

JULY 2022

M.Sc. in Electronics and Computer Engineering

MEHMET METE YILMAZ

T.C.

**HASAN KALYONCU UNIVERSITY
GRADUATE EDUCATION INSTITUTE**

**GROUND MOUNTED ON-GRID SOLAR POWER
PLANT INSTALLATION AND PERFORMANCE
ANALYSIS: A CASE STUDY IN GAZIANTEP**

M.Sc. THESIS

IN

ELECTRONICS AND COMPUTER ENGINEERING

BY

MEHMET METE YILMAZ

JULY 2022

**Ground Mounted On-Grid Solar Power Plant Installation
and Performance Analysis: A case study in Gaziantep**

M.Sc. Thesis
In
Electronics And Computer Engineering
Hasan Kalyoncu University

Supervisor
Asst. Prof. Dr. Kadir Sercan BAYRAM

Mehmet Mete YILMAZ
July 2022



© 2022 [MEHMET METE YILMAZ]



GRADUATE EDUCATION INSTITUTE
M.Sc. ACCEPTANCE AND APPROVAL FROM

Electronics and Computer Engineering Department, Electronics and Computer Engineering Master programme student **Mehmet Mete YILMAZ** prepared and submitted the thesis titled “**Ground Mounted On-Grid Solar Power Plant Installation and Performance Analysis: A Case Study in Gaziantep**” defended successfully on the date of 07/07/2022 and accepted by the jury as a M.Sc. thesis.

Position

Title, Name and Surname

Signature:

Department/University

Supervisor

Asst. Prof. Dr. Kadir Sercan BAYRAM
Electrical-Electronics Engineering Department
Hasan Kalyoncu University

Jury Member

Asst. Prof. Dr. Mustafa BIÇAKÇI
Computer Engineering Department
Hasan Kalyoncu University

Jury Member

Asst. Prof. Dr. Bülent HAZNEDAR
Computer Engineering Department
Gaziantep University

This thesis is accepted by the jury members selected by institute management board and approved by institute management board.

Prof. Dr. İbrahim Halil GÜZELBEY
Director

I hereby declare that all information in this document 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 material and results that are not original to this work.

Mehmet Mete YILMAZ

ABSTRACT

GROUND MOUNTED ON-GRID SOLAR POWER PLANT INSTALLATION AND PERFORMANCE ANALYSIS: A CASE STUDY IN GAZIANTEP

YILMAZ, Mehmet Mete

M.Sc. in Electronics and Computer Engineering

Supervisor: Asst. Prof. Dr. Kadir Sercan BAYRAM

July 2022

55 pages

The danger of rapid depletion of fossil fuels, and the adverse effects on human health and the environment from these sources increase the importance of renewable energy sources day by day. For this reason, the installation of systems that obtain electrical energy from the sun, which is one of the renewable energy sources and is an endless energy source, is increasing rapidly. The study aims to compare the data of the photovoltaic-based solar power plant owned by Gaziantep Hasan Kalyoncu University and the simulation results by changing the module technology and the placement angle of the panels; According to these results, to propose the most suitable angle and module technology for Gaziantep region. This study used four-year production data of Hasan Kalyoncu University's grid-connected Solar Power Plant between 01.01.2017-31.12.2020. In addition, simulations were made with PVGIS and PVSOL programs, both with the same module and with different module technology and different slope configurations from the plant. By comparing the obtained data, the most suitable module technology and inclination angle for the Gaziantep region are shared. The study is a resource for investors and academic studies to evaluate the potential of the region.

Keywords: solar, energy, power plant, electricity, generation, photovoltaic, on-grid, simulation

ÖZET

ARAZİ ÜZERİNE ŞEBEKE BAĞLANTILI GÜNEŞ ENERJİ SANTRALİ KURULUMU VE PERFORMANS ANALİZİ: GAZİANTEP İLİ ÖRNEĞİ

YILMAZ, Mehmet Mete

Yüksek Lisans, Elektronik Bilgisayar Mühendisliği

Tez Danışmanı: Dr. Öğr. Üyesi. Kadir Sercan BAYRAM

Temmuz 2022

55 sayfa

Fosil yakıtların hızla tükenme tehlikesi, insan sağlığının ve çevrenin bu kaynaklardan çok fazla olumsuz etkilenmesi yenilenebilir enerji kaynaklarının önemini her geçen gün daha da artırmaktadır. Bu sebeple yenilenebilir enerji kaynaklarının başında gelen ve sonsuz enerji kaynağı olan güneşten, elektrik enerjisi elde eden sistemlerin kurulumları hızla artış göstermektedir. Çalışmanın amacı Gaziantep Hasan Kalyoncu Üniversitesi'nin sahibi olduğu fotovoltaik temelli güneş enerji santralinin verileri ile modül teknolojisi ve panellerin yerleşim açısı değiştirilerek yapılan simülasyon sonuçlarının karşılaştırılması; bu sonuçlara göre Gaziantep bölgesi için en uygun açı ve modül teknolojisi önermektir. Bu çalışmada Hasan Kalyoncu Üniversitesi'nin şebeke bağlantılı Güneş Enerji Santralinin 01.01.2017-31.12.2020 tarihleri arasındaki dört yıllık üretim verileri kullanılmıştır. Bunun yanı sıra PVGIS ve PVSOL programları ile hem santral ile aynı hem de santralden farklı modül teknolojisi ve farklı eğim konfigürasyonlarıyla simülasyonlar yapılmıştır. Elde edilen veriler karşılaştırılarak Gaziantep bölgesi için en uygun modül teknolojisi ve eğim açısı paylaşılmıştır. Çalışma, bölgenin potansiyelinin değerlendirilebilmesi için yatırımcılara ve akademik çalışmalara kaynak niteliği taşımaktadır.

Anahtar Kelimeler: güneş, enerji, santrali, elektrik, üretim, fotovoltaik, on-grid, simülasyon



To my family...

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Asst. Prof. Dr. Kadir Sercan BAYRAM for his guidance and support throughout the Master of Science Study and for his encouragement and motivation.

I would like to thank the valuable managers of Hasan Kalyoncu University, and the valuable staff of Hasan Kalyoncu University who contributed to the establishment of the solar power plant.

Thanks to Emre Kaynak for sharing his valuable experiences with me and supporting me.

I would like to thank my dear family, my dear wife and dear daughter, who have always been with me at every stage of my life and who have always given me strength with their love and support.

TABLE OF CONTENTS

	Pages
ABSTRACT.....	iv
ÖZET.....	v
ACKNOWLEDGEMENTS	vii
TABLE OF CONTENTS.....	viii
LIST OF TABLES	x
LIST OF FIGURES	xii
LIST OF SYMBOLS AND ABBREVIATIONS	xiv
CHAPTER 1	1
1. INTRODUCTION	1
1.1. The objective of the thesis	1
1.2. Literature Review	1
CHAPTER 2	10
2. RENEWABLE ENERGY	10
2.1. Renewable energy sources and solar energy	10
2.2. Photovoltaic systems.....	12
2.3. Solar power in the world.....	13
2.4. Solar power in Turkey	17
2.5. Solar power in Gaziantep.....	20
CHAPTER 3	22
3. POWER PLANT INSTALLATION	22
3.1. Power plant location	22
3.2. System Components	28

3.2.1. Solar module	28
3.2.2. The inverters	30
3.3. Layout plan	31
3.4. Single line diagram	31
CHAPTER 4	33
4. SIMULATION AND GENERATION DATASETS	33
4.1. Simulation Datasets	33
4.1.1. Simulations with PVSol.....	33
4.1.2. Simulations with Photovoltaic Geographical Information System (PVGIS).....	41
4.2. Generation data of the solar power plant (01.01.2017 – 31.12.2020) ..	45
4.2.1. The Comparison of Simulation Results and Actual Generation Data ..	46
CHAPTER 5	47
5. CONCLUSION	47

LIST OF TABLES

Table 2. 1 Renewable power generation per year (2008-2013)	13
Table 2. 2 Renewable power generation per year (2014-2019)	13
Table 2. 3 Growth rate of renewable energy	14
Table 2. 4 Generation by source in 2018	14
Table 2. 5 Generation by source in 2019	15
Table 2. 6 Growth rate for generation by source in 2019	15
Table 2. 7 Cumulative installed photovoltaic (PV) power (2008-2013).....	16
Table 2. 8 Cumulative installed photovoltaic (PV) power (2014-2019).....	16
Table 2. 9 Growth rate for cumulative installed PV power (2014-2019) (BP, 2020)	16
Table 2. 10 TEİAŞ Installed Power Report – November 2020 (TEİAŞ, 2020).....	18
Table 2. 11 The Installed Capacity of Solar Power Plants between 2020 and 2024 according to TEİAŞ (The optimistic scenario) (TEİAŞ, 2020)	18
Table 2. 12 Solar Capacity in Turkey (2008-2013) (BP, 2020).....	18
Table 2. 13 Solar Capacity in Turkey (2014-2019) (BP, 2020).....	18
Table 2. 14 Growth rate of solar capacity in Turkey (2008-2019) (BP, 2020).....	19
Table 2. 15 Generation: Solar (Turkey, 2014-2019) (BP, 2020)	19
Table 2. 16 Growth rate for generation: Solar (Turkey, 2008-2019) (BP, 2020)	19
Table 2. 17 Renewable power generation in Turkey (2008-2013) (BP, 2020).....	19
Table 2. 18 Renewable power generation in Turkey (2014-2019) (BP, 2020).....	19
Table 2. 19 Growth rate per annum of renewable power generation of Turkey (BP, 2020)	20
Table 2. 20 Generation by source in Turkey (2018) (BP, 2020).....	20
Table 2. 21 Generation by source in Turkey (2019) (BP, 2020).....	20
Table 2. 22 Growth rate of generation by source in Turkey (2019) (BP, 2020).....	20
Table 2. 23 The number and installed power capacity of solar power plants in the province of Gaziantep and Kilis in 2020 (TEDAŞ, 2020).....	21
 Table 3. 1 ED50 - 6° Coordinates of SPPs section corners	 23
Table 3. 2 STC Characteristics.....	29

Table 3. 3 NOCT Characteristics	29
Table 3. 4 Mechanical Characteristics	29
Table 3. 5 Materials and components	30
Table 3. 6 Technical data of the inverters	31
Table 4. 1 Grid-Connected PV System	34
Table 4. 2 Module data.....	34
Table 4. 3 Inverters configuration	36
Table 4. 4 AC Mains	36
Table 4. 5 Simulation results.....	36
Table 4. 6 Grid-Connected PV System	37
Table 4. 7 Module data.....	37
Table 4. 8 Inverter configuration	37
Table 4. 9 AC Mains	38
Table 4. 10 Simulation results.....	38
Table 4. 11 Grid-Connected PV System	39
Table 4. 12 Module data.....	39
Table 4. 13 Inverter configuration	40
Table 4. 14 AC Mains	40
Table 4. 15 Simulation results.....	40
Table 4. 16 Comparative PVSol simulation results	41
Table 4. 17 PVGIS simulation results.....	42
Table 4. 18 PVGIS simulation results.....	43
Table 4. 19 PVGIS simulation results.....	44
Table 4. 20 Comparison table of PVGIS Simulations	45
Table 4. 21 Solar power plant generation data.....	46
Table 4. 22 The comparison of annual energy generation in simulation results and the actual system	46

LIST OF FIGURES

Figure 2. 1 Basic block diagram of stand-alone PV system	12
Figure 2. 2 Basic block diagram of grid-connected PV system.....	12
Figure 2. 3 The map of Turkey’s photovoltaic power potential	17
Figure 2. 4 The map of Gaziantep’s photovoltaic power potential.....	21
Figure 3. 1 Soil and foundation investigation	22
Figure 3. 2 Images from soil and foundation investigation	22
Figure 3. 3 The first image from the area.....	23
Figure 3. 4 The flattened land	24
Figure 3. 5 Concrete legs	24
Figure 3. 6 An image of steel carrier construction.....	25
Figure 3. 7 The installation of modules	25
Figure 3. 8 Dustiness on the modules	26
Figure 3. 9 Gravel stone covered ground.....	26
Figure 3. 10 Hasan Kalyoncu University campus.....	27
Figure 3. 11 Google Earth image	27
Figure 3. 12 Drone image.....	28
Figure 3. 13 Solar Frontier SF160-S module	28
Figure 3. 14 Module dimensions.....	30
Figure 3. 15 Layout plan	31
Figure 3. 16 Single line diagram	32
Figure 4. 1 Terrain view of design	35
Figure 4. 2 String configuration view	35
Figure 4. 3 Horizon Line.....	35
Figure 4. 4 Horizon Line.....	37
Figure 4. 5 Horizon Line.....	39

Figure 4. 6 PVGIS screen.....	42
Figure 4. 7 PVGIS screen.....	43
Figure 4. 8 PVGIS screen.....	44



LIST OF SYMBOLS AND ABBREVIATIONS

°C	Celsius degree
AC	Alternating current
A-Si	Amorphous silicon
CdTe	Cadmium telluride
CF	Capacity factor
CIS	Copper indium selenide
CIS	Commonwealth of Independent States
CO ₂	Carbon dioxide
C-Si	Crystalline silicon
DC	Direct current
EL	Electroluminescence
EVA	Ethylene vinyl acetate
GIS	Geographic information system
GmbH	Gesellschaft mit beschränkter Haftung
GW	Gigawatt
h	hour
IEC	International Electrotechnical Commission
I _{mpp}	Maximum power point current
IR	Infrared
I _{sc}	Short-circuit current
I-V	Current-voltage
JRC	Joint Research Centre
°K	Kelvin degree
kg	Kilogram
km	Kilometer
kWh	Kilowatt hour
kWh/kWp	Kilowatt hour per kilo watt peak
kWh/m ² .year	Kilowatt hour per meter square year
kWh/year	Kilowatt hour per year
kWp	Kilowatt peak

LCOE	Levelized cost of energy
MA thesis	Master of arts thesis
mc-Si	Multicrystalline silicon
mono-Si	Monocrystalline silicon
MPP	Maximum power point
MW	Megawatt
MWh	Megawatt hour
MWh/m ²	Megawatt hour per meter square
MWh/MWp	Megawatt hour per megawatt peak
MWp	Megawatt peak
NOCT	Nominal Operating Cell Temperature
pc-Si	Polycrystalline-silicon
P _{max}	Maximum power
PR	Performance ratio
P-Si	polycrystalline-silicon
PV	Photovoltaic
PVGIS	Solar photovoltaic design tool
PVSOL	The design and simulation software for photovoltaic systems
PVsyst	The design and simulation software for photovoltaic systems
PVUSA	Photovoltaics for Utility Scale Applications
SCADA	Supervisory Control and Data Acquisition
SPP	Solart power plant
ST	Solar tower
TEİAŞ	Turkish Electricity Transmission Corporation
TWh	Terawatt hour
UAE	The United Arab Emirates
V _{mpp}	Maximum power point voltage
V _{oc}	Open-circuit voltage
W	Watt
W/m ²	Watt per meter square
YEKA	Renewable energy resource area

CHAPTER 1

1. INTRODUCTION

1.1. The objective of the thesis

The need for energy in the world is increasing day by day, and it is well-known that a huge amount of electricity is generated from fossil fuels. The danger of depletion for fossil fuels as well as their disadvantages for environment and human health make it compulsory for humanity to resort to alternative and renewable energy sources. Therefore, the number of solar power systems which generate energy from an infinite range of energy sources has remarkably increased in recent years.

