has recorded an average growth rate of 5% in the past ten years and this situation is reflected in the demand for energy. Considering electricity generation in Turkey between the years 1970-2017, it seems to be on a continuous upward trend except for 2001 and 2009 crisis. The electricity generation in Turkey in 2017 was 295 TWh. The distribution of electricity generation between January 2017 and July 2018 by sources showed that 35% of electricity was obtained from natural gas, 21% from hydroelectric power, 18.3% from imported coal and 6.22% from wind.

On the other hand, while energy consumption per capita in the world has increased by only 5% in the last 25 years, the rate of increase in the last 25 years in Turkey is over 100%. Energy generation in Turkey met about 50% of the total energy demand in 1990. However, today it meets about 30%. Therefore, RESs are of vital importance for Turkey [3, 4]. The data of major RESs in terms of installed power capacity obtained at the end of 2018 are given in Figure 1. As it can be seen from Figure 1, solar energy, which is also known as the main source of life, has an important potential among RESs with its 20% share [5].

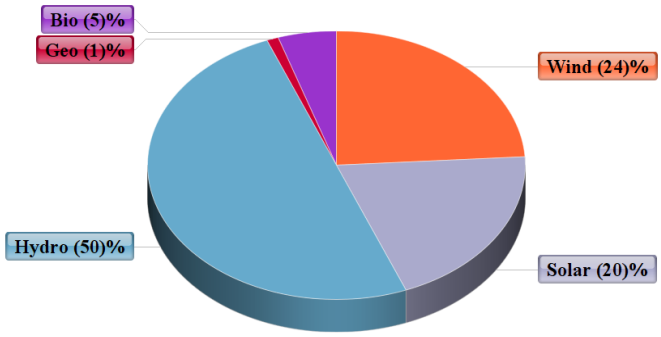

Figure 1. Renewable energy installed power capacity in the world by sources

Figure 2 shows the cumulative installed power capacity among RESs in Turkey at the end of 2018 [3].

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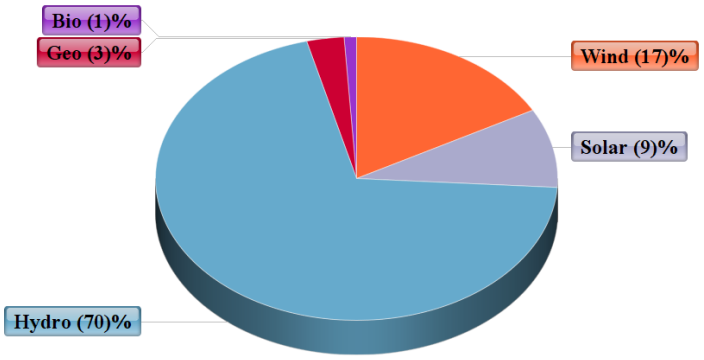

Figure 2. Renewable energy installed power capacity of Turkey by sources

Among the RESs, solar energy has taken great attention especially in recent years since the energy generated by the solar has no polluting effect on the environment [6]. When the literature is reviewed, it is seen that there are varies studies on solar energy. In general, these studies focus on the issues as sizing and feasibility [7], grid connected inverter design for PV systems [8], storage systems [9], solar radiation estimation [10], energy and exergy analysis of different types solar energy applications [11], solar tracking systems [12] the analysis of solar installing power factor [13], the efficiency of PV panels [14], the stand-alone PV system design for farm houses [15] and maximum power point tracking systems [16].

In this study, the use of solar energy as electrical energy was taken into consideration. First, the potential of solar energy was examined and the use of this potential in the world and Turkey was evaluated. Besides, some estimation was made on the use of solar energy in the future in the world and in Turkey. Turkey was examined in terms of solar energy incentives and cost analysis of an unlicensed small scale PV power plant installation for Bilecik city, Turkey was carried out. In the cost analysis, the prices before and after the changes made on purchasing policies in 2018 were examined and the differences in depreciation time were determined.

II. THE POTENTIAL OF SOLAR ENERGY

Sun is the main source of many energy sources. Only a small amount of the solar radiation can reach the earth. The reason for this is the distance of the sun to the world and that much of the solar radiation is absorbed by the atmosphere and clouds. Due to all these factors, the radiation outside the atmosphere is determined to be 1,367 W/m² as the solar constant. However, the radiation reaching to the earth ranges between 0-1,000 W/m² [17].

