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Research Article

Comparison of Payback Periods of Solar Power Plant in Türkiye and Europe

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ABSTRACT

The importance of energy in the world is increasing day by day. Most of the countries' energy needs are met by fossil fuels. Due to the depletion of fossil fuels, their increasing prices and the damage they cause to the environment, researchers have turned to alternative energy sources. The demand for renewable energy sources as alternative energy has increased significantly in recent years. Solar energy is one of the most popular and widely used energy sources among renewable energy sources all over the world. For this reason, efforts are being made to increase the use of solar energy in Türkiye and European countries. Although the amount of solar radiation in Türkiye is high, it has not reached the expected levels. In this study, the payback periods (PBP) of a 1 MW solar power plant (SPP) connected to the grid between Türkiye and European countries were compared. It is assumed that the compared countries use monocrystalline solar panels with an efficiency of 22.6% at their specific solar radiation values. Additionally, due to the impact of the Russia-Ukraine war on energy prices, the PBP of the SPP was determined based on two scenarios. According to the results, in the first scenario, the highest PBP is in Karaman with 2.75 years, followed by Türkiye with 3.17 years. PBPs in Spain, France and Germany are calculated as 3.6, 5.6 and 5.7 years, respectively. In second scenario (after the Russia-Ukraine war), the highest PBPs were determined as Germany with 2.22 years and France with 3.27 years. PBPs in Spain, Karaman and Türkiye were determined as 2.41, 2.75 and 3.17 years, respectively.

Keywords: *Solar energy, Photovoltaic, Payback period, Solar energy potential*

Güneş Enerjisi Santrallerinin Türkiye ve Avrupa'daki Geri Ödeme Sürelerinin Karşılaştırması

ÖZET

Dünya'da enerjinin önemi her geçen gün artmaktadır. Ülkelerin büyük bir bölümü ihtiyaç duydukları enerji gereksinimini fosil yakıtlar tarafından karşılanmaktadır. Fosil yakıtların tükenecek olması, artan

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fiyatı ve çevreye vermiş olduğu zararlardan dolayı araştırmacılar alternatif enerji kaynaklarına yönelmişlerdir. Yenilenebilir enerji kaynaklarına son yıllarda alternatif enerji olarak talep büyük oranda artmıştır. Güneş enerjisi, yenilenebilir enerji kaynakları arasında en popüler ve tüm dünyada yaygın olarak kullanılan enerji kaynaklarından birisidir. Bu sebeple, Türkiye ve Avrupa ülkelerinde güneş enerjisi kullanımı artırılmaya çalışılmaktadır. Türkiye güneş ışınım miktarı yüksek olmasına rağmen beklenen seviyelere ulaşamamıştır. Bu çalışmada, Türkiye ile Avrupa ülkeleri arasındaki şebekeye bağlı 1 MW'lık bir güneş enerjisi santralinin geri ödeme süreleri karşılaştırılmıştır. Karşılaştırılan ülkeler, kendilerine özgü solar radyasyon değerlerinde %22,6 verimliliğe sahip bir monokristal güneş panellerinin kullanıldığı varsayılmıştır. Ayrıca, Rusya-Ukrayna savaşının enerji fiyatlarına etkisi nedeniyle güneş enerjisi santralinin geri ödeme süresi iki senaryo üzerinden değerlendirilmiştir. Elde edilen sonuçlara göre, birinci senaryoda en yüksek geri ödeme süresi 2,75 yıl ile Karaman'da, ardından 3,17 yıl ile Türkiye gelmektedir. İspanya, Fransa ve Almanya'daki geri ödeme süreleri sırasıyla 3,6, 5,6 ve 5,7 yıl olarak hesaplanmıştır. İkinci senaryoda ise (Rusya-Ukrayna savaşı sonrası), en yüksek geri ödeme süreleri 2,22 yıl ile Almanya ve 3,27 yıl ile Fransa olarak belirlenmiştir. İspanya, Karaman ve Türkiye'de geri ödeme süreleri sırasıyla 2,41, 2,75 ve 3,17 yıl olarak tespit edilmiştir.

Anahtar Kelimeler: *Güneş enerjisi, Fotovoltaik, Geri ödeme süresi, Güneş enerjisi potansiyeli*

I. INTRODUCTION

The improvement of economic and technological conditions in the world and the increasing population have led to a raise in global energy demand. This energy demand is met by fossil fuels known as coal, oil and gas [1]. These resources are utilized to produce the energy needed in many industrial processes. One of the general problems of fossil fuels is that they release carbon dioxide (CO_2) into the environment when burned. Since CO_2 is a greenhouse gas, it is one of the factors that increase global warming. Among fossil fuels, coal has the highest CO_2 producer and natural gas has the lowest CO_2 production potential [2]. Interest in fossil fuels is gradually decreasing due to the risk of depletion, the increase in their prices and the increase in greenhouse gases (GHGs) in the ozone layer.

With the decrease in interest in fossil fuels, renewable energy sources (RES) have begun to be used as alternative energy sources [3]. These resources include solar energy, wind, geothermal, hydroelectricity and bioenergy. RES are defined as energy sources that have very little negative impact on the environment. Driven by the need for alternative energy sources and the decrease of carbon footprint, which is the goal of many countries that comply with the UNFCCC global agreements, renewable energy consumption has been increasing steadily since 1950. According to the REN21 2020 report, it was determined that the share of renewable energy in 2018 was around 11% and fossil fuels was 79.9%. Figure 1 shows the distribution of energy resources in 2018 [4].

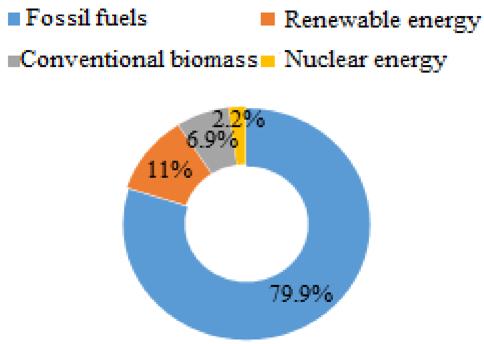

Figure 1. *Estimated Renewable Share of Total Final Energy [4]*

According to the REN21 2020 report, more than 200 GW of new renewable energy generation capacity was installed in 2019, bringing the global total to 2588 GW by the end of the year (Figure 2). Approximately 115 GW of solar PV was added worldwide in 2019. During 2019, 57% of renewable energy capacity additions were solar PV power, followed by wind power (about 60 GW for 30%) and hydropower (about 16 GW for 8%). The remaining 5% of the additions come from bio-energy, geothermal energy and concentrated solar thermal energy (CSE) [4].

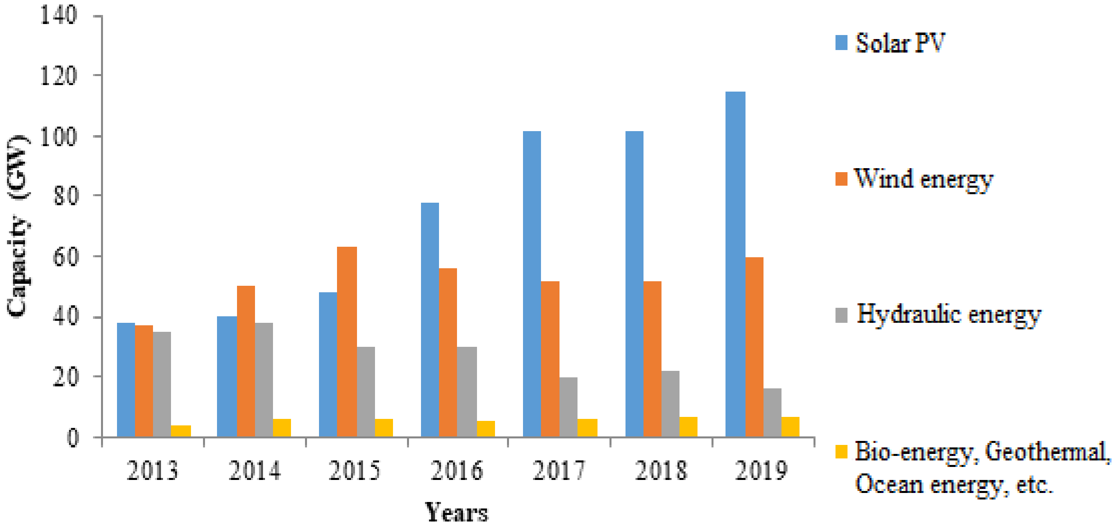

Figure 2. *Annual additions of renewable power capacity, 2013-2019 [4]*

All the advantages of solar energy have led countries, especially energy importers, to turn to solar energy to reduce the import bill in their budgets. For example, in a country like Türkiye, according to the report of TÜRKİYE PETROLLERİ A.O., the ratio of domestic crude oil production to total oil supply was 6.3% in 2019, while this rate became 7.1% in 2020. In other words, Türkiye's dependence on oil imports was 92.9% in 2020. Natural gas consumption amounted to 44.9 billion cubic meters. Net imports of cubic meters in 2020 were approximately 44.4 billion cubic meters [5]. According to Central Bank of the Republic of Türkiye (CBRT) data, Türkiye imported 665 billion 196 million 652 thousand dollars of oil, gas and coal in the 20 years between 2000 and 2019 [6].

The circumstance is no different in the European Union, according to a report in which the European Commission warns about the costs incurred due to the European Union (EU)'s excessive dependence on fossil fuel imports. The Union's energy imports amounted to 331 billion euros in 2018. In 2017 this value was estimated at 266 billion euros, a 26% increase on 2016 (but 34% less than the 400 billion euro peak in 2013). Increasing oil prices accounted for 68% of the total import bill in 2017 with oil, 28% with natural gas and 4% with hard coal [7]. These high figures prompted the EU and Türkiye to turn to solar energy to reduce high energy costs.

According to the report of the International Renewable Energy Agency (IRENA), the EU ranks second in the world after China, and the total capacity of solar photovoltaic energy in the EU reached 152917 MW in 2020. The ratio of solar photovoltaic energy to total electricity consumption in the EU was 6%. Photovoltaic solar energy capacity in Türkiye for 2020 reached 6,668 MW, accounting for 5.9% of the total electricity consumption in Türkiye, where Türkiye ranks sixteenth in the world in terms of solar photovoltaic energy capacity. Table 1 below shows the photovoltaic solar energy capacity and its share in total electricity consumption in the EU and Türkiye [8].

