ANKARA YILDIRIM BEYAZIT UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES



A CASE ANALYSIS FOR OPTIMIZING THE BALANCE BETWEEN SOLAR PHOTOVOLTAIC ELECTRICITY SUPPLY AND ELECTRICITY DEMAND OF A FACILITY

M. Sc. Thesis by

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ANKARA

A CASE ANALYSIS FOR OPTIMIZING THE BALANCE BETWEEN SOLAR PHOTOVOLTAIC ELECTRICITY SUPPLY AND ELECTRICITY DEMAND OF A FACILITY

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by

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M. Sc. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"A CASE ANALYSIS FOR OPTIMIZING THE BALANCE BETWEEN SOLAR PHOTOVOLTAIC ELECTRICITY SUPPLY AND ELECTRICITY DEMAND OF A FACILITY"** completed by **Ali KARAÇOBAN** under the supervision of **Prof. Dr. Bülent YEŞİLATA** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Date: April, 2023 **Ali KARAÇOBAN**

A CASE ANALYSIS FOR OPTIMIZING THE BALANCE BETWEEN SOLAR PHOTOVOLTAIC ELECTRICITY SUPPLY AND ELECTRICITY DEMAND OF A FACILITY

ABSTRACT

Today, energy constitutes the common agenda of the world. Despite the increasing individual and global energy demand with developing technology, the limited conventional fossil fuel reserves cause interruptions in energy supply. Because of this strategic importance, energy has become the security and strategic policy of countries rather than the problem of a family or a production line. In order to meet the increasing energy demand due to the inadequacy and finiteness of fossil resources, renewable energy sources have quickly come to the agenda of the world. Since renewable energy sources are insufficient to meet the consumption demand on their own, research and development studies are carried out to support these systems. With this thesis, the energy production of the unlicensed rooftop solar power plant with a generation capacity of 404.6 kWp connected to the grid from the low voltage level and the energy consumption of the facility where it is installed are analyzed in detail and solution proposals are presented in detail in order to minimize the differences between production and consumption. For the data to be used in the study, real-time data were obtained from the energy analyzers of the production and consumption facilities. In the light of the data obtained, solution suggestions are given in order to achieve the production-consumption balance.

Keywords: Renewable Energy, Solar PV, Energy Demand, Energy Consumption, Energy Efficiency

A CASE ANALYSIS FOR OPTIMIZING THE BALANCE BETWEEN SOLAR PHOTOVOLTAIC ELECTRICITY SUPPLY AND ELECTRICITY DEMAND OF A FACILITY

ÖZET

Enerji günümüzde dünyanın ortak gündemini oluşturmaktadır. Gelişen teknoloji ile artan bireysel ve küresel enerji talebine karşın konvansiyonel fosil yakıt rezervelerinin kısıtlı olması enerji arzında kesintilere sebep olmaktadır. Bu stratejik önemden dolayı enerji günümüzde bir ailenin veya bir üretim hattının probleminden çok ülkelerin güvenlik ve stratejik politikası haline gelmiştir. Fosil kaynakların yetersiz kalması nedeniyle artan enerji talebinin karşılanabilmesi amacıyla yenilenebilir enerji kaynakları hızlı bir şekilde dünya gündemine oturmuştur. Yenilenebilir enerji kaynakları da tüketim talebini karşılamakta tek başına yetersiz olduğundan dolayı bu sistemleri destekleyecek araştırma ve geliştirme çalışmaları yapılmaktadır. Bu tez ile, şebekeye alçak gerilim seviyesinden irtibatlı 404.6 kWp üretim kapasitesine sahip lisanssız çatı üstü güneş enerjisi santralinin enerji üretimi ile kurulu olduğu tesisin enerji tüketimi detaylı şekilde analiz edilerek üretim ve tüketim arasındaki farkları minimize etmek amacıyla çözüm önerileri detayları ile sunulmuştur. Çalışmada kullanılacak veriler için üretim ve tüketim tesislerinin enerji analizörlerinden gerçek zamanlı veriler elde edilmiştir. Elde edilen veriler ışığında üretim-tüketim dengesinin sağlanması için çözüm önerileri verilmektedir.

Anahtar Kelimeler: Yenilenebilir Enerji, Güneş PV, Enerji Talebi, Enerji Tüketimi, Enerji Verimlliliği

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ABBREVIATIONS

EMRA	: Energy Market Regulatory Authority
KPH	: kilometer/hour
kW	: Kilowatt
kWh	: Kilowatt hour
kWp	: Kilowatt peak
MDB	: Main Distribution Board
MW	: Megawatt
MWh	: Megawatt hour
P	: Active Power
PV	: Photovoltaic
SAGE	: Defense Industries Research and Development Institute
TÜBİTAK	: The Scientific and Technological Research Council of Turkey
Wh	: Watt hour

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CHAPTER 1

INTRODUCTION

With the developing technology, the demand for electrical energy continues to increase day by day. The supply and demand balance of electrical energy has multiple meanings for countries, for example, the amount of energy consumed per capita is included in all indices where it is an important factor in determining the development level of countries [1]. The decrease in fossil fuel reserves and the use of fossil energy resources as a strategic and political weapon create serious asset problems for many foreign-dependent countries in energy. With the Russia-Ukraine war, which started with the annexation of Crimea in 2014 and continued in the form of military mobilization, conflicts, cyber wars and economic embargoes in February 2022, European countries directly faced an energy crisis. Considering that the consumption of fossil fuels not only has economic and political consequences, but also directly causes global environmental problems, the interest in renewable energy sources is increasing day by day [2]. By focusing on the cost and technology requirements known in renewable energy sources all over the world, studies on efficiency and the use of various combinations continue at full speed.

1.1 Renewable Energy Sources

Renewable energy sources, as the name suggests, are a type of energy that can be obtained naturally and regenerated cyclically, regardless of the source of human and time. In other words, it is the type of energy obtained by developing and using different technologies from the flow process of energy, which is available in ongoing natural processes and in different forms [3]. Renewable energy sources, which are widely used with the technologies developed today; wind, geothermal water, sun, water, waves and biomass. Water, wind and solar energy resources are the technologies with the most basic usage area, while the others are resources that benefit from the energies released by transforming existing energy forms by using appropriate technologies. Here, information about the most basic renewable energy sources will be given.

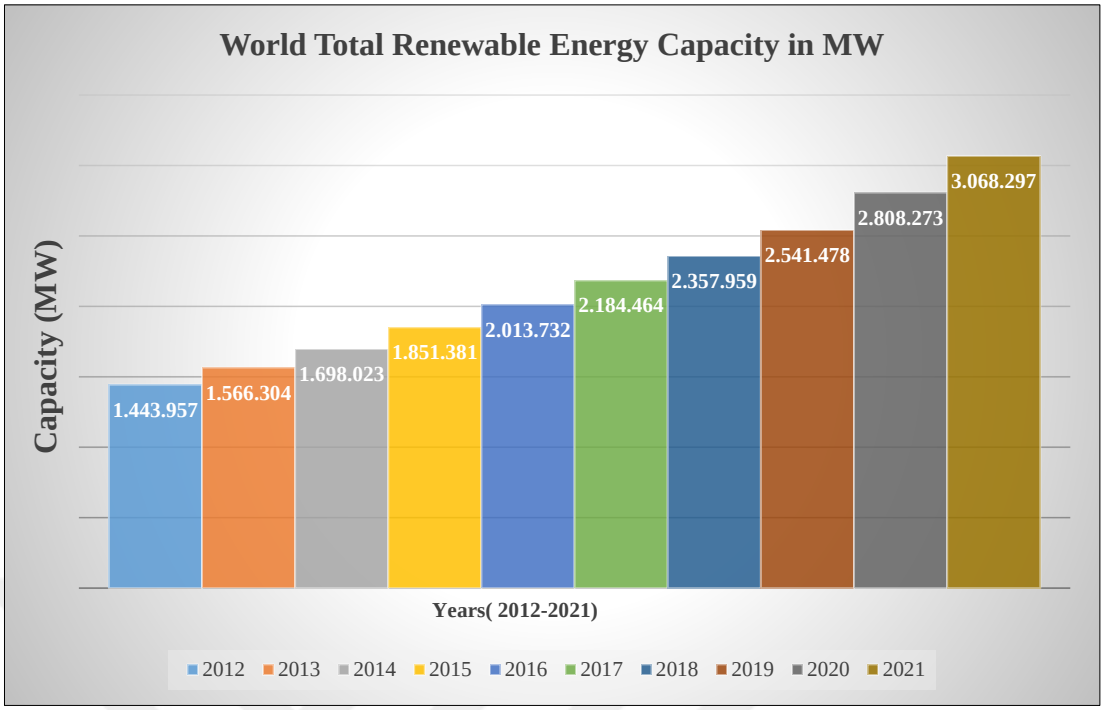


Figure 1.1 World Total Renewable Energy Capacity in MW [4]

As can be seen in Figure 1.1, the capacity of renewable energy sources in the world is increasing in line with the rapidly increasing energy demand.

1.2 Hydroelectric Energy

Hydroelectric energy technology is a renewable energy technology based on the oldest history, and it is a renewable energy source based on the conversion of the motion energy of a moving water body into electrical energy. This technology is used in many different ways due to the fact that it has a very old knowledge in production and has been used for thousands of years. According to the Energy Market Regulatory Authority (EMRA) 2021 Electricity Market Development Report, 16.80% of the electricity produced in Turkey in 2021 was supplied from hydroelectric power plants, including dams and rivers [5].

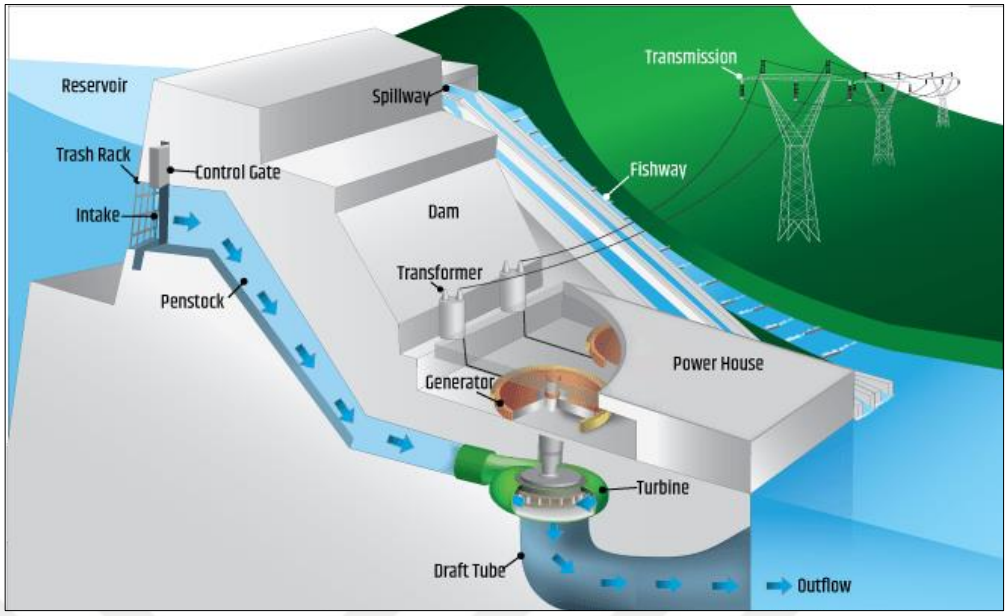


Figure 1.2 Hydropower Facility [6]

1.3 Wind Energy

Wind energy, similar to hydroelectric energy, is a renewable energy source based on the conversion of the motion energy of the air into electrical energy instead of fluid water. In this technology, wind is used as the air source, the air mass carried by the wind activates the wind turbines developed for this technology, and electrical energy is produced from the generators. According to the Energy Market Regulatory Authority (EMRA) 2021 Electricity Market Development Report, 9.39% of the electricity produced in Turkey in 2021 was provided by wind power plants [5].

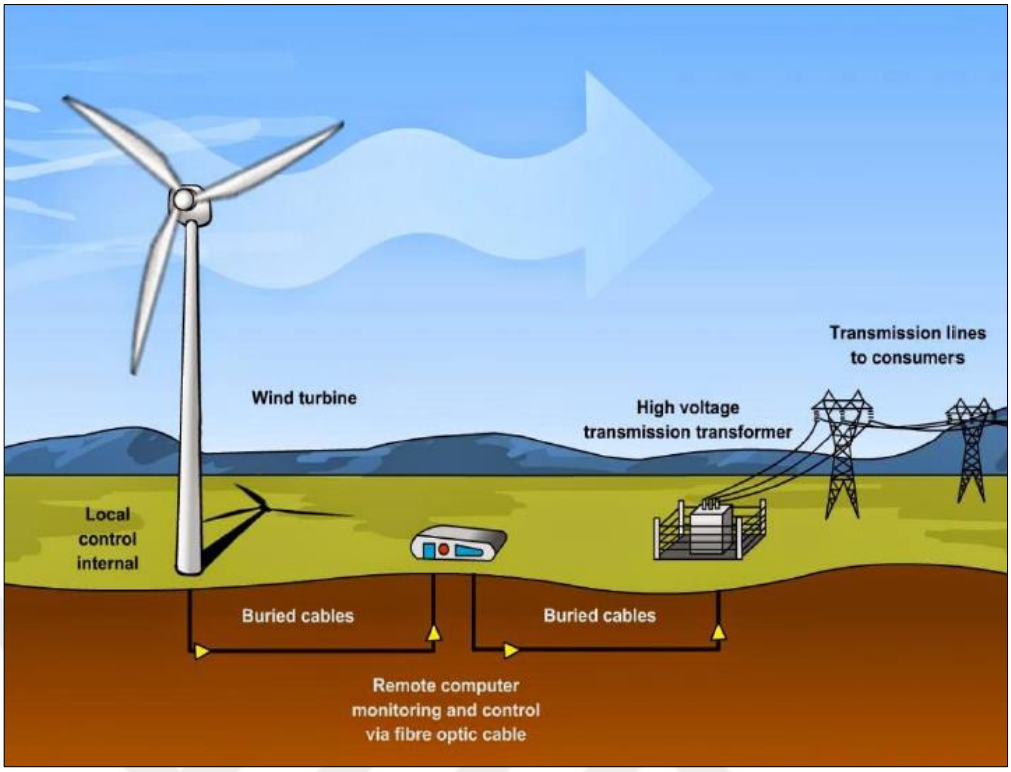


Figure 1.3 Wind Power Plants [8]

1.4 Solar Energy

The energy obtained by utilizing solar heat or light is called solar energy. It is a very new technology compared to wind and hydroelectric energy. It is developing rapidly because it is very convenient to reach and use, both in terms of economy and operating cost. According to the Energy Market Regulatory Authority (EMRA) 2021 Electricity Market Development Report, 4.01% of the electricity produced in Turkey in 2021 was provided by solar power plants [5]. Solar energy, which is very popular among renewable energy sources, increased its production from 381 GW to 3429 GW between 2010 and 2019, taking its place among the most active players in the energy market [6].

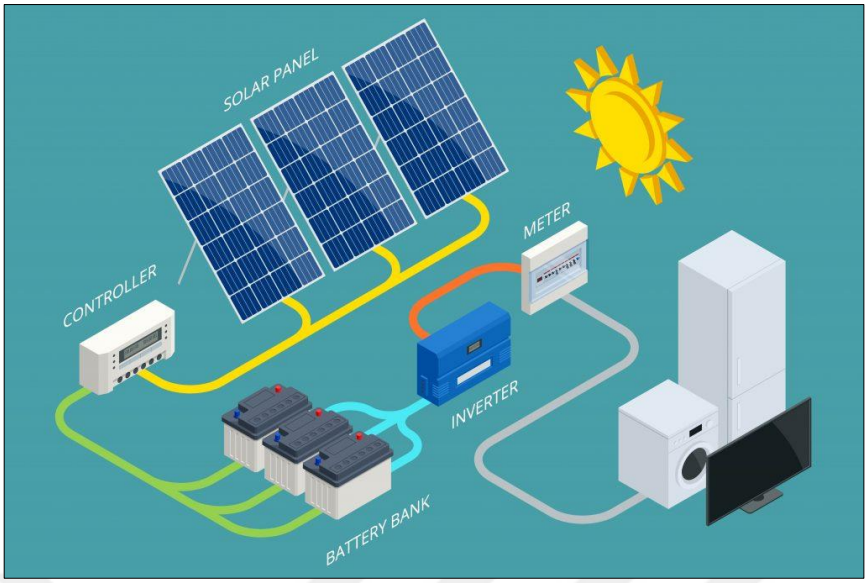


Figure 1.4 Solar Power Plant [9]

1.5 Geothermal Energy

Geothermal energy, hot waters in the layers of the earth's crust; It is a renewable energy source with multiple applications, including heating, drying and electricity generation. According to the Energy Market Regulatory Authority (EMRA) 2021 Electricity Market Development Report, 3.25% of the electricity produced in Turkey in 2021 was provided by geothermal power plants [5].