The total use of solar energy reaching the earth can theoretically meet all the energy consumption of the world. Solar energy is also used in the production of heat energy for industrial enterprises besides generation electricity. In practice, generating electricity from solar energy is achieved by mainly in two ways. One of these is generating steam by taking advantage of thermal effect and generating electricity with the help of turbine-generator, while the second one is direct generation from PV cells [18].

A. The Energy Situation in Turkey and in the World

When the grid connected PV systems are taken into consideration in the world, the Republic of China is the leader with 131,000 MW installed power capacity. United States is in the second order with the installed power capacity of 51,000 MW and Japan is the third with 49,000 MW. On the other hand, Turkey ranks 12th with 5,095 MW power capacity [19].

Electricity generation with existing and planned PV power plants in Turkey continues to increase. While PV energy generation was 4.5 GWh in January-May 2014, was 32.3 GWh in the same period of 2015, was 266.6 GWh in the same period of 2016 and was 844.56 GWh in the same period of 2017 [20]. When the number of PV power plants was examined, the growth rate in the number of power plants commissioned in 2014 was 223% compared to the previous year, all of which were as unlicensed electricity production [21]. 34,000

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MW of hydropower, 20,000 MW of wind energy, 5,000 MW of solar energy, 1,000 MW of geothermal energy and 1,000 MW of biomass energy are planned to be generated in Turkey within the scope of 2023 goals. Energy generation and goals related to RES are given in Table 1. According to these goals, it is planned to provide at least 30% of Turkey's demand for electrical energy (including hydropower) by RESs until 2023. Approximately $ 60 billion is expected to be invested in RESs to achieve this goal [22]. All existing renewable energy investments must be put into practice in order for Turkey to achieve its renewable energy goals of 2023 and improve the goals.

Table 1. Energy generation and goals related to RES (MW) [23].

RES	2015	2017	2019	2023
Hydro	25,526	28,763	32,000	34,000
Wind	5,660	9,549	13,308	20,000
Solar	300	1,800	3,000	5,000
Geothermal	412	559	706	1,000
Biomass	377	530	683	1,000

In Turkey, the number of energy generation power plants constructed by the private sector in the energy sector is increasing day by day. The share of the private sector in electricity generation was 40.2% in 2002 and it was approximately 83% at the end of 2016 [24]. This increase is also resulted by the government support in these investments. With these investments, diversity in energy resources has increased, energy security is ensured and energy imports are prevented and further growth of the current deficit is prevented. When the energy investments realized in Turkey in 2018 are examined, it is seen that the investments are about 55% in hydroelectric power plants, 15% in wind energy and 0.54% in solar energy [25].

Turkey has a geographic location which can be considered rich in terms of solar energy potential. 2/3 of Turkey has solar energy potential of 1,500 kWh/m^2 or more per year [26]. Solar Energy Map prepared by General Directorate of Renewable Energy of the Ministry of Turkish Republic Energy and Natural Sources is given in Figure 3.

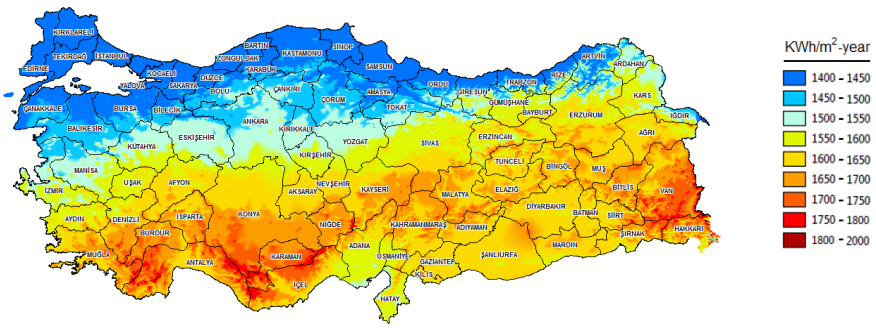
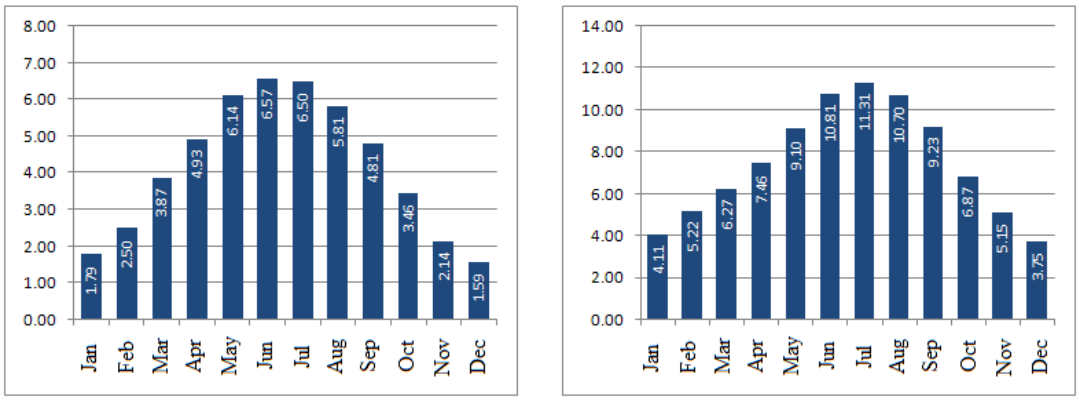