Installing a solar photovoltaic (PV) array is both an environmental and financial decision. Because solar installation is capital intensive, financial arguments often take precedence over environmental factors. Simple Payback Period (SPBP) is an ordinarily stated measure in years of the time between the initial capital outlay on a solar installation and the return on the initial investment. Smets et al.

defined the PBP in solar power plants (SPP), where the PBP is defined in finance as the time required to restore the cost of an investment [9]. The energy PBP in regions with high solar irradiance is significantly shorter than in regions with low irradiance. No matter which PV technology is chosen, the energy PBP is always well below the expected system life, which is usually between 25 and 30 years. Therefore, the energy invested in the PV system is repaid several times throughout the life cycle of the PV system.

Table 1. *Photovoltaic solar energy capacity and its share in total electricity consumption in the EU and Türkiye [8]*

	2018		2019		2020		Total consumption share (2020)
Country or Region	New (MW)	Total (MW)	New (MW)	Total (MW)	New (MW)	Total (MW)	
EU	8147	117530	16599	134129	18788	152917	6.00%
Germany	3000	45158	3889	49047	4736	53783	9.70%
Italy	426	20114	757	20871	729	21600	8.30%
Spain	41	7068	4209	11277	2812	14089	9.00%
UK	313	13073	273	13346	217	13563	4.00%
France	1081	9691	1113	10804	929	11733	2,8%
Netherlands	1697	4608	2569	7177	3036	10213	8.90%
Türkiye	1642	5064	932	5996	672	6668	5.90%

While solar cells were less efficient, it was a correct approach to question the energy return of solar cells. Because the panels were manufactured utilizing electricity obtained from coal, natural gas or nuclear energy, which made solar cells less efficient. Nowadays, solar panels are more efficient and generate more electricity. More efficient production means energy PBPs are reduced to just a few years. In one of the studies conducted in 2018, "Energy payback estimates for rooftop PV systems are 4, 3, 2 and 1 years: 4 years for systems using existing polycrystalline-silicon PV modules, 3 years for existing thin-film modules, 2 years for expected polycrystalline modules and 1 year for expected thin film modules" [10]. With developing technology, solar cells can be made from more efficient materials and production costs can further decrease. With this increased efficiency, PBP will shorten. While the prices of 10 to 100 kWp PV systems in Germany were approximately 14000 EUR/kWp in 1990, at the end of 2020 the price of the same system decreased by 7.4% [11].

SPBP is often evaluated prior to the adoption of solar PV in a residence or business. Although it better reports the value of solar PV electricity from a sustainability perspective, Energy Payback period (EPBP) is rarely utilized to measure the value of an installation [12].

Many studies have been presented before about the PBP in SPPs. Perhaps one of the most important studies conducted recently in Türkiye is a study conducted in 2019 by a group of researchers at Adıyaman University. The results of the study of three identical SPPs in the Adıyaman province of Türkiye, with an installed power of 1025 MW and an installation cost of 1 million USD per SPP, showed that the average annual electricity production was 1696665 kWh. Internal electricity consumption was 10770 kWh. Thus, net electricity production amounted to 1685895 kWh. The average PBP for these SPPs was 5.5 years [13].

In another study conducted by a group of researchers in 2019, the results showed that the PBP of the SPP installed on an area of 20000 m^2 in Aksaray province in Türkiye was 4.5 years, and the profit of the SPP was 501825 USD/year [14].

In another study conducted on the construction of a SPP at Konya Meram Medical Faculty Hospital, the PBP of the SPP was evaluated based on two scenarios in which a 900 kW photovoltaic system was designed. In the first scenario, the circumstance in which there was no support for GHG emission reduction was evaluated and the PBP of the system was found to be 5.1 years. In second scenario, the GHG emission reduction subsidy was accepted as 15 USD per ton of CO_2 and the PBP of the system was determined as 4.8 years [15].

Otovo, a solar platform in Norway, found in a 2019 study that solar PBPs in many Western Europeans have fallen below 10 years and even reached six in some parts of Spain and France. Falling PV panel prices have made solar energy more attractive to consumers in Europe. Otovo has set the system cost at 1800 EUR (2050 USD) per kWp. The study showed that the only country where PBPs fell below six years was France. While this applies to the south and southeast, consumers nationwide can expect PBP between 6 and 7.9 years. While PBPs decrease to 6-6.9 years in central and southern Spain, they can reach up to 10-10.9 years in the north. In Germany, PBP was calculated between 7 and 7.9 years [16].

Based on the literature reviewed, a study comparing the PBP of SPPs in Türkiye and Europe was found. By comparing Türkiye and European countries for the PBPs of SPPs, this study will contribute to knowing the reasons for the delay in the growth of the solar energy sector in Türkiye, even though Türkiye is located in the region with high solar radiation compared to Europe. Additionally, it will contribute to knowing the most important obstacles to the solar energy sector in Türkiye and the reasons for investors' reluctance to invest in SPPs. In this study, it is focused to investigate the PBP of SPPs in Europe and compare it with Türkiye. In addition, it is aimed to evaluate the long-term benefits and costs of electricity production from PV systems and to make recommendations so that this source will provide maximum benefit to the country's economy.

II. SOLAR ENERGY POTENTIAL in TÜRKİYE and EUROPE

A. SOLAR ENERGY POTENTIAL IN TÜRKİYE

Türkiye is located in the Northern Hemisphere, between 36-42 degrees north latitude and 26-45 degrees east longitude. This circumstance has caused the country to be closer to the Equator than to the pole and to be in the temperate zone. Türkiye has a significant solar energy potential due to its geographical location.

According to the Türkiye Solar Energy Potential Atlas (GEPA), the average annual total sunshine duration is 2741 hours and the average annual total radiation value is calculated as 1527.46 kWh/m^2 [20]. Figure 3 shows a map of Türkiye's solar radiation. In Figure 3, the southern regions that benefit from the most solar radiation are shown in light red and dark red, and the northern regions that benefit from the least amount of solar radiation are shown in light blue and dark blue.

Figure 3. *Türkiye's solar energy potential atlas [19]*

Figure 4 shows daily global radiation values for Türkiye on a monthly basis. The global radiation value reaches its highest value in June with 6.57 kWh/m^2-day, and its lowest value in December with 1.59 kWh/m^2-day. The average daily solar radiation for Türkiye on a monthly basis is 4.18 kWh/m^2-day.

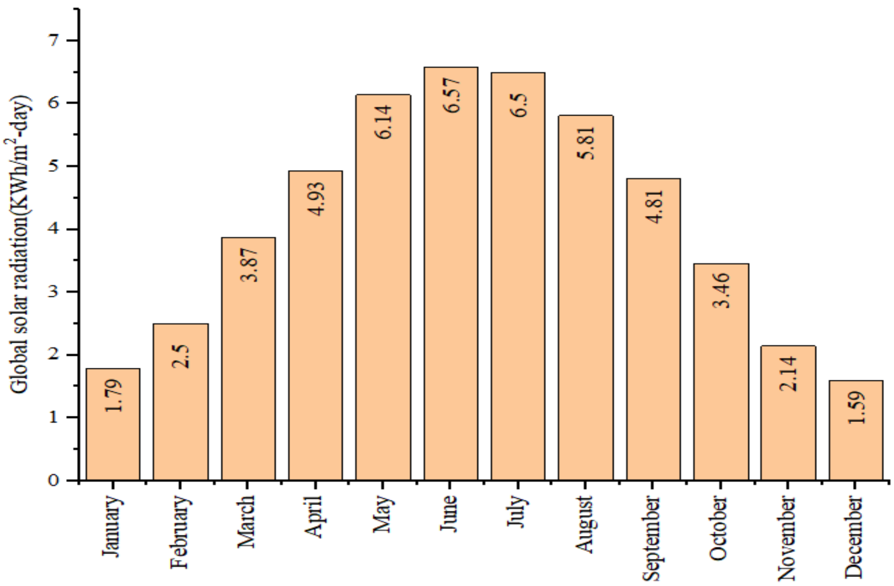

Figure 4. *Türkiye's global radiation values [19]*

Figure 5 shows the sunshine duration on a monthly basis in Türkiye. The highest sunshine duration is in July with 11.31 hours, and the lowest sunshine duration is in December with 3.75 hours. The average daily sunshine duration in Türkiye on a monthly basis is 7.49 hours-day. Considering all these data, it is seen that Türkiye has high solar energy potential.

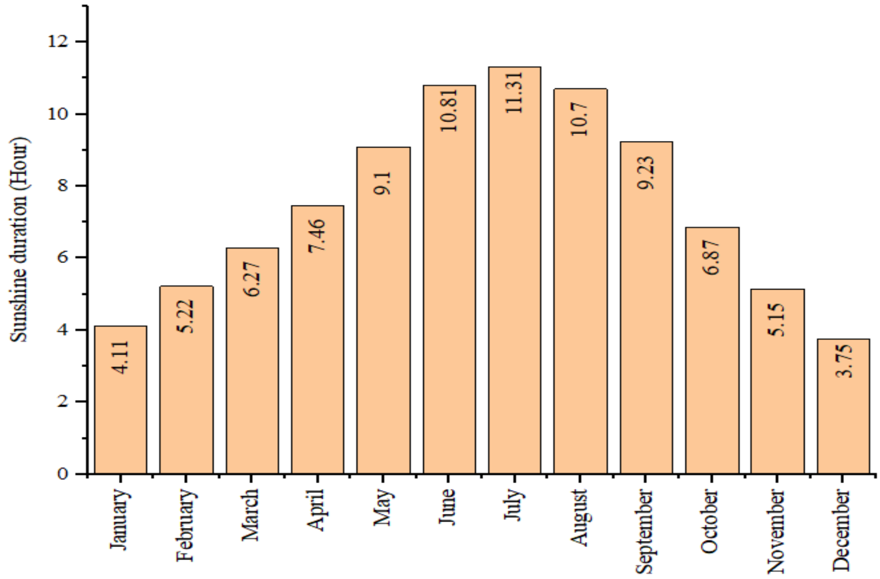

Figure 5. *Türkiye's sunshine duration [19]*

After examining the solar energy potential map of Türkiye, it was determined that Karaman has the highest average annual total radiation value among Turkish cities. Karaman's average annual total solar radiation is 1661 kWh/m^2 and the average annual total sunshine duration is 3009 hours. Figure 6 and Figure 7 show Karaman's global radiation values and sunshine durations.