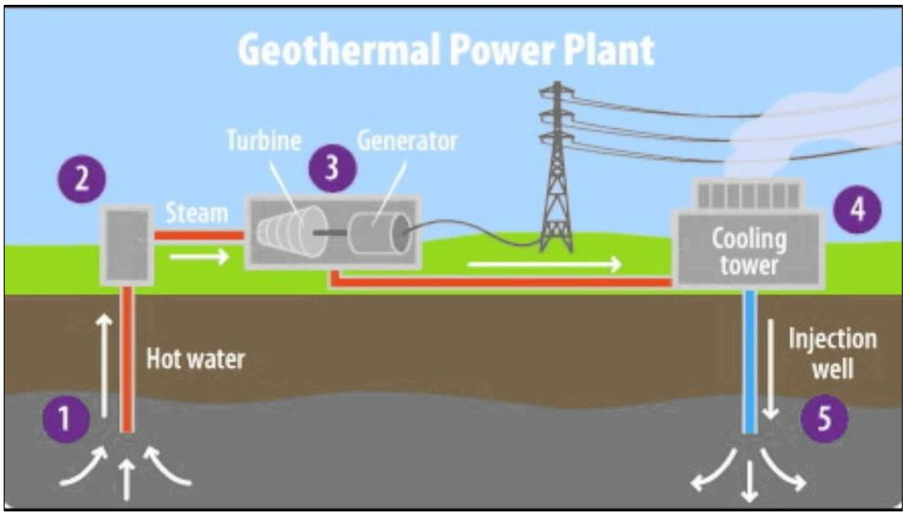


Figure 1.5 Geothermal Power Plant [10]

1.6 Biomass Energy

Biomass energy; It is a form of renewable energy produced from the conversion of biomass to heat, electricity, biogas and liquid fuels. Biomass is basically organic matter obtained from forestry, agriculture and livestock wastes that are present and cyclically maintained. According to the Energy Market Regulatory Authority (EMRA) 2021 Electricity Market Development Report, 2.30% of the electricity produced in Turkey in 2021 was provided by geothermal power plants [5].

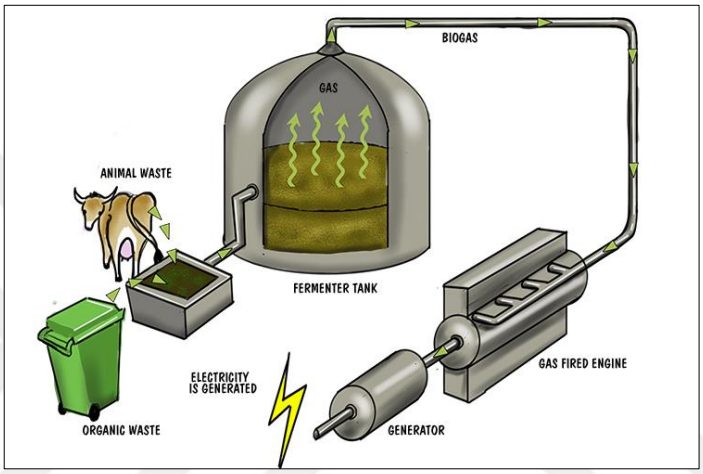


Figure 1.6 Biomass Power Plant [11]

Table 1.1 Installed Capacity and Production by Resources by the end of 2021 [5]

Resource Type	Total Installed Capacity* (MW)	Share (%)	Total Production* (MWh)	Share (%)
Hydraulic	31.492,58	31,55	55.695.231,65	16,80
Natural Gas	25.964,56	26,01	108.438.726,84	32,71
Wind	10.606,98	10,63	31.137.427,23	9,39
Lignite	10.119,92	10,14	43.400.430,26	13,09
Import Coal	8.993,80	9,01	54.888.840,62	16,56
Solar	7.815,63	7,83	13.294.280,97	4,01
Geothermal	1.676,17	1,68	10.770.879,81	3,25
Biomass	1.644,52	1,65	7.616.648,91	2,30
Hard Coal	840,77	0,84	3.539.791,50	1,07
Asphaltite	405,00	0,41	2.372.954,47	0,72
Fuel-oil	251,93	0,25	336.644,04	0,10
Naphta	4,74	0,00	0,00	0,00
LNG	1,95	0,00	0,00	0,00
Diesel	1,04	0,00	78,33	0,00
Total	**99.819,57**	**100,00**	**331.491.934,64**	**100,00**

According to the National Renewable Energy Laboratory of the United States Department of Energy, more than the energy used by all people in the world every hour of the year is reached in one hour by the sun [12]. With a smart city design, energy consumption can be achieved in an economical way with the data to be obtained in advance, for example, the cost of energy produced from individual solar power plants is much more affordable than the energy supplied from the grid [13]. In this study, the energy production profile of a sample rooftop solar power plant and the consumption profile of this facility were analyzed by taking data sets.

1.7 The Relevance of Thesis

Increasing energy demand with developing technology creates problems in our country as well as in the whole world. Due to the rapid increase in the world population and industrial expansions that affect the ecological system, the need for electrical energy is increasing rapidly around the world, although this development sounds good, it is not so. Meeting the increasing energy demand from conventional systems is costing people dearly day by day. Fuels such as petroleum, natural gas and coal derivatives from conventional systems not only have high costs, but also have an avalanche of damage to the environment and ecological balance. The finite nature of the resources is enough to seriously damage the balance of cost and demand. The importance of renewable energy sources intervenes at this point and introduces three concepts into our lives: "efficiency, clean energy and endless resources" [14].

Therefore, renewable energy sources increase their popularity both economically and ecologically. Renewable energy sources, which have many fields within themselves, provide support services to conventional energy systems in many fields. These local power plants, which have a distributed layout on the roofs of houses, lands and building surfaces, can respond to user demands. Since they are of great economic and ecological importance, it is widely seen that they work as hybrid systems. In this study, the consumption and production balance of solar PV plants operating hybridly with the national electricity grid is exemplified in the selected sample facility.

1.8 The Aim of Thesis

The aim of this thesis is to embody the concepts of energy demand, consumption and production balance over a real facility and to show alternative ways. By providing efficient load management, the facilities will approach the maximum efficiency point and the results will be a guide for exemplary facilities. By using the previous annual consumption data of the facility, it has been provided to reach the future load forecasts approximately. By integrating solar power plants into the grid or the facility they are connected to, the energy produced during the day can be transferred to the facility or grid on which it is integrated in the most efficient way. With this study, the most efficient working conditions of the sample facility will be shown by ensuring a sustainable load balance by making use of real-time two-way information transfer at every stage from the production to consumption of energy.

In the whole study, considering the generation and consumer load and loading characteristics, the consumption/produced power data will be collected by means of smart meters, and a balance scenario for generation consumption will be created. Thus, production will be made in line with consumer demands and maximum benefit will be obtained from the production facility.

The concept of smart grids is encountered in many areas today. The definition of smart grids, on the other hand, refers to the whole of the system that provides the integration between the supplier and the consumer, and the simultaneous monitoring, updating, control of electricity distribution networks, energy production facilities and consumption facilities, and transferring them to the consumer in the most efficient and reliable way.

Two main issues are aimed in this study;

1. Industrial Plant Consumption Balance with Solar PV production

2. Solutions to bridge the gap between production and consumption

1.9 The Facility That is an Example for Our Thesis

The facility, whose data are used in this study, is the Solar power plant located in TÜBİTAK SAGE, located in Mamak district of Ankara. The installation of the solar power plant on the roof of the Thermal Battery production facility within the institute started on 14 June 2021 and was completed on 7 July 2021 and put into operation. According to the feasibility study reports made before the installation, it was predicted that approximately 575,000 kWh of electrical energy would be produced annually with the solar power plant, and this value corresponds to 5% of the total electrical energy consumption of the institute. According to the prepared reports, the solar panels were installed on a 2000m² roof area. The design life of the Solar Power Plant is 25 years and the payback period of the initial investment cost is 5.5 years.



Figure 1.7 TÜBİTAK SAGE Solar Power Plant

Table 1.2 TÜBİTAK SAGE Solar Power Plant Technical Specifications

TÜBİTAK SAGE SOLAR POWER PLANT	
Rated Power	404kWp
Number of panels	908
Panel Brand / Model	ELİN / ELNSM72M-HC-HV Series
Rated Power (for each panel)	0,445kW
Number of inverters	4
Inverter Brand / Model	SolarEDGE / SE82.8K-RW0P0BNY4
Rated Power (for each inverter)	82,8kW

The data of the simulation performed on 21.08.2021 with the PVsyst V7.2.4 software are shared with the tables below.

Table 1.3 Project and System Summary by PVsyst V7.2.4

Project: TÜBİTAK SAGE- Isıl Pil

Variant: New simulation variant

PVsyst V7.2.4
VC0, Simulation date:
24/08/21 15:28
with v7.2.4

CMA Enerji Üretim Yatırım San. Tic. Ltd. Şti. (Turkey)

Project summary

Geographical Site	Situation		Project settings	
Lalahan	Latitude	39.97 °N	Albedo	0.20
Turkey	Longitude	33.07 °E		
	Altitude	1165 m		
	Time zone	UTC+3		

Meteo data
Lalahan
Meteonorm 8.0 (2005-2013), Sat=100% - Synthetic

System summary

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation		Near Shadings	User's needs
Fixed plane		No Shadings	Unlimited load (grid)
Tilt/Azimuth	5 / 104 °		

System information

PV Array		Inverters	
Nb. of modules	908 units	Nb. of units	12 units
Pnom total	404 kWp	Pnom total	326 kWac
		Pnom ratio	1.238

Table 1.4 General Parameters by PVsyst V7.2.4

General parameters

Grid-Connected System	**No 3D scene defined, no shadings**	
PV Field Orientation		
Orientation	**Sheds configuration**	**Models used**
Fixed plane		Transposition Perez
Tilt/Azimuth 5 / 104 °		Diffuse Perez, Meteonorm
		Circumsolar separate
Horizon	**Near Shadings**	**User's needs**
Free Horizon	No Shadings	Unlimited load (grid)

Table 1.5 PV Array Characteristics by PVsyst V7.2.4

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Elin (verified by SolPEG)	Manufacturer	SolarEdge
Model	ELNSM-445-72M-HC-HV	Model	SE55K/SE82.8K Unit
(Custom parameters definition)		(Original PVsyst database)	
Unit Nom. Power	445 Wp	Unit Nom. Power	27.6 kWac
Number of PV modules	908 units	Number of inverters	12 units
Nominal (STC)	404 kWp	Total power	326 kWac
SolarEdge Power Optimizer			
Model	P950 Worldwide		
Unit Nom. Power	950 W		
Modules	1 String x 2 in series		
Array #1 - PV Array			
Number of PV modules	380 units	Number of inverters	5 unit
Nominal (STC)	169 kWp	Total power	139 kWac
Optimizer Array	10 Strings x 19 In series		
At operating cond. (50°C)		Operating voltage	750 V
Pmpp	157 kWp	Pnom ratio (DC:AC)	1.14
Output of optimizers			
Voper	750 V		
I at Poper	209 A		
Array #2 - Sub-array #2			
Number of PV modules	288 units	Number of inverters	4 unit
Nominal (STC)	128 kWp	Total power	105 kWac
Optimizer Array	8 Strings x 18 In series		
At operating cond. (50°C)		Operating voltage	750 V
Pmpp	119 kWp	Pnom ratio (DC:AC)	1.14
Output of optimizers			
Voper	750 V		
I at Poper	159 A		
Array #3 - Sub-array #3			
Number of PV modules	240 units	Number of inverters	3 unit
Nominal (STC)	107 kWp	Total power	82.8 kWac
Optimizer Array	6 Strings x 20 In series		
At operating cond. (50°C)		Operating voltage	750 V
Pmpp	99.2 kWp	Pnom ratio (DC:AC)	1.21
Output of optimizers			
Voper	750 V		
I at Poper	132 A		

Table 1.6 PV Array Characteristics by PVsyst V7.2.4

PV Array Characteristics

Total PV power		**Total inverter power**	
Nominal (STC)	404 kWp	Total power	326 kWac
Total	908 modules	Nb. of inverters	12 units
Module area	1974 m²	Pnom ratio	1.24
Cell area	1802 m²		

Table 1.7 Array and DC wiring losses by PVsyst V7.2.4

Array losses

Array Soiling Losses		**Thermal Loss factor**		**LID - Light Induced Degradation**	
Loss Fraction	2.0 %	Module temperature according to irradiance		Loss Fraction	2.0 %
		Uc (const)	20.0 W/m²K		
		Uv (wind)	0.0 W/m²K/m/s		
Module Quality Loss		**Module mismatch losses**		**IAM loss factor**	
Loss Fraction	-0.3 %	Loss Fraction (Fixed voltage)	0.0 %	ASHRAE Param: IAM = 1 - bo(1/cosi -1)	
				bo Param.	0.05

DC wiring losses

Global wiring resistance	10 mΩ		
Loss Fraction	1.5 % at STC		
Array #1 - PV Array		**Array #2 - Sub-array #2**	
Global array res.	50 mΩ	Global array res.	66 mΩ
Loss Fraction	1.5 % at STC	Loss Fraction	1.5 % at STC
Array #3 - Sub-array #3			
Global array res.	79 mΩ		
Loss Fraction	1.5 % at STC		

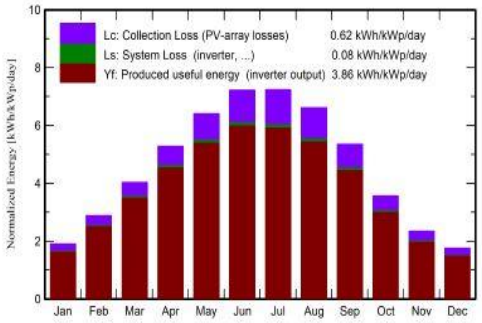
Table 1.8 Main Results by PVsyst V7.2.4

Main results

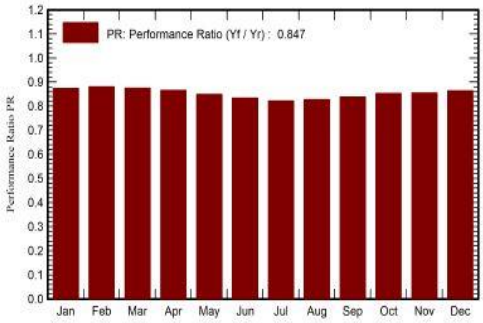
System Production

Produced Energy	569.2 MWh/year	Specific production	1409 kWh/kWp/year
		Performance Ratio PR	84.66 %

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	61.0	25.80	-1.22	59.1	53.6	21.29	20.87	0.873
February	82.7	35.85	0.67	80.8	74.5	29.33	28.77	0.881
March	126.9	49.15	4.89	125.0	117.0	45.05	44.18	0.875
April	159.7	67.66	9.38	158.3	149.5	56.48	55.39	0.866
May	200.8	74.58	14.34	198.6	188.6	69.43	68.09	0.848
June	217.0	60.72	18.41	216.8	206.3	74.49	73.06	0.834
July	225.0	57.85	22.40	224.6	213.4	76.06	74.59	0.822
August	206.7	55.06	22.64	205.1	194.6	69.91	68.56	0.827
September	163.0	45.04	17.33	160.4	150.7	55.39	54.33	0.838
October	112.2	40.49	11.34	110.5	102.5	38.83	38.09	0.853
November	72.3	26.59	5.05	70.4	63.9	24.80	24.32	0.855
December	55.8	24.41	0.37	54.4	48.9	19.38	19.00	0.864
Year	1683.1	563.21	10.53	1664.1	1563.6	580.45	569.25	0.847

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

1.10 Literature Review

In the literature reviews, it has been seen that many different solutions are offered for the controllability of renewable energy sources and to keep the system on their own. The fact that the solution is more than one and specific is directly related to the working conditions of renewable energy sources. For example, while solar power plants are directly affected by environmental conditions such as climate, hydroelectric power plants are more stable in load management.

Since renewable energy sources such as sun and wind are completely dependent on climatic conditions and it is not 100% possible to control the amount of energy that can be produced instantly, these facilities serve as alternative support sources. Hybrid systems solution has been reached from all of the studies on ensuring the balance of production and consumption in the literature reviews.

1. A. Annuk and his friends have a study about Methods for Increasing Shares of Self-Consumption in Small PV Solar Energy Applications. In this study they have aimed find the optimum solution between the energy produced from the solar power plant and the energy consumed by using consumption data of an Estonian house with average values at intervals of 5 minutes and the production data of solar power plants with 2.5kW power belonging to these houses. As a result of this study, the authors showed that the demand fulfillment ratio increased from 0.152 to 0.657 by integrating a hot storage tank with a capacity of 5kWh and a battery storage system with a capacity of 3kWh in the sample house [15].

2. In their article titled F. Chekired, S. Berkane, A. Meflah and A. Mahrane Artificial Neural Network based Controller for Energy Management in a Solar Home in Algeria, using artificial neural networks method, it was determined that the sun rays were at their highest levels with the period of January 2018 when they were at their lowest levels. In the period of June 2018, it has been shown that the production-consumption balance can be achieved without paying for customer comfort. In this study, using artificial neural networks, Home Energy Management Considering the solar power plant production data with the algorithm the amount of energy produced, the real home energy demand, predefined electrical loads are decided by this algorithm controller. The artificial neural networks controller, which was applied to the two specified periods, provided energy savings of 47.67% and 38.18%. [16]

3. M. Kavitha, D. Godwin Immanuel, C.R. Edwin Selva Rex, V. Meenakshi, M. Pushpavalli, Supriya Singari and Vinoba Baskaran In this study, they sampled a roof-mounted solar power plant connected to the grid with battery storage, electric vehicle and consumption load, using the specially designed software. Four different solar performance monitoring programs were used under similar conditions and the results were compared with various parameters such as brightness, performance ratio, solar

energy usage and consumption/production forecast. The results showed that the global irradiance of the biaxial solar tracking system is 1.3 times the spherical irradiance of the other tracking programs included in the simulation analysis. This work has helped to design a more efficient and manageable monitoring system that helps improve efficiency, performance and helps to decide on the right monitoring that is more convenient and reliable. This simulation software has been shown to assist in the selection of solar power plant, inverter and battery storage system for any location before it is implemented in real time [17].

4. In their article titled "Use of Battery Energy Storage Systems for Cement Production Facilities", Tim Corrigan, Steve McKenery, GianPaula Hulten and Christian Gould have stated that battery energy storage systems are an ideal technology to provide significant cost savings to large cement production facilities through meeting high demand, energy arbitrage and other potential region-based value stacks. they have shown. They have also been shown to provide durability and a backup power supply during forced outages or other undesired downtime events. Combined with solar photovoltaics (or wind), it has been shown that they increase the value of power generation technologies that reduce this greenhouse gas effect by changing energy, making it possible to feed the load through charging in low-cost periods and discharging in higher-cost periods. In addition, many large companies have sustainability initiatives to reduce global environmental impact, which values on-site renewable energy generation and energy storage, which can further increase its value by allowing greenhouse gas-free energy to be used at its most valuable times. [18].