Figure 3. Solar Energy Map of Turkey [26]

Monthly distribution of the average daily value of solar radiation and sunshine duration for Turkey obtained by the measurements conducted by General Directorate of Renewable Energy of the Ministry of Turkish Republic Energy and Natural Sources can be seen in Figure 4.



(a) (b)

Figure 4. a) Average solar radiation (kWh/m^2-day), b) average sunshine duration (Hour) for Turkey [26]

B. Solar Energy Potential for Bilecik City

According to Solar Energy Map data, total solar radiation in Bilecik city is given as 1,400-1,550 kWh/m^2 per year and is given in Figure 5 [26]. Moreover, according to the measurements made by General Directorial of Renewable Energy, monthly distribution of average daily solar radiation value and average daily sunshine duration of Bilecik city can be seen in Figure 6.

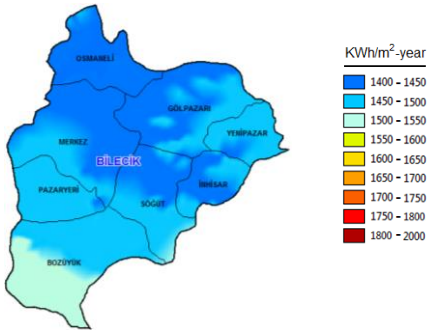
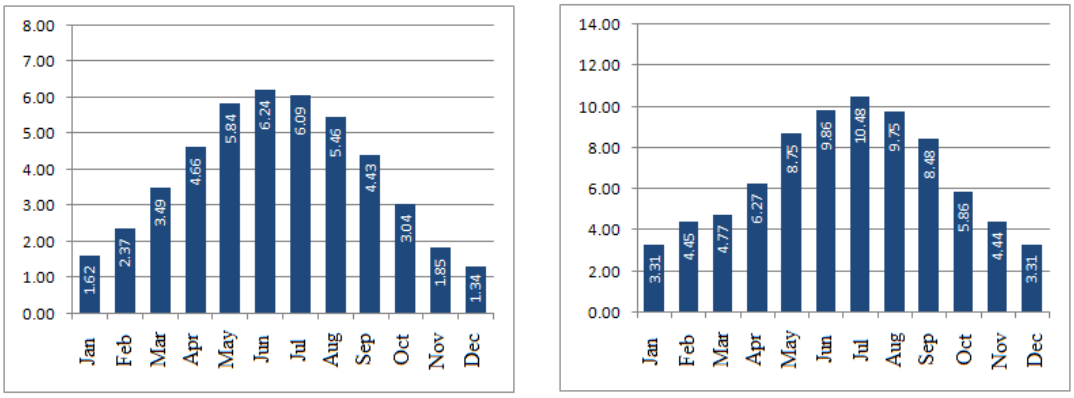


Figure 5. Solar Radiation for Bilecik City kWh/m^2-year [26]



(a) (b)

Figure 6. a) Average solar radiation (kWh/m^2-day), b) average monthly sunshine duration (Hour) for Bilecik city [26]

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Bilecik is located in the southern part of Marmara Region and it has borders with Black Sea, Central Anatolia Region and the Aegean and Marmara regions. Therefore, it is located within the boundaries of four regions. As a result, the solar energy potential of Bilecik city varies by region. Compared to the northern regions, there is a serious potential for solar energy in the southern regions. Table 2 shows the average annual solar radiation values and the average annual sunshine duration of all districts of Bilecik city.

