REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF INDUSTRIAL ENGINEERING

FEASIBILITY, SIMULATION AND SELECTION OF ROOFTOP SOLAR POWER PLANT ALTERNATIVES

SELİN BÜYÜKANT
MASTER OF SCIENCE

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ADANA 2021

I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

[Signature]

Selin BÜYÜKANT

ABSTRACT

FEASIBILITY, SIMULATION AND SELECTION OF ROOFTOP SOLAR POWER PLANT ALTERNATIVES

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Haziran 2021, 80 pages

The energy needs with the development of science and technology in the world and Turkey is increasing day by day. To meet country requirements; it has become inevitable to seek alternative sources in energy production, to follow technical and economic developments closely, to sustain and carry out developments in the field of energy. Today, renewable energy sources have become very important and studies in this area are gaining momentum. Among the renewable energy sources, the share of solar energy in electricity production has an important place.

In this study, a solar power plant was installed on an industrial roof operating in the organized industrial zone. The system components to be used have been determined. With the PV*SOL simulation program, simulations were made for 4 different options consisting of different brands of panels and inverters. With the data obtained as a result of the simulation, the feasibility study of a factory with consumption and how many years the system would pay itself were calculated. AHP-VIKOR integrated approach was used to evaluate the feasibility and simulation results. First of all, the criteria weights were determined by the AHP method, and then a concession solution was reached by sorting with the VIKOR method. As a result of the comparisons made between 4 different options consisting of different brands of panels and inverters, the optimal option was decided.

Keywords: Solar, Energy, Renewable Energy, PV*SOL, Simulation, Feasibility, AHP, VIKOR

ÖZET

ÇATI ÜZERİ GÜNEŞ ENERJİSİ SANTRALİ ALTERNATİFLERİNİN FİZİBİLİTE, SİMÜLASYON VE SEÇİMİ

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Dünyada ve Türkiye'de bilim ve teknolojinin gelişmesiyle birlikte enerji ihtiyacı her geçen gün artmaktadır. Ülke gereksinimlerini karşılamak için; enerji üretiminde alternatif kaynaklar aramak, teknik ve ekonomik gelişmeleri yakından takip etmek, enerji alanındaki gelişmeleri sürdürmek ve yürütmek kaçınılmaz hale gelmiştir. Günümüzde yenilenebilir enerji kaynakları oldukça önemli bir konuma gelmekte ve bu alandaki çalışmalar hız kazanmaktadır. Yenilenebilir enerji kaynakları arasında güneş enerjisinin elektrik üretimindeki payı önemli bir yer tutmaktadır.

Bu çalışmada organize sanayi bölgesinde faaliyet gösteren bir sanayi çatısı üzerine güneş enerjisi santrali kurulumu yapılmıştır. Kullanılması gereken sistem bileşenleri belirlenmiştir. PV*SOL simülasyon programı ile farklı marka panel ve invertörden oluşan dört farklı opsiyon için simülasyon yapılmıştır. Simülasyon sonucunda elde edilen verilerle tüketimi olan bir fabrikanın fizibilite çalışması ve sistemin kendisini kaç yılda amorti edeceği hesaplanmıştır. Fizibilite ve simülasyon sonucu elde edilen sonuçların değerlendirilmesi için AHP-VIKOR bütünleşik yaklaşımı ile kullanılmıştır. Öncelikle kriter ağırlıkları AHP yöntemi ile belirlenmiş, daha sonra VIKOR yöntemi ile sıralama yapılarak uzlaşık bir çözüme ulaşılmıştır. Farklı marka panel ve invertörden oluşan dört farklı opsiyon arasında yapılan karşılaştırmalar sonucunda optimal opsiyona karar verilmiştir.

Anahtar Kelimeler: Güneş, Enerji, Yenilenebilir Enerji, PV*SOL, Simülasyon, Fizibilite, AHP, VIKOR

To my mother, father, sisters and husband who make my life important

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NOMENCLATURE

AC	: Alternating Current
AHP	: Analytical Hierarchy Process
CO2	: Carbon Dioxide
DC	: Direct Current
EJ	: Exajoule
EMRA	: Energy Market Regulatory Authority
EMOC	: Energy Markets Operating Corporation
MENR	: Ministry of Energy and Natural Resources
SEPA	: Solar Energy Potential Atlas
GW	: Gigawatt
IRENA	: International Renewable Energy Agency
kg	: Kilogram
kWh	: Kilowatt-hour
MPPT	: Maximum Power Point Tracking
MW	: Megawatt
$^{\circ}C$	: Centigrade Degree
kWh	: Kilowatt-hour
OPEC	: Organization of the Petroleum Exporting Countries
PV	: Photovoltaic
R&D	: Research and Development
SPP	: Solar Power Plant
STC	: Standard Test Conditions
TEDC	: Turkish Electricity Distribution Corporation
TETC	: Turkish Electricity Transmission Corporation
TL	: Turkish Lira
VAT	: Value-Added Tax

VIKOR	: Vise Kriterijumska Optimizacija I Kompromisno Resenje
AHP	: Analytic Hierarchy Process
V	: Volt
W	: Watt
A	: Current
PID	: Potential Induced Degradation
Hz	: Hertz

1. INTRODUCTION

It is difficult to give a precise definition of energy. In its simplest definition, energy makes it possible for everything that happens around us to occur. In other words, energy is the ability of materials to do work. Energy is used in many areas of our lives. It is the most essential element necessary for the realization of many activities such as heating, transportation, production, lighting, health, technology, and communication etc. The welfare, competitiveness, and development levels of countries are measured by the energy they have. (EDX,2019)

Energy appears in many forms in our daily life. Energy used in all areas of life and there are various types such as kinetic energy, mechanical energy, wave energy, chemical energy, nuclear energy, electrical energy, thermal, geothermal, biomass, solar, wind. Energy is transformed into different forms with appropriate processes. The total amount of energy is always conserved. (İnalı, 2020)

In Turkey and the whole World, the energy demand is increasing each passing day with the development of science and technology. To meet the country's requirements; it has become inevitable to search for alternative sources in energy production, to follow technical and economic developments closely, to maintain and carry out developments in the field of energy. The most important problem encountered in energy is the supply and demand problem. The world population is growing rapidly and it is now 7.8 billion. All these people will need energy, which will increase the global energy demand. Besides, energy consumption per capita is related to the standard of living of a country. (EDX,2019)

Energy resources are classified according to their use and recyclability. According to usage, they are divided into renewable energy and non-renewable energy resources. On the other hand, they are divided into primary and secondary energy sources according to their convertibility.

Non-renewable energy sources are unchanged, limited, and non-continuous energy sources in nature. Fossil fuels such as oil, natural gas, and coal can be cited as examples of this energy source. Fossil fuels are formed as a result of chemical transformations of animal and plant wastes for years. The biggest challenge facing the human being is that the energy produced depends heavily on fossil fuels. Fossil fuels are consumed faster in nature than they are produced by the photosynthetic process. Oil and gas reserves are being depleted rapidly and extracting the remaining reserves is technologically more difficult. (Koç, A., Yağlı, Koç, Y. & Uğurlu,2018) On the other hand, renewable energy resources refer to resources that can be renewed over time and available for a long time. Solar, wind, geothermal, biomass, hydroelectric can be cited as examples of this energy source. (İnalı, 2020)

When looked at energy production and consumption in the world, it is seen that especially renewable energy is growing with rapid acceleration. Renewable energy, with investments in wind and solar energy, accounted for 40% of the growth in primary energy in 2019. The largest source of energy generation is coal, although it has dropped for the fourth time in the last six years. Coal accounts for more than 36% of global power. OPEC oil production has experienced the largest decline since 2009. Oil prices have fallen. This is 2 million barrels / day. With the increasing supply of natural gas, natural gas was produced at a record level (54 billion cubic meters). The share of renewable energy in electricity generation was 10.4% higher than nuclear energy for the first time. (British Petroleum,2020)

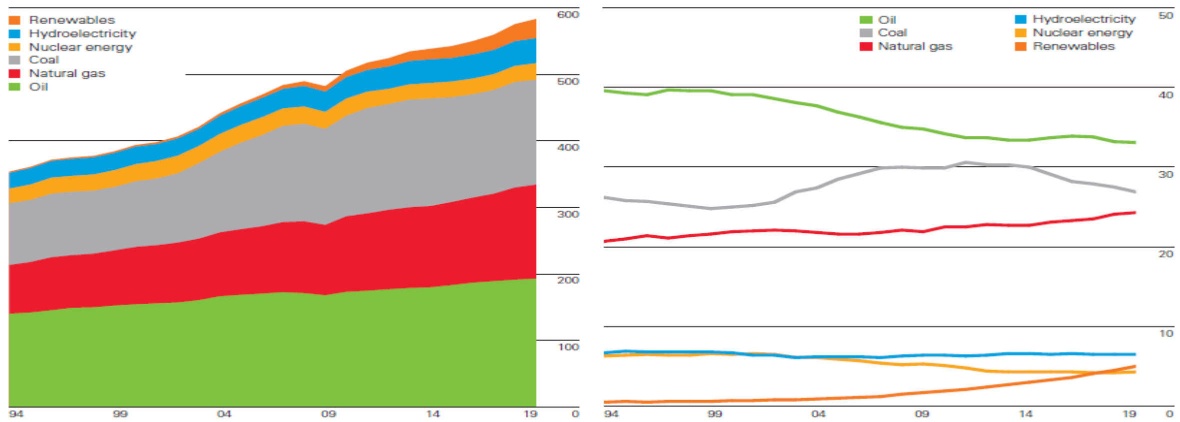


Figure 1. 1 World consumption (EJ) and Shares of global primary energy (%) (British Petroleum,2020)

When Figure 1.1 is examined, it is seen that primary energy consumption has increased by less than half in 2019 compared to 2018. Increases in renewable energy (3.2 EJ) and natural gas (2.8 EJ) provided the growth. Petroleum has the largest share in primary energy with 33.1%. Despite the decline in coal consumption, it still has a second share with 27.0%. As can be seen in Figure

1.1, renewable energy (5%), and natural gas (24.2%) showed the greatest increase. Hydroelectric remained stable at 6%. (British Petroleum,2020)

At the end of 2020, the global renewable energy generation capacity increased by 261 GW from last year to a total of 2,799 GW. Hydroelectric is the highest renewable energy source with an installed power of 1,211 GW. Wind energy has reached 733 GW and solar energy has reached 714 GW. These were followed by 127 GW of bioenergy, 14 GW of geothermal power and renewable energy sources. Compared to 2019 and 2020, solar energy has led the industry with an increase of 22% (127 GW) in the world. This was followed by wind energy with an increase of 18% (111 GW). (IRENA,2021)

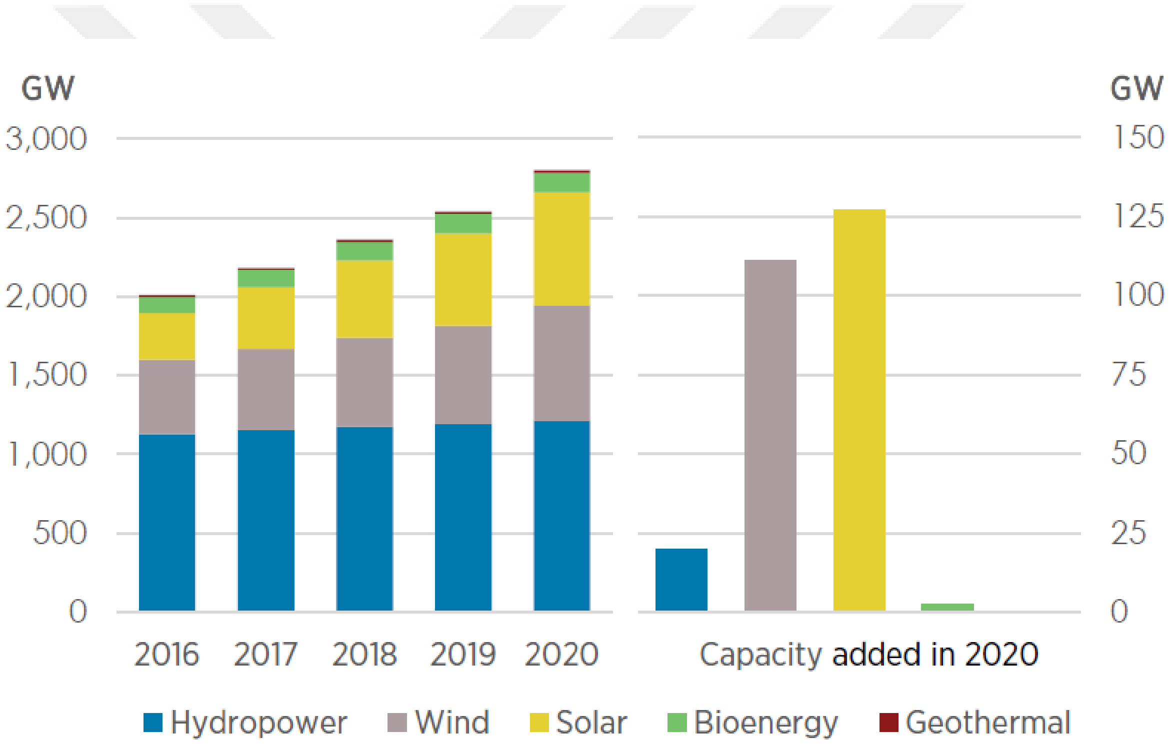


Figure 1. 2 Renewable capacity highlights (IRENA,2021)

The energy sector in Turkey for the past twenty years is seen in the restructuring of the sector. As a result of the work done, it has been largely successful. These studies also contribute to Turkey's economy. Turkey's energy demand is increasing day by day. Growth in the energy sector will also reduce foreign dependency. However, imports of fossil resources, especially natural gas, have increased to meet the rapidly increasing electricity demand. It has become sensitive to constantly changing prices in international markets. The cost of imported fuel spent for energy resources constitutes a large part of our current account deficit. Closing this deficit is the main policy goal, and the importance to be given to renewable energy has been emphasized by taking place in the "2019-2023 Strategic Plan" prepared by the Ministry of Energy and Natural Resources. (SHURA,2020a)

Turkey's total installed capacity in 2021 reached 97,376.5 MW of capacity. In January 2021, the total installed power reached 94,801 MW. (Hakyemez,2021) At the end of April, it was observed that solar power plants reached 7,065.4 MW, wind power plants reached 9,484.9 MW, hydroelectric power plants reached 31,345.30 MW, and natural gas power plants reached 25,715.7 MW installed power. (TETC,2021)

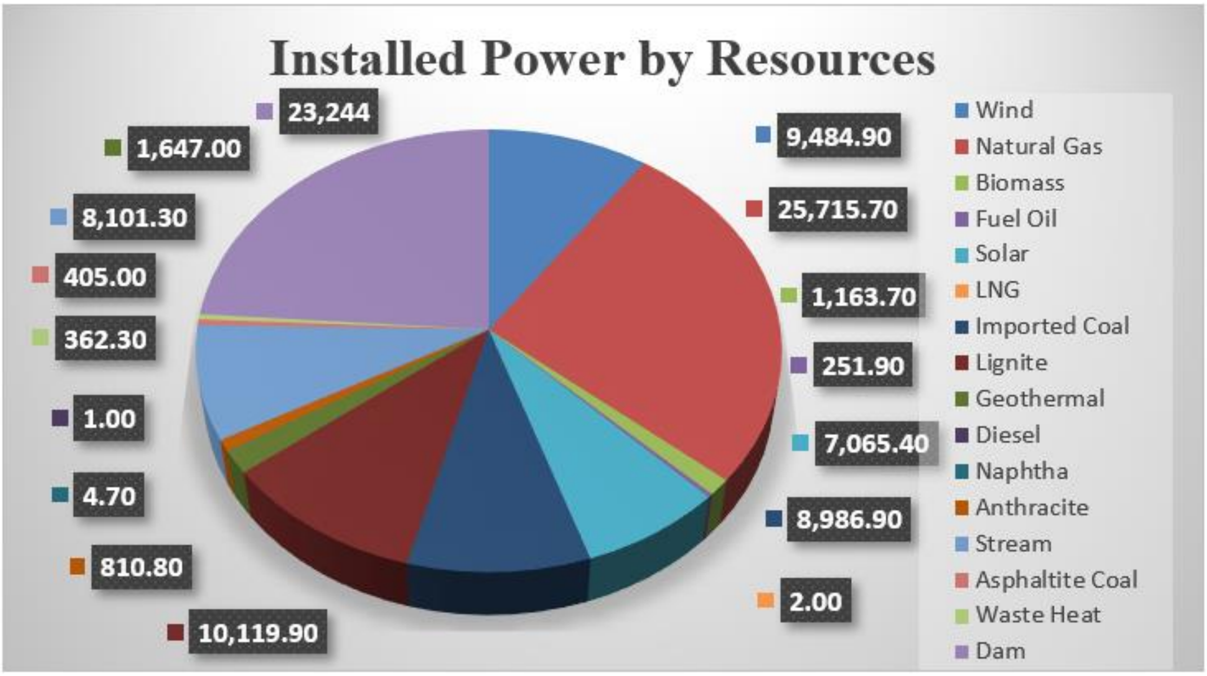


Figure 1. 3 Installed power by resources (TETC,2021)

Looking at the active power plants, 52.5 % of the total installed power consists of renewable energy resources. While hydroelectric power plants represent 32.2 % of the total installed power, it is seen that they correspond to 17.0 % of wind and solar power plants. Figure 1.4 shows the total installed power capacity by years. (Hakyemez,2021)

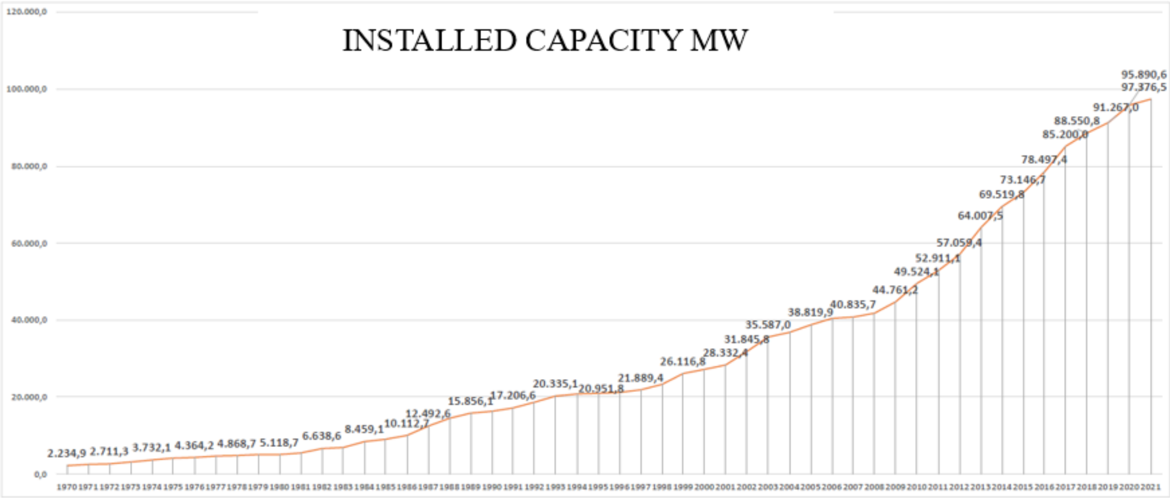


Figure 1. 4 Installed power development over the years (Hakyemez,2021)