Given global solar irradiance values and insolation periods, it can be stated that Gaziantep is located in a region with a high potential for solar power system efficiency.

The present study deals with the 4-year data obtained from the solar power plant operating at Hasan Kalyoncu University since its establishment in December 2016. A solar power plant with a capacity of 890 kWp was installed with thin film panels in Şahinbey district of Gaziantep province in Turkey. For a detailed performance analysis, studies on the design, installation and power generation process of the solar power plant were analyzed to compare simulation and actual generation data.

The present study is expected to guide investors in fulfilling the regional potential and pioneer future academic studies in reaching power plant performance data in the above-mentioned configuration.

This thesis aims to increase awareness on renewable energy sources in electricity generation and analyze and share findings about the performance of a solar power plant with thin film panels at the above-mentioned scale.

1.2. Literature Review

B. Marion et al. (2005) analyzed performance parameters for on-grid PV systems and focused on four different parameters based on their impact on power generation, solar power, and system losses: PV system yield, reference yield, performance ratio and PVUSA rating. They stated that three IEC 61724 standard performance parameters could be used to define overall system performance: final PV system yield, reference yield and performance ratio (Marion et al., 2005).

Jayanta Deb Mondol et al. (2006) analyzed a rooftop on-grid 13 kWp PV system in Northern Ireland for three years. They measured monthly average DC and AC performance of the system as 0.70 and 0.61, respectively (Mondol et al., 2006).

Jung Hung So et al. (2007) monitored four different on-grid PV systems (2 pieces of 3 kW Mono-Si and 2 pieces of 3 kW multi-Si) for one year for data analysis. They found that the annual performance of these four systems varied between 63.3% and 75.1% (So et al., 2007).

A. Drews et al. (2008) conducted a case study using the data obtained in Germany in 2005 to analyze 10 different (3 free standing, 6 rooftop and 1 roof-integrated) PV systems in terms of deviations among different annual specific energy yield data. They found a relative mean bias error of -7.3% and +8.4% between the modelled and measured yield ratios (Drews et al., 2008).

Kymakis et al. (2009) monitored a PV system with an installed capacity of 171.36 kWp which has been running in Crete, Sitia since 2002 for one year to calculate performance ratio and various power losses. The final yield varied between 1.96 and 5.07 hours/day, while the performance ratio varied between 58% and 73%. The annual performance ratio was calculated as 67.36% (Kymakis et al., 2009).

Nowshad Amin et al. (2009) examined solar power systems with C-Si, P-Si, A-Si and CIS PV panels in Malaysia. The performance ratio data demonstrated that thin film technology displayed a significantly higher performance in Malaysia and CIS panels were more favorable for such solar power systems (Amin et al., 2009).

Solar energy technology is preferred more than conventional electricity generation methods, considering the effects of wildlife and land use. SPP was observed to occupy less land per kWh compared to coal plants with a life span of more than 25 years. The land transformation rate of SPP was also lower compared to coal energy with a plant life of more than 27 years (Turney & Fthenakis, 2011).

Jonathan Leloux et al. (2012) analyzed the performance data of 993 residential PV systems in Belgium and calculated a mean performance ratio of 78%. In addition, they found that the differences between real and nominal power reached up to 16% (Leloux et al., 2012).

W Van Sark et al. (2012) analyzed the development of performance ratios for PV systems from the 1980s until the present day. It was observed that the performance ratios for PV systems increased from 50% to 75% during the late 1980s and to 70-80% during the 1990s and, finally, over 80% today (W Van Sark et al. 2012).

Conventional energy sources are depleting rapidly. Nowadays, due to the increasing energy demand, studies usually address newer, more efficient, and greener power plants with advanced technology within the framework of environmental problems, and, as a result, photovoltaic power systems continue to evolve. Therefore, the unit energy price generated from a PV system is higher than the conventional energy through network supply. The energy supplied from the PV system is the function of voltage and current. Power can be maximized by changing one of these two parameters. There are several methods to achieve this goal. Reducing dependence on fossil fuels and addressing environmental issues must be prioritized. Thus, solar energy will play an increasingly important role in the future. Furthermore, the energy technology sector is witnessing a significant change, as manifested by PV technology. This technology does not only provide energy but also leads to the emergence of new areas such as energy management, backup and emergency power, environmental improvements and resource diversity (Singh, 2013).

Panagiotis Moraitis et al. (2014) collected PV system data in the Netherlands, Belgium, France, and Italy using web scraping techniques. The findings indicated that the annual performance ratio of PV systems in the Netherlands was 78%, which could be improved in the future (Panagiotis Moraitis et al. 2014).

Priya Yadav et al. (2015) modelled a 1 kWp PV system in Hamirpur region of India using PVSyst software. They stated that the design of a PV system totally depended on the selected location, and the solar radiation value was 4.4 kWh/m². The annual performance ratio of the modelled system was 0.724, demonstrating that PV systems could be a viable option for the region (Yadav et al., 2015).

Kamal Attari et al. (2016) monitored an on-grid PV system mounted on the roof of a government building in Tangier region of Morocco between January and December 2015. It was stated that PV system generated an annual energy of 6411.3 kWh for the grid system. The final yield and performance ratio varied between 1.96 and 6.42 kWh/kWp and 58% and 98%, respectively, while the annual capacity factor was as

14.84%. As a result, the annual average final yield and performance rate of the PV system was measured as 4.45 kWh/kWp and 79%, respectively. The annual average capacity factor was calculated as 14.83% (Attari et al., 2016).

Ground-mounted PV systems are often large-scale solar power plants. The modules are placed on shelves or frames attached to ground-mounted brackets (Sahu et al., 2016).

Shukla et al. (2016) conducted a study on the feasibility analysis of a rooftop on-grid PV system with a capacity of 110 kWp in Manit, Bhopal region of India. The study was simulated using four different PV modules in order to analyze performance ratios and energy yield. The annual power generation amount of C-Si, a-Si, CdTe and CIS systems were found to be 163.1 MWh, 181.1 MWh, 175.3 MWh and 166.5 MWh, respectively, while the average performance ratios were measured as 71.6%, 79.5%, 77% and 73.1%, respectively (Shukla et al., 2016).

Elibol et al. (2017) focused on testing the performance of PV panels under outdoor conditions to monitor and analyze monocrystalline, polycrystalline, and amorphous silicon PV panels for one year. The rooftop mounted PV panels were located on a building at Düzce University in Düzce province of Turkey for the calculation of annual amount of energy, inverter efficiency and performance ratios. The performances of amorphous silicon, polycrystalline and monocrystalline PV panels were calculated as 73%, 81% and 91%, respectively, while the efficiency rates were measured as 4.79%, 11.36% and 13.26%, respectively. A statistical analysis was also performed in order to reveal the relationship among panel efficiency and performance ratios and environmental temperature, panel temperature and amount of irradiance. The results demonstrated that an increase of 1°C in temperature increased the efficiency of amorphous silicon and polycrystalline panels by 0.029% and 0.033%, respectively, whereas it decreased the efficiency of monocrystalline panels by 0.085% (Elibol et al., 2017).

Ozden et al. (2017) analyzed the performance of three different PV systems in Central Anatolia (Ankara province of Turkey). Under the same climate conditions and weekly surface cleaning, the systems with mono-Si, and a Si thin film and a CdTe thin film array were operated for 48 months to calculate hourly, daily, and monthly efficiency rates. In addition, average efficiency values were also used to calculate long-term

efficiency. It was found that monthly average efficiency values of three systems were 11.86%, 6.40% ve 5.30% for Mono-Si, m-Si/a-Si and CdTe systems, respectively. The degradation rates of these arrays in the calculated efficiency rates were calculated as 0.40%, 1.88% and 10.60%. It was also stated that monthly performance ratios would also yield the same results. While the results of the first two systems were quite similar to the results in the existing literature, the results of CdTe systems were remarkably higher compared to the literature, which can be attributed to production method and technology or overheating (Ozden et al., 2017).

Sharma and Goel (2017) shared the results of an on-grid PV solar power system with an installed capacity of 11.2 kWp at Siksha 'O'Anusandhan University in Bhubaneswar, India in February 2014. The study benefited from the data of a rooftop mounted system with a tilt angle of 21° between September 2014 and August 2015. The total amount of energy generated in this period was 14960 MWh. In addition, PV module efficiency, inverter efficiency and performance ratio were calculated as 13.42%, 89.93% and 0.78, respectively (Sharma & Goel, 2017).

Sampaio and González (2017) conducted a conceptual framework study and analyzed various factors related to energy generation such as advantages, disadvantages, current markets, costs, and technology. They focused on 142 different articles published between 1996 and 2016 and evaluated them from a technical point of view. The findings suggest that more in-depth studies are needed to explore factors such as economic feasibility, supply chain coordination, analysis of incentives and barriers for PV energy and its position in the energy market. Some of the analyzed studies underline the importance of raising awareness on the social, economic and environmental benefits of PV systems in the energy market, research and development activities for more cost-effective and efficient cells, incentive policies for PV production and, finally, training more qualified staff for a well-established energy market (Sampaio & González, 2017).

de Lima et al. (2017) analyzed an on-grid photovoltaic system with an installed capacity of 2.2 kWp at Ceara State University in Fortaleza, Brazil between June 2013 and May 2014. The total output energy and nominal energy output were calculated as 3708.2 kWh and 1685.5 kWh/kWp, respectively (de Lima et al., 2017).

Kumar et al. (2017) analyzed the performance of a 100 kWp on-grid PV system using PVsyst simulation program. The PV system generated 165.38 MWh/year, while 161.60 MWh/year of this amount was injected to the grid. As a result, the annual performance ratio was calculated as 80% (Kumar et al., 2017).

Al-Badi (2018) analyzed the data of a 1.4 kWp on-grid PV system in Oman, Muscat to monitor the performance of a PV system under desert type climate conditions. The maximum value of solar irradiance was calculated as 1344 w/m² in June when the temperature varied between 48.7 C° and 69.14 C°. Finally, the amount of total annual energy and average annual performance ratio were measured as 2217.6 kWh and 65%, respectively (Al-Badi, 2018).

Moraitis et al. (2018) carried out a performance analysis in the Netherlands and some other European countries and collected 5-15 minute high resolution PV yield data from 31844 systems with a total installed capacity of 741 MWp. Geographical Information Systems (GIS) and spatial analysis techniques were used to illustrate yield and performance ratios (Moraitis et al., 2018).

The growth of the world population and the industrialization of developing countries increase global energy consumption. Most of the energy consumed in the world is obtained from fossil sources. In addition to the depletion of fossil resources, alternative energy sources should be taken into consideration for the impact of environmental pollution on climate change in the world. Among renewable energy sources, solar energy is considered as an alternative to fossil fuels due to its ability to be directly converted to electricity as well as its storage capacity and globally unlimited resources (Shorabeh et al., 2019).

Energy demand in developing countries is increasing and developed countries continue to consume large amounts of energy. It is estimated that energy needs will increase by 55% between 2005 and 2030. However, 80% of the world's energy is supplied from fossil sources, which cause critical damage to the world. Fossil fuels cause harmful CO² release and other greenhouse gases. Therefore, it is necessary to switch from conventional energy systems to renewable energy (Roni et al., 2019).

The number of power plants established with renewable energy technology is increasing rapidly. PV SPPs lead this trend both by increasing cell efficiency and lowering panel production costs (Martín-Martínez et al., 2019).

Shuvho et al. (2019) analyzed the performance of an 80 kWp on-grid solar power plant in Dakka, Bangladesh to offer a model which can predict solar irradiance under different ambient conditions in the city of Dakka and contribute to the design and feasibility of solar power projects. The results presented monthly production and specific yield of an 80 kWp solar power plant within a period of two years. While average energy generation and specific yield were calculated as 6140.76 kWh and 77.76 in 2016, respectively, the same values were measured as 4354.51 kWh and 54.43 in 2017, respectively. Thus, the plant capacity was calculated as 77.76% and 54.43% in 2016 and 2017, respectively (Shuvho et al., 2019).

Hachicha et al. (2019) conducted experimental studies to analyze the effects of weather conditions on PV systems in Sharjah, United Arab Emirates. They compared the results of indoor and outdoor experiments to draw concrete conclusions for the prediction of soiling loss in PV systems in UAE and similar weather conditions (Hachicha et al., 2019).

Savaş Alkan (2019) dealt with the design, simulation and installation of a rooftop mounted and east-west oriented solar power plant with an installed capacity of 169 kWp in Hidayet Türkoğlu Sports Center in Istanbul, Turkey for his MA thesis. This study highlighted the advantages and disadvantages of east-west oriented PV systems. It was observed that the amount of annual energy generated was 192.88 MWh in PVSOL simulation program, while it was 200.71 MWh in PVGIS simulation program. The actual amount of annual energy generated was found to be 202.85 MWh. It can be stated that a 30° south-oriented PV system with an installed capacity of 110.5 kWp could be installed on the roof of this building instead of an 11° east-west oriented PV system. Therefore, a production and efficiency analysis were performed for a detailed comparison between two different PV systems, and it was observed that a south-oriented 110.5 kWp PV system generated an annual amount of 137.63 MWh in PVSOL simulation program, while the same amount was calculated as 148.26 MWh in PVGIS simulation program. Finally, it was found that while an east-west oriented PV system could yield a higher amount of energy by 40% in the first year, its initial investment cost was higher by 45% and return of investment was longer by 0.2 year (Alkan, 2019).

Muhammed Said Gündüz (2019) analyzed two unlicensed solar power plants in Kütahya province of Turkey from a techno-economic perspective in his MA thesis. The study benefited from PVSyst simulation program, and the simulation results were lower than the actual amount of energy generated. A production tolerance of 4-5% in PV panels, high inverter efficiency, minimized transformer losses, cable quality and installation labour can account for the difference between simulation and actual PV system data (Gündüz, 2019).