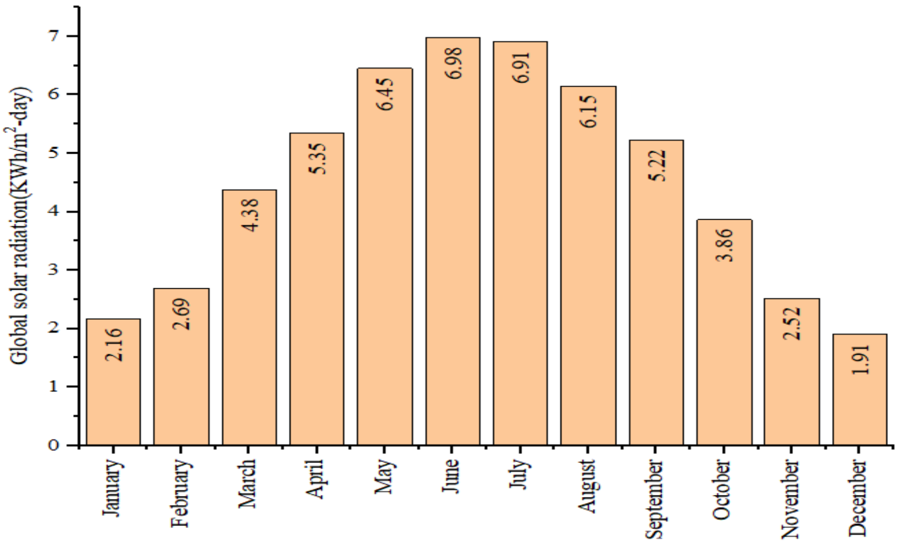

Figure 6. *Karaman's global radiation values [19]*

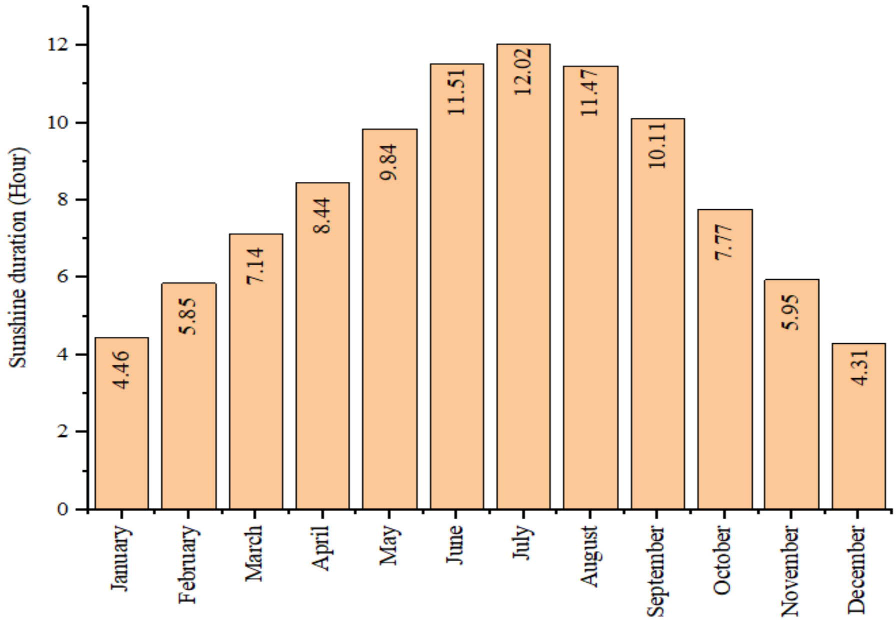

Figure 7. *Karaman's sunshine durations [19]*

However, among Turkish cities, Hakkari city has the highest sunshine durations. Hakkari's average annual total sunshine duration is 3512 hours and its average annual total solar radiation is 1612 kWh/m^2. Figure 8 and Figure 9 show Hakkari's global radiation values and sunshine durations.

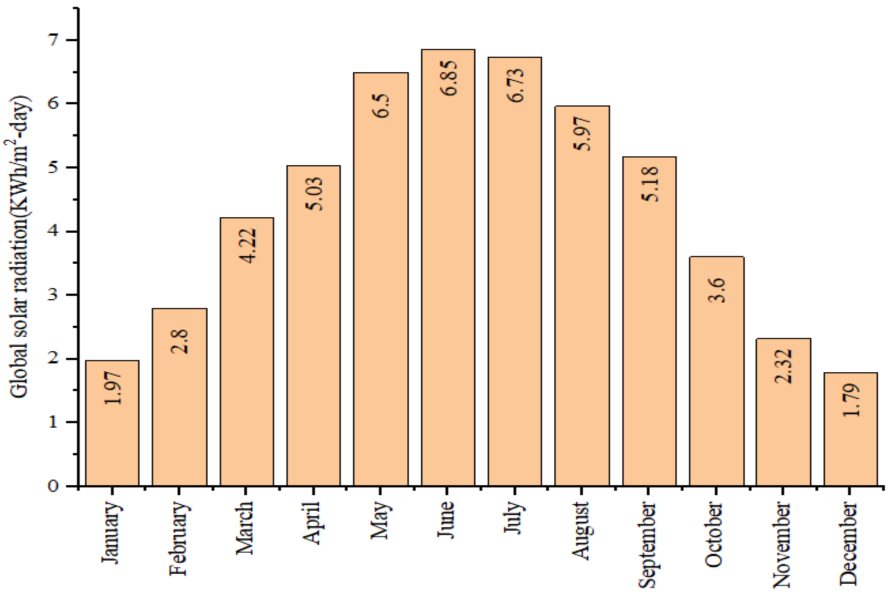

Figure 8. *Hakkari's global radiation values [19]*

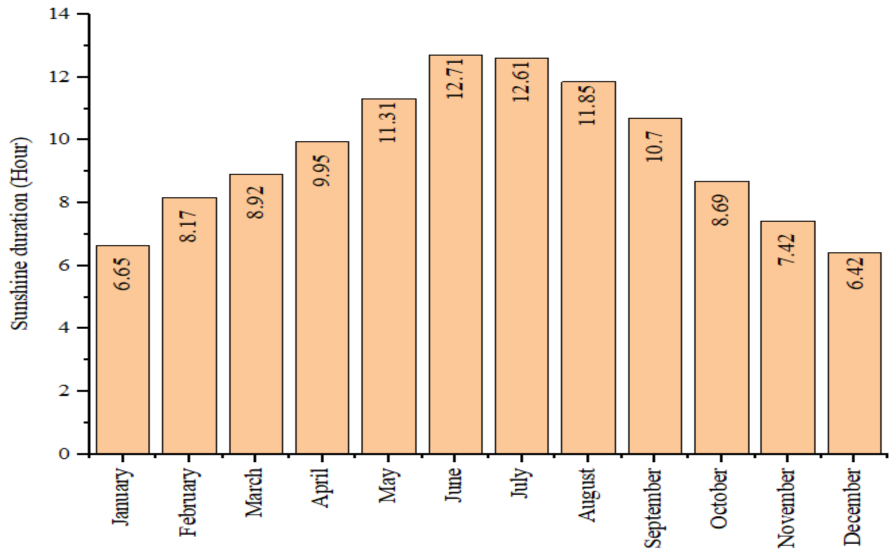

Figure 9. *Hakkari's sunshine durations [19]*

Due to the higher solar energy potential of cities in the south of Türkiye compared to northern cities, cities in the south are expected to have lower PBPs for SPPs.

B. SOLAR ENERGY POTENTIAL IN EUROPE

Global radiation values vary depending on geographical location and are highest in regions close to the equator. Therefore, annual average global radiation values vary between European regions, with southern regions having much better values than northern regions. The average annual total radiation value in Central Europe is approximately 1100 kWh/m^2 [18].

Figure 10 shows the Solar Energy Potential map of Europe. The average annual total sunshine duration in Europe during the reference period (1983-2012) is 2335 hours [21].

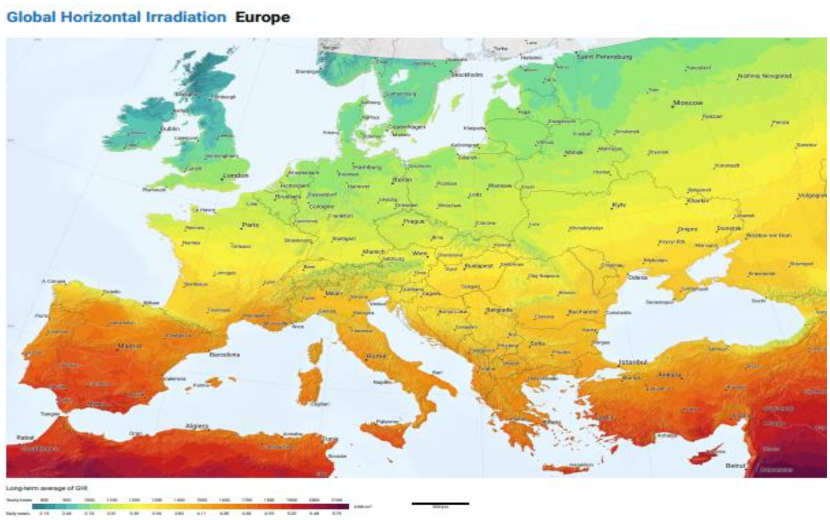

Figure 10. *Solar energy potential map of Europe [22]*

B. 1. Solar Energy Potential in Germany

Germany is located in the middle of Europe. Although Germany ranks first in Europe in terms of installed solar PV capacity, Germany's solar energy potential is considered average. Germany's average annual total solar radiation is 1086 kWh/m^2. Figure 11 shows a map of Germany's solar radiation for the period 1991-2020. Figure 11 shows that the average annual total solar radiation for Germany for the period 1991-2020 varies between 975 and 1259 kWh/m^2 [23]. Since the southern regions are closer to the equator, the average annual total radiation value increases from north to south.