Turkey has a geopolitical position where all the seasons are experienced. Its climatic advantages enable renewable energy investments. However, there is still untapped potential for wind and solar energy today. (Kanat,2019) With the decrease in wind and solar installation costs, wind and solar energy share in energy production will increase even more. At the same time, our country has abundant lignite reserves. However, mining activities are high and the electricity produced is low. Turkey aims to close the current account deficit using local resources most efficiently. (SHURA, 2020a)

Fossil fuels burn while generating electricity from non-renewable energy sources. As a result of combustion, CO_2, NO_x, SO_2, and similar gases and toxic metals such as nickel, cadmium, lead, arsenic are released into the atmosphere. The increase in the number of greenhouse gases in the atmosphere, especially carbon dioxide, causes our world to warm up. This situation is defined as global warming (greenhouse effect) today and causes deterioration of climate balance. Additionally, gases such as SO_2 and NO_x combine with water vapor in the atmosphere and cause acid rain. (Kumbur, Özer, Özsoy & Avcı, 2005)

Renewable energy sources do not directly generate greenhouse gases. Solar, wind, and hydroelectricity create emissions that can be negligible. However, there are very few indirect emissions from the setup, operation, or maintenance of manufactured parts. (Gurung et al, 2020) The fact that renewable energy is nature-friendly, combats climate change, and reduces carbon emissions are led to an increase in investment in this energy source worldwide. (Koç, A., Yağlı, Koç, Y. & Uğurlu, 2018)

Nowadays, action plans are created to reduce the impact of global warming and one of these is the Paris Agreement. The Paris Agreement, adopted on December 12, 2015, aims to reduce the global average temperature increase to 2 °C below pre-industrial levels and limit the increase to 1.5 °C. This marked a major turning point in global warming. (IRENA, 2019) In 2020, many more countries adopted and proposed laws on emissions. These laws and the CO_2 emission reduction targets set by countries are of great importance in the dissemination and development of renewable energy. Under the Paris Agreement, it is predicted that the world will reduce 70% of energy-related carbon dioxide (CO_2) emissions by 2050. More than 90% of this reduction will be provided by renewable resources. (IRENA, 2020a)

Renewable energy sources are obtained naturally, they are local, there is no need for special production. Investments made in these areas reduce the foreign dependency of developing countries. Also, investments have great importance for economic development and the creation of new employment. Renewable energy creates many and varied business areas such as R&D, administrative processes, technology, logistics, etc. In 2019, the number of employees in the field of renewable energy reached 11.5 million, and this number is expected to reach almost 30 million in 2030. Solar photovoltaic (PV) with 3.75 million, bioenergy with 3.58 million, hydroelectric with 1.96 million, and wind energy with 1.17 million are the largest employers. The share of women in the renewable energy workforce is approximately 32%. (IRENA, 2020b)

Figure 1. 5 Global renewable energy employment by technology 2012-2019 (IRENA, 2020b)

PV technology is modular and does not contain any moving parts. It can be integrated into building rooftops, facades, barriers, railways, subway lines, etc. This makes PV technology easy to apply in urban and industrial buildings. (Turkenburg et al, 2012) The industrial sector in Turkey has the highest share of energy consumption. Consumption in buildings ranks second after the industry sector. Renewable energy systems have great importance in supplying the energy consumption of buildings. Especially rooftop photovoltaic systems will provide self-production and on-site consumption, reduce grid dependency, and increase system efficiency. Rooftop PV systems in commercial and public buildings have an economic potential of 4.5 GW. In the study carried out by SHURA, it is observed that when the southern parts of all rooftops are used, in theory, there is 55 GW installed power potential. It is observed that there is a technical potential of 14.9 GW when the system is installed in the buildings that will remove the PV systems. (SHURA, 2020b)

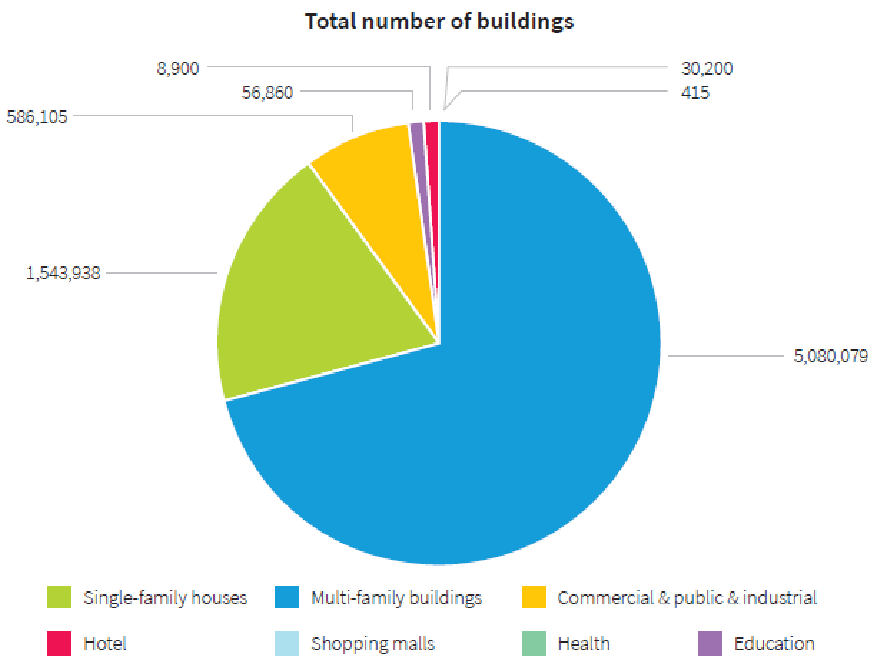


Figure 1. 6 Distribution of buildings in Turkey by types (SHURA, 2020b)

1.1. Sun as Energy Source

The sun is the energy that makes life on earth possible with its radiation. This radiation occurs when hydrogen atoms turn into helium atoms. Since there is a distance between the earth and the sun, a small part of this energy falls on the earth. The energy amount of sunlight falling on the earth is 10 times the energy need in the world. A small part of the sunlight is sufficient to meet the energy needs of the whole world. (Çataklı,2012)

1.2. Photovoltaic Energy

Photovoltaic is the direct conversion of solar energy into electrical energy with photovoltaic cells. Internal combustion systems and rotating equipment are not used in the transformation. The photovoltaic effect was observed in 1839 by Alexander E. Becquerel during studies on platinum layers. In 1883, Charles Fritts developed the first 1% efficiency PV cell using selenium. In 1946, Russell Ohl received a patent for a modern PV cell. Six efficient silicon PV cells are formed and in the following years, productivity increasing R&D studies continued. (Perinçek, 2015)

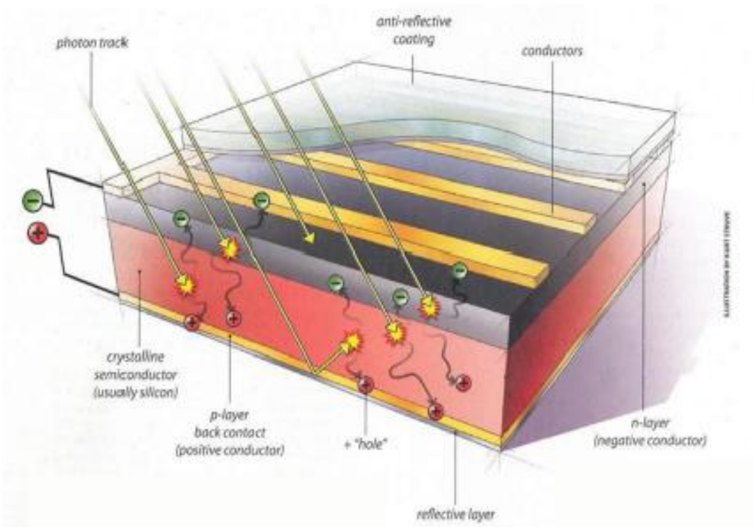


Figure 1. 7 Photovoltaic system

The electron generation process is shown in Figure 1.7. Here, the classical crystalline silicon photovoltaic cell consists of two different layers. The layer that receives the sunlight is negatively doped with Phosphor, and the lower layer is positively doped with the boron element. Thus, an electric field with opposite polarity is created. When it comes to radiation electron bonds are broken. If the electric field captures these electrons, a current is produced. When a consumer is added to the circuit, the generated current feeds the DC load. In this way, DC electricity is generated from the photovoltaic cell. As seen in Figure 1.8, a module is formed by connecting more than one cell in series. A standard module consists of at least 36 cells. The modules league together to form the panels. Panels league together to form an array. The array field is directly proportional to the electricity generated. Arrays are connected in series and parallel to each other to produce the desired voltage and current. (Mohamed et al, 2020)

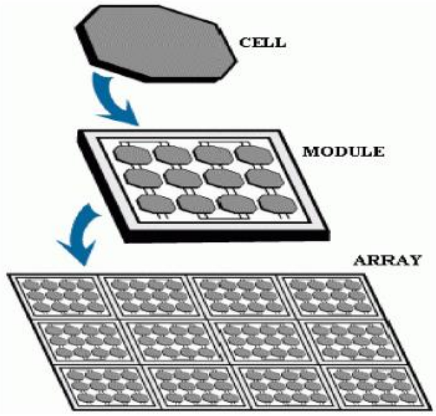


Figure 1. 8 Cell-Module-Array

1.2.1. Types of PV Panels

The types of PV panels are very diverse. The type of semiconductor materials, their capacity to absorb radiation, production technologies cause the diversity. The properties of the crystalline that make up the panels are efficient in the emergence of these species. Generally, three different cells are used: mono-crystalline, poly-crystalline, and thin film. (Çelebi,2002) On the other hand, when the efficiency of the cells is considered, it is known that mono-crystalline cells have 24%, Poly-crystalline cells 17.4%, amorphous silicon cells 14.7% and CD Te-Cds cells 15.82%. (Ayaz, Hocaoğlu, 2019)

1.2.1.1. Monocrystalline Silicon Solar Cells

It consists of mono-crystal silicon cells. Czochralski process is applied during production. There are no defects and impurities in the crystal lattice. It is highly efficient. The manufacturing process is more complex and the technology is more expensive. (Yalçın,2014) Today, monocrystalline cells are widely used due to the decrease in costs.

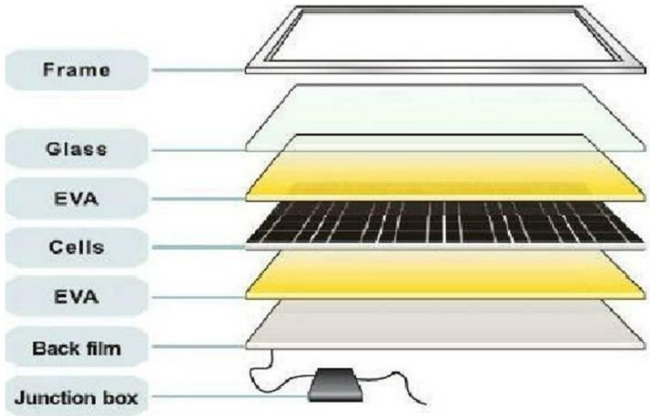


Figure 1. 9 Mono-crystalline solar cell structure (Bagher, Vahid & Mohsen,2015)

1.2.1.2. Polycrystalline Silicon Solar Cells

Poly-crystalline cells are produced using poly-crystalline silicon ingots. Raw silicones are melted, poured into a mold (square or triangle), cooled, and cut. Differently oriented crystals are formed by the block casting method. Different orientations on the surface are clearly seen with the different reflections of the light on the surface. The production method is low cost. (Mohamed et al, 2020)

1.2.1.3. Thin-Film Solar Cells (TFSC)

Thin-Film Solar Cells are the cells used as semiconductors in amorphous silicon (a-Si), copper indium selenide (CIS), copper indium decelenide and cadmium telluride. Their biggest advantages are that they are inexpensive and can be coated on glass, polymer and metal surfaces. They are flexible. Therefore, they provide great material savings. (Perinçek, 2015)

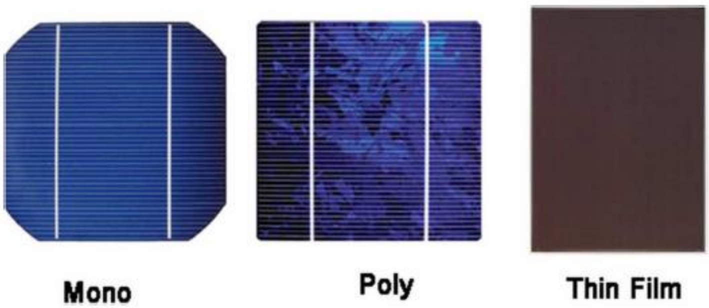


Figure 1. 10 Solar panels (Bagher, Vahid & Mohsen,2015)

Today, with the developing technology, new generation panels are started to be produced. After a few years, it will be difficult to find a polycrystalline panel. The double-sided "bifacial" generates energy with the radiation falling on the back. Efficient panels with no transmission line on the surface, half-cut panels called "Back contact" or half-cut cells are the panels that are sold today. (Çilli, 2020a)

1.3. Photovoltaic System Equipment

Certain equipment is needed to set up a solar energy system. The main ones are the panel, inverter, and construction materials. Panels are materials that produce direct current. Inverters are products that convert the energy produced by the panels from DC to AC. After panel and inverter, the most important equipment is construction, that is, metal carrier systems. Panels are placed on the construction. The stronger the construction system, the stronger the system. It is the equipment that protects the panels against environmental conditions. To create a balanced solar power plant, equipment is required according to the design and type of the system. These are DC / AC cables, distribution panels, grounding system, fire extinguisher safety equipment, lightning rod system, cable tray, MC4 connector, etc. equipment-.

1.4. Parameters Affecting Efficiency in Photovoltaic Systems

Today, with the developing technology, the efficiency rates of the cells that make up the panels are increased. However, the efficiency of the panels is low. While the cell efficiency increases, many factors cause the panel efficiency to decrease. These factors are solar radiation, temperature, shadowing, dust, tilt angle, degradation rate, etc. (Bilgili, Dağtekin, 2017)

1.4.1. The Effect of Solar Radiation and Temperature

Solar radiation intensity and temperature are some of the most important environmental factors affecting system efficiency. Changing atmospheric conditions affect the intensity of radiation and temperature throughout the day. This situation affects the panel efficiency.

Radiation change is the most important factor affecting module current. The module current is directly dependent on the radiation. When the radiation is reduced by half, the generated current decreases by half. In the face of the change in the module temperature, the electric current almost does not change. When the temperature rises, there is only a slight increase in the current.

Temperature affects the module voltage. The temperature should be taken into account for the system voltage in the planning of PV plants. (Çataklı,2012)

However, the increase in panel temperature decreases the panel voltage proportionally. As the voltage drop rate is higher than the current increase rate, the panel power decreases. Considering the temperature and radiation, it is seen that the conditions of low temperature and high solar radiation are optimal. (Karanfil, Özbay & Kesler, 2016)

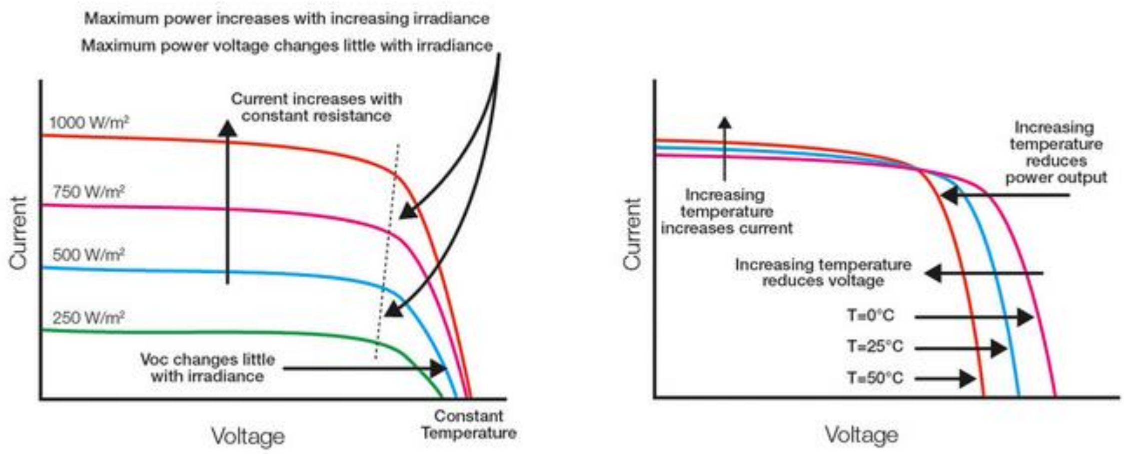


Figure 1. 11 The Effect of Solar Radiation and Temperature (SEWARD)

1.4.2. Shadowing

Shadow is one of the most important environmental factors affecting panel performance. Cloud, tree, building, leaf, satellite dish, chimney, lightning rod, or any other panel due to design error may create the shadow. These obstacles cast a shadow on the panel, causing the system not to receive the same amount of radiation. Cells that receive less radiation cannot generate power. It reduces the total output power of the system. (Genç, 2018) In some modules, bridging diodes (by-pass) are connected in parallel to PV cells. These diodes allow the system current to flow by circling the faulty cell caused by the shadow. Without a bridging diode, the entire current of the module is determined by the shaded cell. (Kilit, 2019)

Figure 1.12 shows the changes in the power output of a standard panel due to the shadow. There are tree bypass diodes in a standard panel. As can be seen in the figure, when there is a small shadow, a certain part of the cell is affected by the shadow, not the whole. Shadow exposure also varies depending on whether the panel is mounted horizontally or vertically. The more the bypass diode is in the panel, the less affected by the shadow. (Çilli, 2020b)

Nowadays, the effects of shadowing are tried to be reduced with micro-inverters or inverters with optimizers. To minimize the shadowing, it is necessary to make the layout according to the shadowing factor at the design stage. (Çilli, 2020b)