Elamim et al. (2019) analyzed the performance and economic benefits of two rooftop mounted 4.08 kWp on-grid PV systems with crystalline technology in Muhammediye, Morocco. Daily final yield, performance ratio and CF values were calculated as 5.17 h, 80.66% and 21.56% for mc-Si and 5.26 h, 82.00% and 21.93 for pc-Si. Monthly system yield varied between 10.59% and 13.60% for mc_Si, while it varied between 10.20% and 13.73% for pc-Si (Elamim et al., 2019).

Murat Kutluca (2020) collected data from a solar power system with an installed capacity of 960Wp in Vize district of Kırklareli province in Turkey and analyzed the impact of various factors affecting performance and efficiency. The study benefited from PVSQLE for analysis, which yielded results similar to those obtained from SCADA (Kutluca, 2020).

Awan et al. (2020) compared two different main technological approaches in solar power and electricity generation: Solar tower (ST) and photovoltaic (PV). In this study, a ST and a PV power plant with an installed capacity of 100 MW was designed with a very effective direct normal and solar horizontal irradiance. The findings demonstrated that the annual energy generation capacity of ST power plant was higher by 89.5% compared to PV power plant. However, its net capital cost was also 5.8-fold higher compared to PV. In addition, the net present value of PV power plant was positive, while it was negative for ST power plant (Awan et al., 2020).

Oh et al. (2020) conducted a study on a 10-year and 1 MW PV solar power plant to perform drone with an infrared (IR) camera, current-voltage (I-V) and electroluminescence (EL) measurements. Failure and degradation were observed in nearly 10% of the modules. In addition, more than 40% of PV strings in certain inverters caused losses higher than the expected annual degradation rate (Oh et al., 2020).

Veríssimo et al. (2020) focused on the design optimization of a single axis tracking PV power plant and proposed a new evaluation metric represented by the annual energy yield normalized by the PV power plant area. This method, which offers an optimization both for the yield and available area, takes into account both energy yield (MWh/m^2) and total energy production efficiency (MWh/MWp). The topology defined using this metric reduced the levelized cost of energy (LCOE) by 12.4%, while it increased energy production by 91.4%, thus increasing investment potential almost by 100% (Veríssimo et al., 2020).

Ameur et al. (2020) studied the impact of various factors system efficiency, performance ratio, energy output and capacity on PV technology to evaluate comparative performances of different PV types such as monocrystalline, polycrystalline, and amorphous silicon. The data obtained within a period of five years were used for performance analysis. The findings demonstrated that the annual amount of energy generated by monocrystalline and polycrystalline systems was higher compared to the energy generated by amorphous silicon system. In addition, the performance ratios, capacity factor and efficiency of three different systems were also calculated. It was found that while performance ratios, capacity factors and efficiency of monocrystalline and polycrystalline systems were 77%, 19% and 12%, respectively, the same values were 73%, 18% and 7% for amorphous silicon system (Ameur et al., 2020).

Ozden et al. (2020) monitored two high efficiency and identical prototypes with back contact modules in different locations (Petten, the Netherlands and Ankara, Turkey) under different climate conditions and evaluated their performance values. A commercial heterojunction module was used for comparison. The results indicated that the module performance was affected by the combination of ambient temperature difference and relative humidity. The annual outdoor efficiency rates were calculated as 19.05% and 18.36% in the Netherlands and Turkey, respectively (Ozden et al., 2020).

CHAPTER 2

2. RENEWABLE ENERGY

2.1. Renewable energy sources and solar energy

Renewable energy sources are safe, non-contaminated, regenerative and infinite (Kimmell et al., 2020). A renewable energy source is defined by its ability to renew itself at a rate equal to the energy obtained from a source or faster than the depletion of the same source (General Directorate of Renewable Energy).

Similarly, renewable energy can be generated from natural sources such as solar power, wind, rain, sea waves, tides and geothermal energy and renewed within a few years (Lund, H., 2009).

From the Industrial Revolution until today, many countries in the world relied on fossil fuels for their energy needs, which significantly affected global climate and human health. Air pollution caused by fossil fuels leads to a serious health problem, resulting in early death of more than 5 million people every year (Ritchie et al., 2020).

Renewable energy also offers different technologies which can transform natural sources into useful energy services: wind, sea waves, tides, hydroelectricity, biomass, biofuel technologies and renewable wastes. (Lund, H., 2009).

The Sun is the leading renewable source for the Earth. The humankind has been using solar energy since the earliest times of human history. In his “Memorabilia”, Xenophon, a Greek historian, mentions how Socrates gave some advice about the importance of orienting a house towards the right direction for cooler summers and warmer winters. In this respect, solar energy has been widely used for different purposes around the world such as heating buildings (actively and passively), domestic and industrial water and swimming pools, powering refrigerators, operating engines and pumps, desalination of drinking water, electricity generation and various chemical applications (Kalogirou, S. 2014).

Solar energy is divided into two different categories as passive solar technologies (direct solar gain, indirect solar gain, isolated solar gain) and active solar technologies (photovoltaic, solar thermal and concentrator solar power). In general, active solar

power technologies fall into two different categories: i. Photovoltaic technology and ii. Solar thermal technology (Kabir et al., 2018).

Emitting an hourly energy of 174 trillion kWh to the Earth, the Sun is the largest source of life and ultimate source for all types of energy with a mass of 2×10^{30} kg and a beam length of 700.000 km. It will continue to exist for the next 5 billion years. The Sun's surface and internal temperature is 5800 °K and 15 million °K, respectively. Due to the impact of electromagnetic radiation, it emits nearly one-third of all energy. Thus, it is possible to convert the emitted solar energy into electricity through thermal and photovoltaic technologies (Tanim et al., 2014).

The word "Photovoltaic" is derived from the combination of two Greek words, "photo" and "voltaic", which mean "light" and "voltage" (Öztürk H.H., 2017).

Discovered by Becquerel in 1839, photovoltaic effect is an important method for converting solar irradiance to electricity. (Goetzberger. A.et al., 2003)

Adams and Day observed photovoltaic effect in solid selenium in 1877. The first photovoltaic cell with an efficiency of less than 1% was developed by Fritz in 1883 (Singh, 2013).

In addition to non-technical obstacles, photovoltaic technology faces various problems such as long-life fossil sources, uneconomical pricing rules, raw material supply, available land and geographical limitations. However, reduced costs, increasing efficiency, integration into buildings and developing energy storage technologies are also important factors in this field. Experts predict three different scenarios until 2050. The "most positive" scenario estimates that the installed power capacity will reach 9000 GW until 2050, as storage systems will be improved by mid-2030s and, consequently, a new infrastructure will be created for PV energy storage. Furthermore, after 2025, new technologies and materials will contribute to the expansion of PV systems around the world. The "optimistic" scenario anticipates that crystalline-Si, thin films and new devices will appear and that while the growth rate of PV market will be lower, the cumulative installed power capacity will display a linear upward trend. It also estimates that the installed power capacity will double in each decade, reaching 2400 W by 2050. Finally, the "pessimistic" scenario estimates that the world will generate 13% of its energy from PV technologies by 2050 (Obeidat, 2018).

2.2. Photovoltaic systems

A PV system consists of PV solar cells, which can be connected together in order to create higher power modules and a higher energy output. Additionally, PV systems and components using modular technology can be restructured for different capacity levels. PV systems, which can be used both for domestic and industrial purposes in today's world, are classified as grid-connected and stand-alone systems (Elbaset A.A., 2019)

Stand-alone PV systems store the generated electricity in a battery to meet the user's energy needs any time of the day. They are usually installed in remote regions far from the grid system (base stations, irrigation systems, rural summer houses etc.) or used for small-size systems with a low level of energy consumption (signaling, lighting, alarm systems etc.).

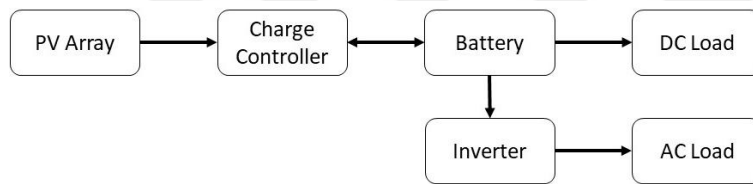


Figure 2. 1 Basic block diagram of stand-alone PV system

A grid-connected PV system, on the other hand, is planned to meet the user's need for electricity and often relies on the electricity grid system if the actual consumption is relatively high. However, if the electricity generation exceeds the consumed amount, it supports the electricity grid system by generating electricity. On some specific occasions, there may be some distance between the user's address and PV system. To eliminate costs as much as possible, an electric meter is used to measure production and consumption levels and thus complete a netting process between two parties.

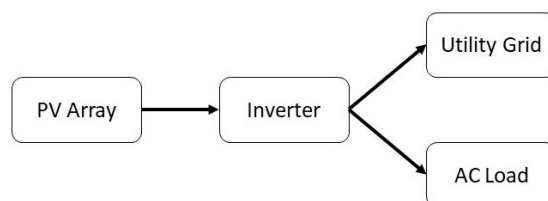


Figure 2. 2 Basic block diagram of grid-connected PV system

2.3. Solar power in the world

Table 2.1 and Table 2.2 presents the amounts of renewable power generation in different continents and in the world between 2008 and 2019. While a total of 238.9 TWh was generated in Europe in 2008, this amount rose to 836.6 TWh in 2019. Similarly, in the world, the whole amount of electricity generated from renewable sources increased from 548.8 TWh to 2.805.5 between 2008 and 2019.

Table 2. 1 Renewable power generation per year (2008-2013)

Terawatt-hours	2008	2009	2010	2011	2012	2013
Total North America	151,1	173,7	201,7	231,9	261,9	301,5
Total S. & Cent. America	34,9	39,2	51,0	54,2	64,3	74,0
Total Europe	238,9	270,3	313,6	379,5	448,7	506,8
Total CIS	0,5	0,6	0,6	0,7	0,6	0,7
Total Middle East	0,2	0,3	0,4	0,7	0,9	1,1
Total Africa	4,7	5,3	6,3	6,9	7,6	8,8
Total Asia Pacific	118,5	147,3	186,4	230,5	278,4	346,0
Total World	548,8	636,7	760,1	904,5	1062,4	1238,9

Table 2. 2 Renewable power generation per year (2014-2019)

Terawatt-hours	2014	2015	2016	2017	2018	2019
Total North America	335,3	372,1	431,0	483,2	522,0	576,9
Total S. & Cent. America	88,9	107,5	126,2	142,8	161,9	184,1
Total Europe	547,2	625,3	638,4	716,7	756,3	836,6
Total CIS	1,0	1,4	1,8	2,1	2,5	3,3
Total Middle East	1,8	2,5	4,1	5,5	7,5	13,3
Total Africa	12,5	19,6	23,5	27,0	32,2	45,1
Total Asia Pacific	418,6	498,2	614,9	793,5	985,5	1146,2
Total World	1405,2	1626,7	1839,9	2170,8	2468,0	2805,5

Asia Pacific, Europe and North America contributed to 40.9%, 29.8% and 20.6% of all energy generated from renewable sources in 2019, respectively. In the same year, the growth rates for renewable energy generation in Asia Pacific, Europe and North America were 15.9%, 10.2% and 10.1%, respectively. The growth rate for the whole world was calculated as 13.3%.

Table 2. 3 Growth rate of renewable energy

	Growth rate per annum		Share
	2019	2008-18	2019
Total North America	10,1%	12,5%	20,6%
Total S. & Cent. America	13,3%	15,9%	6,6%
Total Europe	10,2%	11,5%	29,8%
Total CIS	30,7%	16,1%	0,1%
Total Middle East	77,3%	40,8%	0,5%
Total Africa	39,5%	20,6%	1,6%
Total Asia Pacific	15,9%	22,8%	40,9%
Total World	13,3%	15,5%	100,0%

The amounts of electricity generation by renewable sources in 2018 and 2019 are given in Table 2.4 and Table 2.5. It can be observed that the shares of solar energy in the amount of electricity generated from renewable sources were 101.3 TWh in a total amount of 522 TWh in North America and 138.6 TWh in a total amount of 756.3 TWh in Europe in 2018. The same amounts rose to 125.1 TWh and 154.7 TWh in North America and Europe in 2019, respectively. The total amounts in the world were calculated as 582.8 TWh and 724.1 TWh in 2018 and 2019, respectively.

Table 2. 4 Generation by source in 2018

2018				
Terawatt-hours	Wind	Solar	Other renewables*	Total
Total North America	321,7	101,3	98,9	522,0
Total S. & Cent. America	65,8	12,7	83,4	161,9
Total Europe	402,8	138,6	215,0	756,3
Total CIS	0,8	0,9	0,7	2,5
Total Middle East	1,1	6,1	0,3	7,5
Total Africa	14,3	9,9	8,1	32,2
Total Asia Pacific	463,7	313,2	208,6	985,5
Total World	1270,2	582,8	615,0	2468,0

Table 2. 5 Generation by source in 2019

2019				
Terawatt-hours	Wind	Solar	Other renewables*	Total
Total North America	354,9	125,1	96,9	576,9
Total S. & Cent. America	79,2	17,6	87,4	184,1
Total Europe	461,6	154,7	220,3	836,6
Total CIS	1,1	1,5	0,7	3,3
Total Middle East	1,2	11,9	0,3	13,3
Total Africa	17,5	19,4	8,2	45,1
Total Asia Pacific	514,3	393,9	238,0	1146,2
Total World	1429,6	724,1	651,8	2805,5

The growth rates for generation by energy sources in 2019 indicate significant increases in the growth rates for solar power generation. It is evident that the share of solar power in the amount of electricity generated from renewable energy sources displayed a higher increase compared to other sources. The growth rates for North America and Europe are 23.46% and 11.62%, respectively. Similarly, in the whole world, solar energy surpassed wind power and other renewable energy sources with a growth rate of 24.25%.

Table 2. 6 Growth rate for generation by source in 2019

2019 Growth rate				
Terawatt-hours	Wind	Solar	Other renewables*	Total
Total North America	10,32%	23,46%	-2,07%	10,52%
Total S. & Cent. America	20,39%	38,30%	4,73%	13,73%
Total Europe	14,60%	11,62%	2,48%	10,61%
Total CIS	30,09%	55,78%	0,68%	31,14%
Total Middle East	2,11%	95,36%	0,00%	78,00%
Total Africa	22,54%	96,73%	1,55%	39,98%
Total Asia Pacific	10,90%	25,77%	14,10%	16,30%
Total World	12,55%	24,25%	5,98%	13,68%

When the installed photovoltaic power in different continents between 2008 and 2019 is analyzed, it can be seen that Europe was ranked first until 2016. However, Asia Pacific outrun Europe in the following years. Accordingly, the installed photovoltaic

power in North America, Europe and Asia Pacific in 2019 was 70.048 MW, 146.666 MW and 346.441 MW, respectively. In a similar vein, the cumulative installed power increased from 14.371 MW to 586.421 MW in the world between 2008 and 2019.