Figure 12 shows the average monthly global radiation values for Germany. The global radiation value reaches its highest value in June with 165 kWh/m^2-month, and its lowest solar radiation in December with 17 kWh/m^2-month. Germany's average monthly radiation value is 90.5 kWh/m^2-month [23].

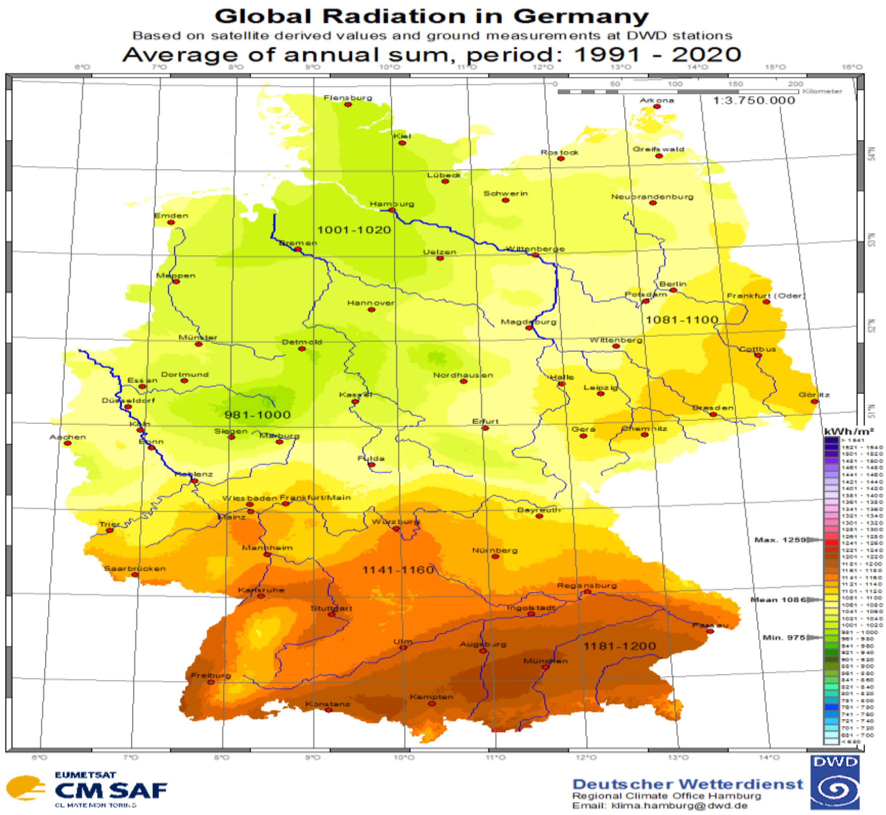

Figure 11. *Solar energy potential atlas of Germany [23]*

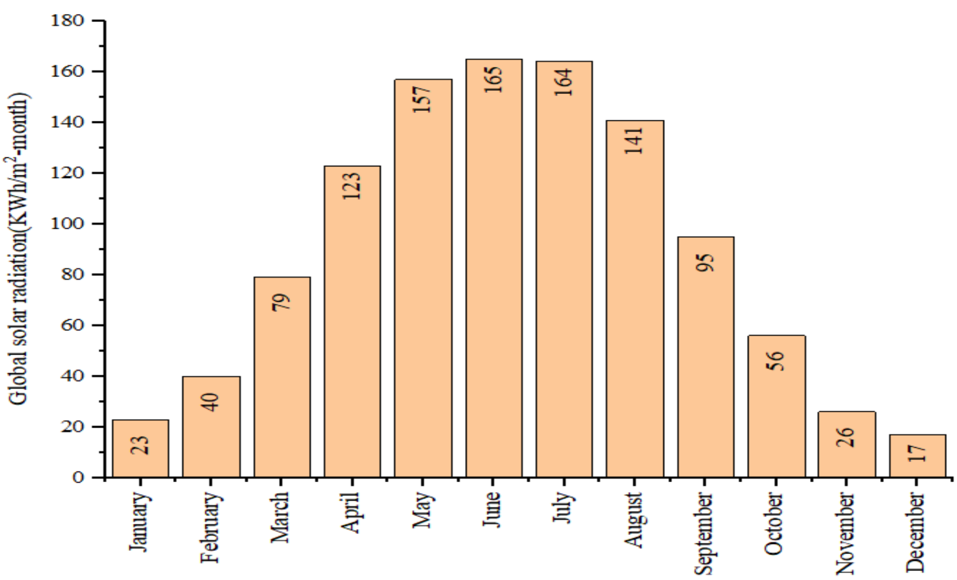

Figure 12. *Germany's global solar radiation values [23]*

Germany's total annual sunshine hours for 2021 are 1631 hours. Figure 13 shows the sunshine duration on a monthly basis in Germany. The highest sunshine duration is in June with 8.57 hours, and the lowest sunshine duration is in January with 0.97 hours. For 2021, the daily sunshine duration in Germany on a monthly basis is 4.47 hours-day [24].

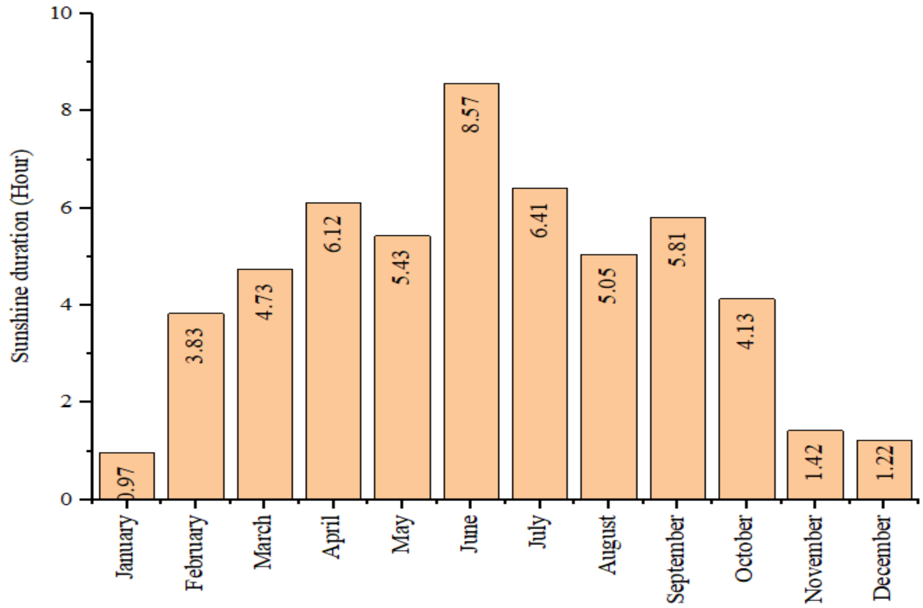

Figure 13. *Germany's sunshine durations*

B. 2. Solar Energy Potential in Spain

Spain is located in southwestern Europe. Spain's average annual total solar radiation is 1600 kWh/m^2. Average solar radiation in the southern regions of Spain varies from 1.5 kWh/m^2 in winter to 7 kWh/m^2 in summer [25]. Figure 14 shows a map of Spain's solar radiation for the period 2001-2011.

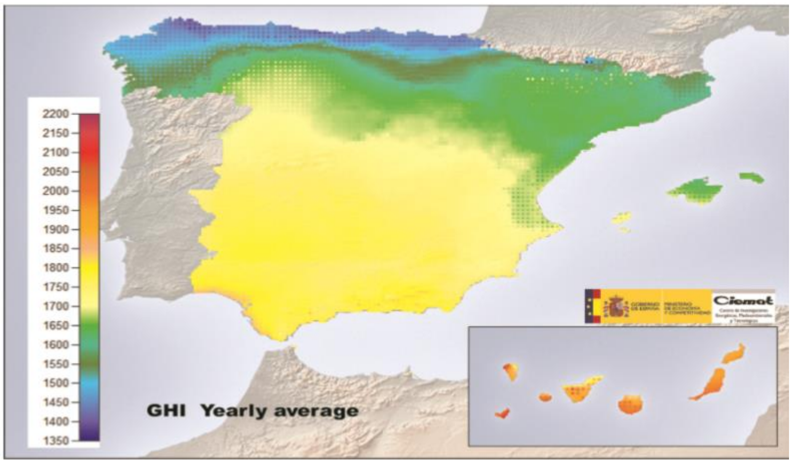

Figure 14. *Solar radiation map of Spain for the period 2001-2011 [26]*

Among the Spanish cities, Huelva has the highest sunshine hours. Huelva's average annual total sunshine duration is 2998 hours [27].

B. 3. Solar Energy Potential in the UK

The United Kingdom is located in Western Europe. The UK's average annual total solar radiation is 949 kWh/m^2, approximately 2.5–3.1 kWh/m^2-day [28]. Although solar potential in the UK is poor, it ranks fourth in Europe in terms of installed PV capacity. Among the regions of the United Kingdom, the "Eastbourne" region has the highest sunshine hours. Eastbourne's average annual total sunshine duration is 1888 hours [27].

B. 4. Solar Energy Potential in France

France is located in Western Europe. The average annual total radiation value of France is 1274.1 kWh/m^2. Figure 15 shows the average monthly global solar radiations for France. The global radiation solar radiation reaches its highest value in July with 183.9 kWh/m^2-month, and its lowest solar radiation in December with 24.9 kWh/m^2-month. France's average monthly radiation value is 90.5 kWh/m^2-month [29].