Table 2. The average annual solar radiation values and the average annual sunshine duration of all districts of Bilecik city.

Districts	Total Sunshine Duration (kWh/m^2-Year)	Sunshine Duration (Hour/Year)
Center	1,405	2,441
Bozüyük	1,458	2,476
Gölpazarı	1,396	2,387
İnhisar	1,402	2,383
Osmaneli	1,372	2,395
Pazaryeri	1,438	2,477
Söğüt	1,407	2,417
Yenipazar	1,413	2,390
Average	1,412	2,421

As can be seen in Table 2, the regions where solar energy is higher are Bozüyük, Pazaryeri and Yenipazar districts. The average solar energy of Bilecik city is 1,412 Wh/m^2 and the average annual sunshine duration is 2,421 hours.

III. FUTURE OF SOLAR ENERGY AND INCENTIVIES IN TURKEY

A. Future Estimations for Turkey and the World

According to the energy scenario published by the World Energy Council in 2016, primary energy demand per capita will reach its highest level before 2030. According to the estimation of the World Energy Council, the development of RESs will lead the generation of electricity in the leadership of the solar and wind by 2060. According to the optimistic scenario, the share of electricity generation from wind and PV systems is predicted to be 39% and to be 20% in the pessimistic scenario [22].

Turkey has an important energy bridge between Europe and Asia due to its geopolitical position. Therefore, Turkey has to undertake significant reforms to sustain the current economic growth and to meet the energy demand and security of the industry. In this context, the Government of the Turkish Republic enacted article 6446 law in 2013 considering the Vision 2023 goals and therefore has paved the way for renewable energy investments. According to Vision 2023, it is aimed to promote domestic energy sources in the energy field in Turkey and to increase the share of renewable energy to 30% [27]. Turkey's installed capacity of solar energy was 1,700 MW at the end of 2017. It is aimed to increase this amount to 3,000 MW in 2019 and it is expected to increase the total installed capacity of solar energy to 5,000 MW in 2023 [22]. When Turkey's solar energy potential is considered, this goal seems to be quite realistic.

B. Incentives in Turkey

The law on the Utilization of RESs for the purpose of generating energy, (Law No. 5346) was enacted in 2005 by the Turkish National Parliament, which has led many developments in renewable energy field. However, due to the lack of secondary legislation and relatively low fixed price feed in tariffs, the investments in RESs were limited between 2005 and 2010. However, with the amendments made on RES in December 2010, a higher fixed price feed in tariffs and monetary/non-monetary incentives were introduced for some resources, which mobilized the Renewable Energy market. Especially after the revision of fixed price feed in tariffs, domestic and foreign investors' interest in environmentally friendly energy sources has increased considerably [23].

New Investment Incentive Program in Turkey has been in effect since January 1, 2012 and offers four different types of plans [28]:

1. General Investment Incentive Plan: This plan applies to all types of investments that are not excluded from the investment category program list and meet the specified minimum fixed investment amount. Within this framework, the facilities that generate electricity from RESs can benefit from VAT and customs duty exemption.

2. Regional Investment Incentive Plan: These incentives are allocated on a regional basis in order to eliminate interregional disparities in the country. Minimum investment amounts are determined for different types of investments. Unless otherwise specified for a specific type of project, the minimum investment amount is 1 million Turkish Lira (TL) for regions 1 and 2, and 500,000.00 TL for regions 3, 4, 5 and 6. In addition, an additional 38% labor cost reduction is applied only for the 6th region. Incentive regions are shown in Figure 7.

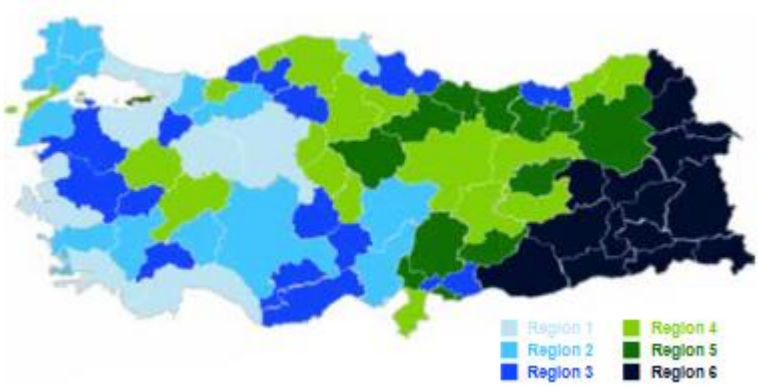

Figure 7. The regions in Turkey according to incentives plan [23]

3. Large-Scale Investment Incentive Plan: The purpose of this program is to increase Turkey's technological capabilities and Research & Development (R&D) capacity.