Table 2. 7 Cumulative installed photovoltaic (PV) power (2008-2013)

Megawatts	2008	2009	2010	2011	2012	2013
Total North America	805	1308	2290	3918	8154	14337
Total S. & Cent. America	39	62	117	169	324	455
Total Europe	10524	17128	30888	54772	73862	84334
Total CIS	>0,5	>0,5	>0,5	1	1	4
Total Middle East	10	42	91	215	275	618
Total Africa	54	65	150	200	257	566
Total Asia Pacific	2939	4034	6594	12095	19803	39145
Total World	14371	22639	40129	71370	102676	139458

Table 2. 8 Cumulative installed photovoltaic (PV) power (2014-2019)

Megawatts	2014	2015	2016	2017	2018	2019
Total North America	19610	26132	37766	46702	58839	70048
Total S. & Cent. America	926	1960	2814	5036	7119	8750
Total Europe	91227	99916	107006	116028	126663	146666
Total CIS	14	125	162	368	800	1697
Total Middle East	905	1103	1589	2281	3312	5583
Total Africa	1552	2056	3202	4052	5968	7236
Total Asia Pacific	61781	90696	143277	214084	286040	346441
Total World	176015	221988	295816	388550	488741	586421

In 2019, Asia Pacific, Europe and North America contributed to 59.1%, 25% and 11.9% of the cumulative installed power around the world. In this respect, the growth rates for cumulative power in these continents were calculated as 21.1%, 15.8% and 19.1%, respectively. The growth rate in the whole world in the same year was 20%.

Table 2. 9 Growth rate for cumulative installed PV power (2014-2019) (BP, 2020)

	Growth rate per annum		Share
	2019	2008-18	2019
Total North America	19,1%	53,6%	11,9%
Total S. & Cent. America	22,9%	68,5%	1,5%
Total Europe	15,8%	28,2%	25,0%
Total CIS	112,0%	145,7%	0,3%
Total Middle East	68,6%	78,0%	1,0%
Total Africa	21,3%	60,2%	1,2%
Total Asia Pacific	21,1%	58,1%	59,1%
Total World	20,0%	42,3%	100,0%

2.4. Solar power in Turkey

Turkey bears a considerable potential for solar power generation thanks to its distinctive geographical location. According to Atlas for Turkey's Solar Power Potential published by Ministry of Energy and Natural Sources, the total annual duration of insolation and total incoming solar irradiance in Turkey are 2741 hours (a daily average duration of 7.5 hours) and 1527 kWh/m².year (a daily average amount of 4.18 kWh/m².year). As the solar energy is utilized in many different forms and applications in today's world, Turkey benefits from two different technologies in electricity generation. (MoENR, Solar Energy Potential Map)

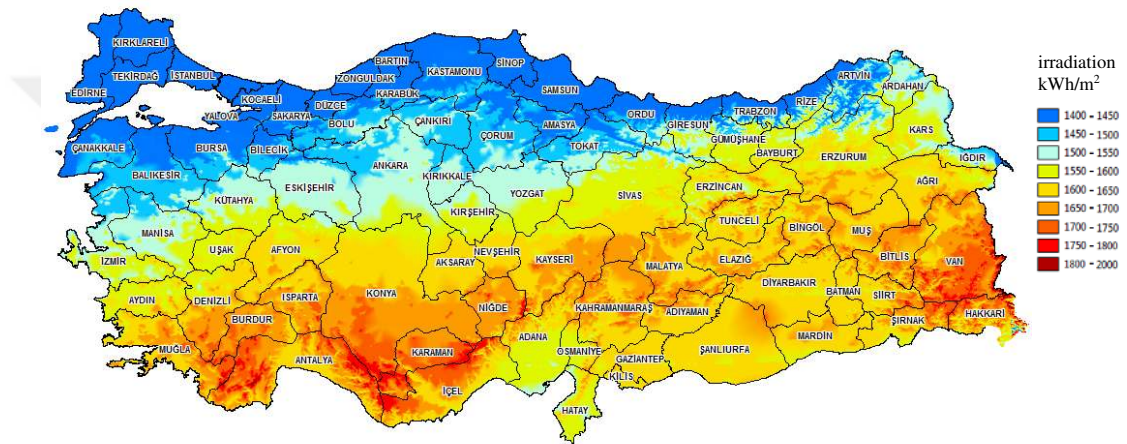


Figure 2. 3 The map of Turkey's photovoltaic power potential

The 11th Development Plan for 2019-2023 was published by Presidency of Strategy and Budget affiliated with Presidency of Republic of Turkey to adopt sectoral policies. In this plan, energy policies aim to offer energy supply with continuous, high-quality, sustainable, reliable and tolerable energy costs. Therefore, it is planned to increase electricity generation from renewable energy sources and their integration into the grid systems, to establish models similar to Renewable Energy Source Area (YEKA) and strengthen the role of renewable energy sources in electricity generation, to increase the number of self-sustaining buildings and unlicensed solar power plants. While the share of renewable sources in electricity generation was 32.5% in 2018, it is aimed to increase to 38.8% by 2023 (Presidency of the Republic of Turkey, Presidency of Strategy and Budget, 2018)

According to the Installed Power Report published by Turkish Electricity Transmission Corporation (TEİAŞ) in November 2020, the total number of solar power plants in Turkey is 7402. 32 of them are corporation power plants, whereas 7370 of them are unlicensed power plants. The cumulative installed power is calculated as 6.513,1 MW, shared by unlicensed and corporation power plants with 6.184,5 MW and 328.6 MW, respectively. In total, the installed electricity power capacity in Turkey is 94.801 MW, and the share of installed solar power in this amount is 6.87%.

Table 2. 10 TEİAŞ Installed Power Report – November 2020 (TEİAŞ, 2020)

	Number	Installed power (MW)
Corporation power plants	32	328.6
Unlicensed power plants	7370	6.184,5
TOTAL	7402	6.513,1

Production Capacity Report Projection published by TEİAŞ envisaged three different scenarios for the period between 2020 and 2024. The optimistic scenario estimates that the installed capacity of solar power plants will increase by 5.824 MW in Turkey by 2024.

Table 2. 11 The Installed Capacity of Solar Power Plants between 2020 and 2024 according to TEİAŞ (The optimistic scenario) (TEİAŞ, 2020)

Source	2020	2021	2022	2023	2024	TOTAL
Solar	1.467	1.157	1.150	1.150	900	5.824

While the installed solar power was 4 MW in Turkey in 2008, it increased by 105.9% annually and reached 5.064 MW in 2018. It displayed a similar increase of 18.4% and rose to 5.996 MW in 2019.

Table 2. 12 Solar Capacity in Turkey (2008-2013) (BP, 2020)

Megawatts	2008	2009	2010	2011	2012	2013
Turkey	4	5	6	7	12	19

Table 2. 13 Solar Capacity in Turkey (2014-2019) (BP, 2020)

Megawatts	2014	2015	2016	2017	2018	2019
Turkey	41	250	834	3422	5064	5996

Table 2. 14 Growth rate of solar capacity in Turkey (2008-2019) (BP, 2020)

	Growth rate per annum		Share
	2019	2008-18	2019
Turkey	18,4%	105,9%	1,0%

In Turkey, the electricity generated from solar power increased to 0.2 TWh in 2015 and to 10.9 TWh in 2019.

Table 2. 15 Generation: Solar (Turkey, 2014-2019) (BP, 2020)

Terawatt-hours	2014	2015	2016	2017	2018	2019
Turkey	< 0.05	0,2	1,0	2,9	7,8	10,9

The annual growth rate for the amount of solar energy generated in Turkey was 40% in 2019. As for the period between 2008 and 2019, the amount generated in 2019 corresponded to 1.5% of the total amount in this period.

Table 2. 16 Growth rate for generation: Solar (Turkey, 2008-2019) (BP, 2020)

	Growth rate per annum		Share
	2019	2008-18	2019
Turkey	40,0%	-	1,5%

The share of renewable energy sources in electricity generation in Turkey was 1.2 TWh in 2008, while it rose to 45.3 TWh in 2019.

Table 2. 17 Renewable power generation in Turkey (2008-2013) (BP, 2020)

Terawatt-hours	2008	2009	2010	2011	2012	2013
Turkey	1,2	2,2	3,9	5,8	7,4	9,8

Table 2. 18 Renewable power generation in Turkey (2014-2019) (BP, 2020)

Terawatt-hours	2014	2015	2016	2017	2018	2019
Turkey	12,0	16,5	23,0	29,0	37,8	45,3

Similarly, the annual growth rate was calculated as 40.9% for the period between 2008 and 2018. The same rate was found to be 19.4% in 2019.

Table 2. 19 Growth rate per annum of renewable power generation of Turkey (BP, 2020)

	Growth rate per annum	
	2019	2008-18
Turkey	19,4%	40,9%

Turkey generated a total amount of 37.8 TWh electricity from renewable energy sources in 2018, and the share of solar energy in this amount was equal to 7.8 TWh.

Table 2. 20 Generation by source in Turkey (2018) (BP, 2020)

Terawatt-hours	2018			Total
	Wind	Solar	Other renewables*	
Turkey	19,9	7,8	10,1	37,8

Similar, a total amount of 45.3 TWh electricity was generated from renewable energy sources in 2019, as the share of solar energy in this amount was equal to 10.9 TWh.

Table 2. 21 Generation by source in Turkey (2019) (BP, 2020)

	2019			Total
	Wind	Solar	Other renewables*	
Turkey	21,7	10,9	12,7	45,3

When the total amount of electricity generated is analyzed, it can be observed that the growth rate of renewable energy sources in electricity generation was 19.84% in Turkey in 2019. The solar power is the leading renewable energy source in this list with a growth rate of 40%.

Table 2. 22 Growth rate of generation by source in Turkey (2019) (BP, 2020)

	2019 Growth rate			
	Wind	Solar	Other renewables*	Total
Turkey	8,80%	40,00%	26,09%	19,84%

2.5. Solar power in Gaziantep

Gaziantep is an important industrial city located in the Southeastern Anatolia Region of Turkey. Köppen-Geiger's climate classification ranks Gaziantep as a temperate

climate (C); warm winter, very hot and dry climate-Mediterranean climate (Csa). The annual sunshine duration throughout the city is over 215 days. It can be said that the very high ambient temperature in Gaziantep, where the average temperature is high, negatively affects the efficiency of solar panels (Kum, 2019).

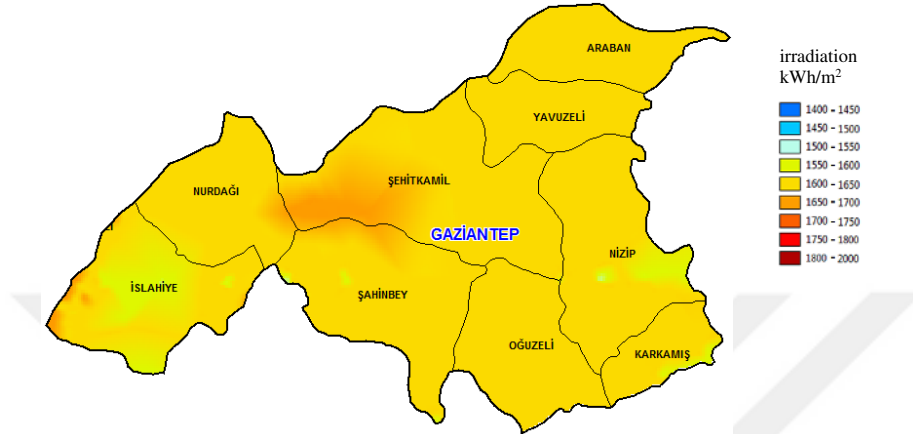


Figure 2. 4 The map of Gaziantep's photovoltaic power potential

According to data obtained from Toroslar Electricity Transmission Corporation, there are 195 SPPs in Gaziantep. The installed power of these power plants is 150.4 MW.

Table 2. 23 The number and installed power capacity of solar power plants in the province of Gaziantep and Kilis in 2020 (TEDAŞ, 2020)

	Number	Installed power (MW)
Gaziantep	195	150,4
Kilis	34	21,9
Total	229	172,3

In addition, within the scope of the YEKA tender made by the Ministry of Energy and Natural Resources in 2021, a total of 50 MW installations will be realized in three different regions determined in Gaziantep.

CHAPTER 3

3. POWER PLANT INSTALLATION

3.1. Power plant location

A Soil and Foundation Investigation Report was prepared to install a solar power plant on Section 8, 12, 17 with 345 lot and 2 block number in Yeşilkent neighborhood of Şahinbey District in the province of Gaziantep, Turkey. According to the report, geological observations and laboratory experiments indicated that safe bearing capacity of the area would not pose any problems in terms of construction activities in the power plant location.



Figure 3. 1 Soil and foundation investigation



Figure 3. 2 Images from soil and foundation investigation

Technical Evaluation Report approved by the Ministry of Energy and Natural Resources presents the section corners and coordinates of the power plant in accordance with ED50 - 6° coordinate system as follows:

Table 3. 1 ED50 - 6° Coordinates of SPPs section corners

Section Corner	Coordinate X	Coordinate Y
1	361494.94	4096396.19
2	361579.28	4096378.36
3	361551.97	4096188.38
4	361530.95	4096160.84
5	361483.43	4096162.38

As shown in Figure 3.3, some excavation wastes were found on the solar power plant location in the coordinates given in Table 3.1. In addition, there was a visible slope on the southern part of the land.



Figure 3. 3 The first image from the area

Some excavation work was performed to flatten the land as shown in Figure 3.4.



Figure 3. 4 The flattened land

After a made-up ground was created on the flattened land, concrete legs (see Figure 3.5) were built under scaffolds which would bear solar power panels.



Figure 3. 5 Concrete legs

Following the completion of concrete legs, to comply with IEC standards, steel carrier construction was manufactured and installed on concrete legs (see Figure 3.6).



Figure 3. 6 An image of steel carrier construction

Afterwards, modules were installed to bear 4 x 8 modules on each scaffold (see Figure 3.7).



Figure 3. 7 The installation of modules

Since Gaziantep is located in a geographical region with a hot and arid weather during summer months, it is very likely for dust to form on the ground easily (see Figure 3.8).



Figure 3. 8 Dustiness on the modules

Therefore, the ground was covered with black gravel stone in order to minimize losses caused by dust (see Figure 3.9).



Figure 3. 9 Gravel stone covered ground

In Figure 3.10, there is a satellite image of Hasan Kalyoncu University dated 8.15.2019 using Google Earth Pro version 7.3.3.7786. The solar power plant, which is the subject of this study, is seen in the upper right corner of the image.