CHAPTER 2

MATERIALS AND METHODS

2.1 Study Method

More than one data was needed in my research area. Production and consumption data have more than one and different variable characteristics on their own. For example, time is at the top of these variables. Due to the different characteristics of the facilities for which the measurement value is requested, detailed analysis was needed. For all these reasons, the analyzed facilities were evaluated individually.

Statistical and real-time data in the study carried out; It should be reached in a state that is convenient to use, has high resolution and has the lowest error rate.

The main variables used in the study carried out; time (month, day, hour and year), power (active power P), energy (kW, kWp, MW, MWh). The case study given on the subject of the thesis has been studied in detail for the year 2022.

2.2 Data Sources

SIEMENS SENTRON PAC4200 model energy analyzer was used to measure the energy produced from the solar power plant and the energy consumption data of the facility it is connected to. Real-time data received from these energy analyzers were processed in the desired date range (during the year 2022).

2.3 Siemens Sentron PAC4200



Figure 2.1 Siemens Sentron PAC4200

The PAC4200 is a power monitoring device that is suitable for use in industrial services, government and commercial applications where basic to advanced metering, logging, and I/O is required. The meter may be used as a standalone device monitoring over 200 parameters or as part of an industrial control, building automation or global enterprise wide monitoring system [19].

Functional features

Instantaneous values		
Voltage	Phase-phase / phase-neutral	✓
Currents	Per phase and neutral (calculated)	✓
Apparent, active and reactive power (kW, kVAR, kVA)	Per phase and total	✓
(PF) and displacement power factor (cos phi)	Per phase and total	✓
Frequency	45...64 Hz	✓
THD for voltage and current	Per phase	✓
Individual harmonics	Through the 63rd for volts and amps	✓
Min. / max. values	Voltage – phase-phase, phase-neutral Current / Power / Power factor / THD φ per phase Frequency, phase angle Three phase average voltage and current Odd harmonics for voltage and current per phase up to the 31st Demand values for active, apparent and reactive power	✓ ✓ ✓ ✓ ✓ ✓
Average values	Voltage – phase-phase, phase-neutral Voltage min. / max. for phase-phase-phase-neutral Current Current min. / max.	✓ ✓ ✓ ✓
Energy measurement – logging		
Real (active) energy (kWH)	Import / export; high / low tariff	✓
Reactive energy (kVARH)	Positive / negative; high / low tariff	✓
Apparent energy (kWH)	High / low tariff	✓
Energy demand per measuring period	Three phase average rating for active and reactive power	1 to 60 min.
Event logging	4000 events in non volatile memory	✓
kW, kWd and Min. / max. logging	40 days Non-volatile log file @ 15 minutes	✓
Meter running counter	Uptime in hours	✓
Universal counter	Pulse counting of external devices like water, gas, etc.	✓
Measurement accuracy		
Zero blind	Measurement per IEC 61577-12	✓
Sampling rate	170 samples/cycle at 60Hz (1) [1)]	✓
True RMS measurement	For voltage and current harmonics up to the 63rd	✓
Voltages		±0.2%
Currents		±0.2%
Power factor / Power		+/-2% / +/-0.2%
Active energy		Class 0.2 according to IEC61557-12 and/or class 0.2S according to IEC62053-2 ANSI C12.20
Reactive energy		Class 2 according to IEC61557-12 and/or IEC62053-23
Monitoring functions		
Set point monitoring	V, I, power, VAR, VA, Freq. THD, PF	Up to 12 values
Simple logic functions for alarming	Alarm via digital	
Phase unbalance	Voltage and / or >< current	✓

[1)] Per IEC61557-12, which defines the accuracy as percentage of reading.

Figure 2.2 Functional features-1 [19]

Functional features (continued)

Communication			
Ethernet	Integrated into meter as standard and supports up to 32 Modbus serial devices in gateway mode with Modbus RTU module. (can support two masters simultaneously)		10/100 Base-T (100 Mbit/sec)
Modbus TCP	Integrated RJ45 port		10/100 Base-T (100 Mbit/sec)
PROFIBUS DP expansion module	Optional • Parameterization via device front or with powerconfig software • Transition of data via GSD file	• Support of all baud rates from 9600 BPS to 12 MBPS (9.6 Kbit/ sec to 12 Mbit/sec)	
Modbus RTU expansion module	Optional – required for gateway feature • Parameterization via device front or with powerconfig software • Transition of data via MODBUS register based points	• Support of all baud rates of 4800, 9600, 19.2K and 38.4K BPS (4.8 / 9.6 / 19.2 and 38.4 kB/sec	
PROFINET expansion module	Optional • Parameterizatio via device front or with powerconfig software • Transition of data via GSDML file	• Support of 10 and 100 Mbit/s baud rates	
General			
Password protection			✓
Inputs / Outputs			
Input voltage / at digital input • initial value for signal<1>-recognition • at DC / rated value • at DC / maximum • Full-scale value for signal <0> recognition		19 V 24 V 30 V 10V	
Number of digital outputs		2	
Number of digital inputs		2	
Digital output version		Switching or pulse output function	
Type of switching output		solid state	
Input current / at digital input • for signal <1>		4 mA	
Output current • at digital output / with signal <0> / maximum • at digital output / for signal <1> / minimum • at digital output / for signal <1> / maximum • at the digital outputs / at DC / limited to 100 ms / maximum • at the digital outputs / at DC / maximum		0.2 mA 10 mA 27 mA 300 mA 100 mA	
Output delay / at digital output • for signal <0> to <1> / maximum • for signal <1> to <0> / maximum		5 ms 5 ms	
Operating conditions for digital inputs / external voltage supply		Yes	
Operating voltage / as output voltage / at DC / maximum permissible		30 V	
Property of the output / Short-circuit proof		Yes	
Input delay time / at digital input • for signal <0> to <1> / maximum • for signal <1> to <0> / maximum		5 ms 5 ms	
Internal resistance / at the digital outputs		55 Ω	
Measuring category / for digital signals		CATI	
Switching frequency / at digital output / maximum		20 Hz	

Figure 2.3 Functional features-2 [19]

Functional features (continued)

Technical data		
Two-quadrant (import) / four-quadrant (import and export) measuring		4Q
Measurement types		1 ph, 2 ph or 3 ph
Applicable for network type		TN, TT, IT
Measured voltage without transformer	Direct connection up to max. delta/wye	690 V / 400 V (CAT III) for IEC 600/347 for UL / CSA
Current inputs	Settable on device	1A or 5A nominal
Power supply	AC/DC	95...240V AC (±10%) / 110...340V DC (±10%) 22...65V DC (=±10%)
Dimensions	L x W x D in mm Installation depth without module (mm) Installation depth with module (mm)	96 x 96 77 mm / 3.03in. 99 mm / 3.90 in.
Degree of protection	Front Rear	IP65 - NEMA 12 IP20 - NEMA 1A
Operating temperature	°C / °F	–10...+55 / +14...+131
Display	Type Resolution (pixels)	Background-illuminated graphic LCD 128 x 96
Text displays		Multilingual
Optional ports	1	Two ports are available for optional modules
MTBF		169.7 Years
Connections		
Type of electrical connection • at the measurement inputs for voltage • of the fast Ethernet interface	 screw-type terminals RJ45 (8P8C)	
Mechanical Design		
Height	96 mm	
Height / of the display	54 mm	
Width	96 mm	
Width • of the display	 72 mm	
Depth	56 mm	
Mounting position	vertical	
Installation depth	51 mm	
Mounting type / panel mounting	Yes	
Net weight	451 g	
Environmental conditions		
Installation altitude / at height above sea level / maximum	2 000 m	

Figure 2.4 Functional features-3 [19]

2.4 Analyzed Data

2.5 Solar PV Power Plant Meteorological Data

The performance of PV panels varies considerably depending on meteorological variables such as temperature, humidity, wind and panel temperature. In this section, real-time data obtained from the sensors of our Solar PV plant for the year 2022 are displayed on a monthly basis with graphs.

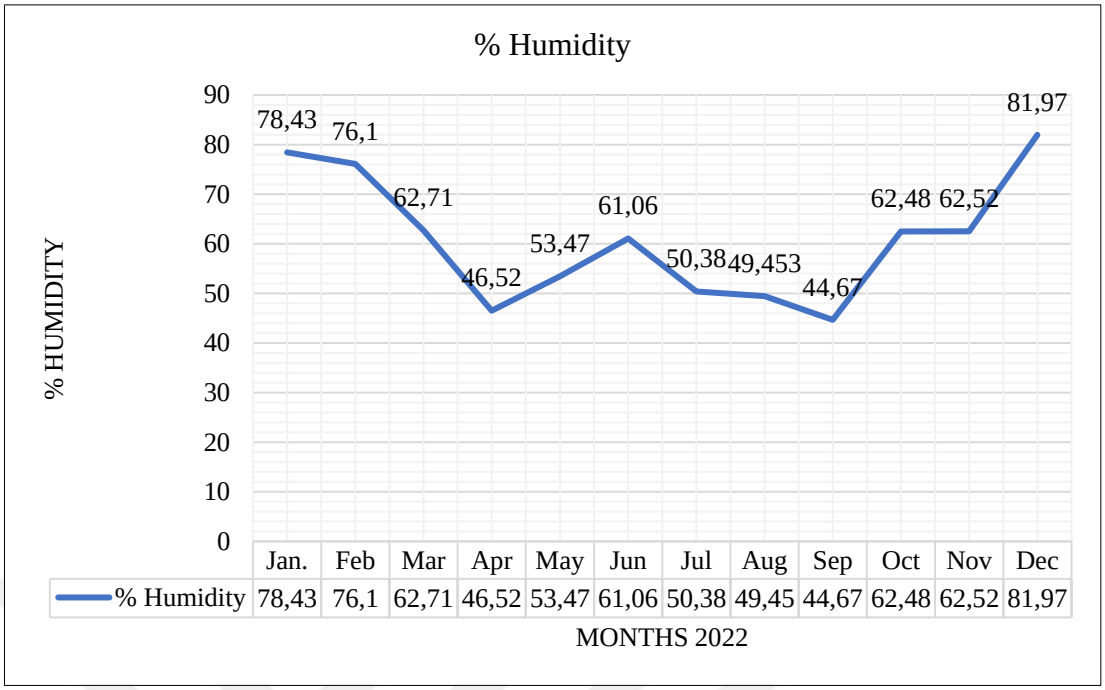


Figure 2.5 % Humidity data on monthly basis for 2022

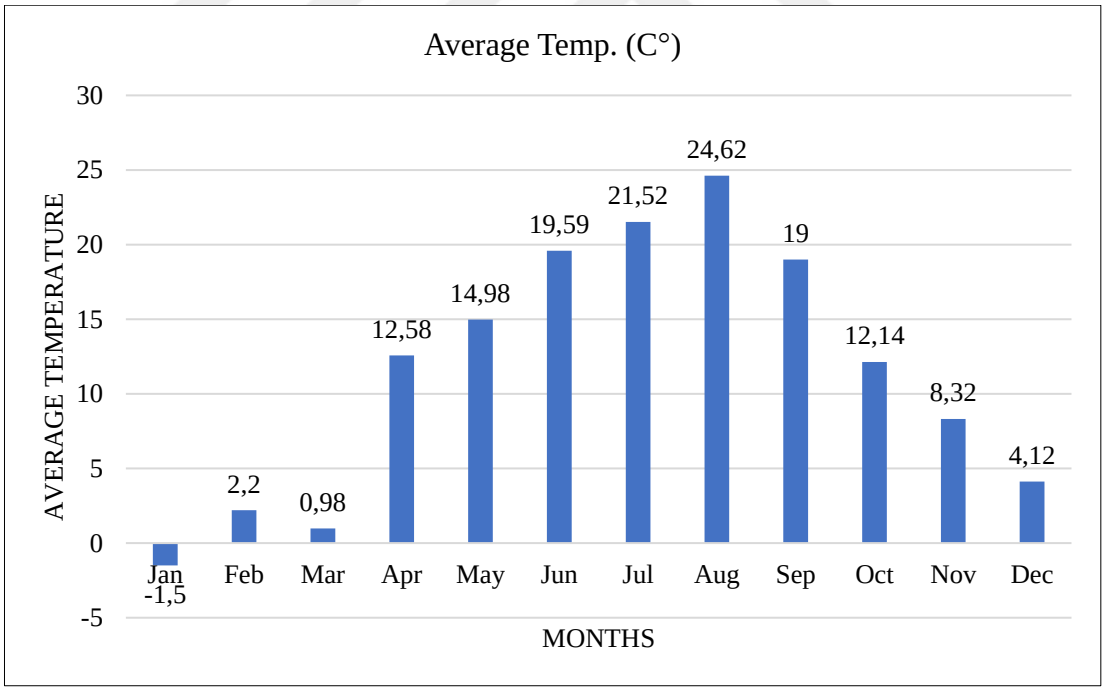


Figure 2.6 Solar power plant monthly average temperature values for 2022

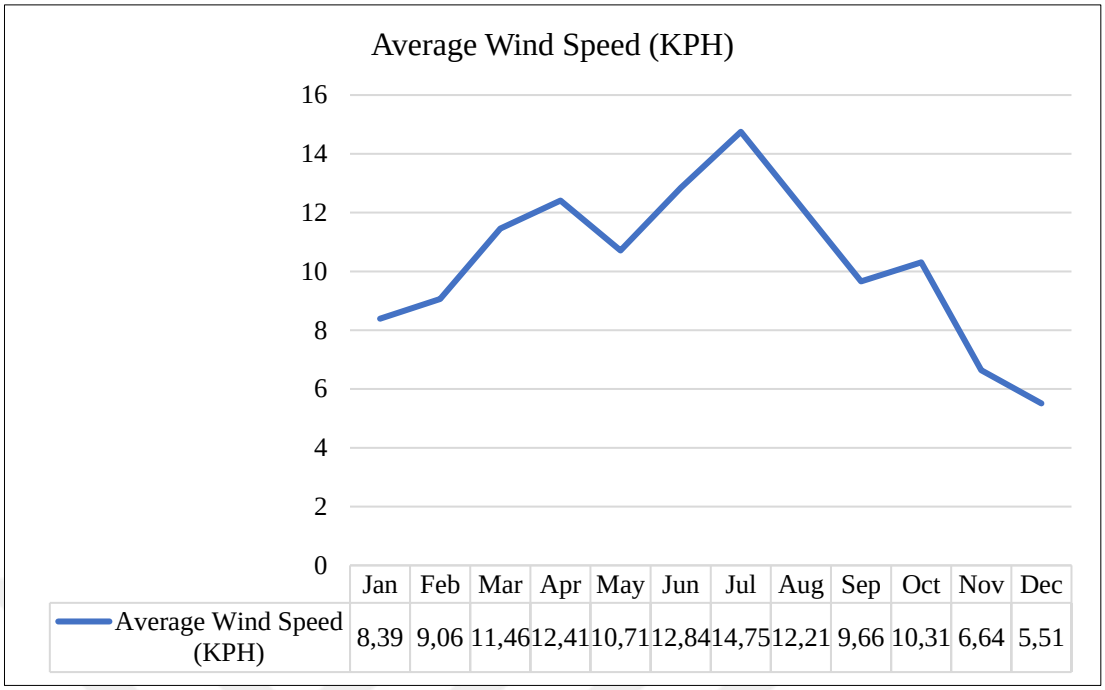


Figure 2.7 Solar power plant monthly average wind speed values for 2022

2.6 Solar PV Energy Production Data

The energy production data of the solar power plant located on the Thermal Battery facility are taken from the PAC4200 energy analyzers located on the MDB-2 panel to which the inverters are connected, annually and monthly, and are shown in graphics below. The internal needs of inverters are also taken into account. While the first chart shows the total production on a monthly basis for 2022; other charts reflect daily production for each month for 2022.

The days when there is no production in the charts given on a monthly basis; These are the days when the solar power plant cannot produce due to maintenance, climate or malfunction.

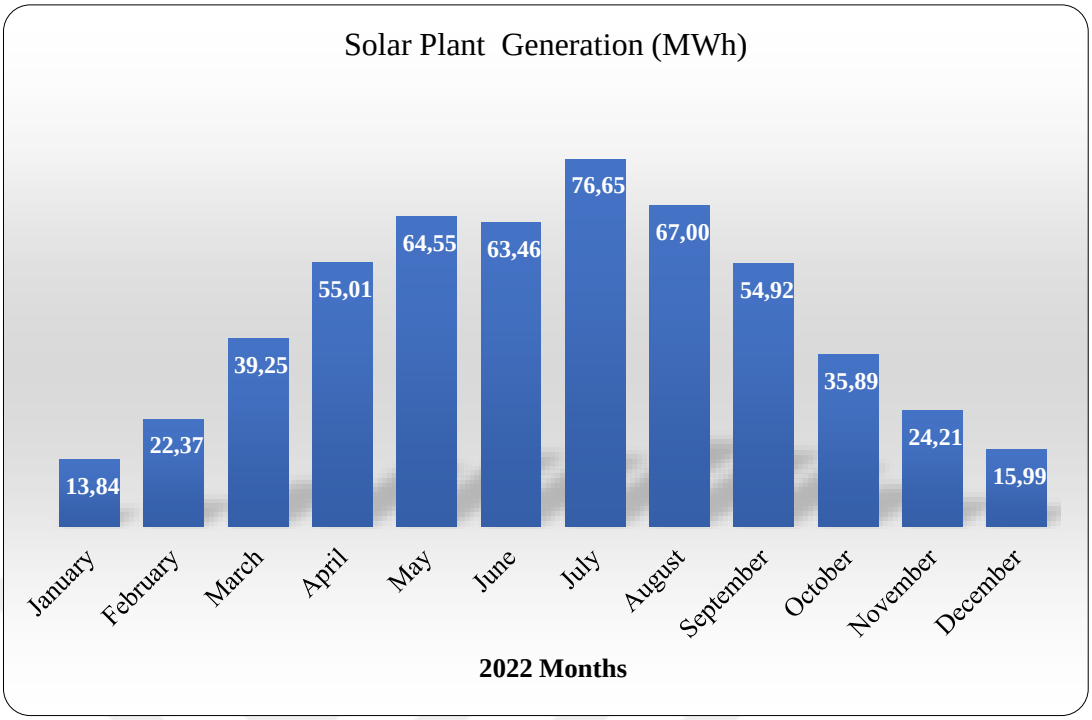


Figure 2.8 Monthly generation data of Sage solar power plant for 2022

Production efficiency in solar energy production facilities generally varies depending on two factors. The first of these factors is environmental conditions, and the other is the design architecture. Environmental conditions are primarily ambient temperature, humidity, wind, precipitation and dusting factors, as we all more or less predict. The factors arising from the design architecture are the electrical losses and the structure or natural geographical location that will prevent the sun rays falling on the power plant.