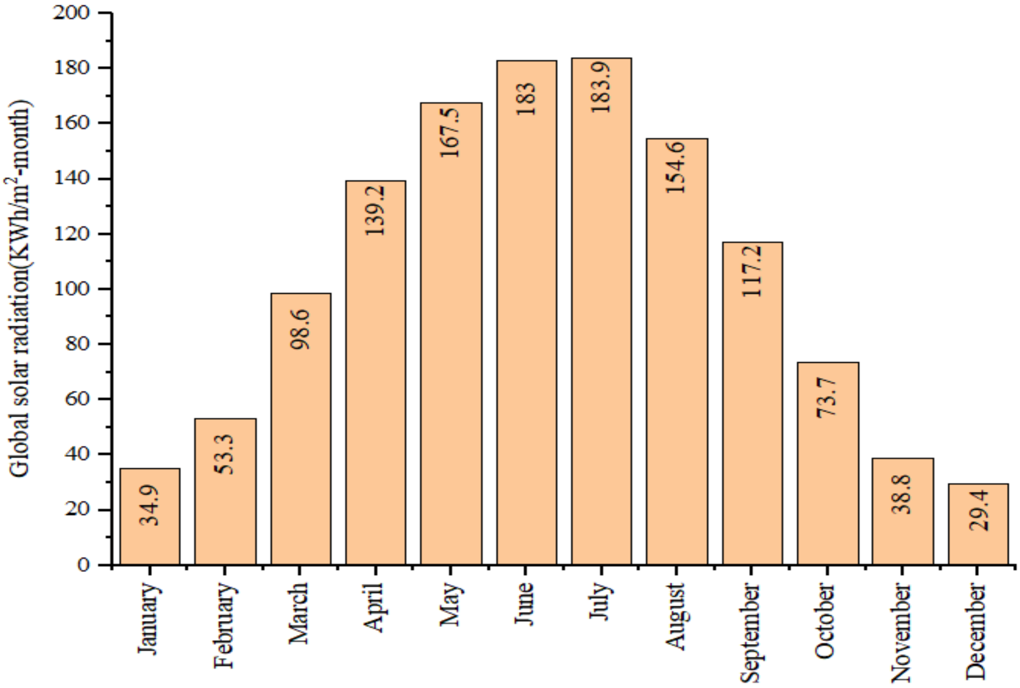

Figure 15. *Global solar radiation values of France*

The highest periods of sunshine occur in the Marseille region in southeastern France. Marseille's average annual total sunshine duration is 2858 hours [27].

B. 5. Solar Energy Potential in the Netherlands

The Netherlands is located in the northwest of Europe. The average annual total solar radiation of the Netherlands is 1,000 kWh/m^2 as shown in Figure 16 [9]. The average annual total sunshine duration is between 1400-1700 hours [30].

Figure 16. *Distribution of solar radiation in the Netherlands [30]*

Despite the weak potential of solar energy in the Netherlands, it ranks sixth in terms of installed photovoltaic energy capacity.

B. 6. Solar Energy Potential in Italy

Italy is located in southern Europe. Italy ranks second in Europe in terms of installed photovoltaic capacity. Italy's average annual total radiation value is 1533 kWh/m^2. Figure 17 shows the radiation between 2014 and 2017, ranging from a minimum of 990 kWh/m^2 in the northern alpine region to a maximum of 1900 kWh/m^2 in the south [31].

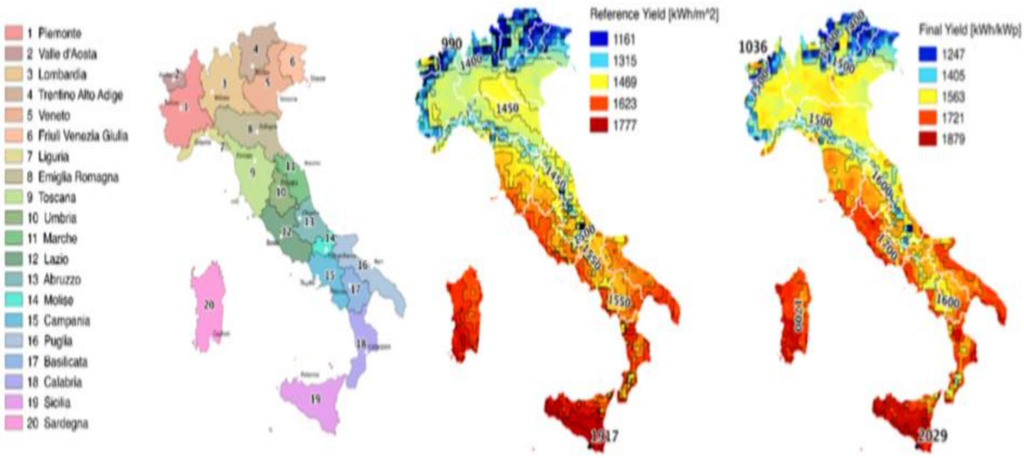

Figure 17. *Average values of satellite-derived radiation and power estimation between 2014 and 2017 [31]*

Among the regions of Italy, the "Ustica Island" region has the highest sunbathing hours. Ustica Island's average annual total sunshine duration is 2660 hours [27].

III. PAYBACK PERIOD FOR TÜRKİYE'S 1 MW PHOTOVOLTAIC SOLAR ENERGY POWER PLANT (SPP)

Türkiye is located in Southeastern Europe and Southwest Asia. Türkiye's surface area is 783562 km² and its population is approximately 85.04 million. The average temperature in Türkiye during the period 1981-2010 was 13.5 °C [32]. Türkiye's average annual total radiation value is 1527.46 kWh/m^2.

A. MAKING ENERGY CALCULATIONS TO BE OBTAINED FROM SPP

In this section, the energy obtained from 1 MW photovoltaic power plant connected to a ground-mounted grid in Türkiye is calculated. It will be assumed that solar panels are used. The solar panels are monocrystalline PERC panels. Table 2 shows the most significant electrical and mechanical data of panels.

Table 2. *The most significant electrical and mechanical data of solar panels [33].*

STC	LXR–400-72M
Nominal Maximum	400 W
Open CIRCUIT Voltage (V_{oc})	47.95 V
Module Efficiency	22.60%
Cell Type	Mono-crystalline 157x157 mm
Cell Arrangement	72 (6x12)
Dimensions	1960 x 992 x 40 mm

It is possible to calculate the energy to be obtained from the solar power system as follows:

$$E = A \times R \times H \times PR \tag{1}$$

Here:
E: Energy (kWh)
A: Total Area of Panel (m²)
R: Solar Panel Efficiency (%)
H: Average Solar Radiation in Curved Panels (kWh/m^2)
PR: Performance Rate

The number of solar panels required for a LEXRON-400-72M PERC type 1MW power plant is 2500 (2500 x 400W = 1MW). The area of one panel (1.960 x 0.992) is 1.944 m^2, thus the total area of solar panels (2500 x 1.944 m^2) is 4860 m^2. The efficiency of the solar panel is 22.6% as shown in Table 2. The performance ratio will be calculated as 0.83. The average solar radiation of Karaman province are shown in Figure 6. Türkiye's average solar radiation values are shown in Figure 4.

Based on Figure 4 and using Equation 1, the results showed that the average amount of electrical energy obtained from the Turkish system in a year is 1392.49 MWh. The average amount of electrical energy to be obtained from the Turkish power plant on a monthly basis is shown in Figure 18.

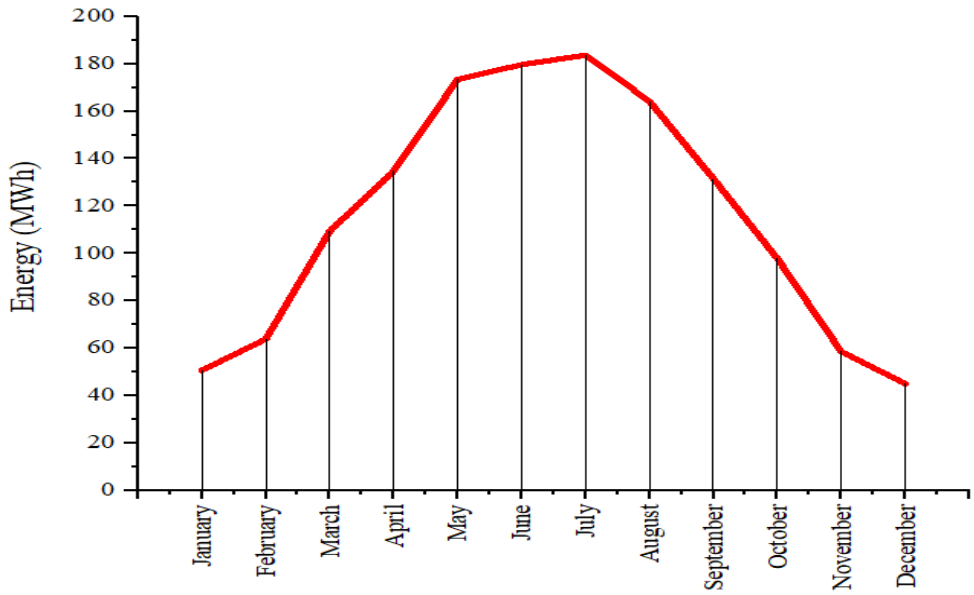

Figure 18. *Average amounts of electrical energy to be obtained from Türkiye's 1 MW Solar System*

According to EPİAŞ Transparency Platform until 17.10.2022, the arithmetic average of market clearing prices was 0.13635 USD/kWh [34]. Therefore, Annual Profit (1392491.02 kWh x 0.13635 USD/kWh) will be calculated as 189866.26 USD.

B. INITIAL INVESTMENT COST OF PHOTOVOLTAIC SYSTEM

The equipment and prices required for 1 MW SPP installation were predetermined in one of the studies conducted in Van province of Türkiye in 2021, as shown in Table 3. The equipment and fittings listed in Table 3 consist of elements that should generally be included in all 1 MW SPP investments.