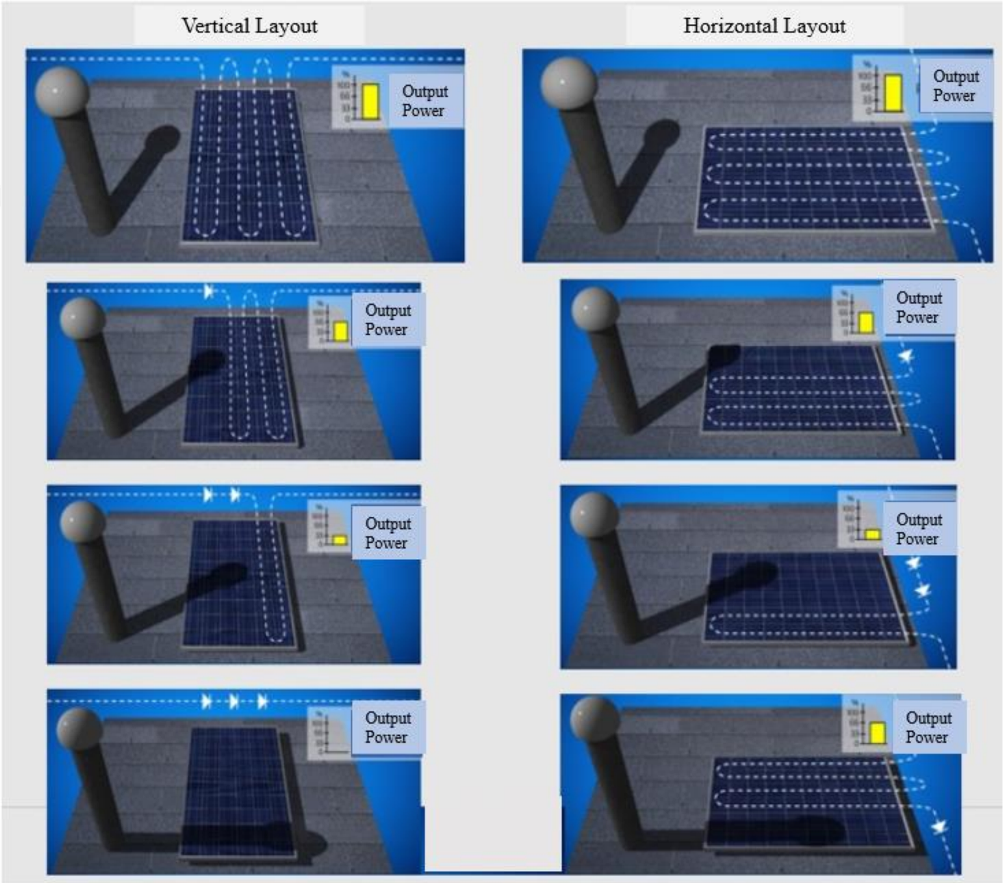


Figure 1. 12 The Effect of Shadow (Çilli, 2020b)

1.4.3. Dusting

Pollination occurs when snow, dust, tree leaves, bird droppings, and other particles partially or completely cover the surface. (Kilit,2019) Dust is an environmental factor that reduces the energy produced by the photovoltaic panel and decreases efficiency. With dusting, a thin or thick layer is formed on the panel. Factors such as surface quality, inclination angle, humidity, wind speed are also effective in the settlement of this layer. With the formation of dusting, the radiation falling on the panel decreases. (Genç,2018)

The type of contamination that may occur in the plant depends on the location. For example; Bird droppings and tree foliage contamination occurs in Central Europe. Pollution is also high in agricultural areas and areas built next to industrial facilities. (Çataklı, 2012) Panel efficiency decreases between 4% and 25% due to the location of the plant and environmental factors and dusting. (Kilit,2019)

1.4.4. Tilt Angle

Electricity generation is directly proportional to the radiation falling on the panel. Therefore, the panel layout is an important issue for the solar system. Since a solar power plant will operate continuously throughout the year, the inclination angle that creates the highest total power generation should be selected. According to the radiation calculations, although there are no significant differences in the total annual energy produced, the highest generation occurs at the closest slope to the latitude values of the region of the power plant. (Boztepe,2017)

The graph of the solar radiation falling on the surface for the system with different inclination angles is given monthly in the year in Figure 1.13. Inclines 20◦, 40◦, and 60◦ are provided. Looking at the graph, it is seen that there are no significant differences between the total production values of three different slope angles. However, it is seen that the system with an inclination angle of 20◦ produces more in summer and less in winter. It is not suitable for the system as it differs between the seasons. Distribution is more normal at 40◦ or 60◦ angles. Therefore, it is seen that these angles are more suitable for the system. (Masters,2004)

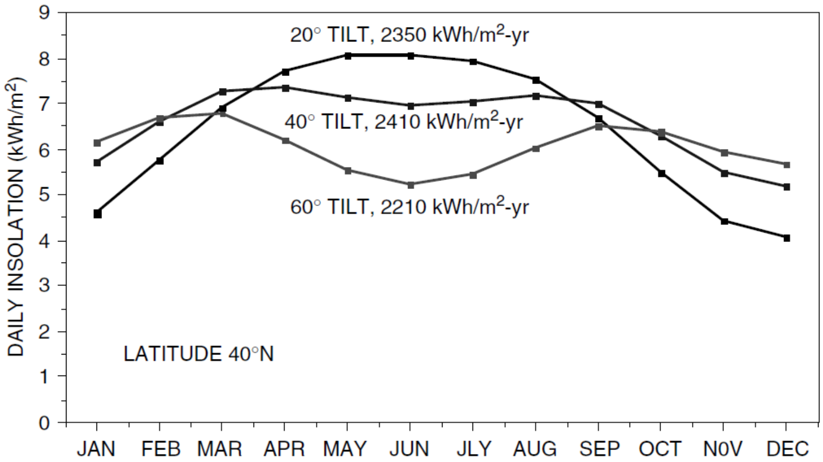


Figure 1. 13 The effect of the angle of tilt (Masters,2004)

Photovoltaic panels are placed at an optimum angle. It is predicted that a 6% production loss will occur in the case of ± 15 ° deviation from the optimum angle. The direction in which the panels should be mounted is south. To avoid low performance, panels are assembled in South-East and South-West directions. According to the summer and winter conditions in Turkey panels’ tilt angle is 30 °. (Bilgili, Dağtekin, 2017)

1.4.5. Degradation Rate

The degradation rate is the decrease in the efficiency of photovoltaic panels over the years. It refers to the loss of output power generated by the PV panel. PV panels are exposed to harsh climatic conditions. (Enerji Portalı,2018)

PV panels lose between 2% and 3% efficiency in the first years of the installation and activation of the facility. In the following years that production continues, it suffers a 0.5% yield loss every year. Some panel manufacturing companies provide a 25-year product warranty. However, due to the degradation rate, the annual yield guarantee decreases from 100% to 85% at the end of 25 years. Monocrystalline silicon panels started to be used with the developing technology. Monocrystalline panels undergo less degradation than polycrystalline panels. (My Enerjisolar, 2020) As a result, the higher the degradation rate, the higher the reduction in electrical power produced by the system. This will cause a decrease in cash flows. (Kilit,2019)

1.5. Turkey's Solar Energy Potential

Only a tiny fraction of the energy emitted by the sun is absorbed by the earth. Only this small fraction of solar energy is enough to meet all our power needs. Some of the Solar energy from Earth's atmosphere is reflected or absorbed by the gases and / or clouds in the atmosphere. The surface receives about 51% of the total solar energy reaching Earth. Only this amount can be used. (TSMS)

Turkey has 783,562 km² surface measurements. It is located on the Earth between 36^o- 42^o north latitudes and 26^o- 45^o east longitudes. Turkey is located in the sunbelt with its mathematics location. All provinces have an important potential to generate electricity from solar energy. Turkey's average annual / daily solar radiation and sunshine duration according to Solar Energy Potential Atlas (SEPA) are given in Table 1.1.(MENR)

Table 1. 1 Turkey's average annual / daily of solar radiation and sunshine duration (MENR)

Average annual total sunshine duration	2,766.5 hour / year
Average daily total sunshine duration	7.58 hour / day
Average annual total radiation intensity	1,512.7 kWh / m^2-year
Average daily total radiation intensity	4.17 kWh / m^2-year

The distribution of the annual total solar energy potential of our country according to the geographical regions is shown in Table 1.2. The maximum sunshine duration is in July and the minimum sunshine duration is in December. However, when the map given in Figure 1.14 is examined, it is seen that the Southern regions have more insolation potential than the Northern regions. The lowest insolation potential is in the Black Sea. It is known that the sunshine potential seen in the Black Sea corresponds to the highest potential of most countries when compared with the world's solar potential. Although the southeastern region has a harsh and cold climate, it receives the most radiation. (Kaynar,2020)

Table 1. 2 Turkey's Total Annual Potential of Solar Energy Distribution by Region (Özgür,2018)

Regions	**Total Energy (kWh/m2/year)**	**Sunshine Duration**
Southeastern Anatolia	1,460	2,993
Mediterranean	1,390	2,956
Eastern Anatolia	1,365	2,664
Central Anatolia	1,314	2,628
Aegean	1,304	2,738
Marmara	1,168	2,409
Black Sea	1,120	1,971

Figure 1. 14 Turkey's SEPA (MENR)

2. LITERATURE REVIEW

Chao and Peng (2016) analyzed the high- efficiency solar electricity strategy with the umbrella designed to different azimuth surface planes using the TRIZ (Theory of Inventive Problem Solving) method. The results of classical and new contradiction matrixes are investigated to optimize efficiency. A total of umbrella samples are given and compared to tree different tropical regions. The optimal design of azimuth surfaces of umbrella can be obtained by electricity gain at a fixed tilted angle.

Candelise, Winskel, and Gross (2013) analyzed PV cost and price with technology estimation. Two methods are used to evaluate PV Costs: experience curves and engineering assessment. Then the production costs and price trends of the modules are examined. The price of the PV modules has also declined as the cost of the crystalline silicones (c-Si) forming the PV modules has decreased. However, with the expansion of the PV sector, the demand for PV modules increased and this created a bottleneck. Overall, a significant decrease in PV costs and prices has been observed in the historical process. The increase in demand for renewable energy, conducting R & D studies, increasing production capacities, decreasing raw material prices, and decreasing production costs and policies have led to a steady decline due to the rapid decrease in energy resources.

Kömürcü (2019) assessed cost analysis made for a 1 MW and created a yearly profit and loss account statement of the solar power plant. Various problems can be encountered during the design phase and after the installation of a power plant. A focus group is established to evaluate various problems. Problems that could be encountered with qualitative data obtained as a result of group discussions are analyzed.

Gezer (2019) explained the installation phase of the 1 MW PV power plant in Çine district of Aydın step by step. Materials and assembly methods used in each stage are explained. The geographic features of Aydin province, the radiation values are examined and compared with Turkey's overall condition. The selected materials simulated with the PV*SOL software program results are analyzed. The installation cost of the plant is calculated as the breakeven point of the investment which was calculated.

Kilit (2019) studied the simulation and feasibility of 28 different buildings in total belonging to İzmir Metropolitan Municipality. The study is carried out in the PVsyst simulation program. The technical parameters that will affect the results to be entered in the simulation program are defined in this way, the simulation study has been carried out for each structure. The parameters that are effective in the feasibility study are also explained in detail and the study was carried out by including it in the feasibility study. Consequently, results are obtained about what would be the return of installing solar energy systems in 28 buildings.

Çiftçi (2020) conducted a study on the use of the direct current in homes. Today, all electronic appliances used in homes work with alternating current. For this reason, the electronic appliances used in the house have been replaced with devices working with direct current and the necessary costs for this have been extracted. At the same time, the advantages and the disadvantages of the system operating with DC compared to the AC system are discussed. Finally, by analyzing the criteria created with an analytical hierarchy process (AHP), it has been concluded that it is more advantageous to use direct current in homes.

Gurung et al. (2020) defined energy and solar energy concepts in general. The history of solar energy, its usage areas, its benefits to the environment, and its differences compared to other energy types are explained. At the same time, the working principles of solar panels are explained. This study can be considered as a general study of solar energy.

Tunçgövde (2020) installed a solar power plant to cover consumers in residences. It has made production and cost analysis with different panel types as monocrystalline and polycrystalline, with other inputs being constant. As a result, it is seen that the payback period is shorter due to the lower investment costs of the polycrystalline panels, but when the system lifetime is considered, the monocrystalline panel is more advantageous. In addition, the effects of SPP on the environment are also examined in the study.

Aksu (2018) addressed the three issues that most affect panel efficiency. These are air velocities, solar radiation, and ambient temperature. To make effective measurements, a test site is created where only the air velocities, solar radiation, and ambient temperature are changed and other factors remain constant. The properties of the test site and the materials to be used for measurement are explained in detail. The ambient temperature is changed between

10 - 40 ° C, the backside temperature of the panel is measured by changing the air velocities between 2 - 5 m / s and it is observed how this affects the panel efficiency. As a result of the measurements, it is concluded that the panel backside temperature is high in cases where the air velocities are low (0 m / s) and the ambient temperature is high (40 ° C) and this situation greatly reduces the production efficiency in the panels (8,5%).

Karamav (2007) explained in detail solar energy. The historical development, working principle, types, efficiency and usage areas of solar cells are explained. External factors that are effective in the operation of solar cells are defined and their effects on the batteries are given in tables. The photo angular effect of these factors is studied by experiment.

Girgin (2011) designed a total of 36 systems with different panel brands and models, including different brands of inverter and different solar panel mounting structures, to be installed in the Karaman region with an installed power of 5 MW. With the PVsyst software, the production values of each system in the simulation program are found. Later, all expenses and income items are determined separately and economic analyses of the systems are made. The most suitable system to be established is determined, taking into account both economic analysis and production values.

Thomas (2019) discussed the simulation of the rooftop solar power plant to be installed in an educational institute in India using different simulation programs and evaluate the feasibility of the system. In the study PVsyst and PV*SOL software programs are used.

Yalçın (2014) made a solar blind design in accordance with the south-facing 8 square meter kitchen window of a house located in Etimesgut district of Ankara province. In the study, 13 different solar blind designs are made by changing the widths of the strips and cells. For these types, whether there is a control system and the evaluation of the generated electricity using batteries are examined. After all, the return period of the system has been determined for the province of Ankara by comparing the situations such as the use within the scope of the Renewable Energy Law. The system is modeled in the Simulink program. Radiation calculations are made with the code prepared, and the total electricity generated in a year is calculated for each hour.

Özçelik (2018) examined in detail all processes from the design phase of the system to commissioning. Referring to the importance of solar radiation, Eskişehir and Isparta provinces with different heating values are compared in the study. The effects of inverter, panel and cable cross sections analyzed on the total annual electricity generation. Finally, the effect of the PV array / inverter ratio on the system has been investigated. With all these analyzes, the importance of accurate and reliable design for grid-connected solar investments, fixing the design criteria that affect the total electricity generation, and highlighted the material selection criteria are emphasized.

Wang et al. (2017) analyzed the effects of environmental factors on the performance of solar photovoltaic power plants. Generally, there is a perception that environmental factors will not have a major impact on the efficiency of solar energy systems. Solar irradiance, elevation, wind speed, soiling, precipitation, latitude and clouds are investigated. As a result of the analysis, it is seen that temperature is the most important environmental factor affecting efficiency. It is emphasized that environmental factors should be taken into account at the design stage in order to obtain higher performance rates from solar power plants.

San Cristóbal (2011) discussed the Renewable Energy Plan initiated by the Spanish Government. Within the scope of this plan, renewable energy alternatives to be installed are determined. To compare these alternatives with each other, AHP and VIKOR methods are used. The weights of the criteria are determined with AHP. The best alternative is selected by sorting among the alternatives with the VIKOR method. As a result of the study, it is determined that the best alternative is biomass. Biomass is followed by Wind Energy and Solar Thermo Electricity alternatives.

Kumar and Samuel (2017) analyzed the most optimum renewable energy power plant to be established in Banaras Hindu University (BHU) Campus in their study. Renewable energy alternatives to be compared and their criteria are determined. AHP and VIKOR methods are used in the evaluation of alternatives. The analyzes showed that wind energy is the most suitable choice among the renewable energy alternatives to be established on the BHU campus.

Zheng and Wang (2019) determined the selection of renewable energy system plans in touristic areas using a multi-criteria decision making method. The criteria, sub-criteria and alternatives are determined. The VIKOR method is used to rank the renewable energy system components. Weights, Sj, Rj and Qj values are determined. Analyzes made, as a result, the most suitable renewable energy system plan is determined.

Solanghi et al. (2019) conducted a study to determine the most suitable location for the establishment of a solar power plant in Pakistan, which has plenty of solar energy. First of all, locations and criteria are determined to enable comparison of locations. The weighting of the criteria is done by the AHP method. Fuzzy Vikor method is used for ranking. As a result of the study, Khuzdar, Badin and Mastung cities are found to be the most suitable location for solar power plant installation.

Rani et al. (2020) analyzed the solar panel selection with a multi-criteria decision making method. Today, solar energy is in demand as an endless source of energy. Solar panels are the main equipment in solar power plants. Many factors affect the efficiency of the panels. In this study, panel alternatives and criteria to be used in selection are determined. The weights of the criteria are found with Stepwise Weight Assessment Ratio Analysis (SWARA) method and then the most suitable panel is decided with VIKOR method.

Taylan et al. (2020), in their study, aimed to find which is the most suitable power generation facility to be established in Saudi Arabia. For this, fuzzy AHP, fuzzy VIKOR and TOPSIS methods are used. A total of 8 alternatives including renewable and non-renewable energy sources have been identified. The identified alternatives are evaluated according to 9 criteria determined by a team of expert decision makers. It is concluded that the best alternative according to both VIKOR and TOPSIS methods is the solar energy system.

Lee, Chang (2018) determined the ranking of renewable energy sources in Taiwan using 4 different multi-criteria decision making methods. Weighted sum method, VIKOR, TOPSIS and ELECTRE are the methods used. With this study, it is to lead the renewable energy sector and offer suggestions to the sector. The analyzes is shown that hydrogen is the best alternative. Then, respectively, solar, wind, biomass and geothermal energy sources. Sensitivity analyzes of the weights are also carried out in the study.

Kaya, Kahraman (2010) worked on the determination of the most suitable renewable energy source for Istanbul and the selection of the most appropriate production site for the solar power plant planned to be established in Istanbul. AHP and VIKOR methods are used to solve the two objectives. Fuzzy logic is preferred in order to minimize the uncertainty in the judgments of the decision makers. As a result of the analysis, it is determined that the most suitable renewable energy is wind energy. As a result of the studies, it is determined that the most suitable place for the wind power plant planned to be established in Istanbul is Çatalca.