The primary reason for design losses is the use of low-efficiency inverters, cables and solar panels.

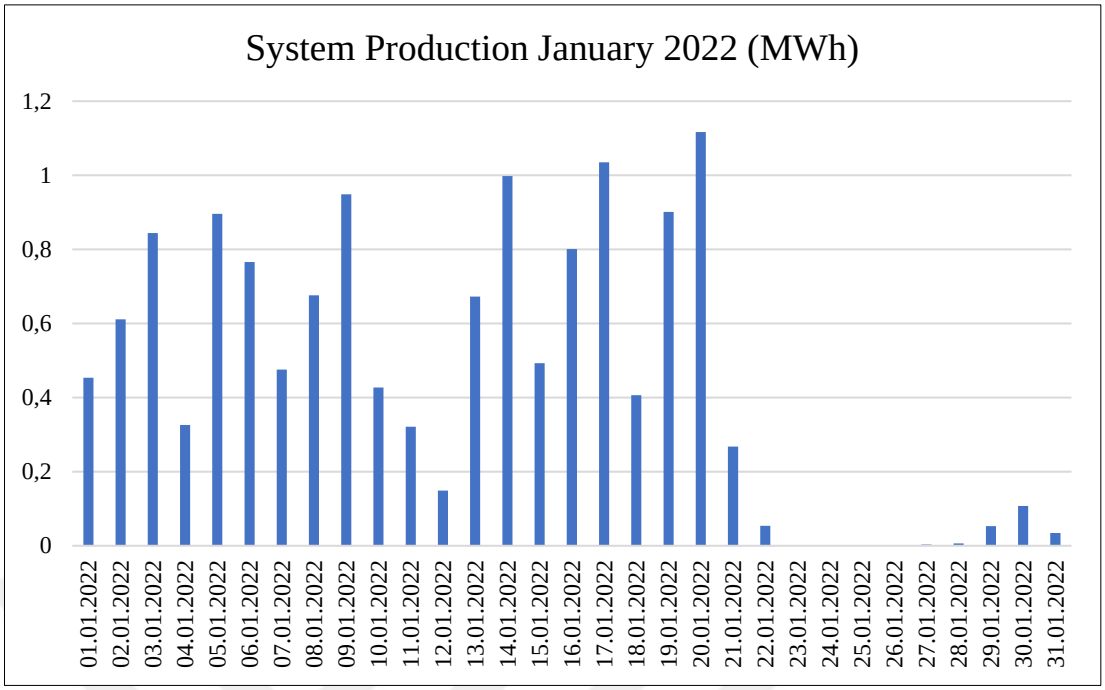


Figure 2.9 System Production January 2022 (MWh)

Between 22.01.2023 and 28.01.2023, the solar power plant could not be benefited due to the failure of the main switch located in the MDB-2 coded main distribution panel to which the inverters are connected. This is why 0 and near zero productions seen in the chart. The company, for which the maintenance agreement was made, changed the main switch on 28.01.2023 and the solar power plant started production again.

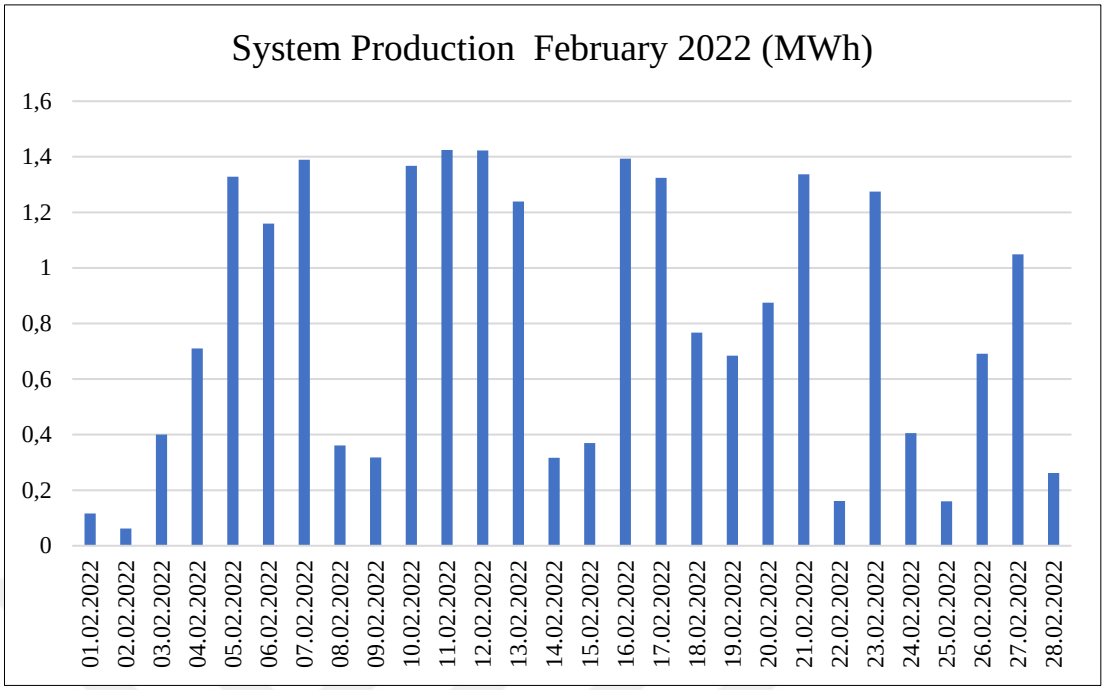


Figure 2.10 System Production February 2022 (MWh)

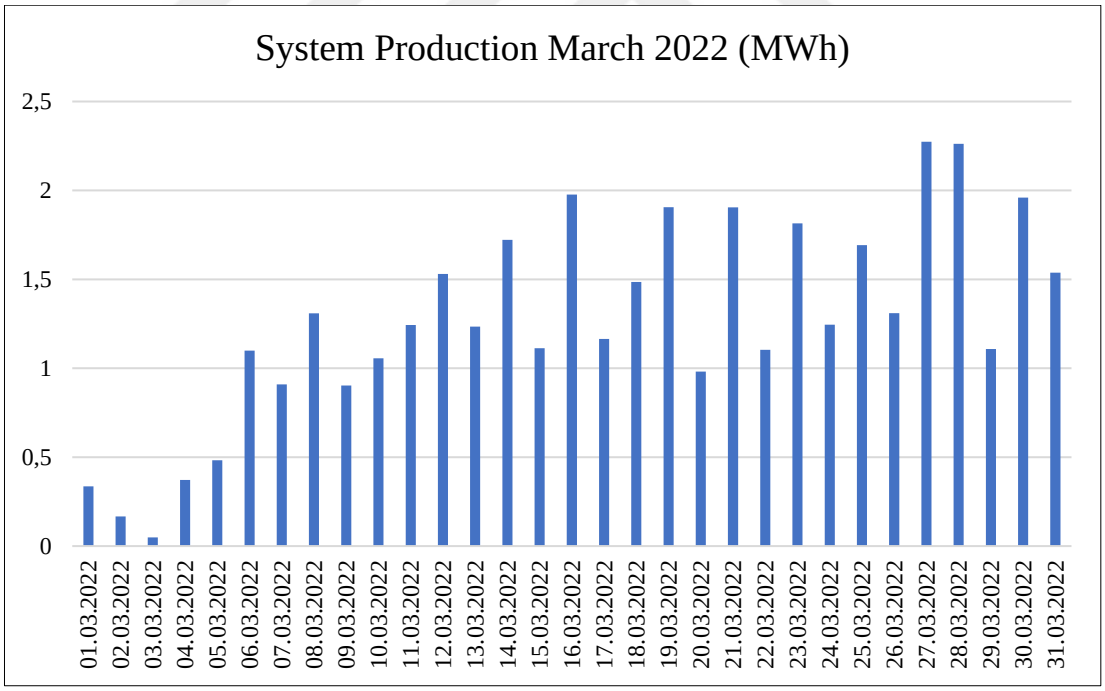


Figure 2.11 System Production March 2022 (MWh)

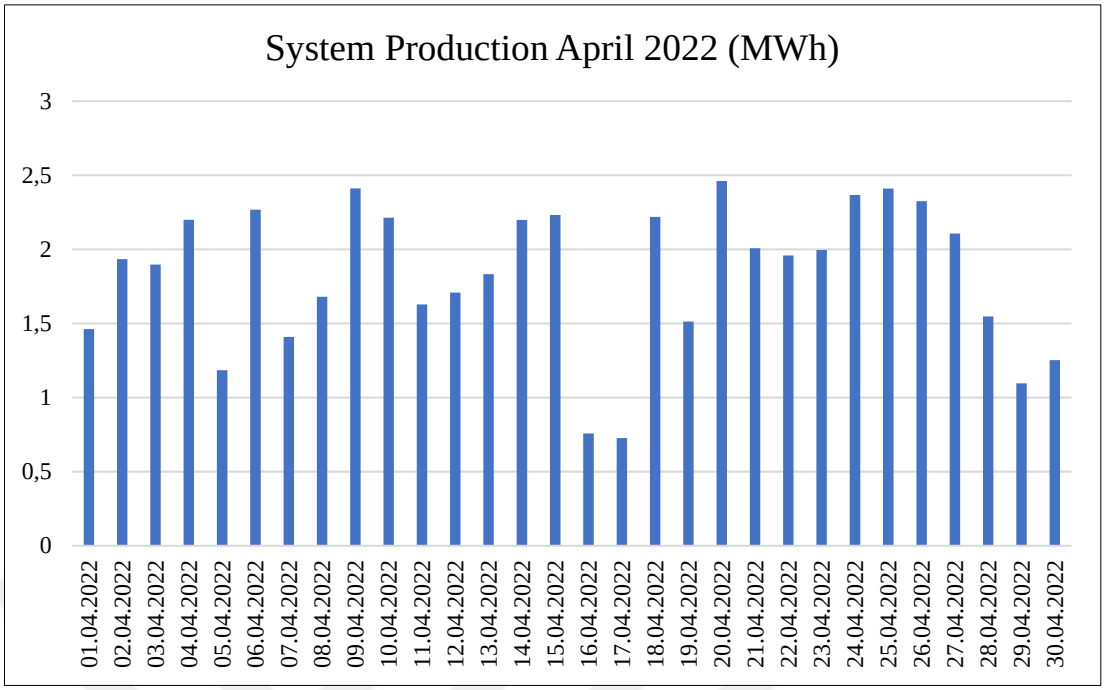


Figure 2.12 System Production April 2022 (MWh)

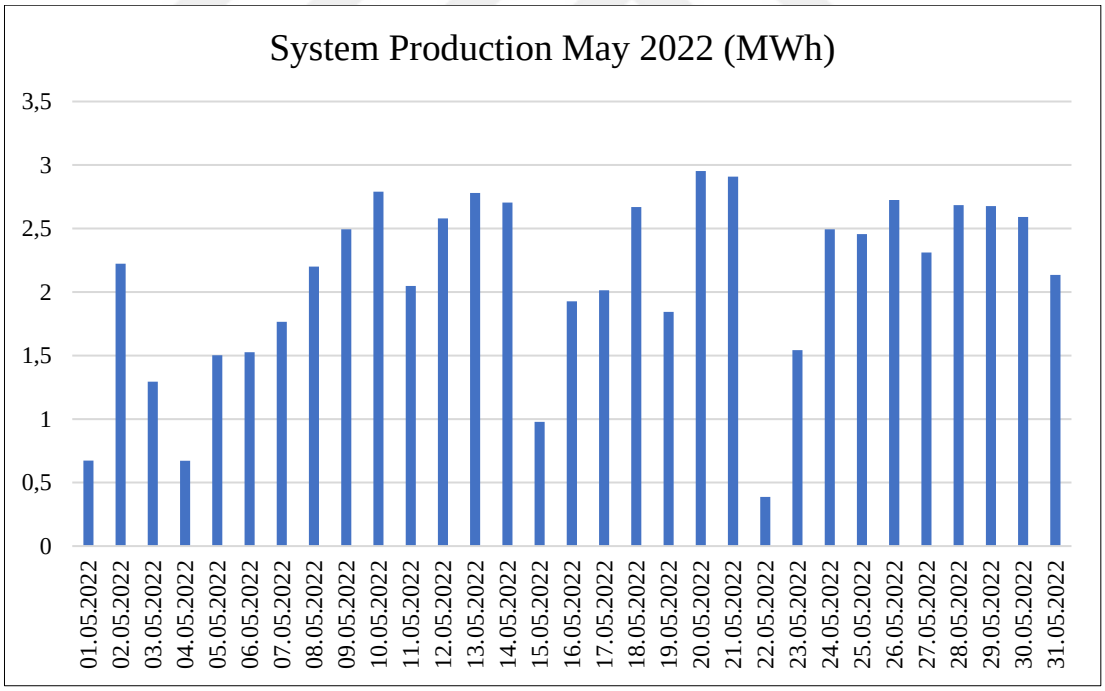


Figure 2.13 System Production May 2022 (MWh)

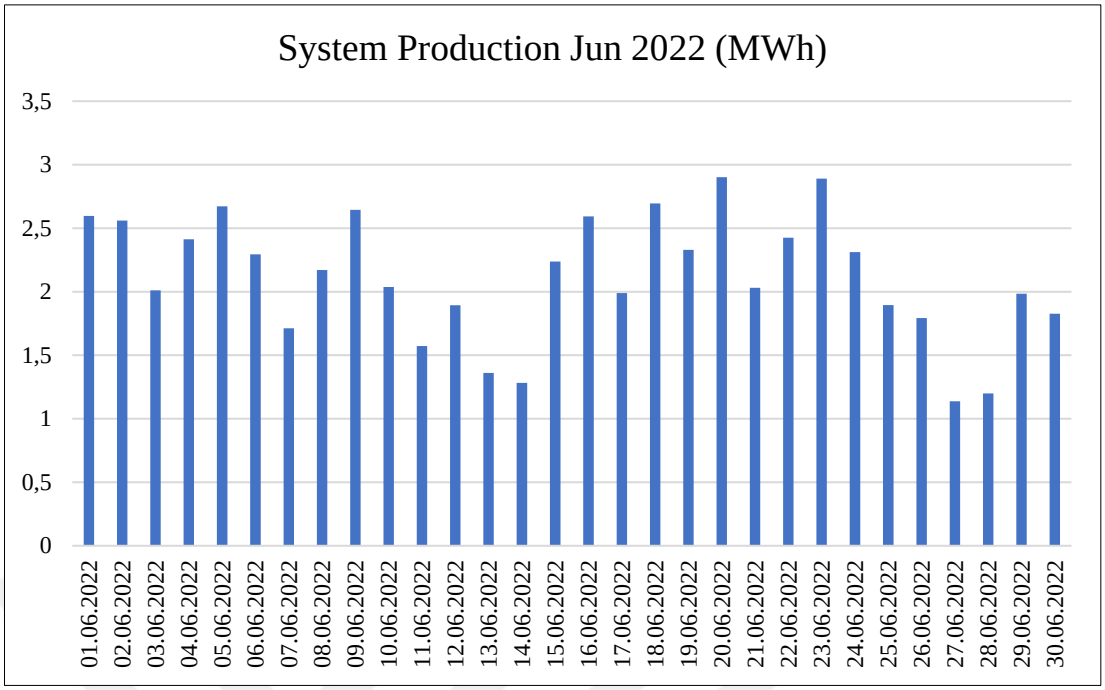


Figure 2.14 System Production Jun 2022 (MWh)

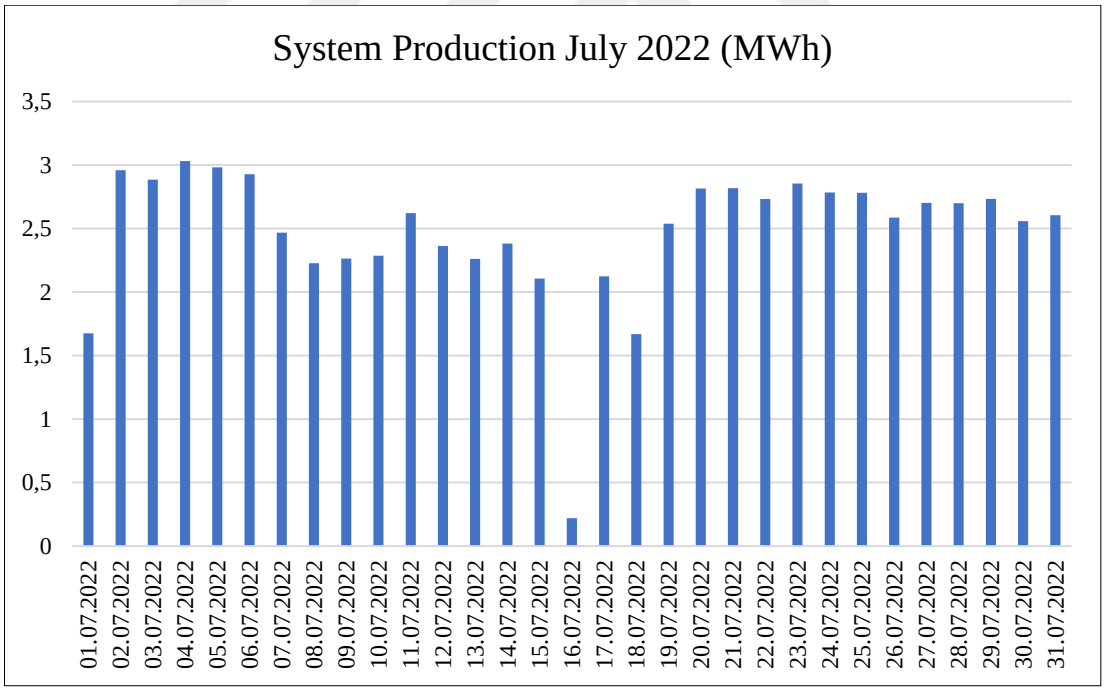


Figure 2.15 System Production July 2022 (MWh)