4. Strategic Investments Incentive Plan: This plan is provided for the production of intermediate and final products with high import dependence (more than 50%). Investments of 50 million TL or more can benefit from this plan.

It is aimed to decrease the energy intensity of Turkey by at least 20% in 2023 compared to 2011. For this purpose, as stated in the 2012-2023 Energy Efficiency Strategy Document of the Ministry of Energy and Natural Resources, it is determined as a strategic objective to expand sustainable environmentally friendly buildings that use RESs [29]. In addition, according to the National Energy Efficiency Action Plan, the cumulative savings to be achieved by 2033 with the reduction of primary energy consumption is $ 30.2 billion, and the effect of some savings is expected to continue until 2040. In Turkey, the Use of RESs for the Purpose of Generating Electrical Energy encouraged by the law provisions has VAT and customs exemptions. In addition, there is government support for the land where the solar field will be constructed. There is also purchase feed in tariffs of government for $ 0.133 per kWh of electricity generated from solar energy [21].

IV. THE SAMPLE COST ANALYSIS OF PV POWER PLANT FOR BİLECİK CITY

In this study, the cost analysis of a PV power plant with 100 kW installed capacity for Bilecik city, which is located in the third region, was carried out. The calculations given below are made approximately in order not to cause complexity by using very fine calculations and by ignoring the maintenance costs. Using the photovoltaic geographic information system of the European Commission, a performance analysis for 100 kW grid connected PV power plant was conducted and the values were given in Table 3 [30].

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Table 3. PV energy generation estimations [30].

Specification	Value
Location [Lat/Lon]:	40.000, 30.000
PV technology	Crystalline silicon
PV installed [kWp]	100 kW
System loss [%]	%10
Slope angle [°]	35°
Azimuth angle [°]	0°
Yearly PV energy production [kWh]	139,000
Yearly in-plane irradiation [kWh/m^2]	1,690

Monthly energy output (kWh) values obtained from fixed tilt angle PV system and average solar radiation per kWh square meter per month (kWh/m²) for Bilecik city are given in Figure 8. In addition, monthly standard deviation values for percentages are given in Table 4 in detail.

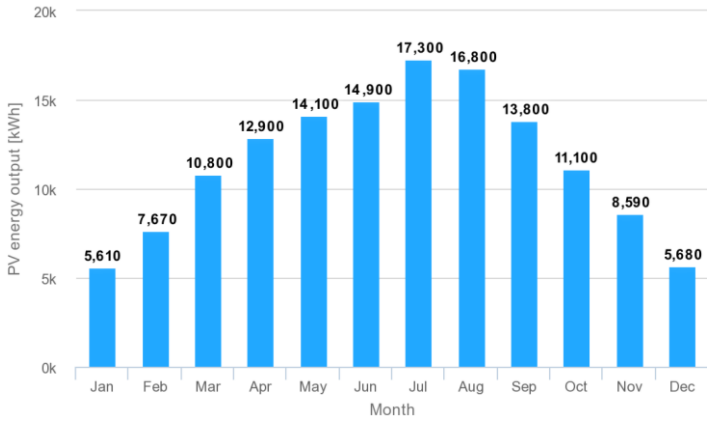

Figure 8. Monthly energy output from fixed tilt angle PV system [30]

Table 4. PV energy generation estimations [30].

Month	Energy production [kWh]	Global irradiation [kWh/m^2]	Standard deviation [kWh]
Jan	5,610	63.4	875
Feb	7,670	87.8	1,490
Mar	10,800	126	574
Apr	12,900	155	1,670
May	14,100	175	1,410
Jun	14,900	187	1,590
Jul	17,300	218	474
Aug	16,800	214	1,060
Sep	13,800	172	1,490
Oct	11,100	133	1,590
Nov	8,590	98.9	1,380
Dec	5,680	63.7	753