Pérez-Velázquez et al. (2020) determined the best supplier for photovoltaic module installation using multi-criteria decision making method. Medium and small-scale suppliers serving on photovoltaic technology located in Northeast Brazil are identified. Entropy method are applied to weight the criteria. Then, the fuzzy VIKOR method is applied to compare the alternatives.

Ridha et al. (2020) studied the optimum placement of stand-alone Photovoltaic systems and the comparison of battery systems. First of all, a hybrid sizing approach are developed considering the techno-economic criteria. PESA-II and AHP-VIKOR methods are used. As a result of the study, the most suitable hybrid system and the necessary products are determined. In addition, it is determined that the lead-acid battery is more reliable and less costly than other batteries.

3. MATERIALS AND METHODS

Nowadays, when the importance of renewable energy resources is increasing, there is a serious increase in electricity consumption unit costs with the last resource use tariff. Firms' costs are increased steadily with continuous increases in electricity prices. With the new regulations, the installation of the rooftop solar power plant enabled the internal electricity to be consumed on site and consumed on the rooftop of the enterprises and production facilities, and this will reduce costs. The surplus electricity left over from self-consumption can also be sold to the state with a ten-year purchase guarantee of electricity. This is one of the advantages of solar power plant installation. Therefore, Solar Power Plant investments have become more attractive. In this study, the solar power plant installation on the rooftop is examined. The savings to be obtained from solar energy are determined.

For this reason, the installation of a solar power plant is carried out on an industrial rooftop operating in the organized industrial zone. During the study, the consumption bills of the factory are examined first. The energy tariff that the factory has, namely the electricity tariff is important here. According to the energy tariff, the change of production is analyzed according to the consumption of more electricity in summer and winter. With this analysis, the feasibility study of a factory with consumption and how many years the system will pay for itself is calculated.

System components that should be used are determined after consumption analysis. The analysis is made with different products using the PV*SOL simulation program. In the PV*SOL simulation program, the rooftop will be drawn in three dimensions. Components on the rooftop creating shading will be included and simulated. System efficiency will be tried to be calculated more accurately. As a result of the study among different products, the optimal product will be tried to decide.

After simulating with minute or hourly data, a detailed result report including diagrams and cash flow table are obtained, and all income and losses of the system are evaluated with the energy balance sheet. The establishment of millions of small solar power plants will reduce the current account deficit and also increases employment at the used areas.

In addition, using the multi-criteria decision making method, the options are ranked with the values obtained in the simulation and feasibility. The most suitable option is determined by the ranking.

3.1. Exploration and Locating

To start the installation of an SPP facility and to plan it better, it is necessary to know the characteristics of the field. It is important to study specific issues thoroughly from the very beginning.

First of all, the location of the project site should be known. Climate information of the area where the project is located and radiation values are the most important factors that will affect the production of SPP. Structures such as businesses, buildings and roads should be determined. Determining these structures is important in determining the pollution rates. For example, the cement factory located next to the area where SPP is planned to be installed will greatly affect the efficiency as it will cause a large amount of dust.

After the location and surroundings of the area are determined, general information about the building is obtained regarding the visit to be made on area. Static, architectural, electrical projects of the building should be examined before starting the SPP installation. Before starting the planof the on-area visit, the following issues should be taken into account while collecting data. (Çataklı,2012)

- Determine the tilt, direction, shape, structure, rooftop construction, properties of the material used in the rooftop.
- Determine the areas of use of the rooftop, front facade or empty areas
- Identify factors that cause shadowing, such as ventilation shafts, production chimneys, lighting cavities, antenna, lightning rod, satellite dishes, rooftop structures, structures close to the rooftop, trees, rooftop or facade sets, etc.
- Determine the connection location
- Determine the place where the panel will be placed
- Determine the inverter room location
- Installation lengths, places of passage and flooring features

- Determine Whether there is a ladder that will allow climbing to the rooftop or the equipment to be used (crane, lift, skeleton)
- Consider the incentive conditions

In this study, the installation of a solar power plant on the rooftop of a factory in Adana Organized Industrial Zone is analyzed. Figure 3.1 shows the image of the factory taken on Google Earth.

Figure 3. 1 Factory rooftop view (Google Earth)

The rooftop of the factory consists of 2 directions, south and north. The south-facing part is 216 meters long, 8 meters wide and 2,763 meters high. Its north-facing part is 216 meters long, 53 meters wide and 2,763 meters high. The rooftop is covered with trapezoidal sheet metal. The height seen above the factory rooftop is due to the administrative building. The administrative building measures 24,500 m Width, 2,000 m height, 14,000 m length. This will be effective in panel placement and cause shadowing. There are 4 chimneys on the rooftop. It is 2 meters long and 1.5 meters radius. Chimneys will also be taken into consideration while designing the system with simulation. Because chimneys will also cause shadowing. At the same time, dust from the chimney causes pollution on the panels.

The solar power plant to be installed on the rooftop is planned to directly generate electricity with the photovoltaic principle. The plant will operate in parallel with the grid and will generate electrical energy depending on solar radiation. Since the factory has its transformer, a direct connection to the transformer was made. The connection method will be with medium voltage. As a result of the simulation and feasibility analysis, how much of the electricity produced will meet the instantaneous consumption of the factory will be analyzed. The factory will make self-consumption with the established SPP, and in case of excess production, it will sell electricity with a connected two-way meter in the transformer. Before the system is installed, the data that should be taken into consideration is collected with the exploration and location determination.

3.2. PV * SOL Simulation Software Program

PV * SOL solar power plant allows drawing the areas to be installed and their surroundings in 2 or 3 dimensions. It offers the capacity to be used up to 5,000 panels. It enables the analysis of mounting systems by changing the panel angle at different slopes. Shading analysis evaluates panel by panel. Thus, it allows us to analyze the optimum design and efficiency of the system accurately. (PV*SOL)

The software uses the MeteoSyn climate database. It also allows the user to enter climate data. Panels and inverters have a large database infrastructure, and the system automatically updates itself as new products are released. System design, shading analysis, simulation results, production tables and cash flows are presented with the report obtained as a result of the simulation. (PV*SOL)

In short, PV * SOL software provides detailed information about the meteorological data of the system, pollution rates, albedo effect, solar radiation values, layouts, solar panel direction and angle, panel and inverter characteristics, network characteristics, performance rate, annual avoided CO_2 emission, annual production values information. (Girgin,2011)

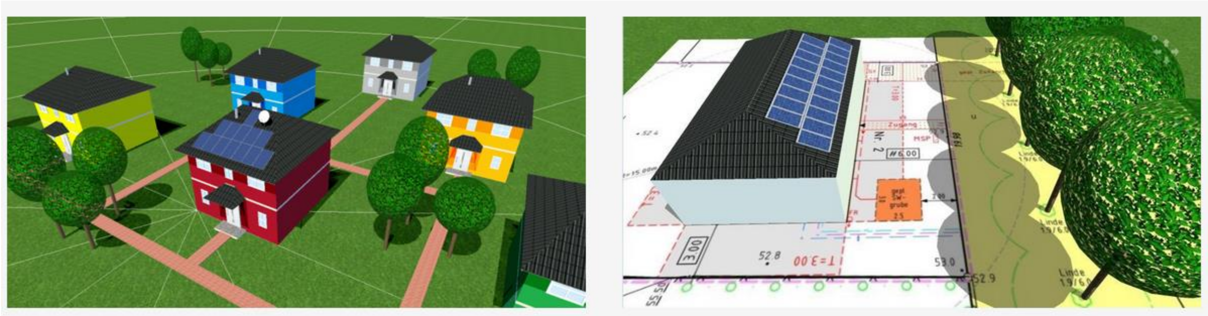


Figure 3. 2 PV*SOL sofware programs (PV*SOL)

3.3. Radiation Values of the Power Plant Area

The place where the solar power plant will be installed is in Adana. Adana province has the characteristics of the Mediterranean climate. Summers are hot and dry, winters are mild and rainy. The coldest month is January and the hottest month is August. The average temperature in January is 9 ºC and the average temperature in August is 28 ºC. The 37-year average temperature is 18,7 ºC. In the summer, it shows the effect of moisture-laden hot weather. The average relative humidity is 66%. It is seen that the relative humidity of the summer exceeds 90%. (MoEU)

An analysis of data from Figure 3.3 Solar Energy Map of Turkey Adana it is seen that one of the areas exposed to the intense radiation. When the graph of global radiation values in Figure 3.4 is examined, Adana has the highest solar radiation in June with 6.68 kWh / m_2-day value. The lowest month is December with 1.81 kWh / m_2-day. When the sunshine duration of Adana province is examined in Figure 3.4, it is seen that the most sunbathing is in July with 11.77 hours and the least sunbathing is in December with 4.21 hours. (SEPA)

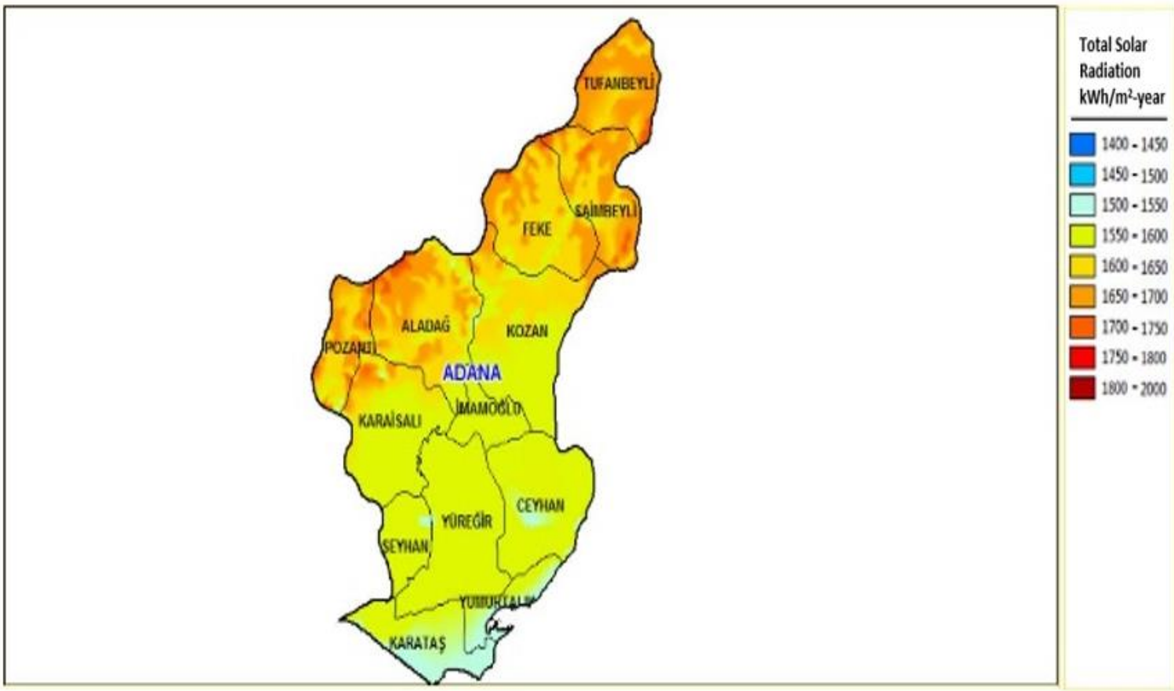


Figure 3. 3 Adana province solar energy potential atlas (SEPA)

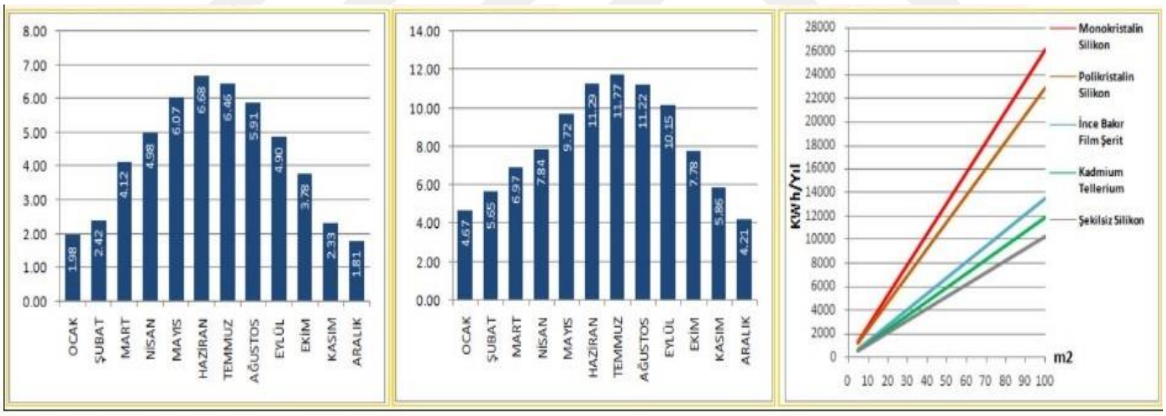


Figure 3. 4 Adana province global radiation values - Adana province sunshine duration (SEPA)

3.4. Examination of the Consumption Invoices of the Plant Area

In this study, the past bills of the factory for 2019 were analyzed. The electricity consumption of the factory in 2019 is given in Table 3.1.

Table 3. 1 Electricity consumption of the factory by months

Period	Electricity Consumption (kWh)			
	Daytime	**Puant**	**Nighttime**	**Total**
2019/01	369,702.90	175,184.10	269,901.45	814,788.45
2019/02	392,855.40	183,726.90	290,549.70	867,132.00
2019/03	451,284.75	209,430.90	340,124.40	1,000,840.05
2019/04	511,849.80	236,902.05	364,741.65	1,113,493.50
2019/05	567,198.45	265,582.80	420,525.00	1,253,306.25
2019/06	457,890.30	211,264.20	340,455.15	1,009,609.65
2019/07	568,020.60	264,921.30	415,166.85	1,248,108.75
2019/08	469,372.05	217,964.25	348,979.05	1,036,315.35
2019/09	631,713.60	287,554.05	453,231.45	1,372,499.10
2019/10	657,757.80	303,912.00	488,215.35	1,449,885.15
2019/11	555,584.40	255,499.65	408,381.75	1,219,465.80
2019/12	610,405.94	275,049.62	449,219.93	1,334,675.48

When Table 3.1 is examined, it is seen that the factory consumption varies between 814,788.45 kWh and 1,334,675.48 kWh. According to the 12-month electricity bills, the average electricity consumption of the factory is 1,143,343.29 kWh. When viewed seasonally, it is seen that there is no difference in consumption. The factory works at full capacity for 24 hours a day, seven days a week.

3.5. Determination of Products to be Used in Simulation

In this study, different brand models of panels and inverters are used. The effects of products produced in different technologies on the system are investigated. In this study, two panels and two inverters with different technology and brand are used. Simulation and feasibility results of 4 different options are compared. The 4 different options to be compared with simulation and feasibility results are given in Table 3.2.

Table 3. 2 Classification of options to analyze

Classification of Options	The used products
1st PV Option	A Brand Panel + A Brand Inverter
2nd PV Option	A Brand Panel + B Brand Inverter
3rd PV Option	B Brand Panel + A Brand Inverter
4th PV Option	B Brand Panel + B Brand Inverter

3.5.1. A Brand Inverter Properties

A brand inverter is an inverter that works with optimizer technology, not string-based inverters. Panels are connected with the optimizer placed under the solar panels. DC electricity produced from the panels is directly transmitted to the optimizers. Optimizer produces electricity from DC to DC. The inverter does not include a circuit that finds the maximum power point tracker (MPPT). As it connects with Optimizer, it can perform MPPT on panel basis. Each optimizer optimizes two panels connected to it and offers two panel-based MPPT logic. In this case, shadow / contamination / malfunction etc. will occur in one or more of the panels in a string. Ensures that errors minimize string production loss by reducing the production of only the other panel connected to the same optimizer, rather than reducing the production of the entire string. Annual total power output is higher than conventional inverters. It differs from standard array inverters with this aspect. It has a wide range of products, and both land and rooftop SPP is used.

To obtain the optimum design of the rooftop to be installed on the factory, two different models of A brand inverter have been used. The data-sheet properties of the A brand inverter are given in Table 3.3 and Table 3.4.

Table 3. 3 A brand inverter 1st model technical properties

A brand inverter 1st Model Technical Properties			
Input		**Output**	
Maximum Input Voltage	1,000 Vdc	Rated AC Power Output	82,800 VA
Nominal DC Input Voltage	750 Vdc	Maximum AC Power Output	82,800 VA
Maximum Input Current	120 Adc	AC Output Voltage	400 Vac
Maximum DC Power (Module STC), Inverter	111,750 W	Max. AC Output Voltage	460 Vac
Maximum Inverter Efficiency	98.3 %	AC Frequency	50/60 ± 5 Hz
		Maximum Continuous Output Current (per Phase)	120 A

Table 3. 4 A brand inverter 2nd model technical properties

A brand inverter 2nd Model Technical Properties			
Input		**Output**	
Maximum Input Voltage	900 Vdc	Rated AC Power Output	27,600 VA
Nominal DC Input Voltage	750 Vdc	Maximum AC Power Output	27,600 VA
Maximum Input Current	40 Adc	AC Output Voltage	380 / 220; 400 / 230 Vac
Maximum DC Power (Module STC), Inverter	37,250 W	Max. AC Output Voltage	184 - 264.5 Vac
Maximum Inverter Efficiency	98.3 %	AC Frequency	50/60 ± 5 Hz
		Maximum Continuous Output Current (per Phase)	40 A

3.5.2. B Brand Inverter Properties

B brand inverter is an inverter that provides string-based monitoring. These inverters come to the fore with low electricity generation costs, LCOE (Levelized Cost of Electricity). It has high MPPT capacity, high inverter efficiency, PID improvement, arc reading with artificial intelligence, modular structure, and I-V curve monitoring over the network. There is a wide range of products. It can be used in area and rooftop SPP. The inverter used in the simulation is 90 kg and its dimensions (Weight x Hight x Dimension) are 1,035 x 700 x 365 mm. Technical properties of the B brand inverter are given in Table 3.5.

Table 3. 5 B brand inverter technical properties

B Brand Inverter Technical Properties			
Input		**Output**	
Max. Input Voltage	1,500 V	Rated AC Active Power	100,000 W
Max. Current per MPPT	22 A	Max. AC Apparent Power	105,000 VA
Max. Short Circuit Current per MPPT	33 A	Max. AC Active Power (cosφ=1)	105,000 W
Start Voltage	650 V	Rated AC Grid Frequency	50 Hz / 60 Hz
MPPT Operating Voltage Range	600 V ~ 1,500 V	Rated Output Current	72.2 A
Rated Input Voltage	1,080 V	Max. Output Current	80.2 A
Number of Inputs	12	Adjustable Power Factor Range	0.8 LG ... 0.8 LD
Number of MPP Trackers	6	Maximum Inverter Efficiency	99.0%

3.5.3. A Brand Panel Proporties

A brand model cell consists of mono-crystalline cells. 6 × 24 mono-crystalline solar half cells are used. Its frame measures 2,015 mm × 1,000 mm × 35 mm. One panel has a weight of 23.5 kg. Panel information is given in Table 3.6. Measurements are made under standard test conditions (STC). Standard test conditions are to be performed at 1,000 W / m² perpendicular to the cell or panel, at 25 ° C solar cell temperature, and AM 1.5 solar spectrum.