Figure 3. 10 Hasan Kalyoncu University campus

In Figure 3.11, it is the power plant images (time-collapse) obtained by zooming in the Google Earth Pro version 7.3.3.7786 image.

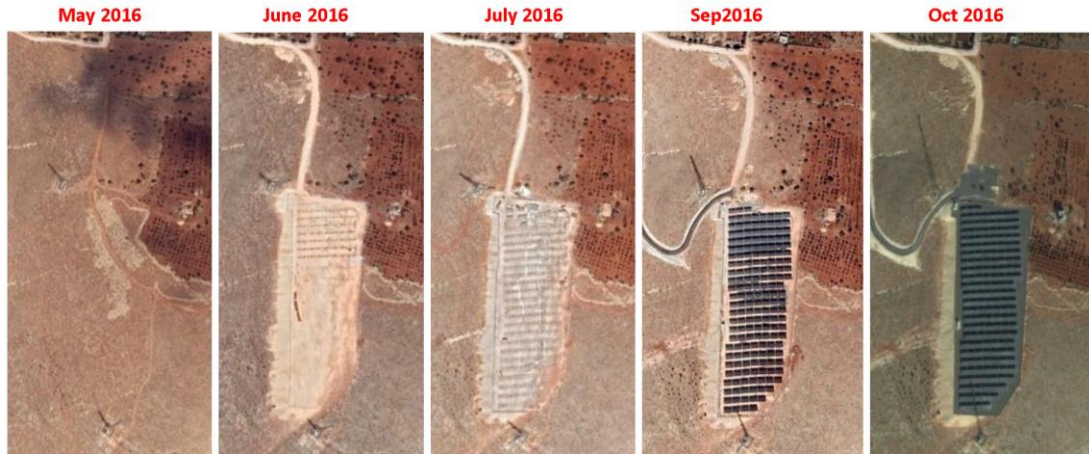


Figure 3. 11 Google Earth image

In Figure 3.12, there is a drone image of the solar power plant. The image above was taken with a drone on 12.06.2020.



Figure 3. 12 Drone image

3.2. System Components

3.2.1. Solar module

5568 pieces of Solar Frontier SF160-S thin film solar modules (see Figure 3.13) were used in Solar Power Plant at Hasan Kalyoncu University. The installed DC power capacity of the plant is 890.88 kWp.



Figure 3. 13 Solar Frontier SF160-S module

The characteristics of the module under $100\text{W}/\text{m}^2$ irradiance, 25°C module temperature and air mass 1.5 conditions are given in Table 3.2.

Table 3. 2 STC Characteristics

Nominal power	P_{max}	160 W
Positive sorting effect		+5W/0W
Module efficiency	%	13.0%
Open circuit voltage	V_{oc}	110.0 V
Short circuit current	I_{sc}	2.20 A
Voltage at nominal power	V_{mpp}	84.0 V
Current at nominal power	I_{mpp}	1.91 A

The characteristic of the module under the conditions of Module operating temperature at 800 W/m² irradiance, 20°C air temperature and 1 m/s wind speed are given in Table 3.3.

Table 3. 3 NOCT Characteristics

NOCT power	P_{max}	119 W
Open circuit voltage	V_{oc}	99.2 V
Short circuit current	I_{sc}	1.76 A
Voltage at NOCT power	V_{mpp}	77.4 V
Current at NOCT power	I_{mpp}	1.49 A

The characteristics of the module regarding length, weight, snow and wind loads are given in Table 3.4.

Table 3. 4 Mechanical Characteristics

Dimensions (L x W x H)	1257 x 977 x 35
Weight	20 kg
Snow & wind load (IEC61646)	2400 Pa

Also, module dimensions are as in Figure 3.14 with technical drawing:

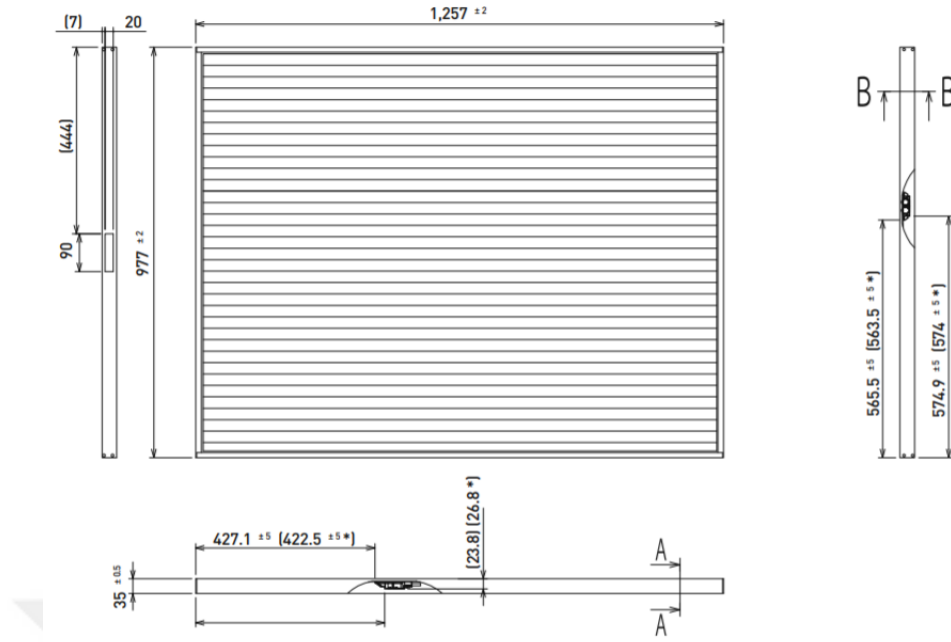


Figure 3. 14 Module dimensions

The materials and components of the module are given in Table 3.5.

Table 3. 5 Materials and components

Cell type	CIS (cadmium free) on glass substrate
Front cover	3.2 mm tempered glass
Encapsulant	EVA
Back sheet	Weatherproof plastic film
Frame	Black anodized aluminum alloy
Edge sealant	Butyl rubber
Junction box	Protection rating: IP67 (with bypass diode)
Adhesive	Silicone
Cables (length/cross section)	2 x 1,200 mm/2.5 mm ² (halogen free)
Connectors	Hosiden HSC (MC4 plug-in)

3.2.2. The inverters

Fourteen pieces of SMA Sunny Tripower 60 inverter were used in Solar Power Plant at Hasan Kalyoncu University. Technical data of SMA Sunny Tripower 60 model inverters are as in Table 3.6.

Table 3. 6 Technical data of the inverters

Input (DC)	
Rated power (DC)	61240 W
Max. input voltage	1000 V
Output (AC)	
Rated power at nominal voltage	60000 W
Max. Apparent AC power	60000 VA
Efficiency	
Max. Efficiency	98.8%

3.3. Layout plan

The situation of the land determined by the corner points, the placement of the panels on the land and the connection route with the underground cables for transmission to the power transmission line are given in Figure 3.15 Layout Plan.

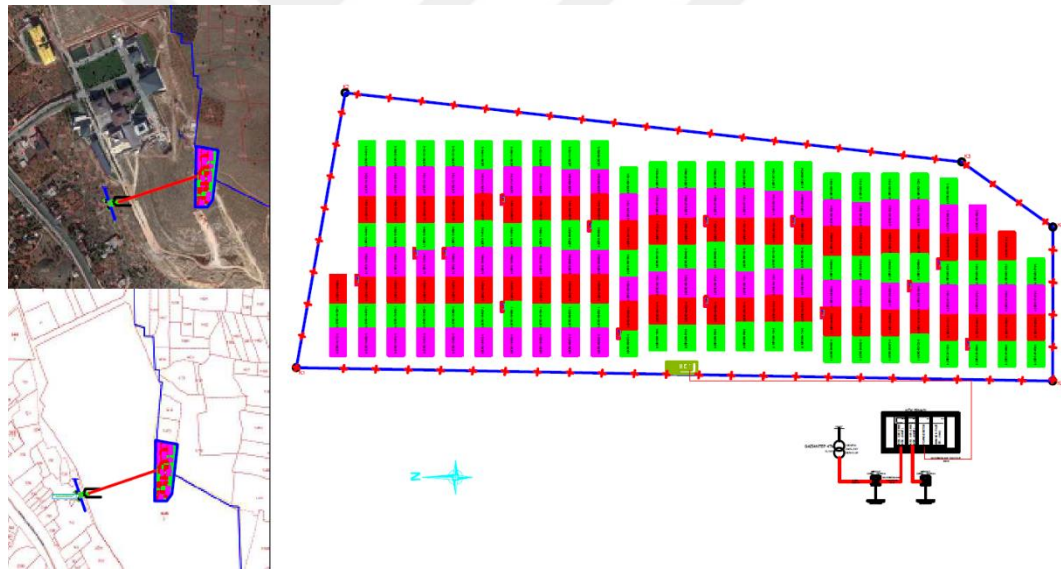


Figure 3. 15 Layout plan

3.4. Single line diagram

Figure 3.16 contains information on the number and placement of modules, string structures, cable details, inverter numbers and connections, transformer built on the plant side, and connection point to the city grid.

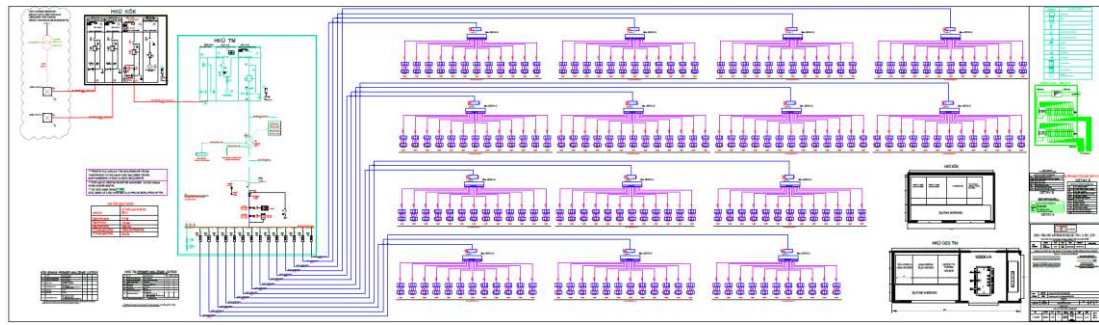


Figure 3. 16 Single line diagram

CHAPTER 4

4. SIMULATION AND GENERATION DATASETS

The present study analyzes two different simulation and actual generation datasets. The first group of simulation data was obtained from PVSol by Valentin Software GmbH, which is a dynamic PV system design and optimization software. On the other hand, the second group of data was obtained from PVGIS, which is an open-source web application giving information about generation values and performances in a PV system. The application was released by Joint Research Centre (JRC), which is the primary science and research service of European Commission. It is one of the most widely used web applications which enable to perform rapid feasibility. PVSol, similarly, is one of the most popular simulation programs in this sector. Hasan Kalyoncu University mainly aims to reduce its carbon footprints by generating electricity from renewable energy sources and to minimize its energy costs, thus contributing to the discipline through academic studies. In this respect, the above-mentioned programs were used in the present study to address the technical necessities in the sector.

4.1. Simulation Datasets

4.1.1. Simulations with PVSol

PVSol was released by Valentin Software GmbH as a PV system design and simulation program.

Three different simulations were performed in three different configurations with PVSol. Gaziantep climate data and 14 pieces of SMA STP 60-10 (v2) inverters were used in all configurations. The variable parameters are module types and their inclination angles:

1. PVSol Simulation for CIS-based, 25° Inclination SPP (HKU's own SPP modelling),
2. PVSol Simulation for CSi-based, 25° Inclination SPP,
3. PVSol Simulation for CSi-based, 31° Inclination SPP,

The simulation results of each configuration were presented in the following sections.

4.1.1.1. PVSol Simulation for CIS based, 25 ° Inclination SPP (HKU's own SPP modelling)

The first PVSol simulation benefited from the exact configuration of the solar power plant at Hasan Kalyoncu University. Solar Frontier CIS module and SMA inverter were preferred under Gaziantep climate conditions. In addition, PV generator output power, surface area, number of modules and number of inverters are given in Table 4.1.

Table 4. 1 Grid-Connected PV System

Climate Data	Gaziantep, TUR (1991 - 2010)
PV Generator Output	890,88 kWp
PV Generator Surface	6.838,0 m ²
Number of PV Modules	5568
Number of Inverters	14

Information about the manufacturer, model and placement angles of the module used in the simulation is as in Table 4.2.

Table 4. 2 Module data

Name	Hasan Kalyoncu University PV SPP
PV Modules	5568 x SF160-S (v1)
Manufacturer	Solar Frontier
Inclination	25°
Orientation	South 180°
Installation Type	Mounted - Open Space
PV Generator Surface	6.838,0 m ²

The terrain view of the power plant design made in the PVSol program is given in Figure 4.1.

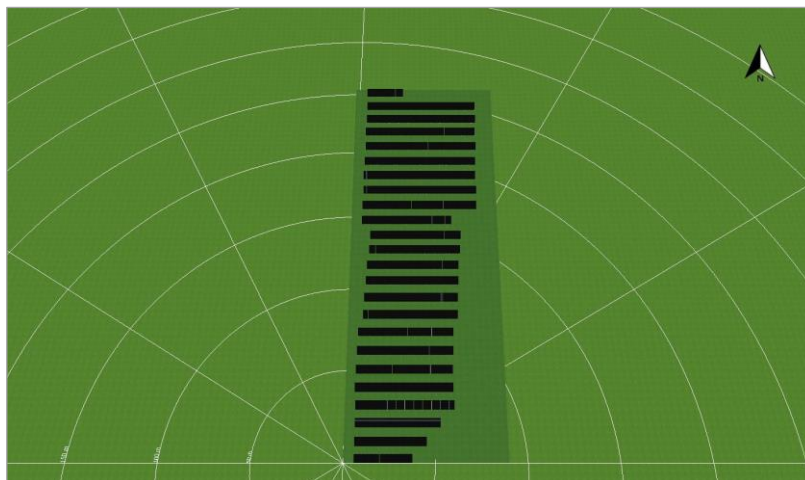


Figure 4. 1 Terrain view of design

Also, the string configuration made in PVSol is indicated with different colors. (See Figure 4.2).