In the study conducted by the International Renewable Energy Agency, the total investment costs required for a PV power plant were calculated as $ 4,394/kW in 2010 and $ 1,388/kW in 2017. In 2017 Renewable Energy Resources Areas (RERAs) Solar Power Plant (SPP) auction, the winning company reduced this price to $ 699/kW [31]. With the advancing technology, the cost is expected to decrease further. The total investment cost for a 100 kW PV power plant is calculated based on the current data of $ 699/kW as follows:

$$C_T = P_{PP} \times C_{INV} \rightarrow 100 \times 699 = 69{,}900.00\ \$ \quad (1)$$

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where, C_T is the total investment cost, P_{PP} is the power of PV power plant and C_{INV} is the investment cost per kW. The annual income of the system is calculated as follows by considering $ 0.133/kWh support grant paid in the past for PV energy and 139.000 kWh annual PV energy generation in Bilecik city:

$$I_A = F_S \times E_{PV} \rightarrow 0.133 \times 139{,}000 = 18{,}487.00\ \$ \quad (2)$$

where, I_A is the annual income, F_S is the support grant and E_{PV} is the annual energy of PV. However, the efficiency of PV power plants varies depending on temperature and time. The electrical efficiency obtained from PV power plants decreases due to the ageing of the PV panels. In the literature, it is accepted that PV panels generate 90% of the power stated in the catalogue values during the first 10 years and 80% after 10 years up to 25 years [32]. PV panels continue to generate energy after 25 years, but their efficiency further decreases. Annual income is obtained as follows when considering 90% power efficiency (η) for the first 10 years:

$$I_{A(10Y)} = I_A \times \eta \rightarrow 18{,}487 \times 0.90 = 16{,}639.00\ \$ \quad (3)$$

where, I_A is the annual income for the first 10 years. Accordingly, when considering a 100 kW PV power plant for Bilecik city, the depreciation time for the system is calculated as follows:

$$D_T = C_T / I_{A(10Y)} \rightarrow 69{,}900.00 / 16{,}639.00 = 4.2 \text{ year} \quad (4)$$

where, D_T is the depreciation time. Amendments were made on the prices and durations to be applied for the plants operating in energy generation activities based on RESs through the Official Gazette published on June 21, 2018. The amount and duration of support were changed with the provision of "For the surplus energy generated in electricity generation plants, the retail single-time active energy price of its own subscriber group announced by the Energy Market Regulatory Authority (EMRA) will be implemented for ten years from the date of operation of the facility". According to the changes made, calculations were made according to facility based tariff information and subscriber type to be applied with January 01, 2019 dated provision approved by EMRA. Investment cost depreciation time based on subscriber is given in Table 5. USD exchange was conducted based on Turkey's Central bank data on May 18, 2019 (1 USD =6.06 TL).

Table 5. Investment depreciation time based on subscriber

Subscriber Type	Value (Kurus)	USD Exchange	Income for the first 10 Years (USD) (PV energy(90%): 125.1 kWh)	Annual Income after 10 years (USD) (PV energy(80%): 111.2 kWh)	Depreciation time (Year) (Cost 69.900 USD)
Industry	38.087	0.0629	7,868.79	6,994.48	8.88
Business Firm	41.501	0.0685	8,569.35	7,617.20	8.15
House	27.910	0.0461	5,767.11	5,126.32	12.38
Agricultural irrigation	37.445	0.0618	7,731.18	6,872.16	9.04

50% of the projects that are accepted in accordance with the principles and procedures determined by the Ministry of Agriculture and Forestry for agricultural irrigation are supported by grants. Therefore, the depreciation time calculated for agricultural irrigation is reduced to half.

V. RESULTS

In this study, the studies on solar energy were examined and evaluated in order to determine the cost analysis and depreciation time of the PV power plant for Bilecik city. Moreover, the depreciation time was calculated for industry, business firm, house and agricultural irrigation. According to the calculations, the shortest depreciation time was obtained for business firms while the longest depreciation time was obtained for houses. In addition, it was seen that the deprecation time of agriculture irrigation decreased significantly with the supported projects. On the other hand, while the depreciation time for business firm was 4.2 years before the change in purchase prices made in 2018, it was at least 8.15 years after the change. However, this is a reasonable time for sustainability of investments. The intense interest in the installation of PV power plants and achieving a fast supply market indicate that the incentives are sufficient. Bureaucratic and legal procedures are considered as

the most important obstacles preventing the penetration of solar energy in Turkey in the short term. It is foreseen that if these procedures are accelerated and simplified, investments can be put into practice rapidly.

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