Table 3. 6 A brand panel technical properties

A Brand Panel Proporties	
Power at MPP (PMPP)	400W
Open Circuit Voltage (Voc)	49.00V
Short Circuit Current (Isc)	10.24A
Voltage at MPP (Vmp)	41.4V
Current at MPP (Imp)	9.75A
Efficiency	≥ 19.9 %
Maximum System Voltage	1,500 V / 1,500 V
Temperature Coefficient of PMPP	-0.365%/K
Temperature Coefficient of Voc	-0.275%/K
Temperature Coefficient of Isc	+0.063%/K

3.5.4. B Brand Panel Proporties

The B brand model cell consists of mono-crystalline cells. 6 × 12 monocrystalline solar cells are used. Its frame measures 2,008 × 1,002 × 35 mm. 1 panel has a weight of 22.5 kg. Panel information is given in Table 3.7. Measurements are made under standard test conditions (STC).

Table 3. 7 B brand panel properties

B Brand Panel Proporties	
Maximum Power at STC(Pmax)	400W
Open-Circuit Voltage (Voc)	48.7V
Short-Circuit Current (Isc)	10.79A
Optimum Operating Voltage (Vmp)	40.7V
Optimum Operating Current (Imp)	9.84A
Module Efficiency	19.9%
Maximum System Voltage	1,000V / 1,500V DC
Temperature Coefficient of Pmax	-0.365%/K
Temperature Coefficient of Voc	-0.275%/K
Temperature Coefficient of Isc	+0.063%/K

3.6. Simulation Analysis

With the exploration and site delivery, the rooftop of the factory is analyzed and the factors affecting the design are determined. The products to be used are determined. In this part of the study, the SPP to be installed on the rooftop is simulated using PV*SOL Premium simulation software. PV*SOL Premium program uses the climate data in the MeteoSyn database while making these designs. MeteoSyn provides climate, radiation etc. data from a map or list. It also allows creating new records manually and updating data. (PV*SOL)

In the design of 4 different options, the following parameters are entered as fixed.

- Loses due to deviation from standard spectrum; 1.00 %
- Power losses resulting from a Drop in Voltage at the Bypass Diodes; 0.5 %
- Power Losses resulting from Mismatching or Reduced Yield for A brand inverter; 0.0% and for B brand inverter; 3.5%
- Ground Reflection (Albedo); 20%
- Output losses due to soiling of the PV Modules; 2.0%

The placement of the panels for 4 different options is designed as in Figure 3.5. The escape distance is 0.5 meters around the factory. This distance is also necessary for occupational health and safety. There are 0.02 m gaps vertically and horizontally between each panel. The distance between the tables is 2 meters horizontally and 1 meter vertically. The distance between the tables is left for pedestrian path, panel cleaning, maintenance and repair. The azimuth angle is 7 degrees.

Figure 3. 5 Rooftop panel placement

3.6.1. Shadow Analysis

In the PV*SOL simulation program, after entering the rooftop dimensions, rooftop angle, and azimuth angles, the system is modeled in three dimensions (3D) to make shading analysis as in Figure 3.6. When the 3D model is examined, it is clear that the chimney and the administrative building will cause shadows. The period between 09:00 and 15:00 when solar radiation is most efficient is very important. The shadow should have a minimal effect on the system and should not cause loss of production. For this reason, the administrative buildings and the surroundings of the chimneys that cause shadowing are analyzed first. There is no shading in other areas of the rooftop.

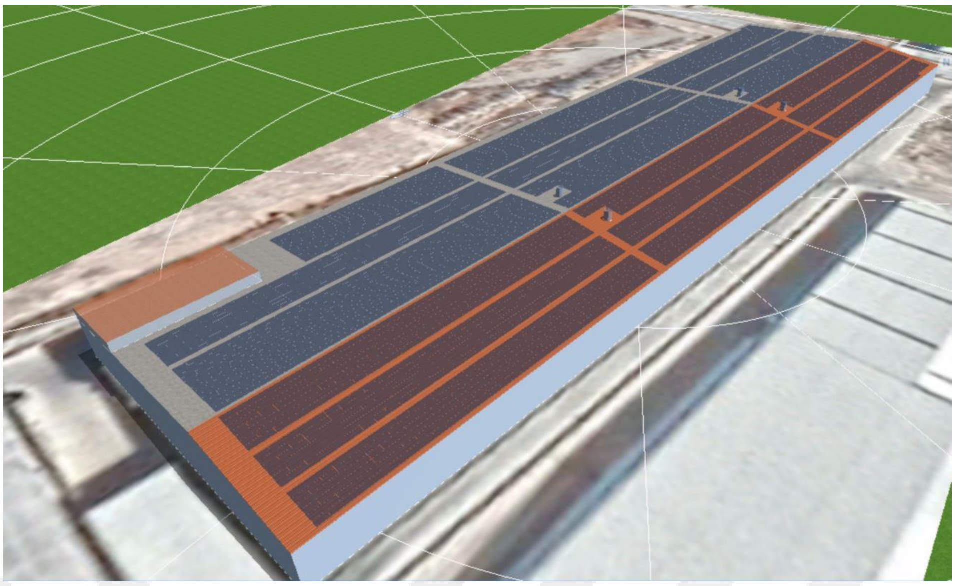


Figure 3. 6 3D view of the rooftop

In Figure 3.7., the losses in panel production caused by shadowing as a result of the shadowing analysis in the panels placed around the chimney are given as a percentage. In Figures 3.8 and 3.9, panels with a shadowing percentage greater than 4% around the chimney have been removed in order to minimize the shadowing losses and to generate maximum electricity at the end of the day.

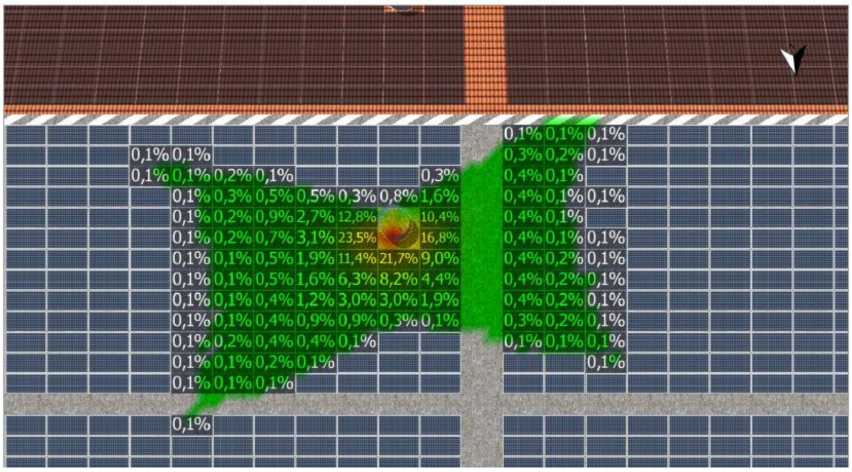


Figure 3. 7 Percentages of loss created by the chimney on the panel

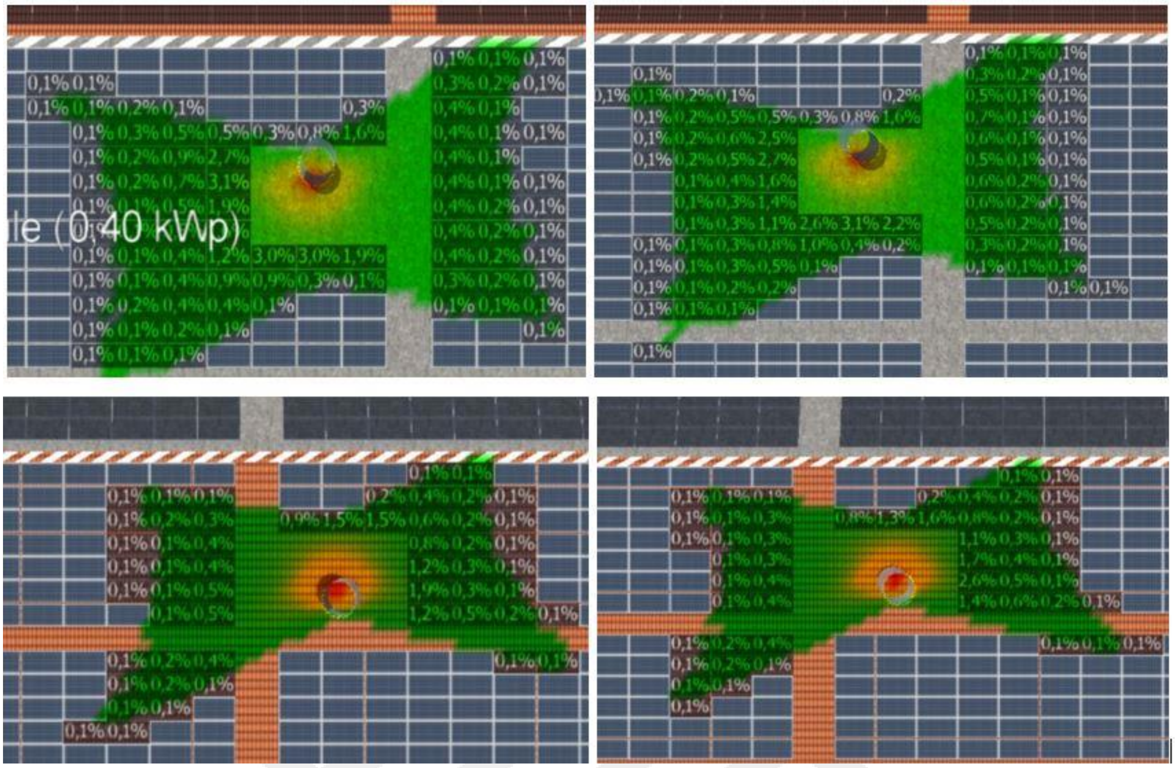


Figure 3. 8 Panel layout around the chimney after shadowing analysis

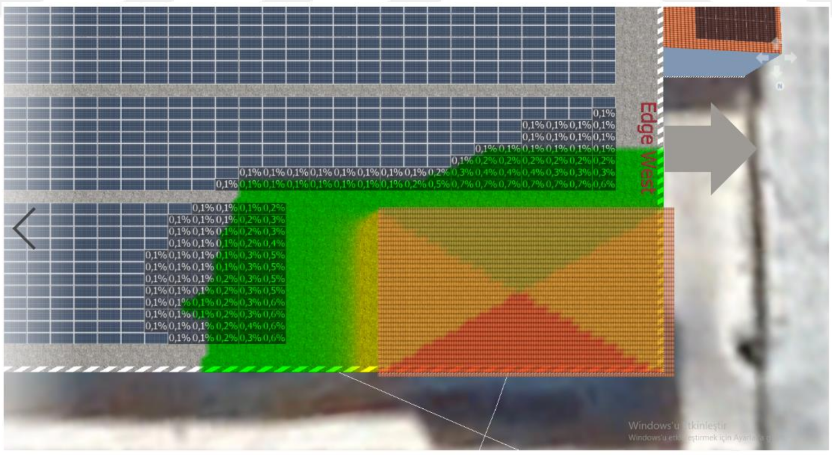


Figure 3. 9 Panel layout around the administrative building after shadowing analysis

3.7. Multi-Criteria Decision Making

Multi-criteria decision making is a group of analytical methods used in selecting the best option from a set of alternatives and ranking these alternatives based on conflicting criteria. Multi-criteria decision making methods are widely used in selection, ranking and classification problems. Evaluations of alternatives are made subjectively by experts. (Ekren & Fındıkçı,2015)

In the study, the solar power plant installed on the roof is evaluated with the multi-criteria decision making. To weigh the criteria, AHP, one of the multi-criteria decision making methods is used. Alternatives are ranked and analyzed by the VIKOR method.

3.7.1. Analytical Hierarchy Process Method

Analytical Hierarchy Process is a multi-criteria decision making method developed by Saaty. It aims to quantify the qualitative data of the determined alternative set depending on the opinions and thoughts of the decision maker. It also checks the consistency of intuitional judgments while performing the quantification process. It is the most widely used multi-criteria decision making method. (Al-S. Al-Harbi, K. M.,2001)

AHP divides a problem into parts, makes pairwise comparisons and manages a systematic process that occurs by determining priorities in a hierarchical structure. (Kara &Ecer, 2016)

The steps of the AHP method are described below:

Step-1: The problem and target are determined.

Step-2: The criteria are determined.

Step-3: Alternatives are determined.

Step-4: Pairwise comparison matrices are created. Pair-wise comparison is the comparison of two criteria with each other according to the determined scale (For example, deciding how important the A criterion is compared to the B criterion). It was developed by Saaty in 1980 and is used in the AHP method. The preference scale with 1-9 points is given in Table 3. (Toksoy,2012)

Table 3. 8 Preference Scale of Pair-wise Comparisons Saaty,1980

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement slightly favour one over the other.
5	Essential or strong importance	Experience and judgement strongly favour one over the other.
7	Very strong importance	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice.
9	Extreme importance	The evidence favouring one over the other is of the highest possible validity
2,4,6,8,	Intermediate values between the two adjacent judgments	When compromise is needed

Values (aij) are selected by giving one of the importance levels given in Table 3.8 and a decision matrix of (nxn) dimension is created. The diagonals of the created matrix (i=j) are 1. In the diagonals, the same criteria are filled in this way because they are compared with each other and there is no priority status between them. It is sufficient to fill the values above the diagonal while creating the matrix. The values in the lower part of the diagonal are the opposite of the values in the upper part. (Aktepe & Ersöz,2014)

$$a_{ji} = \frac{1}{a_{ij}} \qquad (1)$$

Step-5: Normalized matrix is created. After the pairwise comparison matrix is created, the normalized matrix of the aij values must be obtained. When obtaining the normalized matrix, the column sum is taken for each column and the aij values are divided by the corresponding column sum. The column sum in the normalization matrix should be 1. (Ekren & Fındıkçı,2015)

$$c_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

Step-6: Priority vector matrix is created. In the normalized matrix, the row sum is taken for each criterion. The priority vector, in other namely, the eigenvector, is obtained by dividing the row sum by the number of criteria. The w vector is the eigenvector consisting of the weights of the criteria. (n = number of criteria) (Uçakcıoğlu & Eren,2017)

$$w_{ij} = \frac{\sum_{j=1}^{n} c_{ij}}{n} \tag{3}$$

Step-7: The consistency index is calculated. The criteria are compared with each other by the decision makers and are valued according to their importance. Here, it is necessary to calculate the consistency index to measure how consistent the decision makers are. While calculating the consistency index, the following sequential operations should be performed. (Aydoğan et all,2011)

- Firstly, the pairwise comparison matrix and the W vector are multiplied to calculate the consistency. The newly created vector is called the weighted sum vector matrix.
- In the weighted sum vector obtained, each of the row sum values is divided by the corresponding value in the priority vector and the basic values are obtained.
- The arithmetic average of the created basic values is taken. The result is λmax value. λmax represents the maximum eigenvalue.
- After the λmax value is found, the consistency index (CI) is calculated. (n: number of criteria)

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

- When calculating the consistency ratio (CR), the last step is to divide the consistency index (CI) by the index of a random (IR) value. The values in the random index are constant and are given in Table 3.9.

Table 3. 9 Random Consistency Index for Pairwise Comparison Table

Number of elements	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

$$CR = \frac{CI}{IR} \tag{5}$$

If the obtained consistency ratio is less than 0.10, it is concluded that the decision maker behaves consistently when making pairwise comparisons, and if it is not small, it is not consistent. If it is greater than 0.10, the decision maker has to make a pairwise comparison again.

3.7.2. VIKOR Method

VIKOR is a MCDM method that solves decision making problems involving unmeasurable and incompatible criteria by using criterion weights found by different analytical methods. The VIKOR method was first developed by Opricovic and Tzeng in 2004. (Aktepe & Ersöz,2014)

With this method, which has been used frequently especially in recent years, alternatives are listed depending on conflicting criteria. It is ensured that the most suitable alternative is selected among the ordered alternatives. The VIKOR method considers the multi-criteria ranking index based on closeness to the ideal solution. (Taşkan, 2012)

In offering such a compromise solution, VIKOR applies the concepts of "acceptable advantage" and "acceptable stability" to determine "maximum group utility of the majority" and "minimum individual regret of the opponent". (Baylan,2016)

Since the VIKOR method can be applied in all areas, nowadays it is used in quality studies, public transportation problems, supplier selection, water resources planning, bank performance evaluation, robot selection, material selection, renewable energy source and location selection, risk assessment, etc. It is used in multi-criteria decision making problems. (Aktepe & Ersöz,2014)

A_1, A_2, A_3, ...A_m represent m alternatives. C_1, C_2, C_3, …, Cn represent n criteria. w_i represents the weight of the ith criterion. The value of the alternative A_j (j=1, 2, ..., m) for the criterion C_i (i=1, 2, 3, …, n) is fij. The application steps of the VIKOR method are explained below. (Uçakcıoğlu, Eren,2017)

Step-1: The best (f_i*) and worst (f_i^-) values are determined for all criteria. While determining these values, attention is paid to the effect of the criteria on the benefit or cost/risk on the model created. (Anvari, Zulkifli & Arghish,2013)

$$f_i^* = max_j f_{ij}$$
$$f_i^- = min_j f_{ij} \tag{6}$$
$$i = 1,2,\dots,n$$

If criterion i is a criterion expressing cost/risk in terms of evaluation, equation (7) is applied.

$$f_i^* = min_j f_{ij}$$
$$f_i^- = max_j f_{ij} \tag{7}$$
$$i = 1,2,\dots,n$$

Step-2: S_j and R_j values are calculated for j=1, 2, …, m. S_j, j. represents “the maximum group utility” for the alternative. R_j, j. expresses “the minimum individual regret of the opponent” for the alternative. (El-Santawy,2012) S_j and R_j values are found with the following equations.

$$S_j = \sum_{i=1}^{n} \frac{w_i\left(f_i^* - f_{ij}\right)}{f_i^* - f_i^-} \tag{8}$$

$$R_j = max_i \left[\frac{w_i(f_i^* - f_{ij})}{f_i^* - f_i^-}\right] \tag{9}$$

Step-3: The Q_j value is calculated for j=1, 2, …, m. Equation 7 is used when calculating the Q_j value. (Uçakcıoğlu & Eren,2017)

$$Q_j = \frac{v\left(S_j - S_j^*\right)}{S^- - S^*} + \frac{(1 - v)(R_i - R^*)}{R^- - R^*} \tag{10}$$

The S^*, S^-, R^*, R^-parameters used while calculating the Q_j value are calculated with the equation 8 and 9. (Korucuk & Erdal,2018)

$$\begin{aligned} S^* &= min_j S_j \\ S^- &= max_j S_j \\ R^* &= min_j R_j \\ R^- &= max_j R_j \end{aligned} \tag{11}$$

The v parameter in the formula shows the weight of most of the criteria. In other words, it expresses the maximum group utility. The (1-v) parameter expresses the weight of the minimum regret of the dissidents. Usually, the v parameter takes the value 0.5. Compromise; ıt can be achieved in three ways with v>0.5 “voting by majority rule”, v=0.5 “by consensus” or v<0.5 “veto”. However, any value of v from 0 to 1 can be taken. (Kumar & Samuel, 2017)

Step-4: After calculating the S_j, R_j and Q_j values with the steps mentioned above, each alternative is ordered from smallest to largest. The smallest Q_j value obtained as a result of the ranking is the best alternative. (Uçakcıoğlu & Eren,2017)

Step-5: In order for the minimum Q_j value to be the most suitable alternative solution, the following two conditions must be met:

Condition 1: "Acceptable advantage"

When Q_j values are ordered from smallest to largest, the acceptable advantage is calculated by equation (9) when the first alternative is defined as A_1 and the second ranked alternative A_2. (Kara &Ecer, 2016)

$$Q(A_2) - Q(A_1) \geq DQ$$
$$DQ = \frac{1}{j-1} \tag{12}$$
$$j = 1,2, \dots, m$$

Condition 2: "Acceptable stability"

When the Q_j value is ordered from smallest to largest, the smallest value A_1 is accepted as the best alternative. Accordingly, when the S_j and/or R_j values of the A_1 value are ordered from smallest to largest, at least one of them should also have a minimum value. If the condition is satisfied in this way, the consensus solution decision making is stable. (Korucuk & Erdal,2018)

If one of the conditions is not met, the following concession solutions are tried.