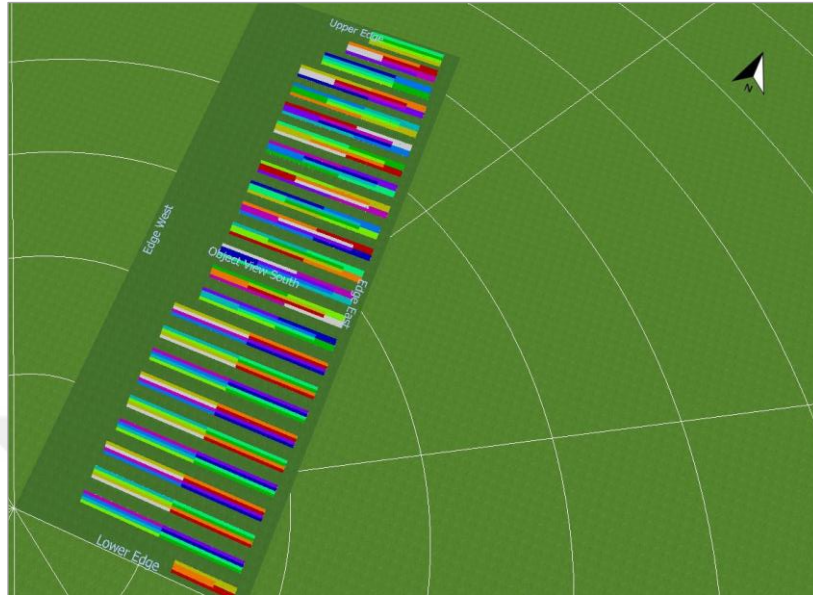


Figure 4. 2 String configuration view

In PVSol, the area where the power plant is installed was selected and the sun exposure angles were calculated. According to Figure 4.3, June is the month when the sun comes to the power plant area at the steepest angle.

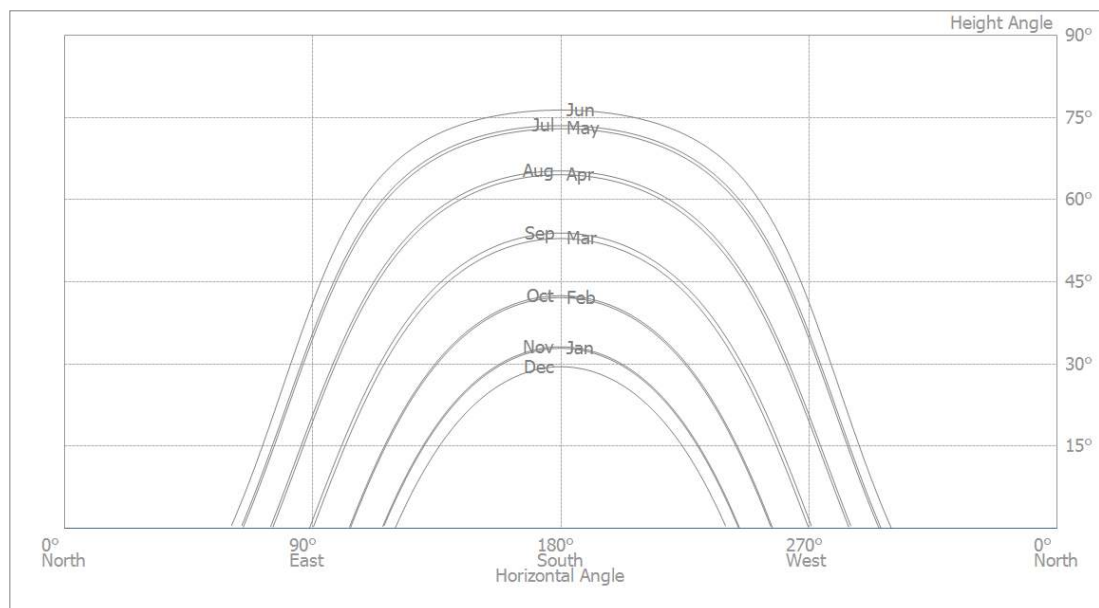


Figure 4. 3 Horizon Line

The configuration for the 14 inverters used in the simulation is given in Table 4.3.

Table 4. 3 Inverters configuration

Module Area	Hasan Kalyoncu University PV SPP
Inverter 1-14	
Model	STP 60-10 (v2)
Manufacturer	SMA Solar Technology AG
Quantity	14
Sizing Factor	102,4 %
Configuration	MPP 1: 32 x 12

Table 4. 4 AC Mains

Number of Phases	3
Mains Voltage (1-phase)	230 V
Displacement Power Factor (cos phi)	+/- 1

The simulation results estimated that the power plant with an installed DC power capacity of 890.88 kWp would generate an annual energy amount of 1.453.528 kWh and thus prevent 683.158 kg CO² emission. The performance ratio of the system was calculated as 77.1% (see Table 4.5).

Table 4. 5 Simulation results

PV Generator Output	890,88 kWp
Spec. Annual Yield	1.631,56 kWh/kWp
Performance Ratio (PR)	77,1 %
Yield Reduction due to Shading	0,7 %/Year
Grid Feed-in	1.453.528 kWh/Year
Grid Feed-in in the first year (incl. module degradation)	1.453.528 kWh/Year
Standby Consumption (Inverter)	196 kWh/Year
CO ₂ Emissions avoided	683.158 kg / year

4.1.1.2. PVSol Simulation for CSi based, 25 ° Inclination SPP

The second PVSol simulation benefited from the CSi-based modules, which are different from the solar power plant at Hasan Kalyoncu University. Phono Solar CSi module and SMA inverter were preferred under Gaziantep climate conditions. In addition, PV generator output power, surface area, number of modules and number of inverters are given in Table 4.6.

Table 4. 6 Grid-Connected PV System

Climate Data	Gaziantep, TUR (1991 - 2010)
PV Generator Output	895,86 kWp
PV Generator Surface	4.563,3 m ²
Number of PV Modules	2268
Number of Inverters	14

Information about the manufacturer, model and placement angles of the module used in the simulation is as in Table 4.7.

Table 4. 7 Module data

Name	Hasan Kalyoncu University PV SPP
PV Modules	2268 x PS395MH-24/TH (v1)
Manufacturer	Phono Solar Technology Co., Ltd.
Inclination	25°
Orientation	South 180
Installation Type	Mounted - Open Space
PV Generator Surface	4.563,3,15 m ²

In PVSol, the area where the power plant is installed was selected and the sun exposure angles were calculated. According to Figure 4.4, June stands out as the month when the sun comes to the power plant area with the steepest angle.

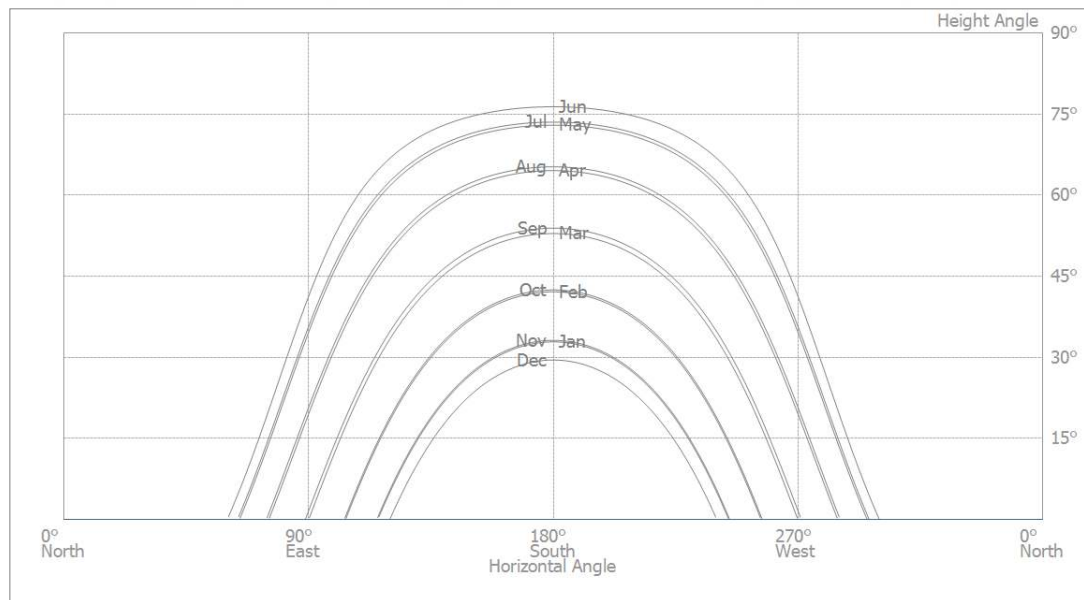


Figure 4. 4 Horizon Line

The configuration for the 14 inverters used in the simulation is given in Table 4.8.

Table 4. 8 Inverter configuration

Module Area	Hasan Kalyoncu University PV SPP
Inverter 1-14	
Model	STP 60-10 (v2)
Manufacturer	SMA Solar Technology AG
Quantity	14
Sizing Factor	106,7 %
Configuration	MPP 1: 9 x 18

Table 4. 9 AC Mains

Number of Phases	3
Mains Voltage (1-phase)	230 V
Displacement Power Factor (cos phi)	+/- 1

The simulation results estimated that the power plant with an installed DC power capacity of 895.86 kWp would generate an annual energy amount of 1.641.355 kWh and thus prevent 771.437 kg CO² emission. The performance ratio of the system was calculated as 86.8% (see Table 4.10).

Table 4. 10 Simulation results

PV Generator Output	895.86 kWp
Spec. Annual Yield	1.832,16 kWh/kWp
Performance Ratio (PR)	86,8 %
Yield Reduction due to Shading	0,6 %/Year
Grid Feed-in	1.641.355 kWh/Year
Grid Feed-in in the first year (incl. module degradation)	1.641.355 kWh/Year
Standby Consumption (Inverter)	183 kWh/Year
CO ₂ Emissions avoided	771.437 kg / year

4.1.1.3. PVSol Simulation for CSi based, 31 ° Inclination SPP

The third PVSol simulation benefited from CSi-based modules and was inclined at 31° instead of 25°, which is different from the solar power plant at Hasan Kalyoncu University. Phono Solar CSi module and SMA inverter were preferred under Gaziantep climate conditions. In addition, PV generator output power, surface area, number of modules and number of inverters are given in Table 4.11.

Table 4. 11 Grid-Connected PV System

Climate Data	Gaziantep, TUR (1991 - 2010)
PV Generator Output	895,86 kWp
PV Generator Surface	4.563,3 m ²
Number of PV Modules	2268
Number of Inverters	14

Information about the manufacturer, model and placement angles of the module used in the simulation is as in Table 4.12.

Table 4. 12 Module data

Name	Hasan Kalyoncu University PV SPP
PV Modules	2268 x PS395MH-24/TH (v1)
Manufacturer	Phono Solar Technology Co., Ltd.
Inclination	31°
Orientation	South 180°
Installation Type	Mounted - Open Space
PV Generator Surface	4.563,3 m ²

In PVSol, the area where the power plant was installed was selected and the sun exposure angles were revealed. According to Figure 4.5, June stands out as the month when the sun comes to the power plant area with the steepest angle.

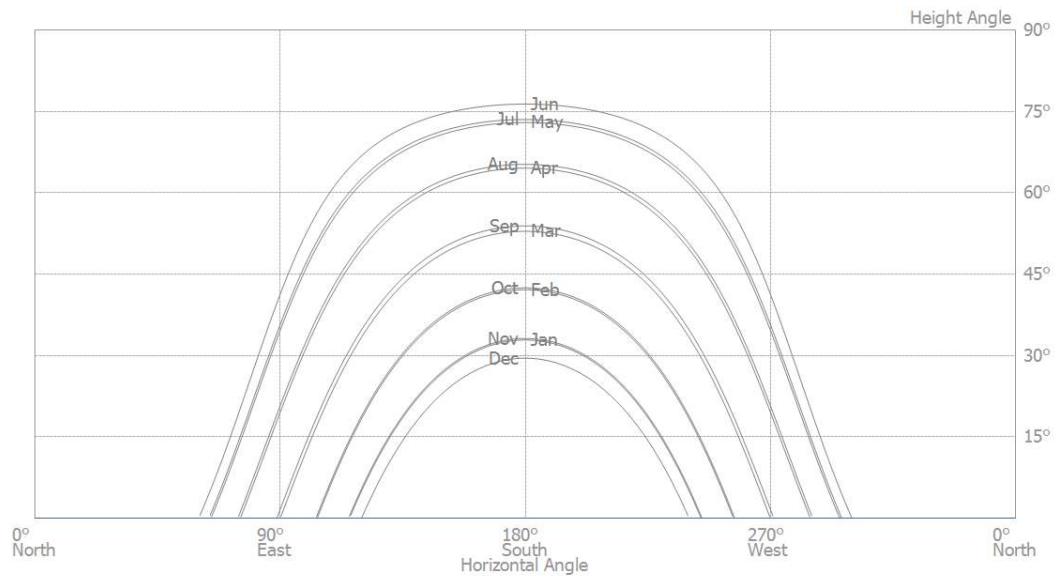


Figure 4. 5 Horizon Line

The configuration for the 14 inverters used in the simulation is given in Table 4.13.

Table 4. 13 Inverter configuration

Module Area	Hasan Kalyoncu University PV SPP
Inverter 1-14	
Model	STP 60-10 (v2)
Manufacturer	SMA Solar Technology AG
Quantity	14
Sizing Factor	106,7 %
Configuration	MPP 1: 9 x 18

Table 4. 14 AC Mains

Number of Phases	3
Mains Voltage (1-phase)	230 V
Displacement Power Factor (cos phi)	+/- 1

The simulation results estimated that the power plant with an installed DC power capacity of 895.86 kWp would generate an annual energy amount of 1.643.203 kWh and thus prevent 772.306 kg CO² emission. The performance ratio of the system was calculated as 86.7% (see Table 4.15).

Table 4. 15 Simulation results

PV Generator Output	895.86 kWp
Spec. Annual Yield	1.834,22 kWh/kWp
Performance Ratio (PR)	86,7 %
Yield Reduction due to Shading	0,8 %/Year
Grid Feed-in	1.643.203 kWh/Year
Grid Feed-in in the first year (incl. module degradation)	1.643.203 kWh/Year
Standby Consumption (Inverter)	183 kWh/Year
CO ₂ Emissions avoided	772.306 kg / year

4.1.1.4. The Comparison of PVSol Simulations

Three different systems with different parameters were designed in three simulations. In the first system, CIS-based PV modules were mounted with an inclination angle of 25° and an orientation angle of 180°. Thus, the existing system at Hasan Kalyoncu University was modelled identically using Solar Frontier panels and SMA inverters.

In the second system, CSi-based PV modules were mounted with an inclination angle of 25° and an orientation angle of 180°. The system was modelled using Phono Solar panels and SMA inverters.

In the third system, CSi-based PV modules were mounted with an inclination angle of 31° and an orientation angle of 180° . The system was modelled using Phono Solar panels and SMA inverters.

Due to system requirements in the second and third system, DC power slightly differs from the actual system to minimize the differences in generation values. When these models are compared together, significant differences can be observed in terms of generation values between CIS- and CSi-based modules. On the other hand, only the inclination angle was modified in CSi-based models, which did not result in any significant differences.