Table 3. *Equipment and prices required for 1 MW SPP installation [35].*

<table>
<tr><th>Equipment</th><th>Explanation</th><th>Amount (USD)</th></tr>
<tr><td>Photovoltaic Solar Panel (Monocrystalline silicon)</td><td>2,500 units 400 Watt, 47.95 V LEXRON brand, Monocrystalline 72 cells</td><td>300000</td></tr>
<tr><td>Inverter</td><td>200 units, 5 kW, GoodWe brand</td><td>45000</td></tr>
<tr><td>Control and Monitoring System (SCADA)</td><td>4 pieces</td><td rowspan="9">200000</td></tr>
<tr><td>Fixed Mounting Structure</td><td>1 set</td></tr>
<tr><td>DC Wiring</td><td>21000 m</td></tr>
<tr><td>AC Wiring</td><td>3750 m</td></tr>
<tr><td>Collection Board</td><td>1 set</td></tr>
<tr><td>Wire Fence and Barbed Wire</td><td>750 m</td></tr>
<tr><td>Landscaping and Earthworks</td><td>1500 m^3</td></tr>
<tr><td>Lightning Rod and Grounding Systems (Active lightning rod head, 6 m pole, 2×50 mm^2 copper down conductor, 3 m pipe)</td><td>1 set</td></tr>
</table>

Video Security and Camera Systems (8 cameras (Outdoor, analog HD, NVR recorder (4 TB HDD), 24″ screen, cabling)	1 set	
Cable Tray Systems	800 kg	
Solar cable (red and blue)	1x6 mm^2 PVI1-F solar cable 6000 m	
5×16 mm^2 NYY	400 m	
3×35 / 16 mm^2 XLPE cable (36 KV)	3000 m	
35 and 16 XLPE cable header	426 and 142 units	
MV+LV external panel	70 pieces	
Modular cubicle with 100×10 mm^2 copper busbar	1 piece	
1250 A current and voltage measurement modular switchgear with switch disconnector	1 piece	
Transformer protection modular switchgear with 1250 breakers	1 piece	
Input-output modular cubicle with 1250 A breaker	1 piece	
Concrete Kiosk	5 m, with roof	
10 kVA dry type transformer	71 pieces	
4x63 A TMŞ+KAKR (300 mA)	104 pieces	
3×63 A NH fuse and carrier	74 pieces	
0.28 kV, 100 kA B+C surge arrester (AG)	71 pieces	
MV surge arrester	1 team	
Grounding stake (65x65x7) 1.5 m long	225 pieces	
Galvanized strip conductor (30×3.5 mm)	600 m	
1×16 mm^2 NYAF ground wire	500 m	
Photovoltaic panel construction	1 system	
Field lighting equipment	1 team	
Total		545000

Due to the difficulty of accessing Türkiye’s land prices, land prices will not be included in this study. Other initial investment cost parameters are shown in Table 4.

Table 4. *Other initial investment cost parameters [35].*

Cost Parameters	Amount (USD)
Preparing project and feasibility reports	2000
Construction, transportation, assembly and installation costs of transportation roads to the power plant site and within the power plant	10000
Company formation cost	4000
Administrative building and social area construction	5000
Expenses related to administrative processes (license fee, project approval and acceptance procedures, zoning and EIA decision)	3000
Total	24000

The initial investment cost of a 1 MW Türkiye power plant will be calculated as 569000 USD.

C. ANNUAL OPERATION AND MAINTENANCE COST

Annual labor costs, solar power insurance fees, distribution system usage fees, commercial, technical and company activity-related transaction costs and other expenses will not be included in maintenance and operation calculations. It is possible to calculate the annual operation and maintenance costs of PV plants as follows:

$$M_t = 0{,}01 \times I_o \quad (2)$$

Here**;**
M_t**:** Annual operating and maintenance costs of PV plants.
I_o**:** Initial investment for PV plants.

Thus, the annual operation and maintenance costs of the Turkish power plant are expected to reach 5690 USD.
It is assumed that these costs will increase by 3% every year to balance the annual inflation rate and changes in exchange rates [35].

D. TÜRKİYE'S PAYBACK PERIOD

It is possible to calculate the PBP of PV plants as follows:

$$PBP \frac{investment\ amount}{average\ annual\ net\ profit} \quad (3)$$

After making the financial calculations shown in Table 5, it was determined that the investment PBP of Türkiye's 1 MW power plant was 3.17 years.

Table 5. *Türkiye's Investment Payback Period.*

Years	Benefit (USD)	Cost (USD)	Net profit (USD)
0	0	569000	-569000
1	189866.26	5690	-384.823.74
2	189866.26	5860.7	-200818.18
3	189866.26	6036.52	-16988.44
4	**189866.26**	**6217.62**	**166660.2**
5	189866.26	6404.15	350122.31
6	189866.26	6596.27	533392.3

E. KARAMAN'S PAYBACK PERIOD

Karaman is a province located in the south of Türkiye. The surface area of the province is 8,678 km^2. Karaman has a suitable climate for solar energy installation as it is characterized by mild temperatures in summer and winter. The average highest outdoor temperature of Karaman in the summer months is 31 °C and the average lowest outdoor temperature in the winter months is 3 °C [36]. The average solar radiation values of Karaman province are shown in Figure 6. Karaman has the highest average annual total solar radiation value in Türkiye with 1661 kWh/m^2. For this reason, Karaman province is considered suitable for installing 1 MW SPP.

Based on Figure 6 and after making calculations using Equation 1, the results showed that the average amount of electrical energy obtained from the Karaman system in a year is 1516803.02 kWh. The average amounts of electrical energy to be obtained from the Karaman power plant on a monthly basis are shown in Figure 19.

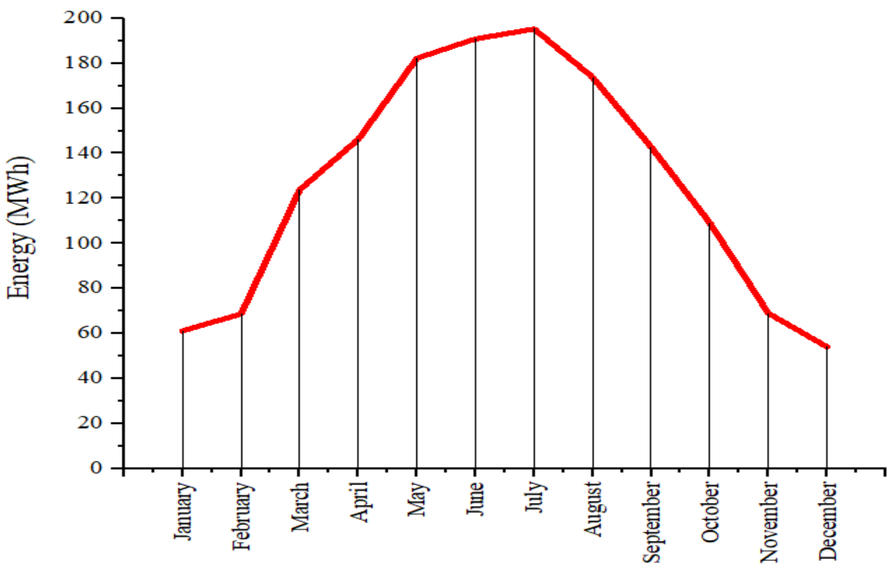

Figure 19. *Average amounts of electrical energy to be obtained from Karaman's 1 MW Solar System*

Annual Profit (1516803.02 kWh x 0.13635 USD/kWh) will be calculated as 206816.09 USD. The initial investment cost of the 1 MW Karaman power plant will be calculated as 569000 USD and the annual operation and maintenance costs will be 5690 USD. After making the financial calculations shown in Table 5, it was determined that the investment PBP of the Karaman 1 MW power plant was 2.75 years.

Table 6. *Karaman's Investment Payback Period.*

Years	Benefit (USD)	Cost (USD)	Net Profit (USD)
0	0	569000	-569000
1	206816.09	5690	-367873.91
2	206816.09	5860.7	-166918.52
3	**206816.09**	**6036.52**	**33861.05**
4	206816.09	6217.62	234459.52
5	206816.09	6404.15	434871.46
6	206816.09	6596.27	637091.28

IV. PAYBACK PERIOD FOR EUROPE'S 1 MW PHOTOVOLTAIC SOLAR POWER PLANT

In this section, a fixed set of factors will be assumed to compare PBPs between Türkiye and Europe, including the use of solar panels with a system size of 1 MW and a Performance ratio of 0.83. A number of constant factors also include operating and maintenance costs, which increase by 3% annually.

A. GERMANY'S PAYBACK PERIOD

From Figure 12, which shows the average values of solar radiation on a monthly basis in Germany, and using Equation 1, it was found that the average amount of electrical energy obtained from the German system in a year is 990.04 MWh. Figure 20 shows the average amount of electrical energy to be obtained from Germany's 1 MW Solar System on a monthly basis. The highest average amount of electrical energy is in June with 150.42 MWh, and the lowest average electrical energy generation is in December with 15.49 MWh.

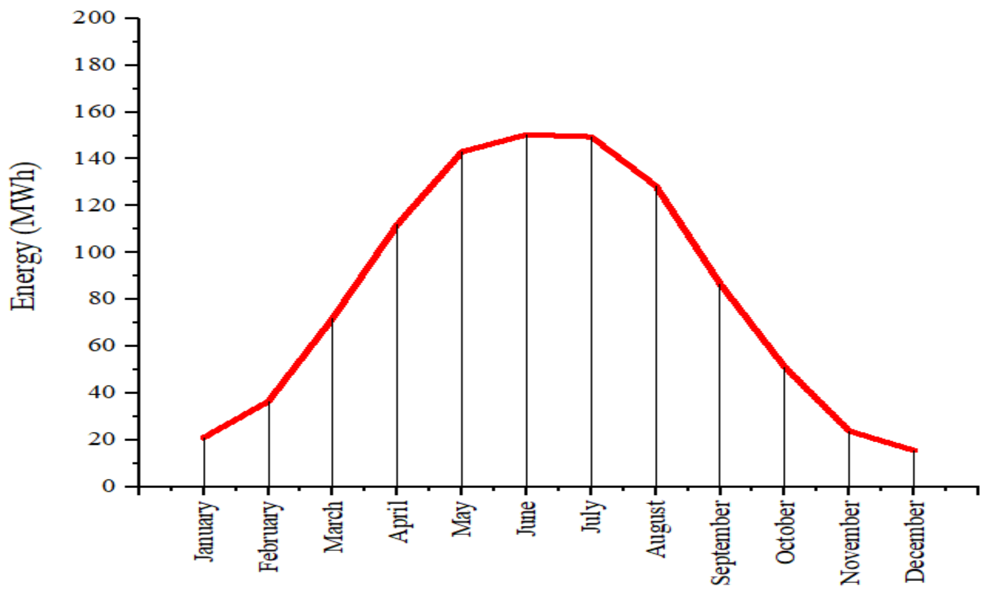

Figure 20. *Average amounts of electrical energy to be obtained from Germany's 1 MW Solar System*

Germany became Europe's largest natural gas consumer, consuming 8.6 billion cubic feet of natural gas daily in 2019. Germany's largest natural gas exporters are Russia, the Netherlands and Norway. Germany has no liquefied natural gas (LNG) terminals, but is well connected to the rest of Europe by natural gas pipelines. Germany imports natural gas from Russia via the Nord Stream pipeline and the Yamal-Europe pipeline [37]. The contribution of gas to electricity generation in Germany in 2021 was approximately 15% [38]. On February 24, 2022, the Russia-Ukraine war broke out, causing a huge increase in gas prices, which in turn caused electricity prices to rise in Europe. According to market clearing prices between 01/01/2021-28/02/2022 in Germany, the average electricity price on a monthly basis was 103.96 EUR/MWh, while the average electricity prices on a monthly basis between 01/03/2022 - 30/09/2022 were 277.08 EUR/MWh [39]. Therefore, two prices will be included to calculate Germany's PBPs during this study. Therefore, the annual profit in the period before the Russian-Ukrainian war (990.04 MWhx103.96 EUR/MWh) will be calculated as 102,924.53 EUR, and the annual profit in the period after the Russian-Ukrainian war will be calculated as (990.04 MWh x 277.08 EUR/MWh) 277320.21 EUR.