- If Condition 2 is not met, both alternatives A_1 in the first place and A_2 in the second place are both determined as the best compromised joint solution. (Uçakcıoğlu & Eren,2017)
- If Condition 1 is not met, all A_1, A_2, …A_m alternatives are included in the consensus best common solution set. Here, the maximum m is determined by the equation, $Q(A_m) - Q(A_1) < DQ$. (Korucuk & Erdal,2018)

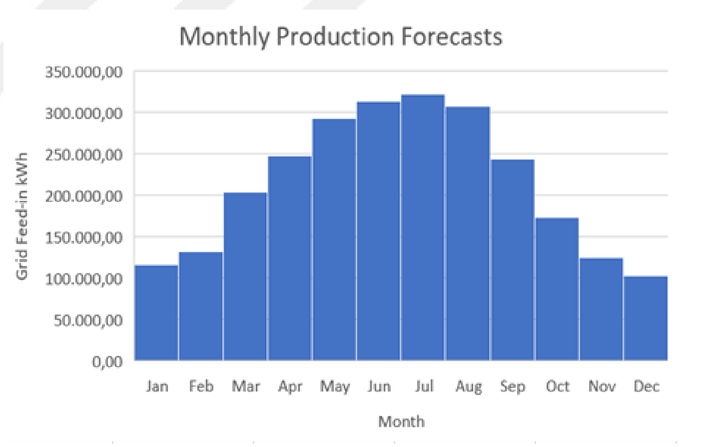
4. RESULT AND DISCUSSIONS

4.1. Simulation Analysis of 4 Different Options

4.1.1. 1st PV Option Simulation Analysis

SPP is established and simulated by using A brand panel and A brand inverter. A total of 5.034 panels are used. 19 pieces of model 1, 2 pieces of model 2 inverters are used. Since it is an optimized system, 2,517 optimizers are used. The installed power of the system is 2,013.6 kWp.

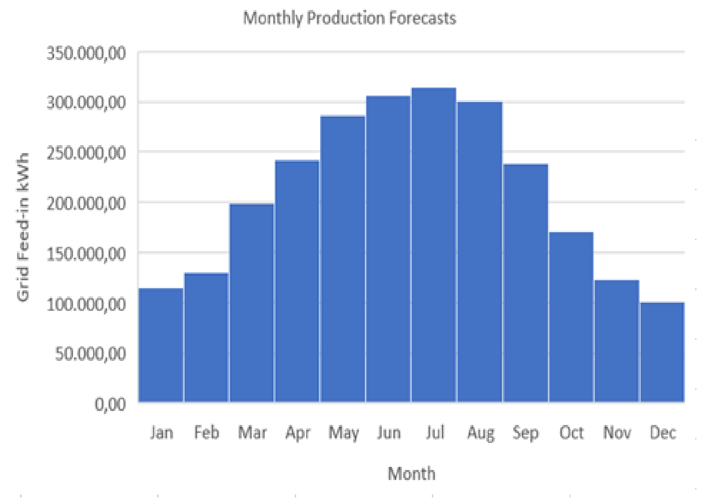
Table 4. 1 1st PV option simulation analysis results

Time	Irradiance onto horizontal plane kWh/m²	Grid Feed-in kWh		
Year	1,512	2,582,252.00		
Jan	64.452	116,692.00		
Feb	73.533	132,650.00		
Mar	115.02	203,530.00		
Apr	141.89	247,240.00		
May	172.03	293,010.00		
Jun	188.27	313,460.00		
Jul	195.52	322,020.00		
Aug	186.07	307,180.00		
Sep	145.26	243,880.00	Spec. Annual Yield	1,282.41 kWh / kWp
Oct	101.66	174,070.00	Performance Ratio (PR)	85.80%
Nov	70.815	125,150.00	Yield Reduction due to Shading	0.1 % / Year
Dec	57.52	103,370.00	CO2 Emissions Avoided	1,213,659 kg / year

4.1.2. 2 nd PV Option Simulation Analysis

SPP is installed and simulated by using A brand panel and B brand inverter. A total of 5,034 panels are used. 16 inverters are used. The installed power of the system is 2,013.6 kWp.

Table 4. 2 2nd PV option simulation analysis results

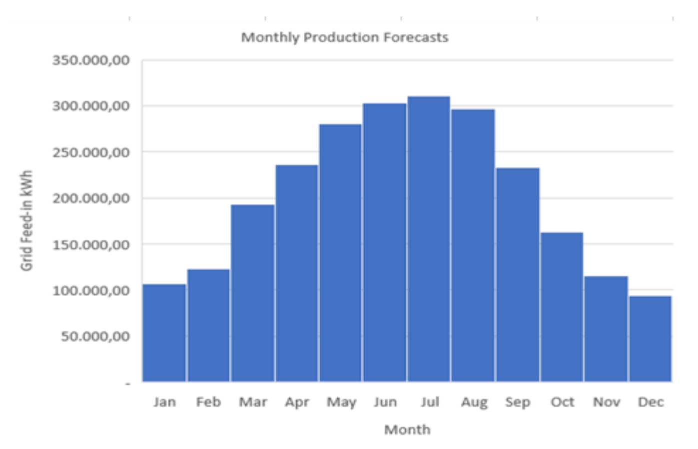


Time	Irradiance onto horizontal plane kWh/m²	Grid Feed-in kWh		
Year	1,512	2,528,686.00		
Jan	64.452	114,486.00		
Feb	73.533	129,940.00		
Mar	115.02	199,390.00		
Apr	141.89	242,130.00		
May	172.03	286,810.00		
Jun	188.27	306,750.00		
Jul	195.52	315,180.00		
Aug	186.07	300,600.00		
Sep	145.26	238,750.00	Spec. Annual Yield	1,255.80 kWh / kWp
Oct	101.66	170,650.00	Performance Ratio (PR)	84.10%
Nov	70.815	122,620.00	Yield Reduction due to Shading	0.2 % / Year
Dec	57.52	101,380.00	CO2 Emissions Avoided	1,188,482 kg / year

4.1.3. 3rd PV Option Simulation Analysis

SPP is established and simulated by using B brand panel and A brand inverter. A total of 5,034 panels are used. 19 pieces of model 1, 2 pieces of model 2 inverters are used. Since it is an optimized system, 2,517 optimizers are used. The installed power of the system is 2,013.6 kWp.

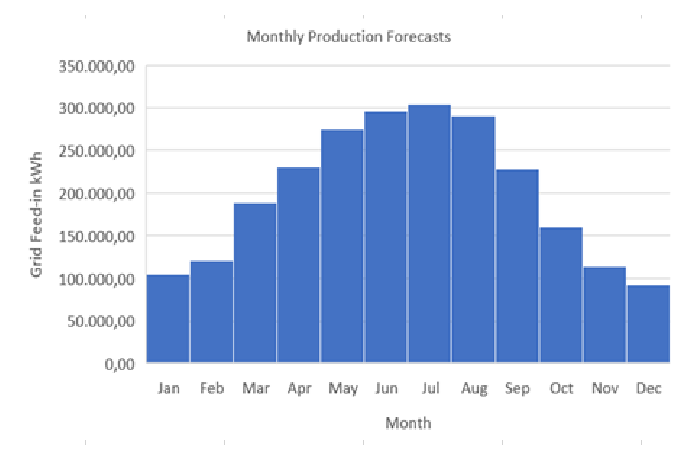
Table 4. 3 3rd PV option simulation analysis results

Time	Irradiance onto horizontal plane kWh/m²	Grid Feed-in kWh		
Year	1,512	2,455,144.00		
Jan	64.452	106,659.00		
Feb	73.533	123,260.00		
Mar	115.02	192,740.00		
Apr	141.89	235,920.00		
May	172.03	280,840.00		
Jun	188.27	302,680.00		
Jul	195.52	311,100.00		
Aug	186.07	296,300.00		
Sep	145.26	232,920.00	Spec. Annual Yield	1,219.28 kWh / kWp
Oct	101.66	163,230.00	Performance Ratio (PR)	81.50%
Nov	70.815	115,620.00	Yield Reduction due to Shading	0.1 % / Year
Dec	57.52	93,875.00	CO2 Emissions Avoided	1,153,918 kg / year

4.1.4. 4th PV Option Simulation Analysis

SPP is installed and simulated by using B brand panel and B brand inverter. A total of 5,034 panels are used. 16 inverters are used. The installed power of the system is 2,013,6 kWp.

Table 4. 4 4th PV option simulation analysis results

Time	Irradiance onto horizontal plane kWh/m²	Grid Feed-in kWh		
Year	1,512	2,404,619.00		
Jan	64.452	104,760.00		
Feb	73.533	120,800.00		
Mar	115.02	188,890.00		
Apr	141.89	231,090.00		
May	172.03	274,940.00		
Jun	188.27	296,150.00		
Jul	195.52	304,480.00		
Aug	186.07	289,950.00		
Sep	145.26	228,000.00	Spec. Annual Yield	1,194,19 kWh / kWp
Oct	101.66	160,070.00	Performance Ratio (PR)	79.80%
Nov	70.815	113,320.00	Yield Reduction due to Shading	0.2 % / Year
Dec	57.52	92,169.00	CO2 Emissions Avoided	1,130,171 kg / year

Simulation studies are conducted for 4 different options. It is simulated that the 1st option will generate 2,582,252 kWh of electricity in one year. The annual CO_2 emission avoided is 1,213,659 kg. It is simulated that the 2nd option will generate 2,528,686 kWh of electricity in one year. The annual CO_2 emission avoided is 1,188,482 kg. It is simulated that the option 3rd will generate 2,455,144 kWh of electricity in one year. The annual CO_2 emission avoided is 1,153,918 kg. It is simulated that the option 4th will generate 2,404,619 kWh of electricity in one year. The annual CO_2 emission avoided is 1,130,171 kg.

The reason why options with A brand inverter produce more electricity than B brand inverter is that it works with optimizer technology. With this technology, it is ensured that the entire string is not affected by the shadowing effect.

The characteristics of the cells in the panels and the technologies used while combining the cells affect the production values.

4.2. Feasibility Analysis

Feasibility analysis of 4 different solar power plants with a power of 2,013.6 kWp is made. The investment cost of the power plant, which consists of A brand panel and A brand inverter, is 510 $ / kWp. The cost of the power plant, which consists of A brand panel and B brand inverter, is 470 $ / kWp. The cost of the power plant, which consists of a B brand panel and A brand inverter, is 490 $ / kWp. The cost of the power plant, which consists of a B brand panel and a B brand inverter, is 450 $ / kWp.

To obtain the investment costs, all materials required for solar power plant installation, project design, mechanical and electrical works and acceptance processes have been calculated. It can also be considered as a turnkey solar power plant installation.

While analyzing investment costs, 2019 consumption invoices and PV*SOL electricity generation values are analyzed. The 2019 exchange rates are based on the market clearing price of the transparency platform of Energy Markets Operating Corporation. Since the firm is a subscriber type industry, the in-house electricity sales unit price is taken from Turkish Electricity Distribution Corporation tariffs approved by the Energy Markets Regulatory Authority.

4.2.1. 1st PV Option Feasibility Analysis

When the feasibility analysis of the solar power plant installed by using A brand panel and A brand inverter is made, it is seen in Table 4.5 that the solar power plant does not meet the factory's consumption. For this reason, the factory will use the electricity generated by SPP itself. This is self-consumption in place. When Table 4.6 is examined, it is seen as a result of the feasibility that the return on investment of the SPP investment is 5.82 years.

Table 4. 5 1st PV option monthly based production/ consumption

MONTHLY BASED PRODUCTION / CONSUMPTION TABLE					
Period	**Installed Power (kWp)**	**Monthly Consumption (kWh)**	**PV*SOL Monthly Generation (kWh)**	**Monthly Difference (kWh)**	**Coverage Rate**
Jan	2,013.60	814,788.45	116,692.00	-698,096.45	14%
Feb	2,013.60	867,132.00	132,650.00	-734,482.00	15%
Mar	2,013.60	1,000,840.05	203,530.00	-797,310.05	20%
Apr	2,013.60	1,113,493.50	247,240.00	-866,253.50	22%
May	2,013.60	1,253,306.25	293,010.00	-960,296.25	23%
Jun	2,013.60	1,009,609.65	313,460.00	-696,149.65	31%
Jul	2,013.60	1,248,108.75	322,020.00	-926,088.75	26%
Aug	2,013.60	1,036,315.35	307,180.00	-729,135.35	30%
Sep	2,013.60	1,372,499.10	243,880.00	-1,128,619.10	18%
Oct	2,013.60	1,449,885.15	174,070.00	-1,275,815.15	12%
Nov	2,013.60	1,219,465.80	125,150.00	-1,094,315.80	10%
Dec	2,013.60	1,334,675.48	103,370.00	-1,231,305.48	8%
TOTAL		13,720,119.53	2,582,252.00		19%

Table 4. 6 Comparative tables of rooftop SPP (1st PV Option)

COMPARATIVE TABLES OF ROOFTOP SPP (1st PV OPTION)										Installed Power		2,013.60	Cost (kWp)	$ 510.00
Num.	**Option**	**Jan.19**	**Fab.19**	**Mar-19**	**Apr.19**	**May-19**	**Jun.19**	**Jul.19**	**Aug.19**	**Sep.19**	**Oct.19**	**Nov.19**	**Dec.19**	**Total**
1	Estimated Invoice Amount for No SPP for the First 12 Months (TL) (Excluding VAT) (Invoice)	250,217.39	334,858.51	382,671.58	366,484.01	508,897.63	477,197.09	511,269.36	392,971.25	531,100.40	560,344.96	475,174.85	430,535.14	**5,221,722.17**
2	Monthly Consumption (kWh)	814,788.45	867,132.00	1,000,840.05	1,113,493.50	1,253,306.25	1,009,609.65	1,248,108.75	1,036,315.35	1,372,499.10	1,449,885.15	1,219,465.80	1,334,675.48	**13,720,119.53**
3	SPP Monthly Generation (kWh)	116,692.00	132,650.00	203,530.00	247,240.00	293,010.00	313,460.00	322,020.00	307,180.00	243,880.00	174,070.00	125,150.00	103,370.00	**2,582,252.00**
4	Production Consumed in the Factory (kWh) (If Production > Consumption [2]) (If Consumption > Production [3])	116,692.00	132,650.00	203,530.00	247,240.00	293,010.00	313,460.00	322,020.00	307,180.00	243,880.00	174,070.00	125,150.00	103,370.00	**2,582,252.00**
5	The Ratio of Production to Consumption	14.32%	15.30%	20.34%	22.20%	23.38%	31.05%	25.80%	29.64%	17.77%	12.01%	10.26%	7.74%	**18.82%**
6	Energy Absorbed on Production (kWh) (If Consumption> Production [2] - [3]) (If Production> Consumption (0))	698,096.45	734,482.00	797,310.05	866,253.50	960,296.25	696,149.65	926,088.75	729,135.35	1,128,619.10	1,275,815.15	1,094,315.80	1,231,305.48	**11,137,867.53**
7	Monthly Average Electricity Consumption Purchase Price Excluding VAT Unit Price (TL / kWh) (Invoice)	0.3071	0.3862	0.3824	0.3291	0.4060	0.4727	0.4096	0.3792	0.3870	0.3865	0.3897	0.3226	**0.38**
8	Monthly Excess Production (kWh) (If Production> Consumption [2-3]) (If Consumption> Production (0))	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
9	Electricity Sales Unit Price (TL / kWh) (EMRA Price List)	0.3726	0.3726	0.3726	0.3645	0.3645	0.3645	0.4254	0.4254	0.4254	0.4900	0.4900	0.4900	**0.4131**
10	Invoice Amount To Be Paid In Case Of SPP (TL) ([6] x [7])	214,381.87	283,633.34	304,851.81	285,109.93	389,922.64	329,038.64	379,358.61	276,488.45	436,728.92	493,071.19	426,409.13	397,190.39	**4,216,184.93**
11	Consumption Surplus Production Sales Price (TL) ([8] x [9])	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
12	Monthly Earnings (TL) ([1] - [10] + [11])	35,835.52	51,225.17	77,819.77	81,374.08	118,974.99	148,158.45	131,910.75	116,482.80	94,371.48	67,273.77	48,765.72	33,344.75	**1,005,537.24**
13	Monthly Average Exchange Rate of Dollar	5.36	5.26	5.44	5.72	6.05	5.82	5.67	5.61	5.71	5.78	5.72	5.82	**5.66**
14	Monthly Earnings ($)	6,682.21	9,736.87	14,309.31	14,231.22	19,668.44	25,458.46	23,259.26	20,774.00	16,520.55	11,647.93	8,526.27	5,726.48	**176,540.99**
15	**Annual Total Earnings (TL) (Total Earnings Between the 1 st and 12 th Months)**	**1,005,537.24**												
16	**Annual Total Earnings ($) (Total Earnings Between the 1 st and 12 th Months)**	**176,540.99**												
17	**Investment Cost**	**1,026,936.00**												
18	**Return on Investment (Year)**	**5.82**												

4.2.2. 2nd PV Option Feasibility Analysis

When the feasibility analysis of the solar power plant installed by using A brand panel and B brand inverter is made, it is seen in Table 4.7 that the solar power plant does not meet the factory's consumption. For this reason, the factory will use the electricity generated by SPP itself. This is self-consumption in place. When Table 4.8 is examined, it is seen as a result of the feasibility that the return on investment of the SPP investment is 5.47 years.