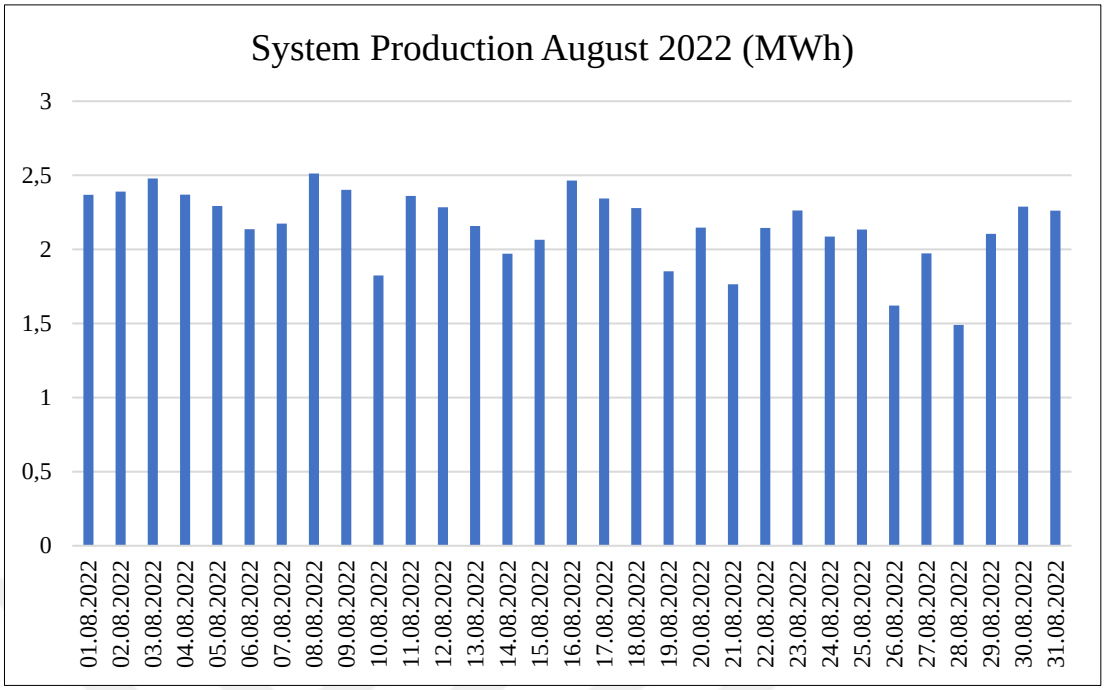


Figure 2.16 System Production August 2022 (MWh)

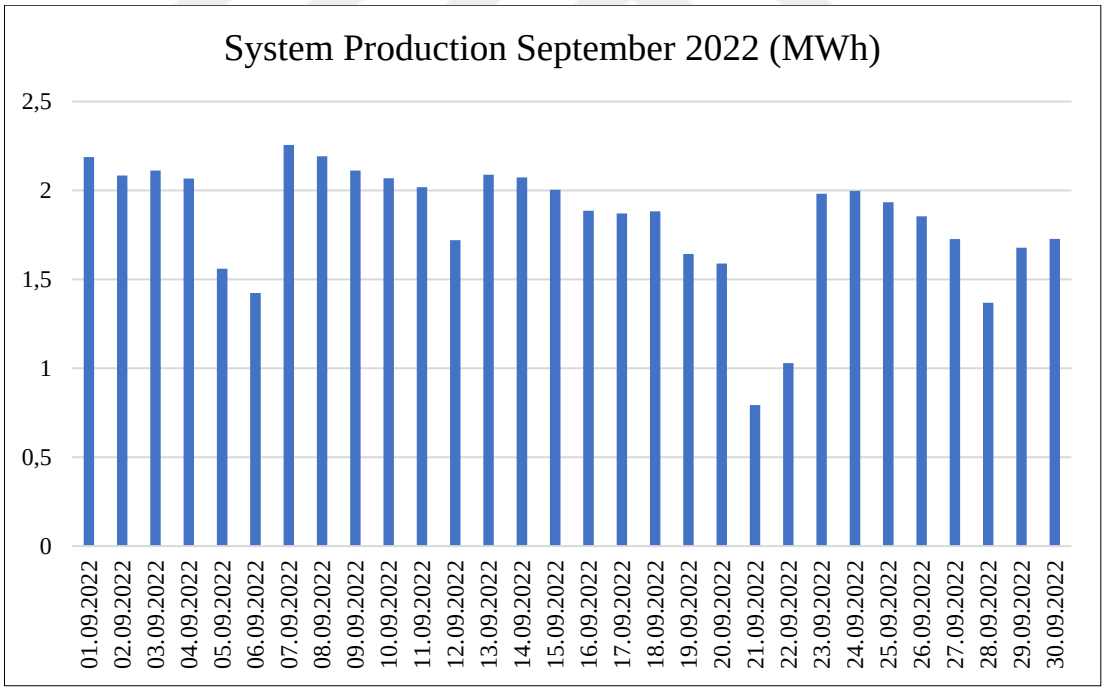


Figure 2.17 System Production September 2022 (MWh)

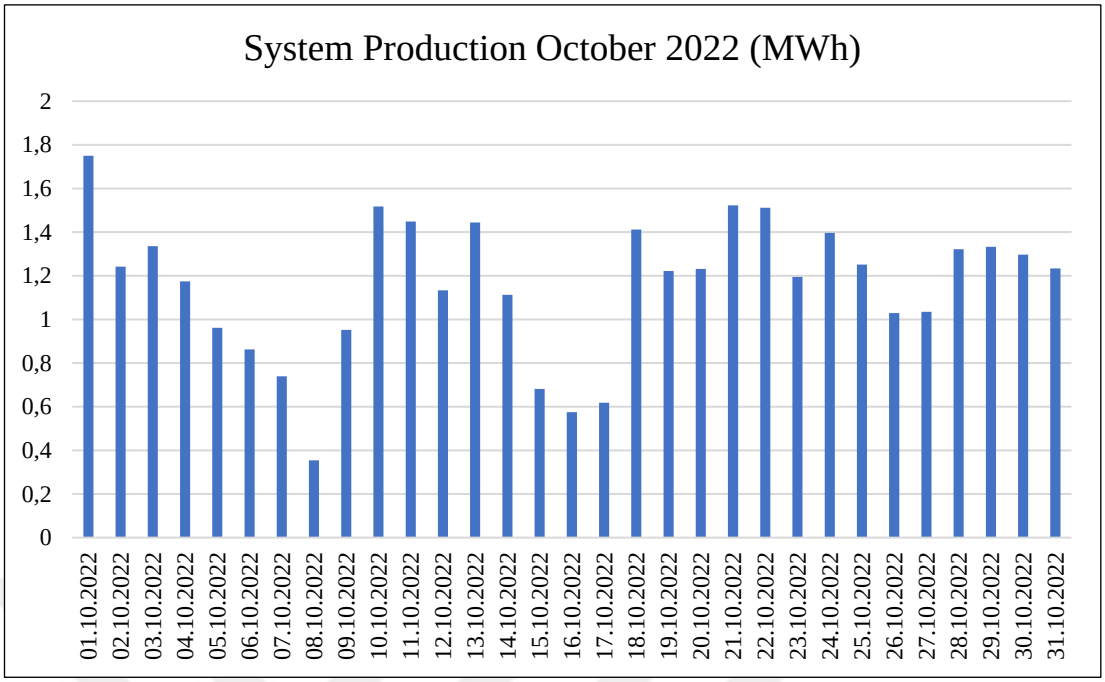


Figure 2.18 System Production October 2022 (MWh)

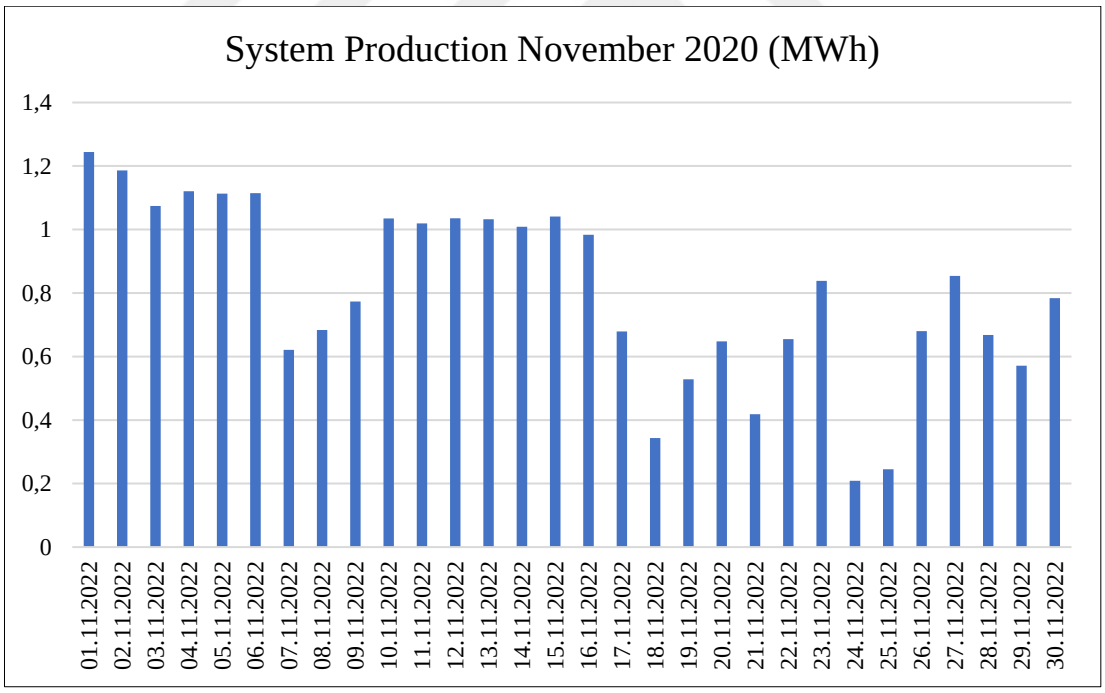


Figure 2.19 System Production November2022 (MWh)

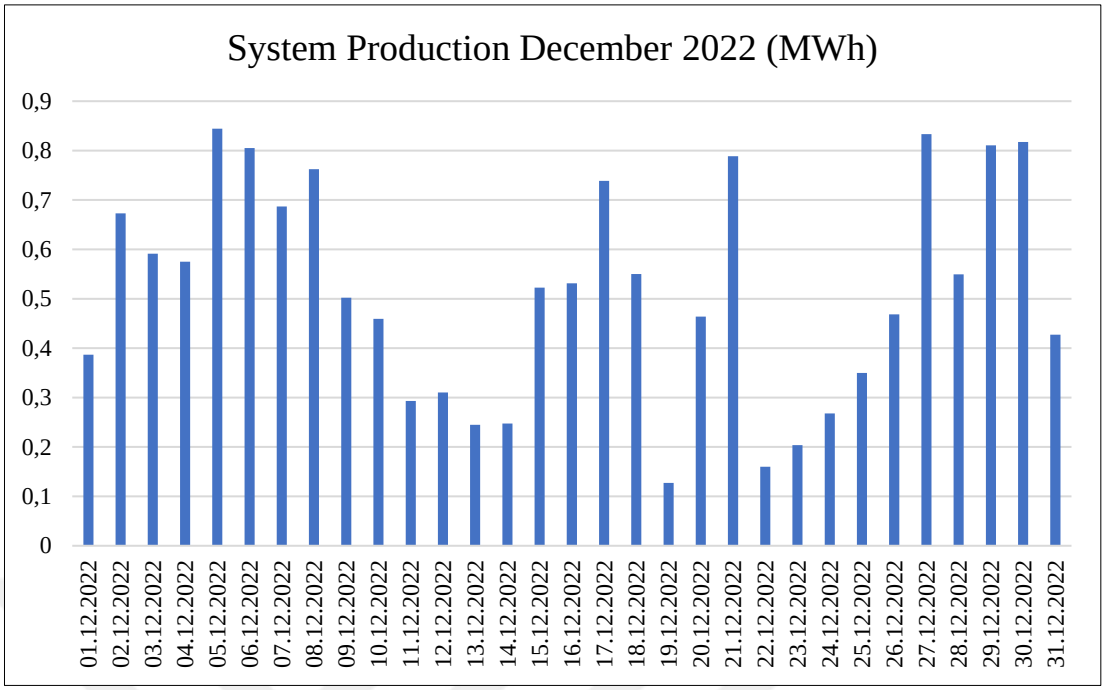


Figure 2.20 System Production December 2022 (MWh)

2.7 Thermal Battery Manufacturing Plant Energy Consumption Data

The production facility operates in three shifts and has various electrical loads such as pumps, heaters, furnaces, special ventilation installations and more. The MDB-1 coded panel belonging to the battery production facility receives its mains energy from 2x1000kVA transformers at 34,5/0,4kV voltage level belonging to the same facility. The PAC4200 energy analyzer located on the MDB-1 panel provides many electrical data of the facility. In our study, energy consumption data in Wh scale were taken from these analyzers with retrospective queries and brought into a form that can be processed.

Inverters connected to the solar power plant are connected to the MDB-2 coded panel with a bidirectional counter. Inverters receive the energy they consume in the dark periods when it is not possible to use the solar source and during the maintenance-revision periods via the MDB-1 panel via cables. The bidirectional electricity meter located on the MDB-2 panel provides the offset between the energy produced from the solar plant and the energy it consumes. In the periods when solar energy is available,

the energy transfer to the MDB-1 panel over the MDB-2 panel is provided over the same cables.

The energy consumption data of the thermal battery manufacturing facility are taken from the energy analyzers in annual and monthly periods and are presented below with charts. While the first chart shows the monthly total production for 2022; other charts reflect daily production in the months of 2022.

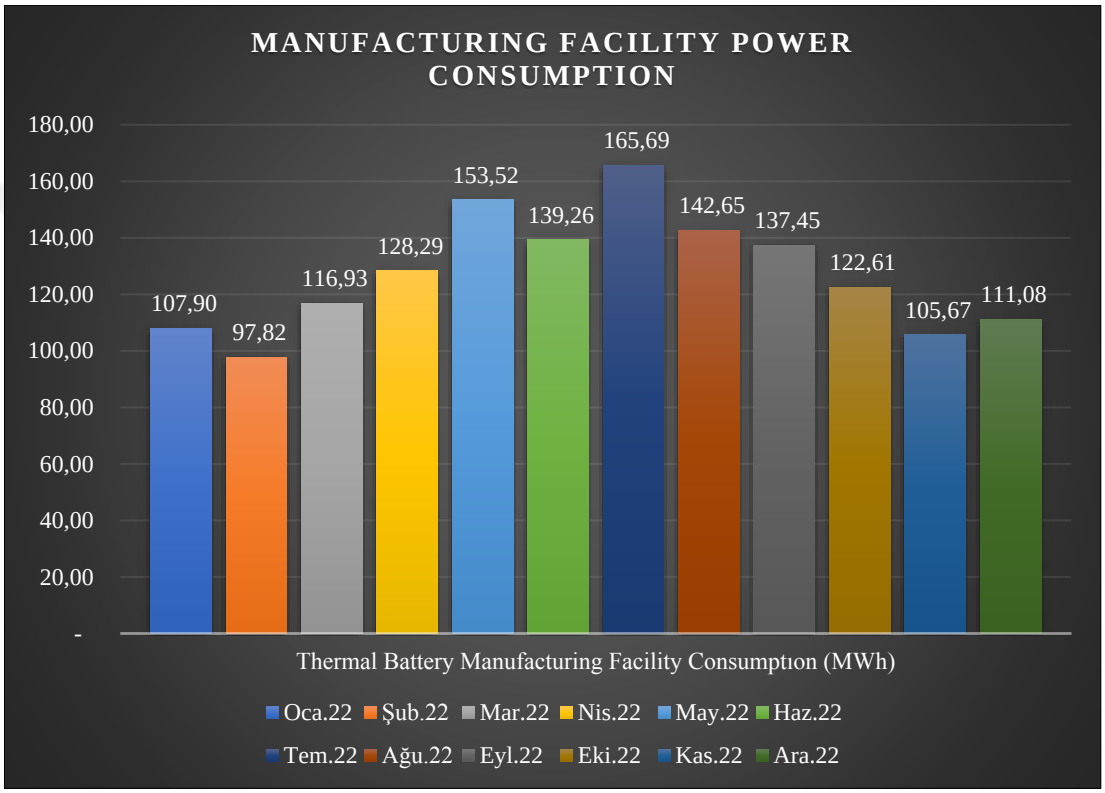


Figure 2.21 Monthly Consumption Data of Manufacturing Facility for 2022

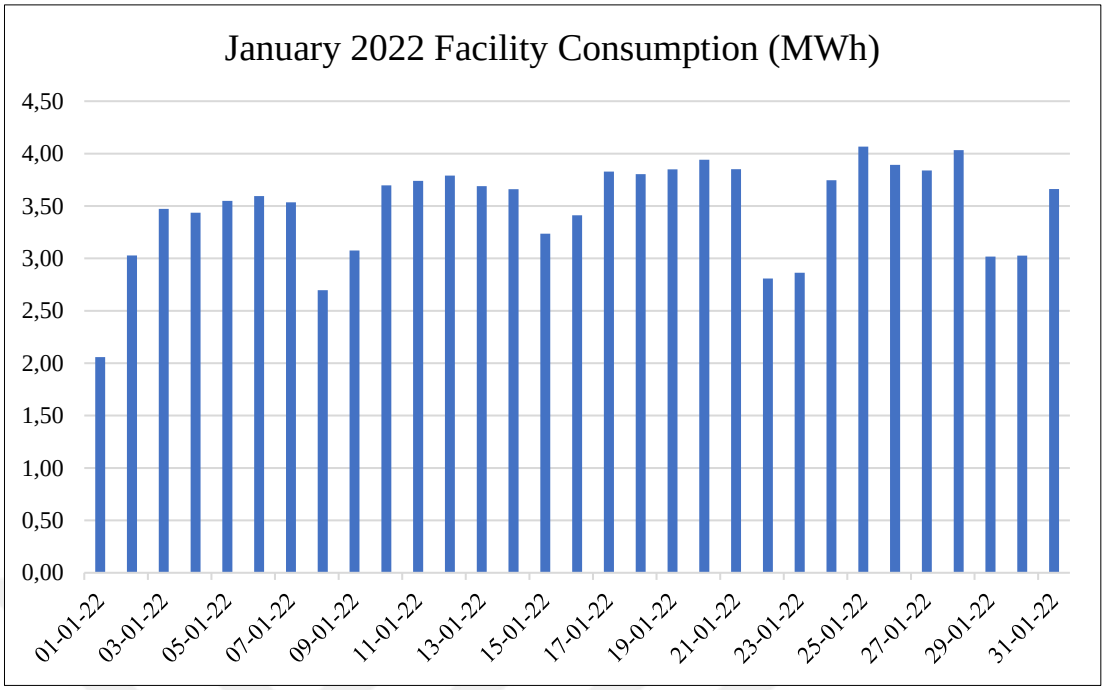


Figure 2.22 System Consumption January 2022 (MWh)