According to a report published by the Fraunhofer Institute for Solar Energy Systems in February 2022, the average initial investment cost in Germany for 2020 was 570 EUR/KWp [17]. Thus, the average initial investment cost of a 1 MW PV plant will be 570000 EUR. Using Equation 2, the annual operation and maintenance cost will be determined as 5700 EUR.

After making the financial calculations shown in Table 7 and Table 8, it was determined that the pre-war investment PBP for a 1 MW power plant was 5.7 years, and after the war PBP was 2.22 years.

Table 7. *Pre-war Germany's Investment Payback Period.*

Years	Benefit (EUR)	Cost (EUR)	Net Profit (EUR)
0	0	570000	-570000
1	102924.53	5700	-472775.47
2	102924.53	5871	-375721.94
3	102924.53	6047.13	-278844.54
4	102924.53	6228.54	-182148.56
5	102924.53	6415.40	-85639.43
6	**102924.53**	**6607.86**	**10677.24**
7	102924.53	6806.10	106795.67
8	102924.53	7010.28	202709.92
9	102924.53	7220.59	298624.17
10	102924.53	7437.21	394111.49

Table 8. *Germany's Investment Payback Period after the war.*

Years	Benefit (EUR)	Cost (EUR)	Net Profit (EUR)
0	0	570000	-570000
1	277320.21	5700	-298379.79
2	277320.21	5871	-26930.58
3	**277320.21**	**6047.13**	**244342.5**
4	277320.21	6228.54	515434.17

B. FRANCE'S PAYBACK PERIOD

From Figure 15, which shows the average values of solar radiation on a monthly basis in France, and using Equation 1, it was found that the average amount of electrical energy obtained from the French system in a year is 1161.06 MWh. Figure 21 shows the average amount of electrical energy to be obtained from France's 1 MW Solar System on a monthly basis. The highest average amount of electrical energy is in July with 167.19 MWh, and the lowest average electrical energy generation is in December with 26.80 MWh.

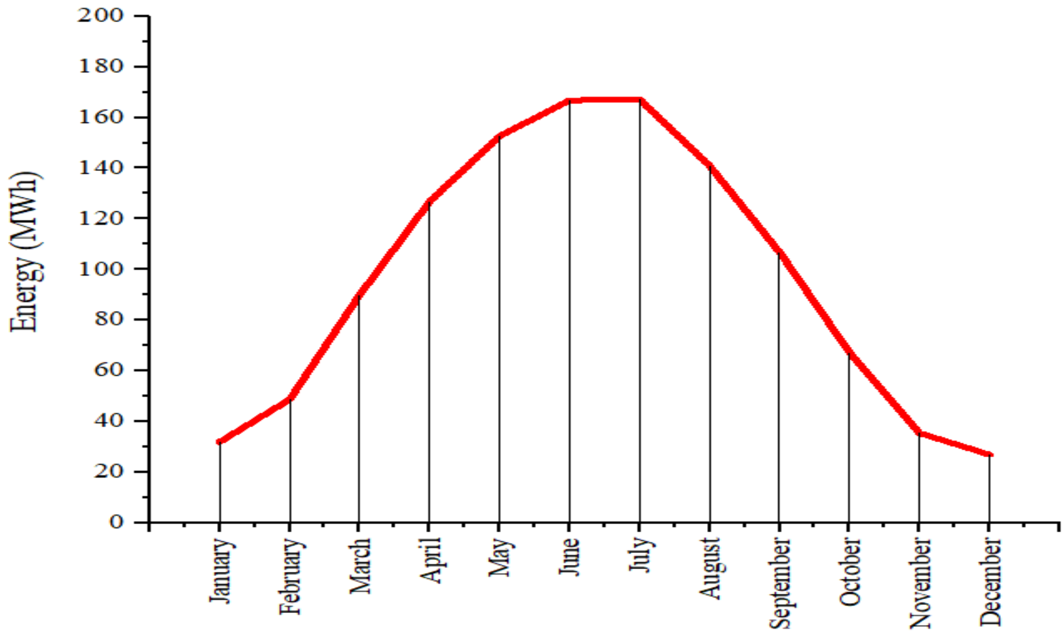

Figure 21. *Average amounts of electrical energy to be obtained from France's 1 MW Solar System*

France's domestic natural gas production is very low. As a result, France imported almost all of its natural gas resources, amounting to approximately 1.4 trillion cubic feet in 2015. France imports natural gas from the Netherlands, Norway and Russia through various cross-border pipelines [40]. Therefore, after the Russian-Ukrainian war in France, electricity prices rose dramatically, as in Germany. According to market clearing prices between 01/01/2021 - 28/02/2022 in France, the average electricity price on a monthly basis was 121.62 EUR/MWh, while the average electricity prices on a monthly basis between 01/03/2022 -22/10/2022 were 305.13 EUR/MWh [39]. Therefore, the annual profit in the period before the Russian-Ukrainian war will be calculated as (1161.06 MWh x 121.62 EUR/MWh) 141208.5 EUR, and the annual profit in the period after the Russian-Ukrainian war will be calculated as (1161.06 MWh x 305.13 EUR/MWh) 354275.21 EUR.

According to a report published by the Fraunhofer Institute for Solar Energy Systems in February 2022, the average initial investment cost in France for 2020 was 768 EUR/kWp [17]. Thus, the average initial investment cost of a 1 MW PV plant will be 768000 EUR. Using Equation 2, the annual operation and maintenance cost will be determined as 7680 EUR.

After making the financial calculations shown in Table 9 and Table 10, it was determined that the pre-war investment PBP for a 1 MW power plant was 5.6 years, and after the war PBP was 2.27 years.

Table 9. *Pre-war France's Investment Payback Period.*

Years	Benefit (EUR)	Cost (EUR)	Net Profit (EUR)
0	0	768000	-768000
1	141208.5	7680	-634471.5
2	141208.5	7910.4	-501173.4
3	141208.5	8147.71	-368112.61
4	141208.5	8392.14	-235296.25
5	141208.5	8643.90	-102731.65
6	**141208.5**	**8903.22**	**29573.63**
7	141208.5	9170.32	161611.81
8	141208.5	9445.43	293968.88
9	141208.5	9728.79	425448.59
10	141208.5	10020.65	556636.44

Table 10. *Investment Payback Period of France after the war.*

Years	Benefit (EUR)	Cost (EUR)	Net Profit (EUR)
0	0	768000	-768000
1	354275.21	7680	-421404.79
2	354275.21	7910.4	-75039.98
3	**354275.21**	**8147.71**	**271087.52**
4	354275.21	8392.14	616970.59

C. SPAIN'S PAYBACK PERIOD

Spain has the highest solar energy potential in Europe, with an annual average total radiation value of 1600 kWh/m^2. Using Equation 1, the average electrical energy production from a 1 MW capacity photovoltaic power plant in Spain is expected to be 1458.62 MWh/year.

Spain, Europe's seventh largest consumer of natural gas, burned nearly 1 trillion cubic feet in 2016. Natural gas accounted for approximately 19% of Spain's total energy consumption in 2016. Spain produces almost no natural gas and has negligible reserves, forcing the country to import almost all natural gas to meet demand. Spain imports natural gas from Algeria through two subsea pipelines. In 2016, pipeline imports from Algeria constituted 42% of total natural gas imports. Almost half of Spain's natural gas imports in 2016 (466 Billion cubic feet) were liquefied natural gas (LNG). Spain's three largest LNG suppliers were Algeria, Qatar and Nigeria. In 2016, Algeria supplied approximately 52% of Spain's total natural gas imports [41]. Natural gas accounts for almost a third of electricity production [42]. Due to Spain's lack of dependence on Russian gas, its electrical energy markets were not as significantly affected as those in France and Germany after the outbreak of the Russian-Ukrainian war. In Spain, the average electricity price on a monthly basis according to market clearing prices between 01/01/2021 - 28/02/2022 was 124.25 EUR/MWh, while the average electricity prices on a monthly basis between 01/03/2022 and 31/09/2022 were 181.77 EUR/MWh [43]. Therefore, the annual profit in the period before the Russian-Ukrainian war will be calculated as (1458.62 MWh x 124.25 EUR/MWh) 181233.79 EUR, and the annual profit in the period after the Russian-Ukrainian war will be calculated as (1458.62 MWh x 181.77 EUR/MWh) 265133.74 EUR.

According to a report published by the Fraunhofer Institute for Solar Energy Systems in February 2022, the average initial investment cost in Spain for 2020 was 620 EUR/KWp [17]. Thus, the average initial investment cost of a 1 MW PV plant will be 620000 EUR. Using Equation 2, the annual operation and maintenance cost will be determined as 6200 EUR.

After making the financial calculations shown in Table 11 and Table 12, it was determined that the pre-war investment PBP for a 1 MW power plant was 3.6 years, and the post-war PBP was 2.41 years.