Table 4. 7 2nd PV option monthly based production/ consumption

MONTHLY BASED PRODUCTION / CONSUMPTION TABLE					
Period	**Installed Power (kWp)**	**Monthly Consumption (kWh)**	**PV*SOL Monthly Generation (kWh)**	**Monthly Difference (kWh)**	**Coverage Rate**
Jan	2,013.60	814,788.45	114,486.00	-700,302.45	14%
Feb	2,013.60	867,132.00	129,940.00	-737,192.00	15%
Mar	2,013.60	1,000,840.05	199,390.00	-801,450.05	20%
Apr	2,013.60	1,113,493.50	242,130.00	-871,363.50	22%
May	2,013.60	1,253,306.25	286,810.00	-966,496.25	23%
Jun	2,013.60	1,009,609.65	306,750.00	-702,859.65	30%
Jul	2,013.60	1,248,108.75	315,180.00	-932,928.75	25%
Aug	2,013.60	1,036,315.35	300,600.00	-735,715.35	29%
Sep	2,013.60	1,372,499.10	238,750.00	-1,133,749.10	17%
Oct	2,013.60	1,449,885.15	170,650.00	-1,279,235.15	12%
Nov	2,013.60	1,219,465.80	122,620.00	-1,096,845.80	10%
Dec	2,013.60	1,334,675.48	101,380.00	-1,233,295.48	8%
TOTAL		13,720,119.53	2,528,686.00		18%

Table 4. 8 Comparative tables of rooftop SPP (2nd PV Option)

COMPARATIVE TABLES OF ROOFTOP SPP (2nd PV OPTION)										Installed Power		2,013.60	Cost (kWp)	$ 470.00
Num.	Option	Jan.19	Fab.19	Mar-19	Apr.19	May-19	Jun.19	Jul.19	Aug.19	Sep.19	Oct.19	Nov.19	Dec.19	Total
1	Estimated Invoice Amount for No SPP for the First 12 Months (TL) (Excluding VAT) (Invoice)	250,217.39	334,858.51	382,671.58	366,484.01	508,897.63	477,197.09	511,269.36	392,971.25	531,100.40	560,344.96	475,174.85	430,535.14	**5,221,722.17**
2	Monthly Consumption (kWh)	814,788.45	867,132.00	1,000,840.05	1,113,493.50	1,253,306.25	1,009,609.65	1,248,108.75	1,036,315.35	1,372,499.10	1,449,885.15	1,219,465.80	1,334,675.48	**13,720,119.53**
3	SPP Monthly Generation (kWh)	114,486.00	129,940.00	199,390.00	242,130.00	286,810.00	306,750.00	315,180.00	300,600.00	238,750.00	170,650.00	122,620.00	101,380.00	**2,528,686.00**
4	Production Consumed in the Factory (kWh) (If Production > Consumption [2]) (If Consumption > Production [3])	114,486.00	129,940.00	199,390.00	242,130.00	286,810.00	306,750.00	315,180.00	300,600.00	238,750.00	170,650.00	122,620.00	101,380.00	**2,528,686.00**
5	The Ratio of Production to Consumption	14.05%	14.99%	19.92%	21.75%	22.88%	30.38%	25.25%	29.01%	17.40%	11.77%	10.06%	7.60%	**18.43%**
6	Energy Absorbed on Production (kWh) (If Consumption> Production [2] - [3]) (If Production> Consumption (0))	700,302.45	737,192.00	801,450.05	871,363.50	966,496.25	702,859.65	932,928.75	735,715.35	1,133,749.10	1,279,235.15	1,096,845.80	1,233,295.48	**11,191,433.53**
7	Monthly Average Electricity Consumption Purchase Price Excluding VAT Unit Price (TL / kWh) (Invoice)	0.3071	0.3862	0.3824	0.3291	0.4060	0.4727	0.4096	0.3792	0.3870	0.3865	0.3897	0.3226	**0.38**
8	Monthly Excess Production (kWh) (If Production> Consumption [2-3]) (If Consumption> Production (0))	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
9	Electricity Sales Unit Price (TL / kWh) (EMRA Price List)	0.3726	0.3726	0.3726	0.3645	0.3645	0.3645	0.4254	0.4254	0.4254	0.4900	0.4900	0.4900	**0.4131**
10	Invoice Amount To Be Paid In Case Of SPP (TL) ([6] x [7])	215,059.32	284,679.86	306,434.74	286,791.79	392,440.12	332,210.16	382,160.52	278,983.59	438,714.02	494,392.93	427,394.96	397,832.32	**4,237,094.32**
11	Consumption Surplus Production Sales Price (TL) ([8] x [9])	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
12	Monthly Earnings (TL) ([1] - [10] + [11])	35,158.07	50,178.65	76,236.84	79,692.22	116,457.51	144,986.93	129,108.84	113,987.66	92,386.38	65,952.03	47,779.89	32,702.82	**984,627.85**
13	Monthly Average Exchange Rate of Dollar	5.36	5.26	5.44	5.72	6.05	5.82	5.67	5.61	5.71	5.78	5.72	5.82	**5.66**
14	Monthly Earnings ($)	6,555.88	9,537.95	14,018.24	13,937.09	19,252.27	24,913.49	22,765.21	20,329.01	16,173.04	11,419.08	8,353.90	5,616.24	**172,871.40**
15	**Annual Total Earnings (TL)** **(Total Earnings Between the 1 st and 12 th Months)**	**984,627.85**												
16	**Annual Total Earnings ($)** **(Total Earnings Between the 1 st and 12 th Months)**	**172,871.40**												
17	**Investment Cost**	**946,392.00**												
18	**Return on Investment (Year)**	**5.47**												

4.2.3. 3rd PV Option Feasibility Analysis

When the feasibility analysis of the solar power plant installed by using A brand panel and B brand inverter is made, it is seen in Table 4.9 that the solar power plant does not meet the factory's consumption. For this reason, the factory will use the electricity generated by SPP itself. This is self-consumption in place. When Table 4.10 is examined, it is seen as a result of the feasibility that the return on investment of the SPP investment is 5.87 years.

Table 4. 9 3rd PV option monthly based production/ consumption

MONTHLY BASED PRODUCTION / CONSUMPTION TABLE					
Period	**Installed Power (kWp)**	**Monthly Consumption (kWh)**	**PV*SOL Monthly Generation (kWh)**	**Monthly Difference (kWh)**	**Coverage Rate**
Jan	2,013.60	814.788,45	106.659,00	-708.129,45	0,13
Feb	2,013.60	867.132,00	123.260,00	-743.872,00	0,14
Mar	2,013.60	1.000.840,05	192.740,00	-808.100,05	0,19
Apr	2,013.60	1.113.493,50	235.920,00	-877.573,50	0,21
May	2,013.60	1.253.306,25	280.840,00	-972.466,25	0,22
Jun	2,013.60	1.009.609,65	302.680,00	-706.929,65	0,30
Jul	2,013.60	1.248.108,75	311.100,00	-937.008,75	0,25
Aug	2,013.60	1.036.315,35	296.300,00	-740.015,35	0,29
Sep	2,013.60	1.372.499,10	232.920,00	-1.139.579,10	0,17
Oct	2,013.60	1.449.885,15	163.230,00	-1.286.655,15	0,11
Nov	2,013.60	1.219.465,80	115.620,00	-1.103.845,80	0,09
Dec	2,013.60	1.334.675,48	93.875,00	-1.240.800,48	0,07
TOTAL		13.720.119,53	2.455.144,00		18%

Table 4. 10 Comparative tables of rooftop SPP (3rd PV Option)

COMPARATIVE TABLES OF ROOFTOP SPP (3rd PV OPTION)										Installed Power		2,013.60	Cost (kWp)	$ 490.00
Num.	**Option**	**Jan.19**	**Fab.19**	**Mar-19**	**Apr.19**	**May-19**	**Jun.19**	**Jul.19**	**Aug.19**	**Sep.19**	**Oct.19**	**Nov.19**	**Dec.19**	**Total**
1	Estimated Invoice Amount for No SPP for the First 12 Months (TL) (Excluding VAT) (Invoice)	250,217.39	334,858.51	382,671.58	366,484.01	508,897.63	477,197.09	511,269.36	392,971.25	531,100.40	560,344.96	475,174.85	430,535.14	**5,221,722.17**
2	Monthly Consumption (kWh)	814,788.45	867,132.00	1,000,840.05	1,113,493.50	1,253,306.25	1,009,609.65	1,248,108.75	1,036,315.35	1,372,499.10	1,449,885.15	1,219,465.80	1,334,675.48	**13,720,119.53**
3	SPP Monthly Generation (kWh)	106,659.00	123,260.00	192,740.00	235,920.00	280,840.00	302,680.00	311,100.00	296,300.00	232,920.00	163,230.00	115,620.00	93,875.00	**2,455,144.00**
4	Production Consumed in the Factory (kWh) (If Production > Consumption [2]) (If Consumption > Production [3])	106,659.00	123,260.00	192,740.00	235,920.00	280,840.00	302,680.00	311,100.00	296,300.00	232,920.00	163,230.00	115,620.00	93,875.00	**2,455,144.00**
5	The ratio of production to consumption	13.09%	14.21%	19.26%	21.19%	22.41%	29.98%	24.93%	28.59%	16.97%	11.26%	9.48%	7.03%	**17.89%**
6	Energy Absorbed on Production (kWh) (If Consumption> Production [2] - [3]) (If Production> Consumption (0))	708,129.45	743,872.00	808,100.05	877,573.50	972,466.25	706,929.65	937,008.75	740,015.35	1,139,579.10	1,286,655.15	1,103,845.80	1,240,800.48	**11,264,975.53**
7	Monthly Average Electricity Consumption Purchase Price Excluding VAT Unit Price (TL / kWh) (Invoice)	0.3071	0.3862	0.3824	0.3291	0.4060	0.4727	0.4096	0.3792	0.3870	0.3865	0.3897	0.3226	**0.38**
8	Monthly Excess Production (kWh) (If Production> Consumption [2-3]) (If Consumption> Production (0))	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
9	Electricity Sales Unit Price (TL / kWh) (EMRA Price List)	0.3726	0.3726	0.3726	0.3645	0.3645	0.3645	0.4254	0.4254	0.4254	0.4900	0.4900	0.4900	**0.4131**
10	SPP Durumunda Ödenecek Fatura Tutarı (TL) ([6] x [7])	217,462.95	287,259.46	308,977.37	288,835.68	394,864.20	334,133.86	383,831.83	280,614.16	440,969.99	497,260.58	430,122.57	400,253.26	**4,264,585.90**
11	Consumption Surplus Production Sales Price (TL) ([8] x [9])	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
12	Monthly Earnings (TL) ([1] - [10] + [11])	32,754.44	47,599.05	73,694.21	77,648.33	114,033.43	143,063.23	127,437.53	112,357.09	90,130.41	63,084.38	45,052.28	30,281.88	**957,136.27**
13	Monthly Average Dollar Rate	5.36	5.26	5.44	5.72	6.05	5.82	5.67	5.61	5.71	5.78	5.72	5.82	**5.66**
14	Monthly Earnings ($)	6,107.68	9,047.62	13,550.71	13,579.64	18,851.53	24,582.93	22,470.52	20,038.21	15,778.12	10,922.57	7,877.00	5,200.48	**168,006.99**
15	**Annual Total Earnings (TL)** **(Total Earnings Between the 1 st and 12 th Months)**	**957,136.27**												
16	**Annual Total Earnings ($)** **(Total Earnings Between the 1 st and 12 th Months)**	**168,006.99**												
17	**Investment Cost**	**986,664.00**												
18	**Return on Investment (Year)**	**5.87**												

4.2.4. 4th PV Option Feasibility Analysis

When the feasibility analysis of the solar power plant installed by using B brand panel and B brand inverter is made, it is seen in Table 4.11 that the solar power plant does not meet the factory's consumption. For this reason, the factory will use the electricity generated by SPP itself. This is self-consumption in place. When Table 4.12 is examined, it is seen as a result of the feasibility that the return on investment of the SPP investment is 5,51 years.

Table 4. 11 4th PV option monthly based production/ consumption

MONTHLY BASED PRODUCTION / CONSUMPTION TABLE					
Period	**Installed Power (kWp)**	**Monthly Consumption (kWh)**	**PV*SOL Monthly Generation (kWh)**	**Monthly Difference (kWh)**	**Coverage Rate**
Jan	2.013,60	814,788.45	104,760.00	-710,028.45	13%
Feb	2.013,60	867,132.00	120,800.00	-746,332.00	14%
Mar	2.013,60	1,000,840.05	188,890.00	-811,950.05	19%
Apr	2.013,60	1,113,493.50	231,090.00	-882,403.50	21%
May	2.013,60	1,253,306.25	274,940.00	-978,366.25	22%
Jun	2.013,60	1,009,609.65	296,150.00	-713,459.65	29%
Jul	2.013,60	1,248,108.75	304,480.00	-943,628.75	24%
Aug	2.013,60	1,036,315.35	289,950.00	-746,365.35	28%
Sep	2.013,60	1,372,499.10	228,000.00	-1,144,499.10	17%
Oct	2.013,60	1,449,885.15	160,070.00	-1,289,815.15	11%
Nov	2.013,60	1,219,465.80	113,320.00	-1,106,145.80	9%
Dec	2.013,60	1,334,675.48	92,169.00	-1,242,506.48	7%
TOTAL		13,720,119.53	2,404,619.00		18%

Table 4. 12 Comparative tables of rooftop SPP (4th PV Option)

COMPARATIVE TABLES OF ROOFTOP SPP (4th PV OPTION)										Installed Power		2,013.60	Cost (kWp)	$ 450.00
Num.	Option	Jan.19	Fab.19	Mar-19	Apr.19	May-19	Jun.19	Jul.19	Aug.19	Sep.19	Oct.19	Nov.19	Dec.19	Total
1	Estimated Invoice Amount for No SPP for the First 12 Months (TL) (Excluding VAT) (Invoice)	250,217.39	334,858.51	382,671.58	366,484.01	508,897.63	477,197.09	511,269.36	392,971.25	531,100.40	560,344.96	475,174.85	430,535.14	5,221,722.17
2	Monthly Consumption (kWh)	814,788.45	867,132.00	1,000,840.05	1,113,493.50	1,253,306.25	1,009,609.65	1,248,108.75	1,036,315.35	1,372,499.10	1,449,885.15	1,219,465.80	1,334,675.48	13,720,119.53
3	SPP Monthly Generation (kWh)	104,760.00	120,800.00	188,890.00	231,090.00	274,940.00	296,150.00	304,480.00	289,950.00	228,000.00	160,070.00	113,320.00	92,169.00	2,404,619.00
4	Production Consumed in the Factory (kWh) (If Production > Consumption [2]) (If Consumption > Production [3])	104,760.00	120,800.00	188,890.00	231,090.00	274,940.00	296,150.00	304,480.00	289,950.00	228,000.00	160,070.00	113,320.00	92,169.00	2,404,619.00
5	The Ratio of Production to Consumption	12.86%	13.93%	18.87%	20.75%	21.94%	29.33%	24.40%	27.98%	16.61%	11.04%	9.29%	6.91%	17.53%
6	Energy Absorbed on Production (kWh) (If Consumption> Production [2] - [3]) (If Production> Consumption (0))	710,028.45	746,332.00	811,950.05	882,403.50	978,366.25	713,459.65	943,628.75	746,365.35	1,144,499.10	1,289,815.15	1,106,145.80	1,242,506.48	11,315,500.53
7	Monthly Average Electricity Consumption Purchase Price Excluding VAT Unit Price (TL / kWh) (Invoice)	0.3071	0.3862	0.3824	0.3291	0.4060	0.4727	0.4096	0.3792	0.3870	0.3865	0.3897	0.3226	0.38
8	Monthly Excess Production (kWh) (If Production> Consumption [2-3]) (If Consumption> Production (0))	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Electricity Sales Unit Price (TL / kWh) (EMRA Price List)	0.3726	0.3726	0.3726	0.3645	0.3645	0.3645	0.4254	0.4254	0.4254	0.4900	0.4900	0.4900	0.4131
10	Invoice Amount To Be Paid In Case Of SPP (TL) ([6] x [7])	218,046.13	288,209.43	310,449.42	290,425.38	397,259.86	337,220.30	386,543.61	283,022.08	442,873.83	498,481.84	431,018.78	400,803.57	4,284,354.23
11	Consumption Surplus Production Sales Price (TL) ([8] x [9])	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	Monthly Earnings (TL) ([1] - [10] + [11])	32,171.26	46,649.08	72,222.16	76,058.63	111,637.77	139,976.79	124,725.75	109,949.17	88,226.57	61,863.12	44,156.07	29,731.57	937,367.94
13	Monthly Average Exchange Rate of Dollar	5.36	5.26	5.44	5.72	6.05	5.82	5.67	5.61	5.71	5.78	5.72	5.82	5.66
14	Monthly Earnings ($)	5,998.94	8,867.05	13,280.03	13,301.62	18,455.49	24,052.58	21,992.36	19,608.77	15,444.83	10,711.12	7,720.31	5,105.97	164,539.06
15	**Annual Total Earnings (TL)** **(Total Earnings Between the 1 st and 12 th Months)**	**937,367.94**												
16	**Annual Total Earnings ($)** **(Total Earnings Between the 1 st and 12 th Months)**	**164,539.06**												
17	**Investment Cost**	**906,120.00**												
18	**Return on Investment (Year)**	**5.51**												

A feasibility study is conducted for 4 different options. While conducting the feasibility study, the dollar rate, electricity unit sales price, electricity purchase unit price, monthly consumption of the factory are taken as constant for all 4 options. One of the most important values determining the feasibility results is the production value obtained as a result of simulation. The return on investment varies according to the electricity production values.

Apart from the production value obtained in the simulation, the cost of the materials (projecting, maintenance and repair costs, etc.) that create the system to be installed is also effective.

As a result of feasibility, the closest option where the investment cost reaches the return on investment is Option 2nd. 1st option takes 5.82 years, 2nd option takes 5.47 years, 3rd option takes 5.87 years, and 4th option takes 5.51 years comes to return on investment.