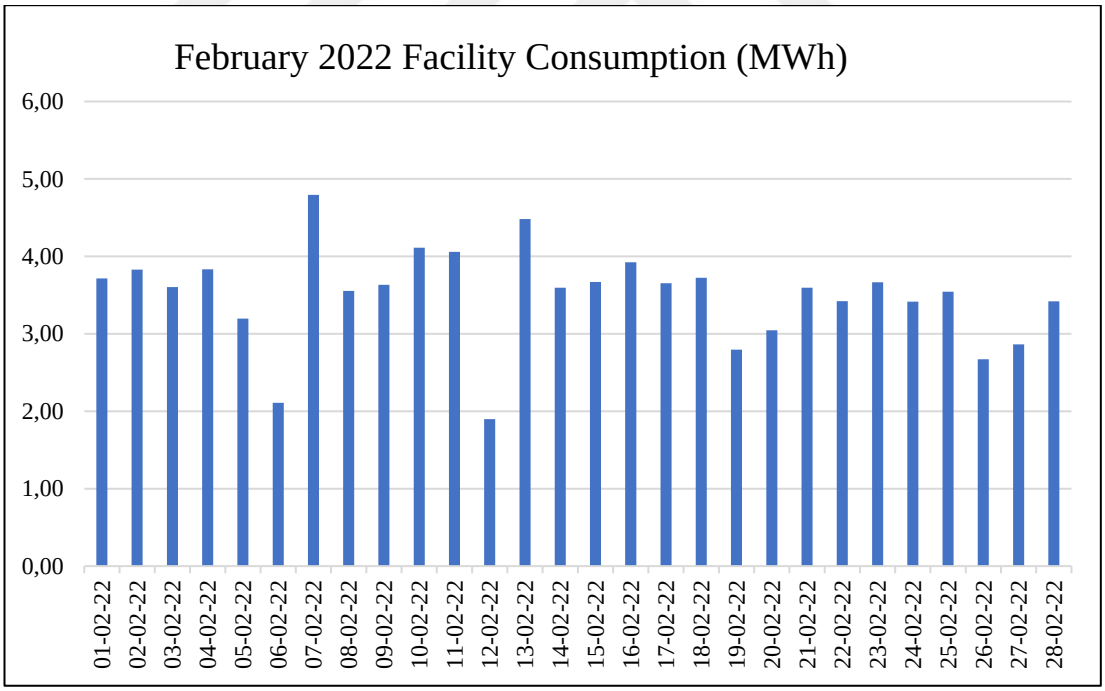


Figure 2.23 System Consumption February 2022 (MWh)

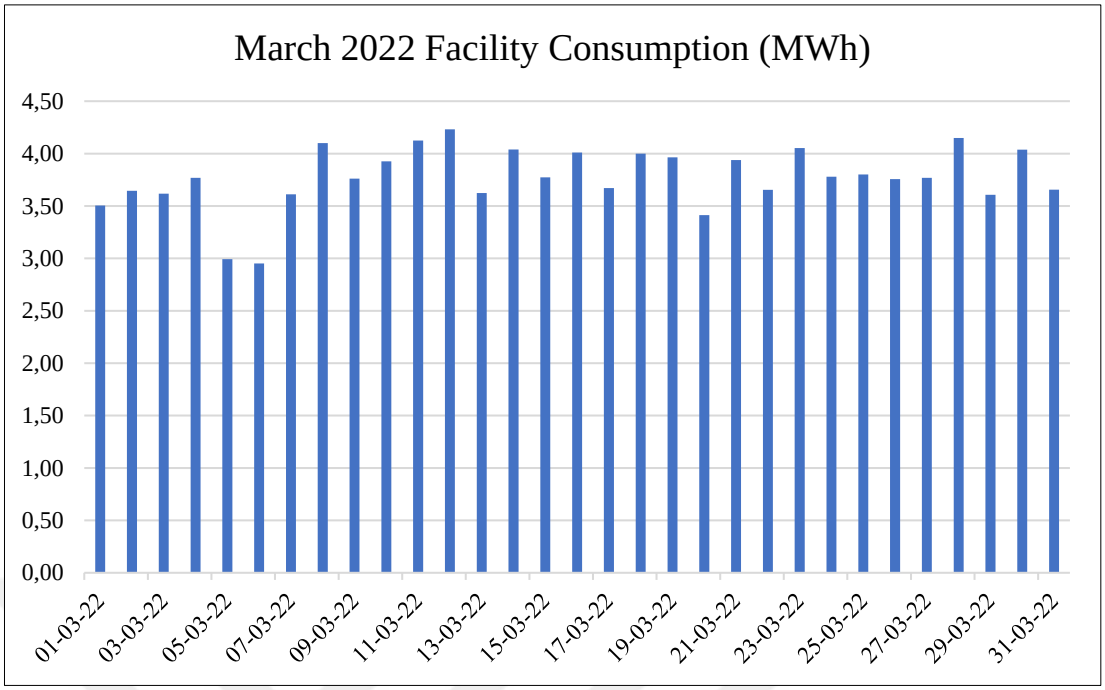


Figure 2.24 System Consumption March 2022 (MWh)

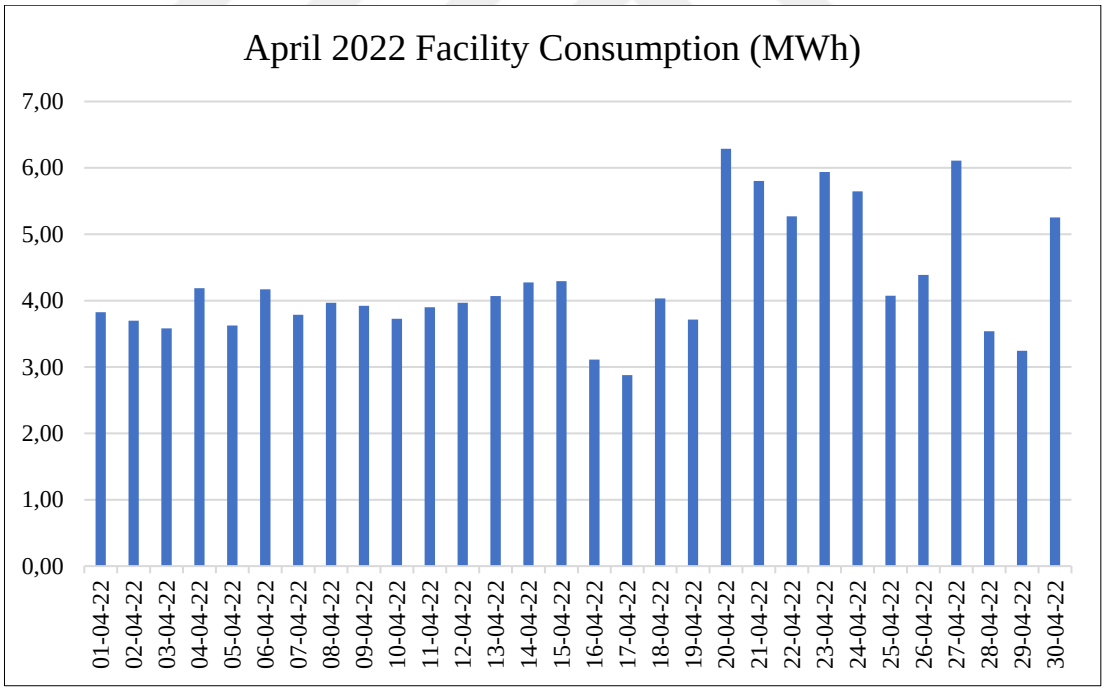


Figure 2.25 System Consumption April 2022 (MWh)

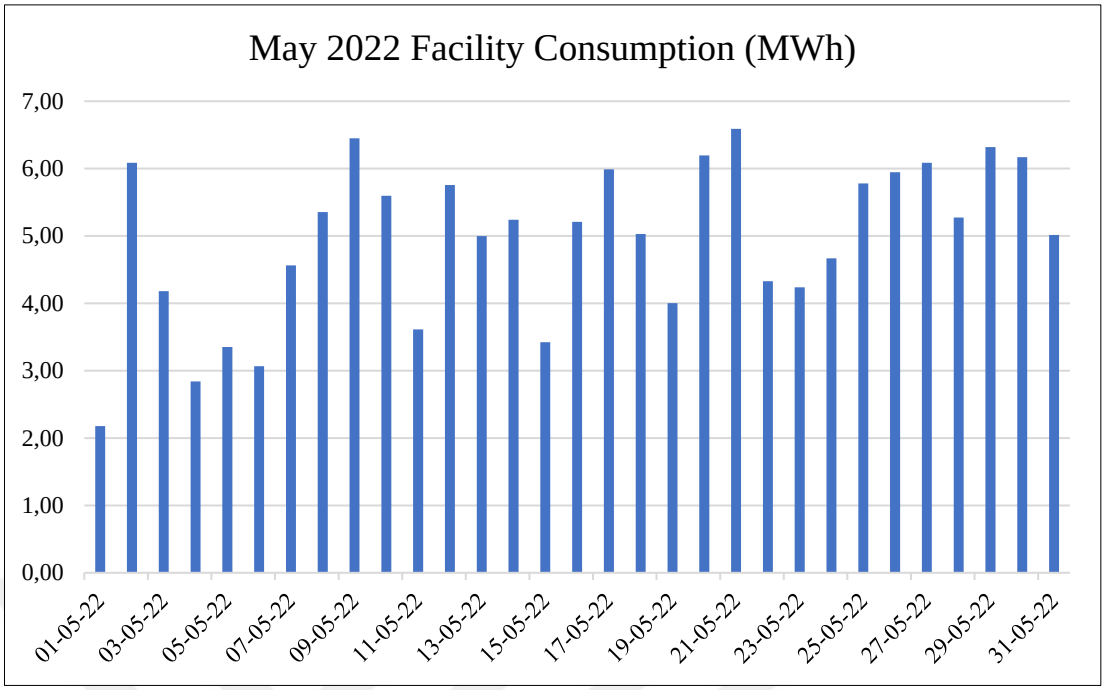


Figure 2.26 System Consumption May 2022 (MWh)

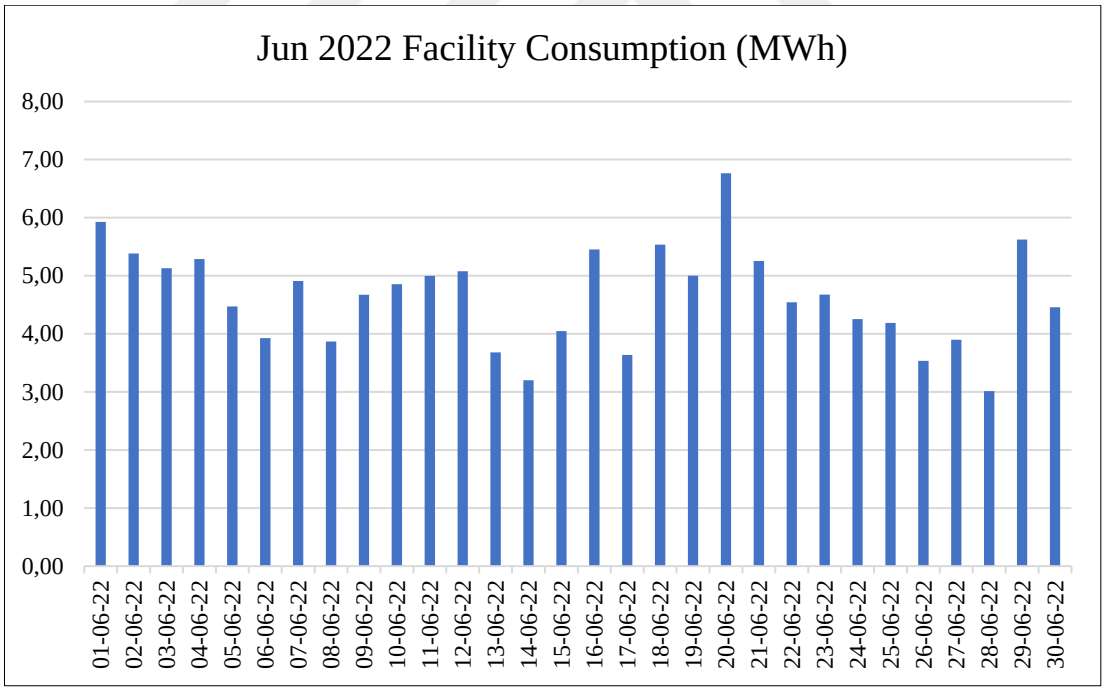


Figure 2.27 System Consumption Jun 2022 (MWh)

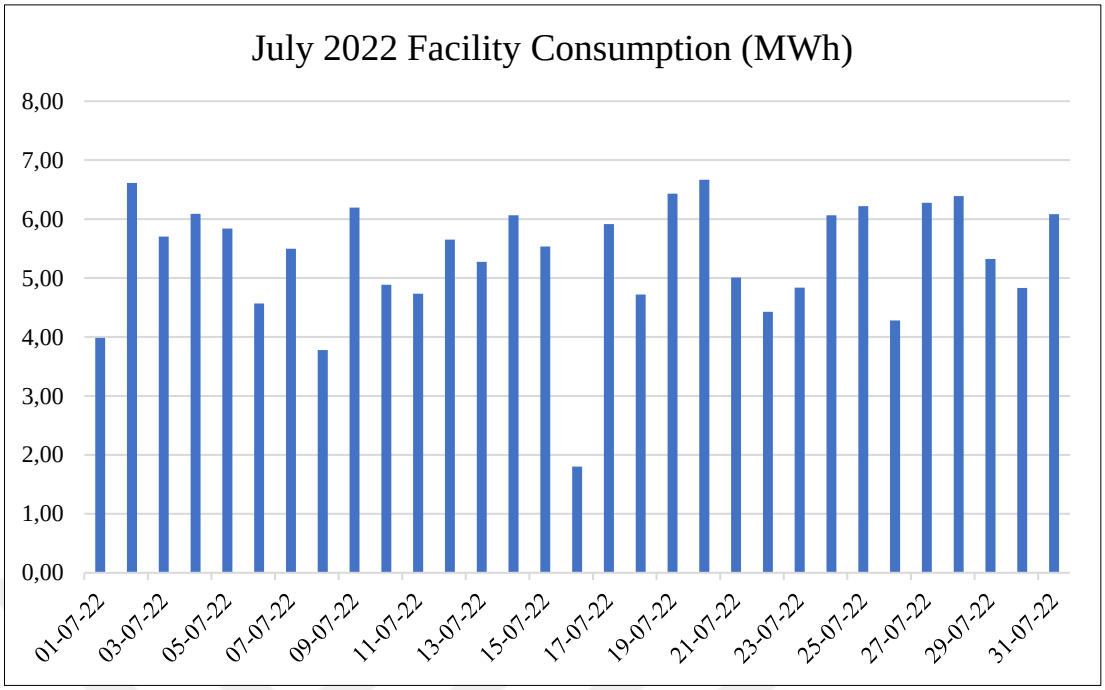


Figure 2.28 System Consumption July 2022 (MWh)