Table 4. 16 Comparative PVSol simulation results

	1 st case	2 nd case	3 rd case
PV Technology	CIS	CSi	CSi
Inclination	25°		31°
Orientation	180°		
Inverters	14 x SMA 60-10(v2)		
DC Power	890,88 kWp	895,86 kWp	
Number of PV Modules	5568	2268	
Annual Energy Production	1.453.528 kWh	1.641.355 kWh	1.643.203 kWh
Annual CO ₂ Emission Reduced	683.158 kg	771.437 kg	772.306 kg

4.1.2. Simulations with Photovoltaic Geographical Information System (PVGIS)

Geographical and technical data belonging to the Solar Power Plant at Hasan Kalyoncu University were logged in the application for simulation studies. In addition, PVGIS-SARAH database, which was generated for various regions in Europe, Africa, Asia and South America using CM SAF algorithm, was also included in the simulation studies. The following simulations were performed with different module technologies and inclination angles:

1. PVGIS Simulation for CIS based, 25° Inclination SPP (HKU's own SPP modelling),
2. PVGIS Simulation for CSi based, 25° Inclination SPP,
3. PVGIS Simulation for CSi based, 31° Inclination SPP.

A more general configuration was needed in PVGIS, as it was not possible to change parameters such as brand names or models. The obtained simulation results are given below.

4.1.2.1. PVGIS Simulation for CIS-based, 25 ° Inclinacion SPP (HKU's own SPP modelling)

Similar to the solar power plant at Hasan Kalyoncu University, CIS modules in the first simulation using PVGIS were positioned at an inclination angle of 25°. The location of the power plant was marked on the map under Gaziantep climate conditions (see Figure 4.6).

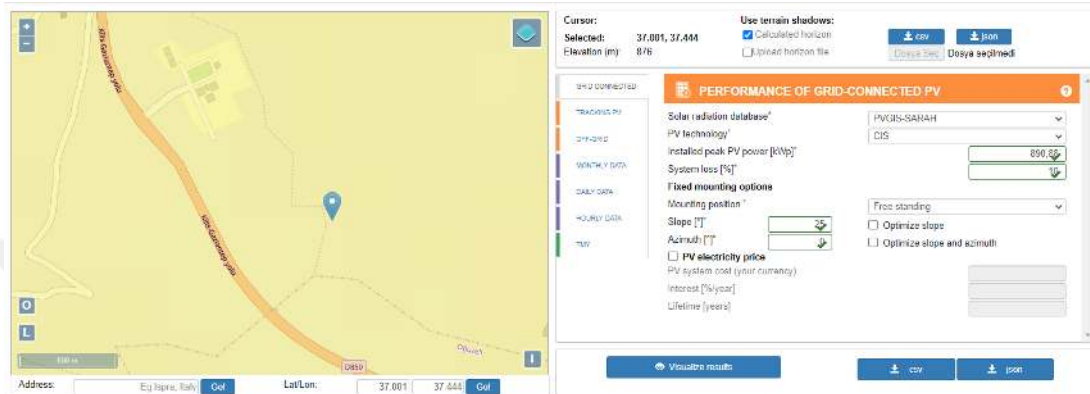


Figure 4. 6 PVGIS screen

The simulation results showed that the highest amount of energy was generated in July and the annual amount of energy generated by the system was 1.457.819 kWh (see Table 4.17).

Table 4. 17 PVGIS simulation results

	Monthly average generation in kWh	Average monthly sum of global tilted irradiance in kWh/m ²
JAN	71.550	93,78
FEB	78.271	103,94
MAR	116.201	156,91
APR	130.611	180,35
MAY	149.300	210,81
JUNE	160.035	230,86
JULY	165.095	243,46
AUG	157.242	232,14
SEP	142.640	206,22
OCT	116.334	162,97
NOV	92.381	125,38
DEC	78.159	103,63
TOTAL	1.457.819	2.050,44

4.1.2.2. PVGIS Simulation for CSi-based, 25 ° Inclination SPP

Unlike the configuration in the solar power plant at Hasan Kalyoncu University, CSi modules were preferred in the second simulation using PVGIS. The location of the power plant was marked on the map under Gaziantep climate conditions (see Figure 4.7).

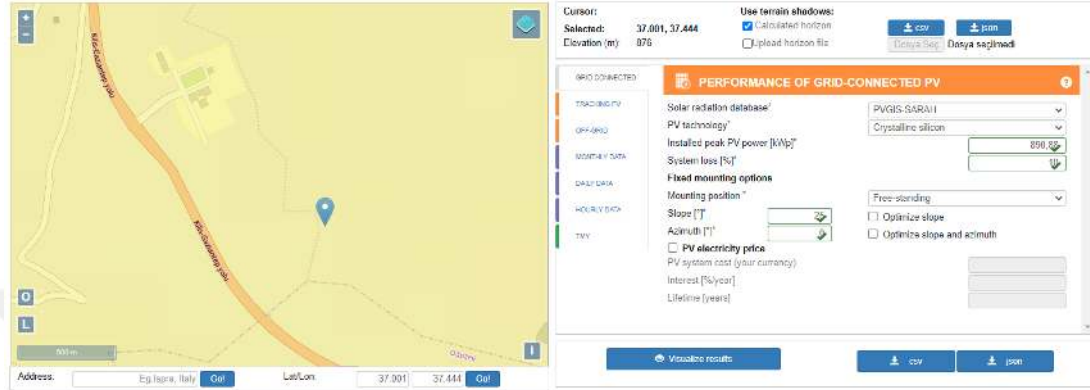


Figure 4. 7 PVGIS screen

According to the simulation results, the highest amount of energy was generated in July, and the annual amount of energy generated by the system was 1.463.023 kWh (see Table 4.18).

Table 4. 18 PVGIS simulation results

	Average monthly production in kWh	Average monthly sum of global tilted irradiance in kWh/m ²
JAN	73.773	93,78
FEB	80.307	103,94
MAR	117.844	156,91
APR	131.131	180,35
MAY	149.303	210,81
JUNE	156.247	230,86
JULY	160.332	243,46
AUG	156.837	232,14
SEP	143.575	206,22
OCT	117.804	162,97
NOV	95.349	125,38
DEC	80.521	103,63
TOTAL	1.463.023	2.050,44

4.1.2.3. PVGIS Simulation for CSi-based, 31° Inclination SPP

Contrary to the configuration in the solar power plant at Hasan Kalyoncu University, CSi modules were positioned at an inclination angle of 31° in the third simulation using PVGIS. The location of the power plant was marked on the map under Gaziantep climate conditions (see Figure 4.8).

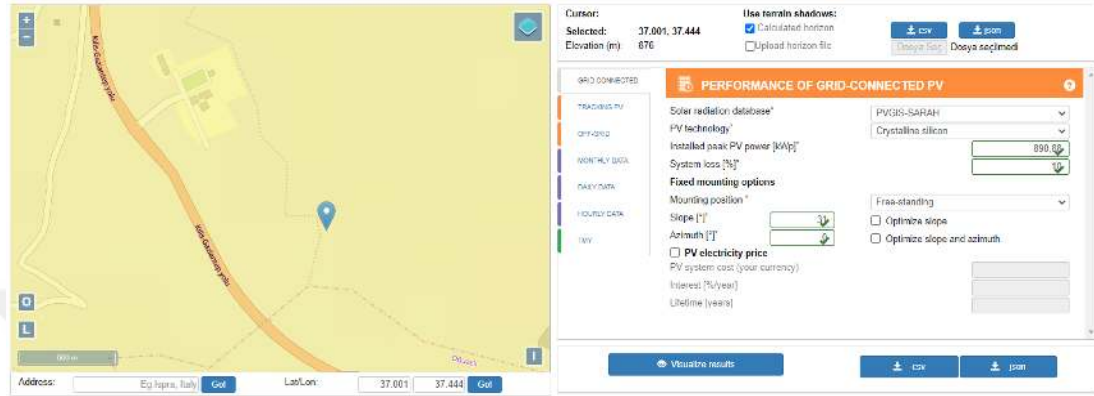


Figure 4. 8 PVGIS screen

It can be seen in simulation results that the highest amount of energy was generated in July, and the annual amount of energy generated by the system was 1.471.094 kWh (see Table 4.19).

Table 4. 19 PVGIS simulation results

	Monthly average generation in kWh	Average monthly sum of global tilted irradiance in kWh/m ²
JAN	77.885	98,76
FEB	83.114	107,56
MAR	119.546	159,26
APR	130.343	179,38
MAY	145.931	206,22
JUNE	151.042	223,52
JULY	155.544	236,58
AUG	154.863	229,46
SEP	144.993	208,44
OCT	121.576	168,31
NOV	100.469	132,15
DEC	85.788	110,3
TOTAL	1.471.094	2.059,94

4.1.2.4. Comparison of PVGIS Simulations

Three different systems with different parameters were designed in PVGIS simulations. In the first system, CIS-based PV modules were mounted with an inclination angle of 25° and an orientation angle of 180°.

In the second system, CSi-based PV modules were mounted with an inclination angle of 25° and an orientation angle of 180°.

In the third system, CSi-based PV modules were mounted with an inclination angle of 31° and an orientation angle of 180°.

DC power was set to 890.88 kWp in all three system designs. When the models were compared, it became clear that the systems with CIS modules were less efficient compared to other systems. However, there were not any significant differences in the simulation results.

Table 4. 20 Comparison table of PVGIS Simulations

	1 st case	2 nd case	3 rd case
PV Technology	CIS	CSi	CSi
Inclination	25°		31°
Orientation	180°		
DC Power	890,88 kWp		
Annual Energy Generation	1.457.819 kWh	1.463.023 kWh	1.471.094 kWh
Annual CO ₂ Emissions Reduced	685.175 kg	687.621 kg	691.414 kg

4.2. Generation data of the solar power plant (01.01.2017 – 31.12.2020)

Generation values in a photovoltaic solar power plant are directly proportional to solar irradiance. In a system simulation, these data are usually calculated based on average values and long-term data. Nevertheless, it is likely to encounter some differences between simulation results and actual generation data due to various factors such as technical problems in the field and/or changing climate conditions throughout a year.

The following table presents the monthly and annual generation values of the Solar Power Plant at Hasan Kalyoncu University between 01.01.2017 and 31.12.2020. It can be seen that the highest amounts of energy were generated during July and August. Four-year data also demonstrate that the annual average amount of energy generated was 1.389.554 kWh. Thus, the deviation values from PVSol simulation and PVGIS results were -%4.68 and -%4.68, respectively.

Table 4. 21 Solar power plant generation data

	2017	2018	2019	2020	Avg.
JAN	76.929	64.879	58.712	74.504	68.756
FEB	108.131	74.032	66.519	82.769	82.863
MAR	111.927	139.776	97.336	109.423	114.616
APR	138.989	136.548	117.261	132.890	131.422
MAY	157.376	114.351	159.584	145.404	144.179
JUNE	160.438	120.950	157.376	139.143	144.477
JULY	175.163	148.026	153.719	136.450	153.340
AUG	148.977	154.649	165.647	194.372	165.911
SEP	140.135	119.247	141.121	131.483	132.997
OCT	115.206	71.842	104.136	117.455	102.160
NOV	90.143	75.731	95.750	81.541	85.791
DEC	83.977	41.459	51.860	74.879	63.044
TOTAL	1.507.391	1.261.490	1.369.021	1.420.313	1.389.554

4.2.1. The Comparison of Simulation Results and Actual Generation Data

The annual generation data of all simulations and the actual generation data are given in the Table 4.22. According to the table, the generation values were lower in the actual system with CIS modules with an inclination angle of 25° compared to other CIS-based models. In addition, the most efficient system was designed with CSi-based modules with an inclination angle of 31°.

Table 4. 22 The comparison of annual energy generation in simulation results and the actual system

Annual Energy Generation	CIS based 25° Inclination	CSi based 25° Inclination	CSi based 31° Inclination
PVSol	1.453.528 kWh	1.641.355 kWh	1.643.203 kWh
PVGIS	1.457.819 kWh	1.463.023 kWh	1.471.094 kWh
Actual System (avg.)	1.389.554 kWh	N/A	N/A

CHAPTER 5

5. CONCLUSION

The present study focused on the data obtained from a solar power plant which has been running at the campus of Hasan Kalyoncu University since late 2016. In this solar power plant, 5568 pieces of 160W CIS-based modules were mounted with an inclination angle of 25° and at an orientation angle of 180° towards south. The total generation and installation areas were 6838 m^2 and 16500 m^2 , respectively. The installed DC power capacity was 890.88 kWp, and 14 pieces of 60 KVA inverters were used.

Based on the above-mentioned parameters, inclination angles and panel technologies were modified to perform three different simulations. PVSol, which is a widely used commercial computer software with detailed parameter inputs, and PVGIS, which is a rapid and general-purpose web application, were preferred for simulation studies. Three different scenarios were simulated on these programs. The first case was digitally identical to the actual power plant at the campus (CIS module, 25° inclination), which yielded an annual energy amount of 1.453.528 kWh and 1.457.819 kWh in PVSol and PVGIS, respectively. In the second case (CSi module, 25° inclination), the annual amounts of energy generated were calculated as 1.641.355 kWh and 1.463.023 kWh PVSol and PVGIS, respectively. Finally, in the third case, (CSi module, 31° inclination), PVSol and PVGIS simulations yielded an annual amount of 1.643.203 kWh and 1.471.094 kWh, respectively.

In addition, four-year complete cycle generation data of the power plant between 2017 and 2020 were also analyzed in the present study. Actual generation data include the measured values after taking different pauses into account such as technical problems caused by the grid and power plant systems, maintenance and cleaning. As a result, the average generation amount during the four-year period was calculated as 1.389.554 kWh.

Because PVSol allows various data inputs affecting generation data such as module brand name and model, inverter brand name, model and special design conditions in the study field, it is acknowledged that the simulation accuracy in PVSol is often higher compared to PVGIS (González-Peña, D. Et al., 2021). When the actual four-year generation data and simulation results based on these data were compared, it was

found that the error rate of PVSol was 4.60%, while it was 4.91% for PVGIS. Additionally, it was also observed that the generation data obtained from PVSol and PVGIS displayed an increase when parameters were modified in both softwares.

The findings also demonstrated that the solar power plants with CSi-based modules yielded more efficient generation data compared to those with CIS-based modules, and the number of modules and generation area in these systems were reduced to 2268 and 4563.3 m², respectively. Thus, a smaller area of land was needed for a solar power plant.