Table 11. *Pre-war Spain's Investment Payback Period*

Years	Benefit (EUR)	Cost (EUR)	Net Profit (EUR)
0	0	620000	-620000
1	181233.79	6200	-444966.21
2	181233.79	6386	-270118.42
3	181233.79	6577.58	-95462.21
4	**181233.79**	**6774.91**	**85996.67**
5	181233.79	6978.16	260252.3
6	181233.79	7187.50	434298.59

Table 12. *Investment Payback Period of Spain after the war.*

Years	Benefit (EUR)	Cost (EUR)	Net Profit (EUR)
0	0	620000	-620000
1	265133.74	6200	-361066.26
2	265133.74	6386	-102318.52
3	**265133.74**	**6577.58**	**156237.64**
4	265133.74	6774.91	414596.47

V. CONCLUSION

In this study, a fixed number of factors were assumed to compare the PBPs of solar systems in Türkiye and Europe, including the use of solar panels with a system size of 1 MW and a Performance ratio of 0.83. A number of constant factors also include operating and maintenance costs, which increase by 3% annually. In addition, energy prices in Europe increased significantly due to the Russia-Ukraine war that broke out in early 2022, and as a result, the PBPs of photovoltaic power plants were calculated over two periods: before and after the Russia-Ukraine war. At the time of this study, the arithmetic average of market clearing prices in Türkiye after Russia-Ukraine until 17-10-2022 was 0.13635 USD/kWh. As for the period before the Russia-Ukraine war, according to the annex I table of the Law No. 5346 on the Use of Renewable Energy Resources for the Purpose of Electrical Energy Production, if licensed electricity production facilities based on solar energy come into operation until 30/06/2021, for the electrical energy produced from these power plants. A purchase guarantee of 0.133 USD/kWh is provided within the scope of the RES Support Mechanism (YEKDEM) for 10 years [35]. For this reason, the PBP for Türkiye is calculated over one period.

The results in the first period, before the Russia-Ukraine war, found the highest repayment periods in Karaman province with 2.75 years, followed by 3.17 years in Türkiye. In Spain, France and Germany, the repayment periods are 3.6, 5.6 and 5.7 years, respectively. The results of the second period after the Russia-Ukraine war showed that the highest repayment periods were determined in Germany with 2.22 years, followed by France with 3.27 years. In Spain, Karaman province and Türkiye, the PBPs are 2.41, 2.75 and 3.17 years, respectively.

VI. REFERENCES

[1] A. Ustaoglu, H. Torlaklı, A. Ergün, E. Erdoğmuş and M. E. Akay, "Advanced exergy analysis of an integrated solid waste fueled cogeneration system based on organic Rankine Cycle for different working fluids", Energy Conversion and Management, vol. 270, pp. 116294, 2022.

[2] A. H. A. Al-Waeli, H. A. Kazem, M. T. Chaicha and K. Sopian, "Photovoltaic/thermal (PV/T) Systems: Principles, design, and applications", Springer Nature, Switzerland, pp. 1-3, 2019.

[3] A. Ergün and H. Eyinç, "Performance assessment of novel photovoltaic thermal system using nanoparticle in phase change material", International Journal of Numerical Methods for Heat & Fluid Flow, vol. 29, no. 4, pp. 1490-1505, 2019.

[4] REN21, "Renewables 2020 Global Status Report", Paris, 2020.

[5] TÜRKİYE PETROLLERİ A.O., "Petrol ve Doğal Gaz Sektör Raporu", Ankara, 2020.

[6] Duvar Gazete, "665 Milyar Doları Nasıl Yaktık?", https://www.gazeteduvar.com.tr/665-milyar-dolari-nasil-yaktik-makale-1535547, 2022.

[7] EUROPEAN COMMISSION, "Energy prices and costs in Europe", Brussels, 2019.

[8] International Renewable Energy Agency (IRENA), "Renewable capacity statistics 2021", Abu Dhabi, 2021.

[9] A. H. Smets, K. Jäger, O. Isabella, R. A. Swaaij and M. Zeman, "Solar energy the physics and engineering of photovoltaic conversion, technologies and systems", UIT Berlin, Germany, pp. 726-729, 2015.

[10] Internet: Clean Technica, "Solar Power Energy Payback Time Is Now Super Short - CleanTechnica", https://cleantechnica.com/2018/03/25/solar-power-energy-payback-time-now-super-short/, 2022.

[11] Fraunhofer Institute for Solar Energy Systems and PSE Projects GmbH, "Photovoltaics Report", Freiburg, 2021.

[12] W. Kessler, "Comparing energy payback and simple payback period for solar photovoltaic systems", E3S Web of Conferences**.**, vol. 22, pp.80, 2017.

[13] F. Lüle, T. Koyuncu and A. Kaya, "Payback periods of three identical solar photovoltaic power plants", Engineering Sciences, vol. 14, no. 4, pp. 200–206, 2019.

[14] T. Taner and A. S. Dalkilic, "A feasibility study of solar energy-techno economic analysis from Aksaray city, Turkey", Journal of Thermal Engineering, vol. 3, no. 5, pp. 1–1, 2017.

[15] R. Büyükzeren, H. B. Altintaş, K. Martin, and A. Kahraman, "Binalardaki fotovoltaik uygulamasının teknik, çevresel ve ekonomik incelenmesi: meram tıp fakültesi hastanesi örneği", EMO Bilimsel Dergi, vol. 5, no. 10, pp. 9–14, 2015.

[16] T. Tsvetomira, "Solar Payback Times in Europe on the Slide - Otovo", https://renewablesnow.com/news/solar-payback-times-in-europe-on-the-slide-otovo-644921/, 2022.

[17] Fraunhofer Institute for Solar Energy Systems and ISE, "Photovoltaics Report", Freiburg, 2022.

[18] Wild-Scholten, D. and Schottler, M., "Solar as an environmental product. Thin-film modules. Production processes and their environmental assessment", Netherlands, 2009

[19] Enerji İşleri Genel Müdürlüğü, "GEPA", https://gepa.enerji.Gov.tr/MyCalculator/Default. Aspx, 2022.

[20] T.C. Enerji ve Tabii Kaynaklar Bakanlığı, "Güneş - T.C. Enerji ve Tabii Kaynaklar Bakanlığı", https://enerji.gov.tr/bilgi-merkezi-enerji-gunes 2022.

[21] Copernicus Climate Change Service (C3S), "Sunshine duration and clouds", https://climate.copernicus.eu/ESOTC/2019/sunshine-duration-and-clouds, 2022.

[22] Global Solar Atlas, "Solar resours map", https://globalsolaratlas.info/download/europe-and-central-asia, 2022.

[23] Deutscher Wetterdienst DWD, "Global radiation (Mean 30-year monthly and annual sums)", https://www.dwd.de/EN/ourservices/solarenergy/maps_globalradiation_mvs.html#buehneTop, 2022.

[24] RU-GELD.DE, "Sunshine in Germany: the number of sunny days, hours of sunshine quantity in Germany by year, season, month, and also by federated state", https://ru-geld.de/en/country/weather-and-climate/sunshine.html, 2022.

[25] F. G: Montoya, M. J. Aguilera and F. Manzano-Agugliaro, "Renewable energy production in Spain: A review", Renewable and Sustainable Energy Reviews, vol. 33, pp. 509–531, 2014.

[26] J. Polo, "Solar global horizontal and direct normal irradiation maps in Spain derived from geostationary satellites", Journal of Atmospheric and Solar-Terrestrial Physics, vol. 130, no. 131, pp. 81–88, 2015.

[27] Current Results, "Average sunshine a year in Europe", https://www.Currentresults.com/Weather/Spain/annual-days-of-sunshine.php (2022).

[28] R. R. Urs, Z. Ali, M. Marzband, K. Saleem, B. Mohammadi-Ivatloo and A. Anvari-Moghaddam, "A technical assessment on photovoltaic power generation under varying weather profile – Northumbria university pilot", 2020 IEEE 29th International Symposium on Industrial Electronics (ISIE), pp. 811–815, 2020.

[29] A. Kalyanpur, M. Mercadier and P. Blanc, "Gisement solaire en France : caractérisation de la ressource énergétique, profil de répartition et volatilité", Environnement & Technique, vol. 331, pp. 54–59, 2017.

[30] Y. B. Hinssen and W. H. Knap, "Comparison of pyranometric and pyrheliometric methods for the determination of sunshine duration", Journal of Atmospheric and Oceanic Technology, vol. 24, no. 5, pp. 835–846, 2007.

[31] M. Pierro, D. Moser, R. Perez and C. Cornaro, "The value of PV power forecast and the paradox of the “single pricing” scheme: The Italian case study", Energies, vol. 13, no. 15, pp. 3945 2020.

[32] Çevresel Etki Değerlendirmesi İzin ve Denetım Genel Müdürlüğü, "Çevresel göstergeler", https://webdosya.csb.gov.tr/db/ced/icerikler/cevresel_gostergeler_-2021tr-rev-20220622105837.pdf, 2022.

[33] ACS Enerji ve Teknoloji Ltd Sti, "LEXRON-72M Data Sheet", https://www.acsenerji.com/, 2022.

[34] EPİAŞ Şeffaflık Platformu, "Piyasa takas fiyatı ", https://seffaflik.epias.com.tr/transparency/piyasalar/gop/ptf.xhtml (2022).

[35] M. Yalılı, "Lisanslı fotovoltaik güneş enerji santrali yatırımının finansal analizi: Van ili örneği", Bitlis Eren Üniversitesi Fen Bilimleri Dergisi, vol.10, no. 3, pp. 1055–1074, 2021.

[36] Weather Spark, "Karaman iklimi, aylık hava durumu, ortalama sıcaklığı (Türkiye)", https://tr.weatherspark.com/y/97718/Karaman-Türkiye-Ortalama-Hava-Durumu-Yıl-Boyunca, 2022.

[37] U.S. Energy Information Administration (EIA), "Energy sector in Germany", https://www.eia.gov/international/analysis/country/DEU.

[38] Statistisches Bundesamt, "Gross electricity production in Germany", https://www.destatis.de/EN/Themes/Economic-SectorsEnterprises/Energy/Production/Tables/gross-electricity-production.html (2022).

[39] NORD POOL, "DAY-AHEAD PRICES", https://www.nordpoolgroup.com/en/Market-data1/Dayahead/Area-Prices/de-lu/monthly/?view=table, 2022.

[40] U. S. Energy Information Administration (EIA), "Energy sector in France", https://www.eia.gov/international/analysis/country/FRA, 2022.

[41] U. S. Energy Information Administration (EIA), "Energy sector in Spain", https://www.eia.gov/international/analysis/country/ESP, 2022.

[42] International Energy Agency (IEA), "Spain natural gas security policy", https://www.iea.org/articles/spain-natural-gas-security-policy, 2022.

[43] The nominated electricity market operator (NEMO), "Monthly report on the development of the electricity market", https://www.omie.es/en/publications?page=0, 2022.