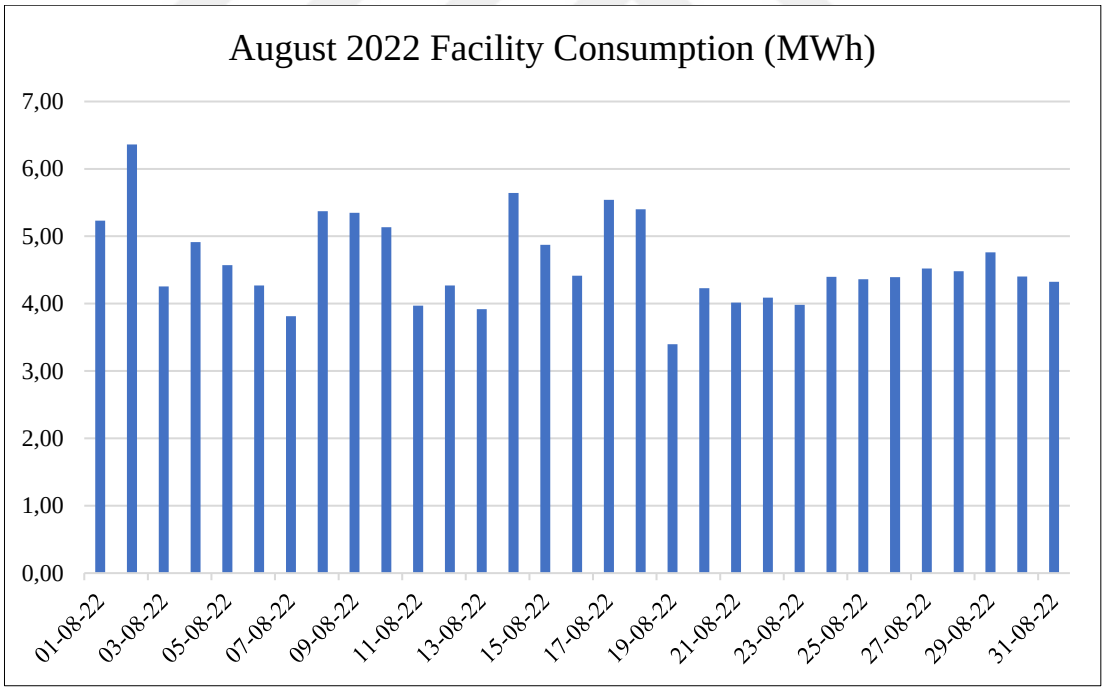


Figure 2.29 System Consumption August 2022 (MWh)

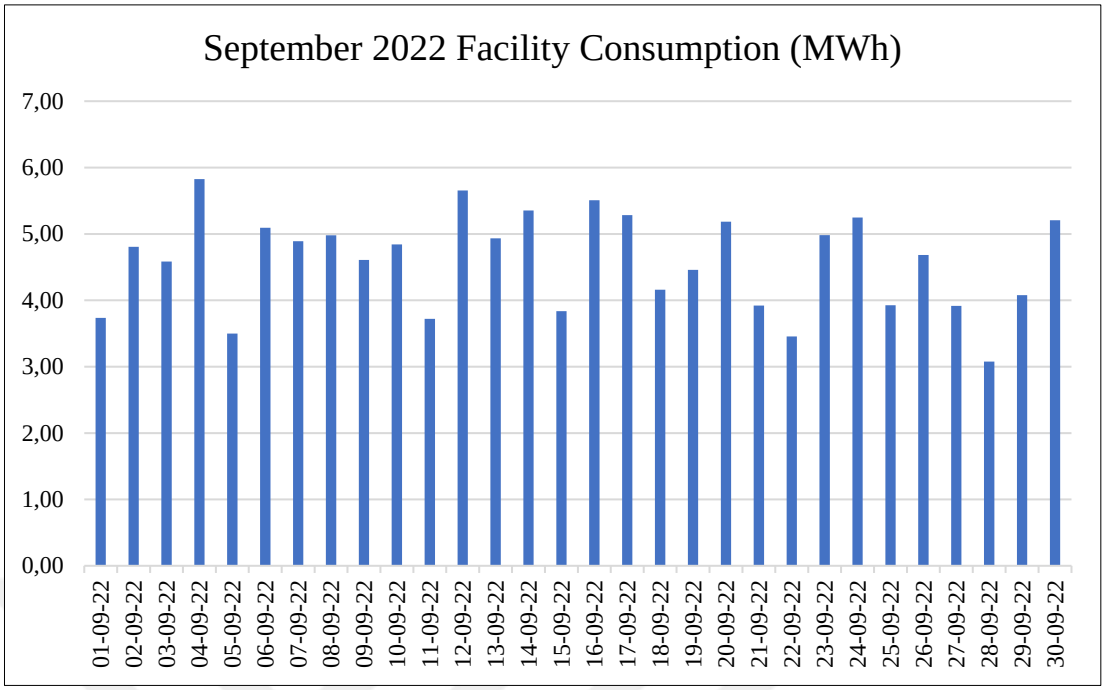


Figure 2.30 System Consumption September 2022 (MWh)

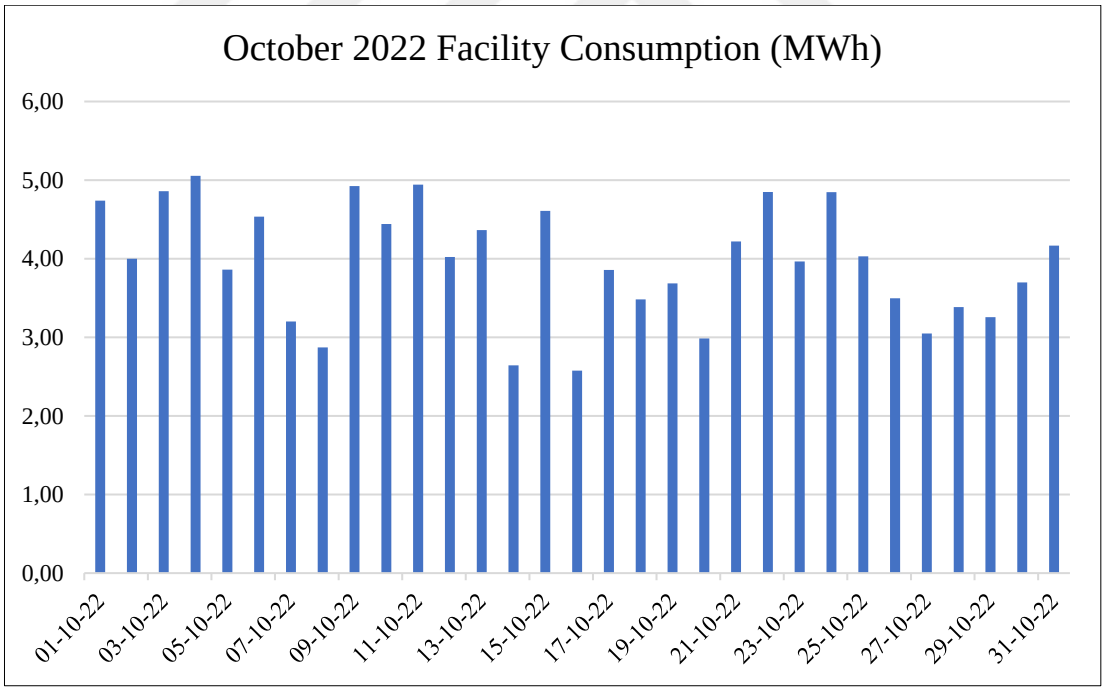


Figure 2.31 System Consumption October 2022 (MWh)

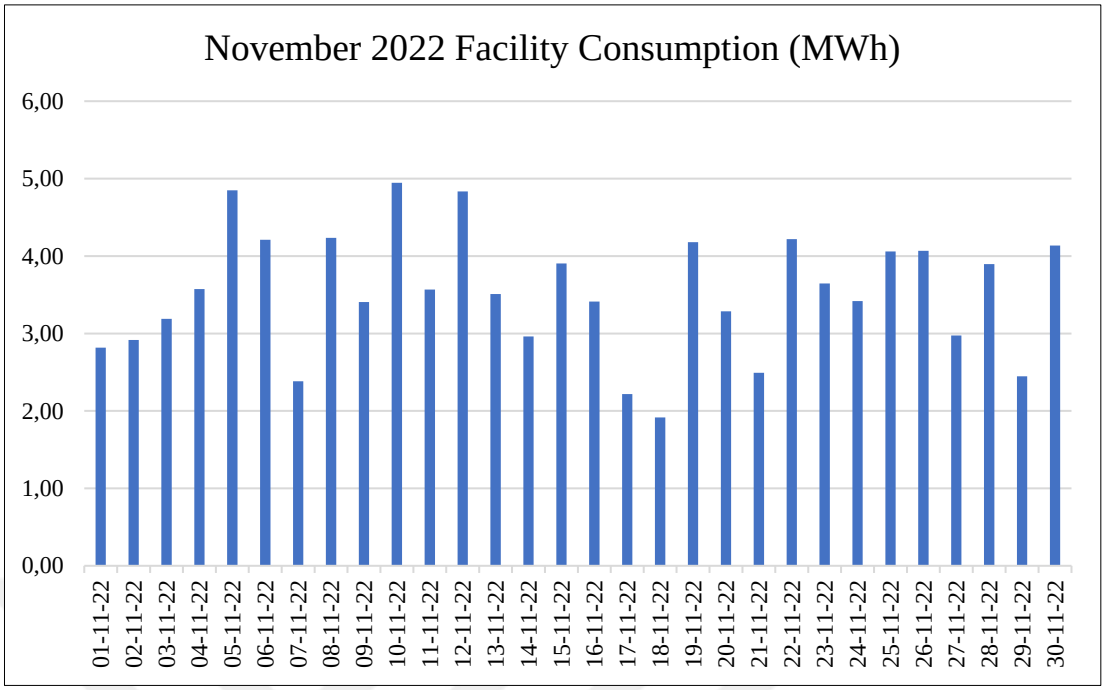


Figure 2.32 System Consumption November 2022 (MWh)

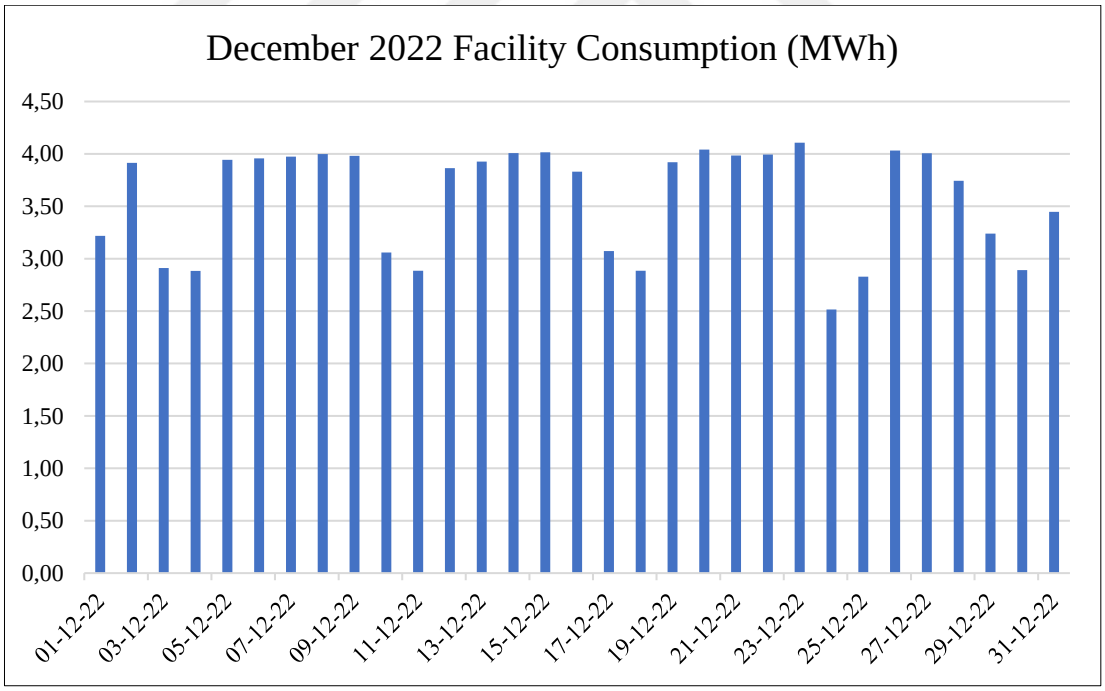


Figure 2.33 System Consumption December 2022 (MWh)

CHAPTER 3

RESEARCH RESULTS

3.1 Results Of The Research For One-Year Period

The energy production and consumption at the facility in 2022 are shown in the Figure 3.1 below, on a yearly basis. As can be seen from the graph, the energy consumption of the facility is well above the production values of the solar power plant connected to the same facility. The contribution of the seasonal conditions and the energy consumption of the facility to the energy produced from the solar power plant can be observed very clearly. It is also seen how much the increase in production acceleration with the beginning of the summer season contributes to plant efficiency.

Figure 3.1 is obtained from the total amount of energy produced and consumed on a monthly basis in 2022. The orange bars indicate the energy produced from the solar power plant facility (MWh), and the blue bars the energy consumed by the facility to which the solar power plant is connected (MWh). On the other hand, the table below the graph shows the consolidated generated energy values for the months of 2022 and the amount of energy consumed.

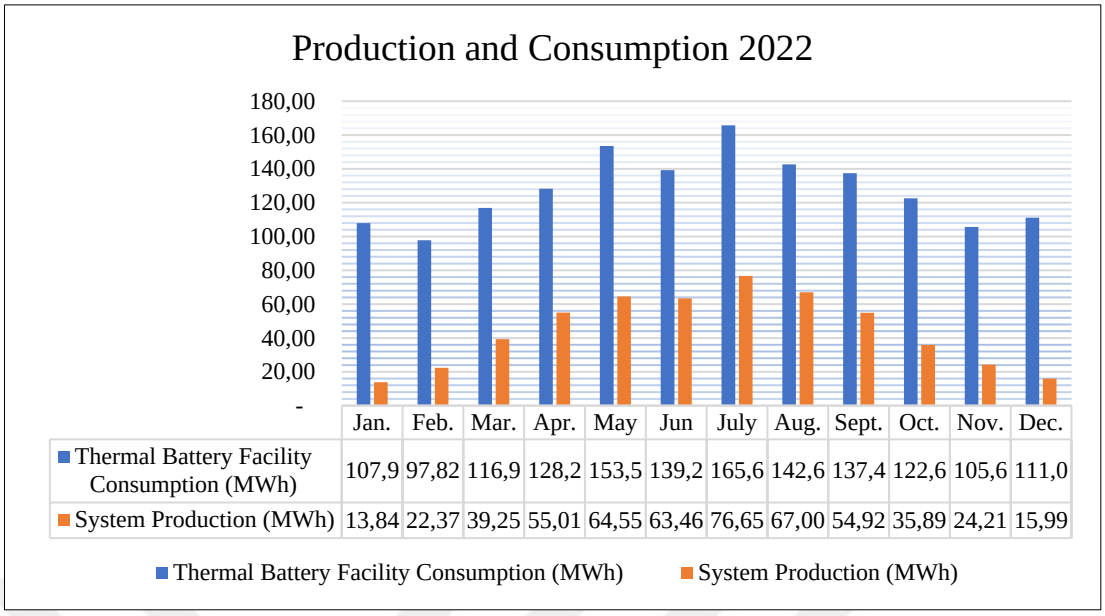


Figure 3.1 Solar PV Production and Thermal Battery Facility Consumption 2022 (MWh)

3.2 Results of The Research For Monthly Periods

In 2022, production and consumption facilities; The monthly results of the energy produced (MWh) data and the energy consumed (MWh) data are mentioned in the graphs given below.

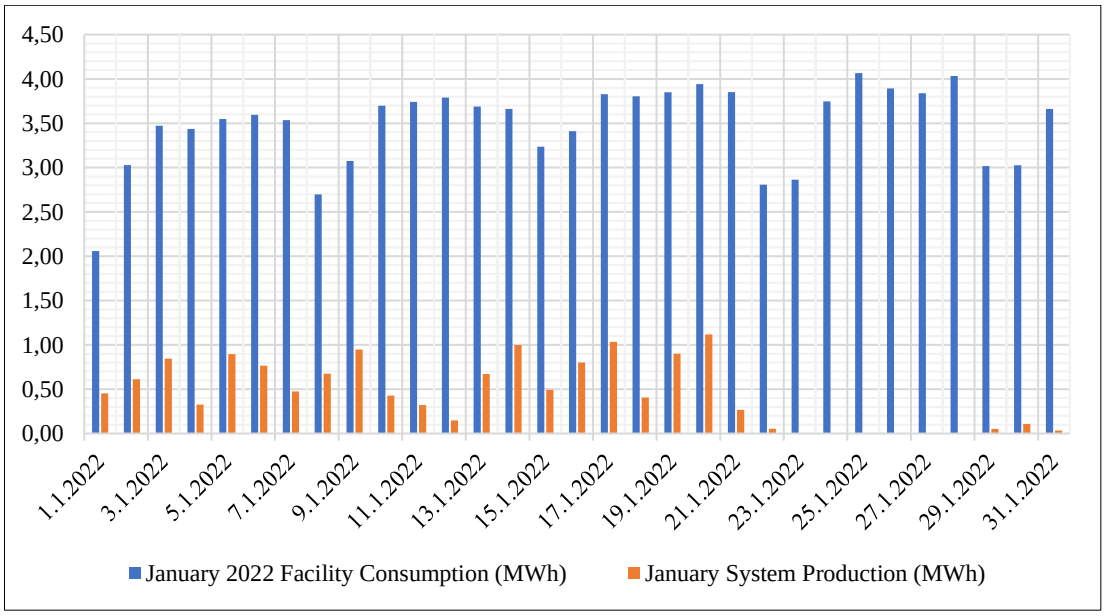


Figure 3.2 January 2022 Solar PV Production and Facility Consumption (MWh)

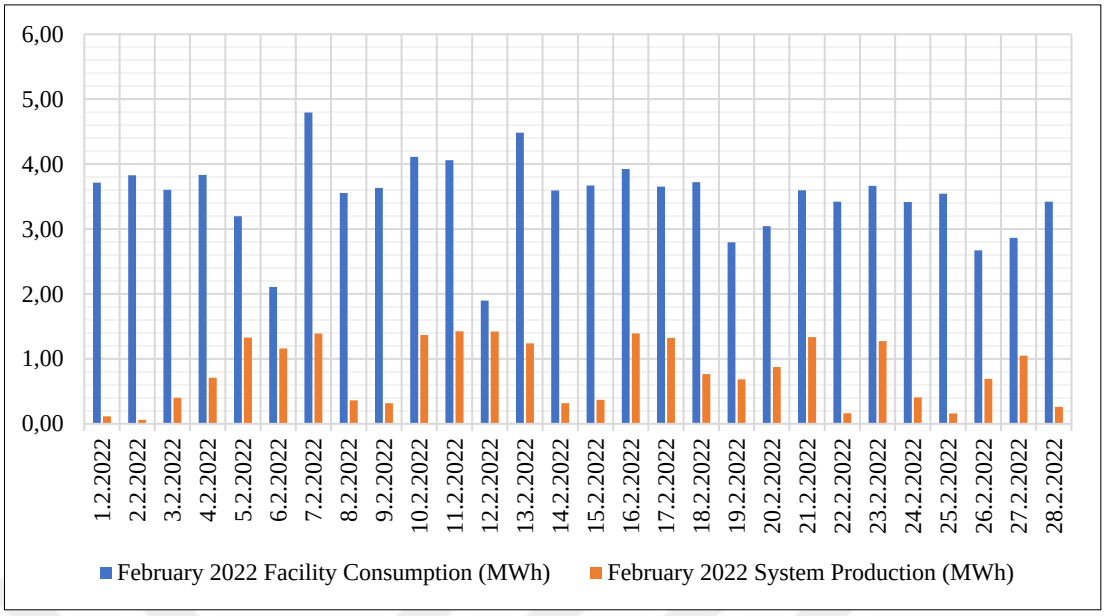


Figure 3.3 February 2022 Solar PV Production and Facility Consumption (MWh)

As can be seen in Figure 3.2 and Figure 3.3, the amount of energy (MWh) obtained from the solar plant always remains below the daily consumption due to seasonal conditions (rainfalls and sunshine) in January and February.