In conclusion, it was found in the present study that there were not any significant differences between the actual generation data and simulation results. Different comparisons between solar power plants with different inclination angles and module technologies suggest that the most efficient system for the province of Gaziantep can be designed with CSi-based modules with an inclination angle of 31°. Since efficient systems are more likely to reduce carbon emission and improve energy generation, they will contribute to the environmental sustainability significantly.

REFERENCES

- Al-Badi, A. H. (2018). Measured performance evaluation of a 1.4 kW grid connected desert type PV in Oman. *Energy for Sustainable Development*, 47, 107–113. <https://doi.org/10.1016/j.esd.2018.09.007>
- Alkan S., (2019). The East-West Oriented of Optimized Solar Energy Power Plant Pilot Application on The Roof and the Economic Analysis And Production Evaluation of The South Oriented Solar Power Plant. Institute of Science and Technology, Istanbul Arel University, MSc thesis, Istanbul. (Advisor: Dr. Yavuz Ateş)
- Ameur, A., Berrada, A., Loudiyi, K., & Aggour, M. (2020). Forecast modeling and performance assessment of solar PV systems. *Journal of Cleaner Production*, 267, 122167. <https://doi.org/10.1016/j.jclepro.2020.122167>
- Amin, N., Lung, C. W., & Sopian, K. (2009). A practical field study of various solar cells on their performance in Malaysia. *Renewable Energy*, 34(8), 1939–1946. <https://doi.org/10.1016/j.renene.2008.12.005>
- Attari, K., Elyaakoubi, A., & Asselman, A. (2016). Performance analysis and investigation of a grid-connected photovoltaic installation in Morocco. *Energy Reports*, 2(December 2015), 261–266. <https://doi.org/10.1016/j.egyr.2016.10.004>
- Awan, A. B., Zubair, M., & Chandra Mouli, K. V. V. (2020). Design, optimization and performance comparison of solar tower and photovoltaic power plants. *Energy*, 199, 117450. <https://doi.org/10.1016/j.energy.2020.117450>
- BP. British Petroleum. 2020. “BP Statistical Review of World Energy 2020 | 69th edition”. Available at: <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf>
- de Lima, L. C., de Araújo Ferreira, L., & de Lima Morais, F. H. B. (2017). Performance analysis of a grid connected photovoltaic system in northeastern Brazil. *Energy for Sustainable Development*, 37, 79–85. <https://doi.org/10.1016/j.esd.2017.01.004>

- Drews, A., Beyer, H. G., & Rindelhardt, U. (2008). Quality of performance assessment of PV plants based on irradiation maps. *Solar Energy*, 82(11), 1067–1075. <https://doi.org/10.1016/j.solener.2008.04.009>
- Elamim, A., Hartiti, B., Haibaoui, A., Lfakir, A., & Thevenin, P. (2019). Comparative study of photovoltaic solar systems connected to the grid: Performance evaluation and economic analysis. *Energy Procedia*, 159, 333–339. <https://doi.org/10.1016/j.egypro.2019.01.006>
- Elbaset, A.A., Abdelwahab, S. A. M., Ibrahim, H., & Eid, M. (2019). Performance Analysis of Photovoltaic Systems with Energy Storage Systems. Switzerland. Springer Nature. <https://doi.org/10.1007/978-3-030-20896-7>.
- Elibol, E., Özmen, Ö. T., Tutkun, N., & Köysal, O. (2017). Outdoor performance analysis of different PV panel types. *Renewable and Sustainable Energy Reviews*, 67, 651–661. <https://doi.org/10.1016/j.rser.2016.09.051>
- Goetzberger, A., Hebling, C., Schock, H., (2003) Photovoltaic materials, history, status and outlook, *Materials Science and Engineering: R: Reports*, Volume 40, Issue 1, 2003, Pages 1-46, ISSN 0927-796X, [https://doi.org/10.1016/S0927-796X\(02\)00092-X](https://doi.org/10.1016/S0927-796X(02)00092-X).
- González-Peña, D., García-Ruiz, I., Díez-Mediavilla, M., Dieste-Velasco, M. I., & Alonso-Tristán, C. (2021). Photovoltaic Prediction Software: Evaluation with Real Data from Northern Spain. *Applied Sciences*, 11(11), 5025. <https://doi.org/10.3390/app11115025>
- Gündüz M. S., (2019). Techno-Economic Analysis of a Photovoltaic Solar Power Plant. Kütahya – Simav Case Study. Institute of Science and Technology, Kütahya Dumlupınar University, MSc thesis, Kütahya. (Advisor: Prof. Dr. Mustafa Arif Özgür)
- Hachicha, A. A., Al-Sawafta, I., & Said, Z. (2019). Impact of dust on the performance of solar photovoltaic (PV) systems under United Arab Emirates weather conditions. *Renewable Energy*, 141, 287–297. <https://doi.org/10.1016/j.renene.2019.04.004>
- Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A., & Kim, K. H. (2018). Solar energy: Potential and future prospects. *Renewable and Sustainable Energy Reviews*,

82(August 2017), 894–900. <https://doi.org/10.1016/j.rser.2017.09.094>

Kalogirou, S. (2014). *Solar Energy Engineering: Processes and Systems: Second Edition*. Academic Press.

Kimmell, Tommy; Kimmell, Philip; Sorensen, Matthew; Ruggiero, Cameron; and Coit, Ben (2020) "Investing in a Green Future: Universities and Renewable Energy," *Bryant University Journal of Interdisciplinary Studies*: Vol. 1: Iss. 1, Article 5.

Kum, G., Sönmez, M.E., & Karabaş, M. (2019). Determination of Solar Energy Potential in Gaziantep Province by Analytical Hierarchy Process Method (AHP). *Journal of Geography*, 0(39), 61-72. <https://doi.org/10.26650/JGEOG2019-0031>

Kumar, N. M., Kumar, M. R., Rejoice, P. R., & Mathew, M. (2017). Performance analysis of 100 kWp grid connected Si-poly photovoltaic system using PVsyst simulation tool. *Energy Procedia*, 117, 180–189. <https://doi.org/10.1016/j.egypro.2017.05.121>

Kutluca M., (2020). *Analysis and Design of Off-Grid Micro Solar Power Plant*. Institute of Science and Technology, Kırklareli University, MSc thesis, Kırklareli. (Advisor: Assist. Prof. Dr. Evren İşen)

Kymakis, E., Kalykakis, S., & Papazoglou, T. M. (2009). Performance analysis of a grid connected photovoltaic park on the island of Crete. *Energy Conversion and Management*, 50(3), 433–438. <https://doi.org/10.1016/j.enconman.2008.12.009>

Leloux, J., Narvarte, L., & Trebosc, D. (2012). Review of the performance of residential PV systems in Belgium. *Renewable and Sustainable Energy Reviews*, 16(1), 178–184. <https://doi.org/10.1016/j.rser.2011.07.145>

Lund, H. (2009). *Renewable Energy Systems, The Choice and Modeling of 100% Renewable Solutions*. 1st edition. Academic Press.

Marion, B., Adelstein, J., Boyle, K., Hayden, H., Hammond, B., Fletcher, Canada, B., Narang, D., Kimber, A., Mitchell, L., Rich, G., & Townsend, T. (2005). Performance parameters for grid-connected PV systems. *Conference Record of the IEEE Photovoltaic Specialists Conference*, 1601–1606. <https://doi.org/10.1109/PVSC.2005.1488451>

- Martín-Martínez, S., Cañas-Carretón, M., Honrubia-Escribano, A., & Gómez-Lázaro, E. (2019). Performance evaluation of large solar photovoltaic power plants in Spain. *Energy Conversion and Management*, 183(December 2018), 515–528. <https://doi.org/10.1016/j.enconman.2018.12.116>
- MoENR. Ministry of Energy and Natural Resources of Republic of Turkey. “Solar Energy Potential Map”. <https://gepa.enerji.gov.tr/MyCalculator/>, 22.05.2022
- Mondol, J. D., Yohanis, Y., Smyth, M., & Norton, B. (2006). Long term performance analysis of a grid connected photovoltaic system in Northern Ireland. *Energy Conversion and Management*, 47(18–19), 2925–2947. <https://doi.org/10.1016/j.enconman.2006.03.026>
- Moraitis, P., Kausika, B. B., Nortier, N., & Van Sark, W. (2018). Urban environment and solar PV performance: The case of the Netherlands. *Energies*, 11(6). <https://doi.org/10.3390/en11061333>
- Moraitis, P., & van Sark, W. (2014). Operational performance of grid-connected PV systems. 2014 IEEE 40th Photovoltaic Specialist Conference, PVSC 2014, 1953–1956. <https://doi.org/10.1109/PVSC.2014.6925308>
- Obeidat, F. (2018). A comprehensive review of future photovoltaic systems. *Solar Energy*, 163(March), 545–551. <https://doi.org/10.1016/j.solener.2018.01.050>
- Oh, W., Choi, H., Seo, K. W., Kim, D., Kim, S. Y., Lee, H. S., Hwang, H., & Kim, D. (2020). Evaluation based on performance and failure of PV system in 10 years field-aged 1 MW PV power plant. *Microelectronics Reliability*, 114(July), 113763. <https://doi.org/10.1016/j.microrel.2020.113763>
- Ozden, T., Akinoglu, B. G., & Turan, R. (2017). Long term outdoor performances of three different on-grid PV arrays in central Anatolia – An extended analysis. *Renewable Energy*, 101, 182–195. <https://doi.org/10.1016/j.renene.2016.08.045>
- Ozden, T., Carr, A. J., Geerligs, B. (L J.), Turan, R., & Akinoglu, B. G. (2020). One-year performance evaluation of two newly developed back-contact solar modules in two different climates. *Renewable Energy*, 145, 557–568. <https://doi.org/10.1016/j.renene.2019.06.045>
- Öztürk H.H. (2017). “Power Conversion Efficiency and Effective Factors in

Electricity Generation From Solar Energy by Photovoltaic Method”. Proceedings of the Electrical Installation National Congress and Exhibition, 1, 1-14.

Presidency of the Republic of Turkey, Presidency of Strategy and Budget. 2018. “11th Development Plan”. Available at: <https://www.sbb.gov.tr/wp-content/uploads/2019/07/OnbirinciKalkinmaPlani.pdf>

Ritchie, H. and Roser M. (2020). "Energy". <https://ourworldindata.org/energy>, 28.05.2022.

Roni, M. M., Hoque, I. U., & Ahmed, T. (2019). Comparative Study of Levelized Cost of Electricity (LCOE) for Concentrating Solar Power (CSP) and Photovoltaic (PV) Plant in the Southeastern Region of Bangladesh. 2nd International Conference on Electrical, Computer and Communication Engineering, ECCE 2019, 7–9. <https://doi.org/10.1109/ECACE.2019.8679173>

Sahu, A., Yadav, N., & Sudhakar, K. (2016). Floating photovoltaic power plant: A review. *Renewable and Sustainable Energy Reviews*, 66, 815–824. <https://doi.org/10.1016/j.rser.2016.08.051>

Sampaio, P. G. V., & González, M. O. A. (2017). Photovoltaic solar energy: Conceptual framework. *Renewable and Sustainable Energy Reviews*, 74(March), 590–601. <https://doi.org/10.1016/j.rser.2017.02.081>

Sharma, R., & Goel, S. (2017). Performance analysis of a 11.2 kWp roof top grid-connected PV system in Eastern India. *Energy Reports*, 3, 76–84. <https://doi.org/10.1016/j.egyr.2017.05.001>

Shorabeh, S. N., Firozjaei, M. K., Nematollahi, O., Firozjaei, H. K., & Jelokhani-Niaraki, M. (2019). A risk-based multi-criteria spatial decision analysis for solar power plant site selection in different climates: A case study in Iran. *Renewable Energy*, 143, 958–973. <https://doi.org/10.1016/j.renene.2019.05.063>

Shukla, A. K., Sudhakar, K., & Baredar, P. (2016). Simulation and performance analysis of 110 kWp grid-connected photovoltaic system for residential building in India: A comparative analysis of various PV technology. *Energy Reports*, 2, 82–88. <https://doi.org/10.1016/j.egyr.2016.04.001>

Shuvho, M. B. A., Chowdhury, M. A., Ahmed, S., & Kashem, M. A. (2019). Prediction

- of solar irradiation and performance evaluation of grid connected solar 80KWp PV plant in Bangladesh. *Energy Reports*, 5, 714–722. <https://doi.org/10.1016/j.egyr.2019.06.011>
- Singh, G. K. (2013). Solar power generation by PV (photovoltaic) technology: A review. *Energy*, 53, 1–13. <https://doi.org/10.1016/j.energy.2013.02.057>
- So, J. H., Jung, Y. S., Yu, G. J., Choi, J. Y., & Choi, J. H. (2007). Performance results and analysis of 3 kW grid-connected PV systems. *Renewable Energy*, 32(11), 1858–1872. <https://doi.org/10.1016/j.renene.2006.10.003>
- Tanim, M. M., Chowdhury, N. A., Rahman, M. M., & Ferdous, J. (2014). Design of a photovoltaic-biogas hybrid power generation system for Bangladeshi remote area using HOMER software. *Proceedings of 2014 3rd International Conference on the Developments in Renewable Energy Technology, ICDRET 2014*, 3–7. <https://doi.org/10.1109/icdret.2014.6861694>
- TEDAŞ. Toroslar Electricity Transmission Corporation. 2020. Installed Power of Solar Power Plants in Gaziantep. Gaziantep.
- TEİAŞ. Turkish Electricity Transmission Corporation. 2020. Installed Power Report. <https://webapi.teias.gov.tr/file/6b415d95-c1c2-4f4f-9588-372368c87a14?download>. 28.05.2022.
- Turney, D., & Fthenakis, V. (2011). Environmental impacts from the installation and operation of large-scale solar power plants. *Renewable and Sustainable Energy Reviews*, 15(6), 3261–3270. <https://doi.org/10.1016/j.rser.2011.04.023>
- van Sark, W., Reich, N., Müller, B., Armbruster, A., Kiefer, K., & Reise, C. (2012). Review of PV performance ratio development. <https://doi.org/10.13140/2.1.2138.7204>
- Veríssimo, P. H. A., Campos, R. A., Guarnieri, M. V., Veríssimo, J. P. A., do Nascimento, L. R., & Rüther, R. (2020). Area and LCOE considerations in utility-scale, single-axis tracking PV power plant topology optimization. *Solar Energy*, 211(October), 433–445. <https://doi.org/10.1016/j.solener.2020.09.070>
- Yadav, P., Kumar, N., & Chandel, S. S. (2015). Simulation and performance analysis of a 1kWp photovoltaic system using PVsyst. 4th IEEE Sponsored International

Conference on Computation of Power, Energy, Information and Communication,
ICCPEIC 2015, 358–363. <https://doi.org/10.1109/ICCPEIC.2015.7259481>