4.3. Multi-Criteria Decision Making Steps

In the study, VIKOR method is used for the selection of the system components of the solar power plant planned to be built on the factory roof. First of all, the problem is determined and the criteria and alternatives for this problem are defined. Pair-wise comparison is made by the expert using the stages of the AHP method. The values obtained as a result of the comparison are normalized and the priority matrix to be used in weighting is created. The consistency index is calculated to check whether the comparison is consistent. Using the weights obtained by the AHP method, the following steps are applied to select the most optimal alternative with the VIKOR method.

First the problem and the target are determined. The problem is the selection of the system components of the solar power plant planned to be installed on the factory roof. Our goal is to select the most optimum system components in terms of cost and power generation among the system components created using different products.

Then the criteria are determined. When the studies on energy issues using the multi-criteria decision making method are examined, it is seen that the criteria given in Table 4.13 are generally used. Experts' opinions are taken to determine the criteria. Based on these views, it is decided to use commonly used criteria. Technically, power generation, performance ratio, environmentally, CO2 emissions avoided, economically, investment cost and return on investment criteria are selected. The power generation, performance ratio and CO_2 emissions avoided obtained as a result of the simulation are used as criteria. The investment cost accepted in the feasibility study and return on investment obtained as a result of the feasibility study are considered as other criteria.

Table 4. 13 List of evaluation criteria used in MCDM studies conducted on energy issues (Kaya &Kahraman, 2010)

Aspects	Criteria
Technical	Power Generation
	Active Operation Time
	Efficiency
	Energy System Reliability and Security
	Storability
	Location
	Know How
	Performans Ratio
	R&D Capability
Environmental	Air -Noise-Water Pollution
	Land Usage
	Gas Emission (NO_x, CO_2, CO, SO_2)
Economic	Return On Investment
	Initial Investment Cost
	Payback Period
	Total Annual Cost
	Operation and Maintenance Cost
	Depletable
	Net Present Value
	Enhanced Local Economic Development
	Taxes and Tariff
	Economic Lifetime
Social	Social Acceptability
	Job Creation
	Social Benefits
	Governmental Support
	Social Awareness
	Social Trust & Fairness

Table 4. 14 Criteria used to evaluate the alternatives

Criteria	Name	Unit
C_1	Power Generation	kWh
C_2	Investment Cost	$
C_3	Return on Investment	Year
C_4	Performance Ratio	%
C_5	CO2 Emissions Avoided	kg/Year

Power Generation (C1): It is the annual energy produced by the system as a result of the simulation.

Investment Cost (C2): It is the cost required for the establishment of a turnkey solar power plant.

Return on Investment (C3): It is the time during which the investment made for the solar power plant is recovered.

Performance Ratio (C4): It refers to the division of the energy produced by the SPP into the highest possible production in theory. It is one of the parameters used to measure the efficiency of SPPs. (Deniz,2013)

CO2 Emissions Avoided (C5): It is the annual avoided greenhouse gas emission. Greenhouse gases consist of gases such as carbon dioxide, methane, nitrous oxide, etc., which have the property of retaining heat in the atmosphere. These gases cause global warming and climate change by causing the earth to warm up more. (Erdogan,2020)

After determining criteria, alternatives are determined. While creating alternatives, 4 different options consisting of different brand models of panels and inverters are used. These are the options used in the simulation and feasibility study.

Table 4. 15 Identifying alternatives to consider

Alternative	Name	The Used Products
A_1	1.Option	A Brand Panel + A Brand Inverter
A_2	2.Option	A Brand Panel + B Brand Inverter
A_3	3.Option	B Brand Panel + A Brand Inverter
A_4	4.Option	B Brand Panel + B Brand Inverter

4.3.1. AHP Application Steps

The weights of each criterion are calculated using the AHP method. The steps used in calculating the weights of the criteria are given below.

Step-1: Pair-wise comparison matrices are created. The preference scale with 1-9 points given in Table 3.8 is used.

The determined 5 criteria are compared using the pairwise comparison method and the pair-wise comparison matrix given in Table 4.15 is created. While making the pair-wise comparison, the opinion of an expert working in the field of renewable energy was taken.

Table 4. 16 Pair-wise Comparison Matrix for Criteria

Criteria	C_1	C_2	C_3	C_4	C_5
C_1	1	3	5	5	7
C_2	0.333	1	3	3	7
C_3	0.200	0.333	1	3	7
C_4	0.200	0.333	0.333	1	3
C_5	0.143	0.143	0.143	0.333	1

Step-2: Normalized matrix is created. The normalized matrix obtained using the equation (2) is given in Table 4.16.

Table 4. 17 Normalized Matrix of Criteria

Criteria	C_1	C_2	C_3	C_4	C_5
C_1	0.53	0.62	0.53	0.41	0.28
C_2	0.18	0.21	0.32	0.24	0.28
C_3	0.11	0.07	0.11	0.24	0.28
C_4	0.11	0.07	0.04	0.08	0.12
C_5	0.08	0.03	0.02	0.03	0.04
Sum	1	1	1	1	1

Step-3: Priority vector matrix is created. The weight of each criterion is found by using the equation (3).

Table 4. 18 Weights of Criteria

Criteria	Weights
C_1	0.474
C_2	0.245
C_3	0.161
C_4	0.082
C_5	0.038

According to Table 4.17, the criterion with the highest weight is the power generation. The second highest weight is the investment cost. Third is the highest weight return on investment, followed by the performance ratio and blocked CO_2 emissions avoided.

Step-4: The Consistency Index (CI) is calculated.

1. The weighted sum vector matrix is obtained by multiplying the values given in Table 4.15 and Table 4.17.

Table 4. 19 Weighted sum vector matrix

Criteria	C_1	C_2	C_3	C_4	C_5
C_1	0.47	0.74	0.8	0.41	0.26
C_2	0.16	0.25	0.48	0.25	0.26
C_3	0.09	0.08	0.16	0.25	0.26
C_4	0.09	0.08	0.05	0.08	0.11
C_5	0.07	0.04	0.02	0.03	0.04

2. The basic values of the criteria are given in Table 4.19.

Table 4. 20 Obtaining basic values

Criteria	C_1	C_2	C_3	C_4	C_5	Sum	Weights	Basic Values
C_1	0.47	0.74	0.8	0.41	0.26	2.69	0.47	5.67
C_2	0.16	0.25	0.48	0.25	0.26	1.40	0.25	5.70
C_3	0.09	0.08	0.16	0.25	0.26	0.85	0.16	5.27
C_4	0.09	0.08	0.05	0.08	0.11	0.43	0.08	5.16
C_5	0.07	0.04	0.02	0.03	0.04	0.19	0.04	5.08

3. When the arithmetic average of the basic values given in Table 4.19 is taken, the value of λmax = 5.37 is obtained.
4. After the λmax value was found, the consistency index (CI) is calculated. The CI value is calculated using the equation (4) and the value of 0.093 is obtained.
5. The consistency ratio (CR) is calculated. The CR value is calculated using the equation (5). Since there are 5 criteria (n=5), the IR value is 1.11 (Table 3.19). The CR value is calculated as 0.084 as a result of the transactions.

   The value of 0.084 being less than 0,10 indicates that the pair-wise comparison is consistent.

The weights of each criterion are found by the pair-wise comparison method and the consistency index is calculated. After this stage, the best alternative will be selected using the VIKOR method.

4.3.2. VIKOR Application Steps

In study, the number of alternatives is 4 (m=4) and the number of criteria is 5 (n=5). The data to be used in the application are given in Table 4.20. Power Generation (C_1), Performance Ratio (C_4) and CO_2 Emissions Avoided (C_5) values from the data given in the table are obtained for each alternative as a result of simulation. Investment Cost (C_2) is obtained by multiplying the unit prices used in feasibility with the installed capacity of the system. Return on Investment (C_3) is obtained as a result of feasibility for each alternative.

Table 4. 21 Numerical values of each criterion for each alternative

Altenative / Criteria	C_1	C_2	C_3	C_4	C_5
A_1	2,582,252	1,026,936	5.82	85.80	1,213,659.00
A_2	2,528,686	946,392	5.47	84.10	1,188,482.00
A_3	2,455,144	986,664	5.87	81.50	1,153,918.00
A_4	2,404,619	906,120	5.51	79.80	1,130,171.00

Step-1: The best (f_i*) and worst (f_i^-) values are determined for all criteria. While creating the table, attention is paid to the effect of the criteria on benefit or cost/risk. Benefit phrase is added next to the criteria expressing benefit. Cost/risk phrase is added next to the criteria expressing cost/risk. Equation (6) is used for criteria expressing benefit and equation (7) is used for criteria expressing cost/risk.

Table 4. 22 Benefit and cost/risk values of each criterion

Altenative/Criteria	C_1 (benefit)	C_2 (cost/risk)	C_3 (cost/risk)	C_4 (benefit)	C_5 (benefit)
A_1	2,582,252	1,026,936	5.82	85.80	1,213,659.00
A_2	2,528,686	946,392	5.47	84.10	1,188,482.00
A_3	2,455,144	986,664	5.87	81.50	1,153,918.00
A_4	2,404,619	906,120	5.51	79.80	1,130,171.00
Best (f_i*)	2,582,252	906,120	5.47	85.80	1,213,659.00
Worst (f_i^-)	2,404,619	1,026,936	5.87	79.80	1,130,171.00

Step-2: S_j ve R_j values are calculated for j=1, 2, …, j. The criteria weights, which were found in advance by the AHP method and given in Table 4.17, are used for the w_j values. Equation (8) is used to find the S_j values, and equation (9) is used to find the R_j values. The S_j and R_j values obtained by using equation (8) and equation (9) are given in Table 4.22.

Using Equation (8), the S_1 value is calculated as follows;

$S_1=\sum(0.474 * ((2{,}582{,}252 - 2{,}582{,}252))/(2{,}582{,}252 - 2{,}404{,}619)) + (0.245 * ((906{,}120 - 1{,}026{,}936))/(\ 906{,}120\ - 1{,}026{,}936))\ + 0.161 * ((5.47 - 5.82))/(\ 5.47 - 5.87) + 0.082 * (85.80 - 85.80)/(85.80 - 79.80)) + (0.038 * (1{,}213{,}659.00 - 1{,}213{,}659.00)/(1{,}213{,}659.00 - 1{,}130{,}171.00)\ ]$

$S_1=0.0000 + 0.245 + 0.141 + 0.0000 + 0.0000$

$S_1= 0.386$

Using Equation (9), the R_1 value was calculated as follows;

R_1 =max $[0.0000 + 0.245 + 0.141 + 0.0000 + 0.0000]$

R_1 =0.245

Table 4. 23 S_j and R_j Values

Altenative/ Criteria	C_1	C_2	C_3	C_4	C_5	S_j	R_j
A_1	0.000	0.245	0.141	0.000	0.000	0.386	0.245
A_2	0.143	0.082	0.000	0.023	0.011	0.259	0.143
A_3	0.339	0.163	0.161	0.059	0.027	0.749	0.339
A_4	0.474	0.000	0.016	0.082	0.038	0.610	0.474

S^*,S^-,R^*, R^- values are found by using Equation (11).

S^* = min [(S_j) | j =1, 2, …, m] = min [0.386-0.259-0.749-0.610]

S^*= 0.259

S^- = max [(S_j) | j =1, 2, …, m] =max [0.386-0.259-0.749-0.610]

S^-= 0.749

R^*= min [(R_j) | j =1, 2, …, m] = min [0.245-0.143-0.339-0.474]

R^*= 0.143

R^- = max [(R_j) | j =1, 2, …, m] = max [0.245-0.143-0.339-0.474]

R^-=0.474

Step-3: The Q_j value is calculated for j=1, 2, …, j. Equation (10) is used while calculating the Q_j value. The Q_j values calculated for different v values using equation (10) are given in Table 4.23.

Table 4. 24 Values of ideal solution "Q" for different values of v

Alternative/ Max. Grup Utility	Q_j (v=0)	Q_j (v=0.25)	Q_j (v=0.5)	Q_j (v=0.75)	Q_j (v=1)
A_1	0.309	0.296	0.283	0.271	0.258
A_2	0.000	0.000	0.000	0.000	0.000
A_3	0.593	0.695	0.796	0.898	1.000
A_4	1.000	0.929	0.858	0.787	0.716

$$Q_1 = \left[\frac{0.5(0.386-0.259)}{0.749-0.259} + \frac{(1-0.5)(0.245-0.143)}{0.474-0.143}\right]$$

$$Q_1 = 0.283$$

Step-4: After calculating the S_j, R_j and Q_j values, each is ordered from smallest to largest. The ranking result is given in Table 4.24.

Table 4. 25 The scoring of S_j, R_j and Q_j and rank of each alternative

Alternative	S_j	Rank	R_j	Rank	Q_j (v=0)	Rank	Q_j (v=0.25)	Rank
A_1	0.386	2	0.245	2	0.309	2	0.296	2
A_2	0.259	1	0.143	1	0.000	1	0.000	1
A_3	0.749	4	0.339	3	0.593	3	0.695	3
A_4	0.610	3	0.474	4	1.000	4	0.929	4

Alternative	Q_j (v=0.5)	Rank	Q_j (v=0.75)	Rank	Q_j (v=1)	Rank
A_1	0.283	2	0.271	2	0.258	2
A_2	0.000	1	0.000	1	0.000	1
A_3	0.796	3	0.898	4	1.000	4
A_4	0.858	4	0.787	3	0.716	3

Step-5: It is checked whether the minimum Q_j value satisfies both conditions in order to be the most suitable alternative solution. According to the results of the calculations made in the VIKOR method, A_2 (which has the lowest value among its values, seems to have an acceptable advantage compared to other alternatives.

Condition 1: Q (A_2) – Q (A_1) ≥ DQ must satisfy equation (12). In the calculations made using equation (12), the DQ value was taken as 0.333 (DQ=1 / (4-1)).

Since v = 0 is 0.309-0≥0.333, the advantage condition is not met.
Since v = 0.25 is 0.296-0≥0.333, the advantage condition is not met.
Since v = 0.5 is 0.283-0≥0.333, the advantage condition is not met.
Since v = 0.75 is 0.271-0≥0.333, the advantage condition is not met.
Since v = 1 is 0.258-0≥0.333, the advantage condition is not met.

Condition 2: The alternative A_2 with the smallest Qj value is the best alternative. When the S_j and R_j values of the A_2 alternative are also listed, they are in the first place. In this case, Condition-2 is satisfied.

Since condition 1 is not met, the solution set is determined by the equation $Q(A_m)$- $Q(A_1)$ <DQ. Failure to provide condition-1 indicates that there is no significant difference between the alternatives.

Since 0.309-0.000 <0.333 for case v = 0, the advantage condition is fulfilled.

Since 0.296-0.000 <0.333 for case v = 0.25, the advantage condition is fulfilled.

Since 0.283-0.000 <0.333 for case v = 0.50, the advantage condition is fulfilled.

Since 0.271-0.000 <0.333 for case v = 0.75, the advantage condition is fulfilled.

Since 0.258-0.000 <0.333 for case v = 1, the advantage condition is fulfilled.

5. CONCLUSIONS

In this study, a simulation and feasibility study are conducted for the installation of SPP on the roof of a factory that produces in the Organized Industrial Zone. 4 options are created using different brands of 2 panels and 2 inverters. Areas that will cause shadingare determined by exploration on the roof. Panels are not placed in areas where shading would affect production. As a result of the panel layout, the installed power of the system is calculated as 2,013.6 kWp.

Simulations are made with the PV*SOL simulation program for 4 different options without changing the installed power of the system. When the simulations are compared, it is seen that the system that will generate the most electricity is 1st option. According to electricity generation options are ranked as 1st option, 2nd option, 3rd option and 4th option, respectively.

A feasibility study is conducted for 4 different options. Looking at the feasibility result, it is seen that the shortest return on investment is in Option 2nd. According to the return on investment options are ranked as 2nd Option, 4th Option, 1st Option and 3rd Option, respectively.

Table 5. 1 Comparison of simulation and feasibility results of 4 different options

Options	Power Generation (kWh)	CO_2 Emissions Avoided (kg /year)	Investment Cost	Return on Investment (year)
1st PV Option	2,582,252	1,213,659	$ 1,026,936.00	5.82
2nd PV Option	2,528,686	1,188,482	$ 9,463,920.00	5.47
3rd PV Option	2,455,144	1,153,918	$ 9,866,640.00	5.87
4th PV Option	2,404,619	1,130,171	$ 9,061,200.00	5.51

In this study, multi-criteria decision making is also used to select the best option. The values obtained as a result of simulation and feasibility analyzes are accepted as criteria. AHP method is used for weighting the criteria. Alternatives are ranked according to the criteria using the VIKOR method. The order of the alternatives according to their Q_j values is given in Table 5.2.

Table 5.2 Acceptable stability in decision making

Q_j (v =0)	$A_2 > A_1 > A_3 > A_4$
Q_j (v =0.25)	$A_2 > A_1 > A_3 > A_4$
Q_j (v =0.50)	$A_2 > A_1 > A_3 > A_4$
Q_j (v =0.75)	$A_2 > A_1 > A_3 > A_4$
Q_j (v =1)	$A_2 > A_1 > A_3 > A_4$
S_j	$A_2 > A_1 > A_4 > A_3$
R_j	$A_2 > A_1 > A_3 > A_4$

According to Table 5.2, the most suitable alternative is the 2nd option. The secondbest alternative is the 1st option. Option 2nd is followed by Options 3rd and 4th, respectively. According to the results of the application, it is decided to establish a solar power plant with the 2nd option, A brand panel and B brand inverter.

As a result of the analysis, it has been observed that the production and return times of a solar power plant with the same installed power are different when different materials are used. While the solar power plant is being installed, the exploration of the settlement should be done at the design stage. Shading conditions of the power plant area, radiation values, pollution status, tiltl angles should be taken into account during the design phase. Depending on these external factors, appropriate equipments should be selected that will enable the system to operate at maximum efficiency.

6. RECOMMENDATIONS

Turkey has a geopolitical position and different production technologies. Due to these features, it has a strong electrical system infrastructure. In particular, the efficient use of renewable energy sources will reduce our dependence on foreign energy sources. Since 2019, investments in rooftop solar installation have increased. Especially with rooftop solar power plants made by the private sector, the manufacturer has found the ability to cover all or part of the invoice amount. Continuity of private sector investments in solar power plant should be ensured.

The current COVID-19 pandemic will have a long-term impact on prices in many sectors. Based on this report, comparisons of different options can be made by conducting feasibility studies with current prices. It can be analyzed whether the turnaround times obtained as a result of feasibility with increasing prices also increase.

All the factors affecting the efficiency of the system can be discussed in more depth, as this research will be a roadmap. Accordingly, new technologies can be developed.

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