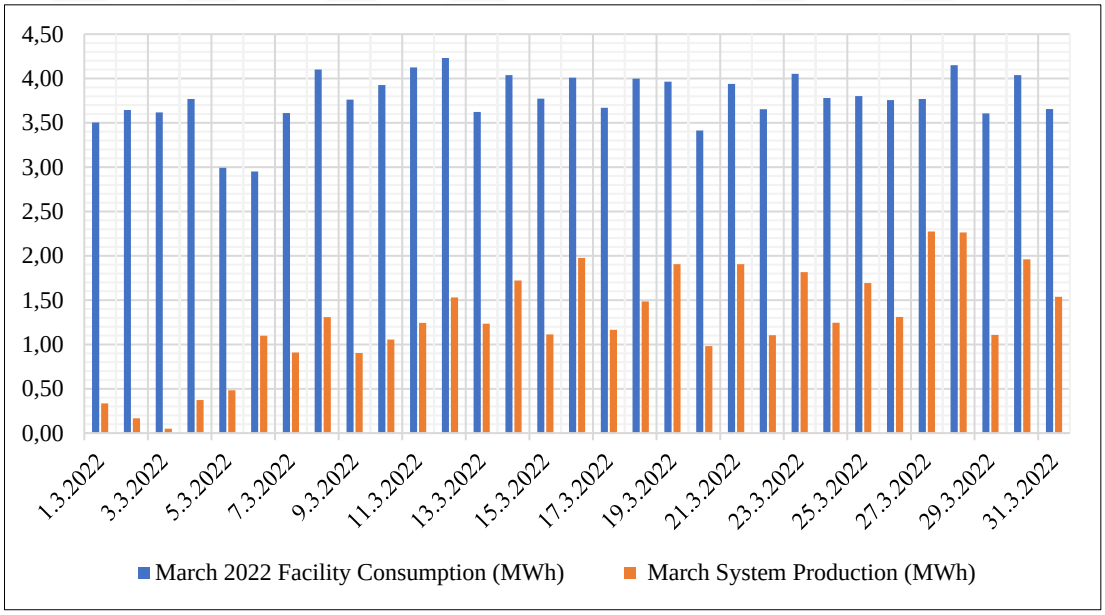


Figure 3.4 March 2022 Solar PV Production and Facility Consumption (MWh)

In the data of March in Figure 3.4, the reflection of the increase in solar radiation to the production at the power plant is clearly seen at the end of the month. In 2022, the

days when the generation from the solar power plant exceeds the consumption of the facility it is connected to are 27.03.2022 and 28.03.2022.

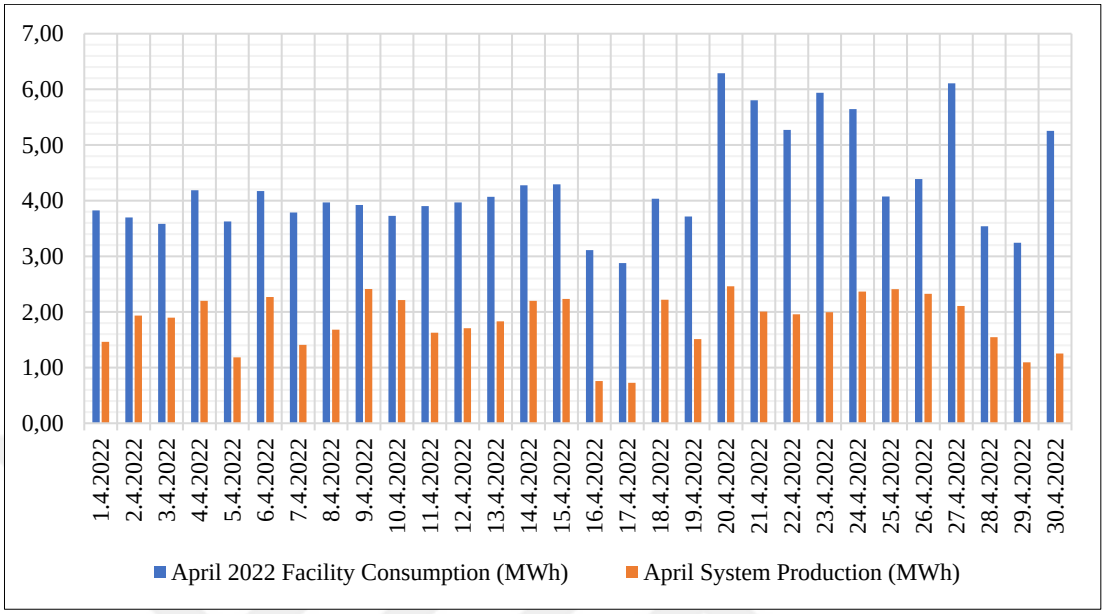


Figure 3.5 April 2022 Solar PV Production and Facility Consumption (MWh)

Looking at Figure 3.5 data, it is seen that the number of days where production exceeds consumption has increased as of April.

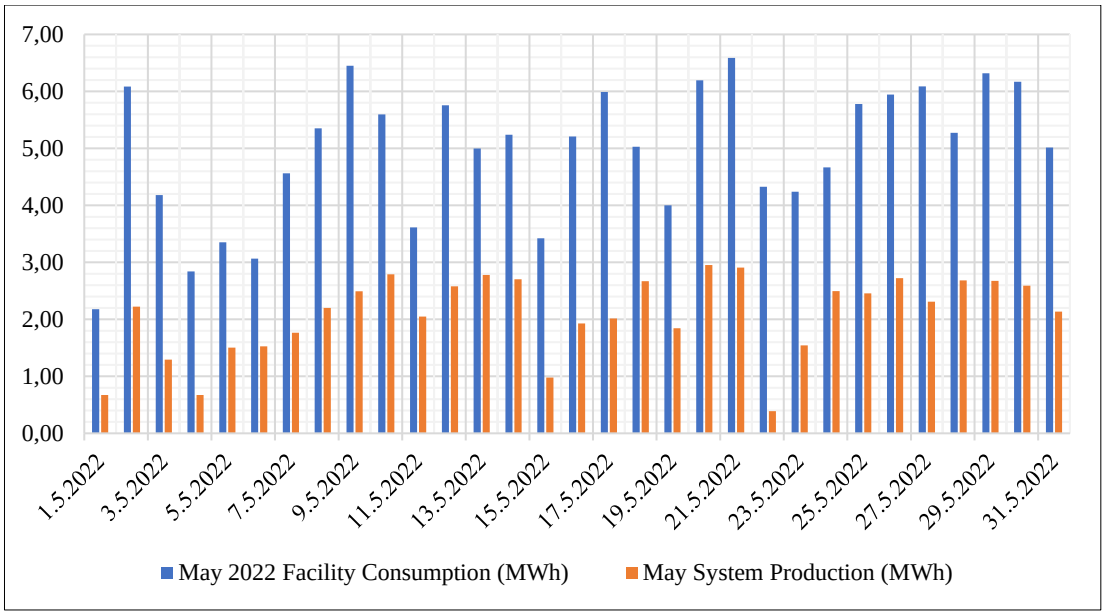


Figure 3.6 May 2022 Solar PV Production and Facility Consumption (MWh)

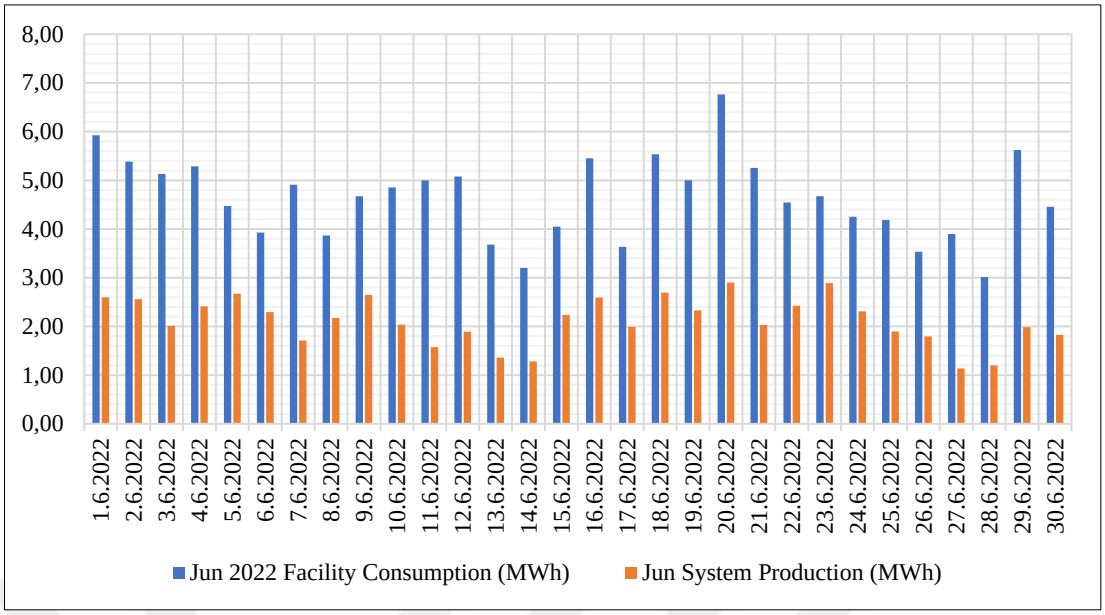


Figure 3.7 Jun 2022 Solar PV Production and Facility Consumption (MWh)

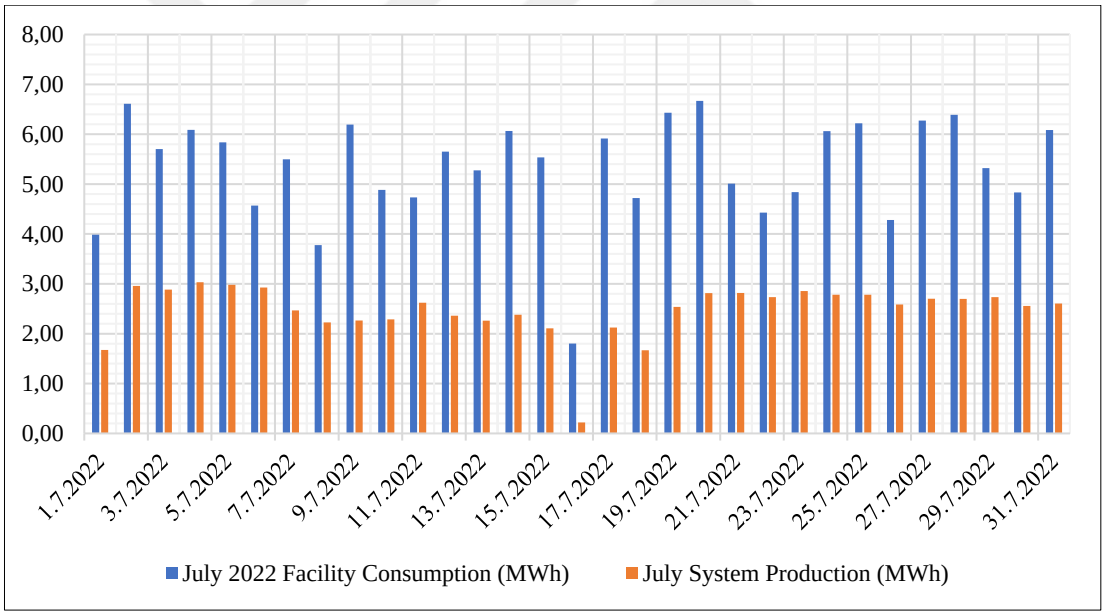


Figure 3.8 July 2022 Solar PV Production and Facility Consumption (MWh)

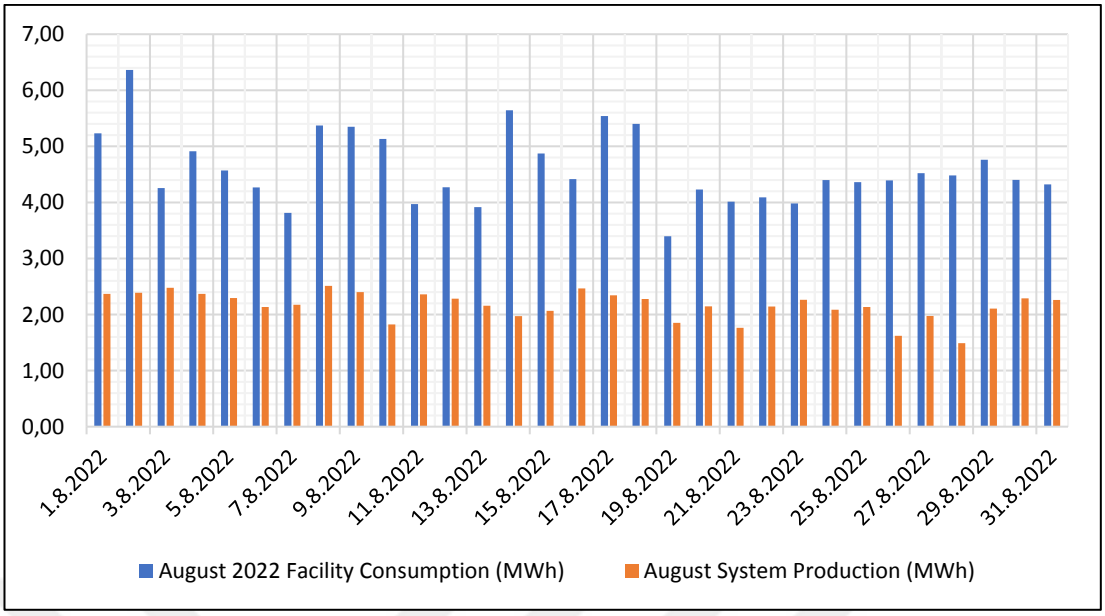


Figure 3.9 August 2022 Solar PV Production and Facility Consumption (MWh)

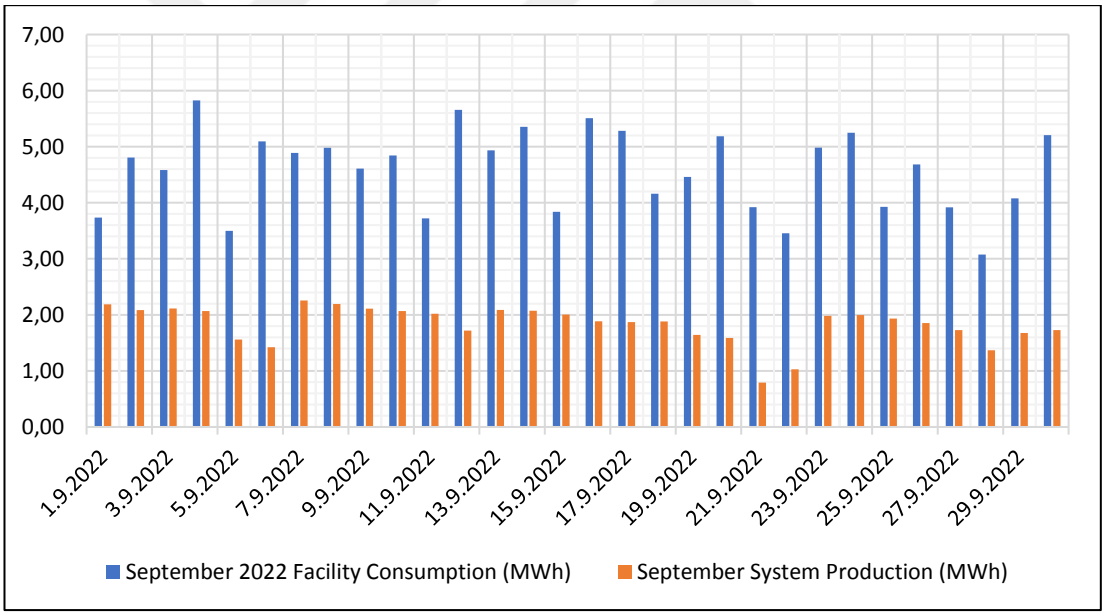


Figure 3.10 September 2022 Solar PV Production and Facility Consumption (MWh)

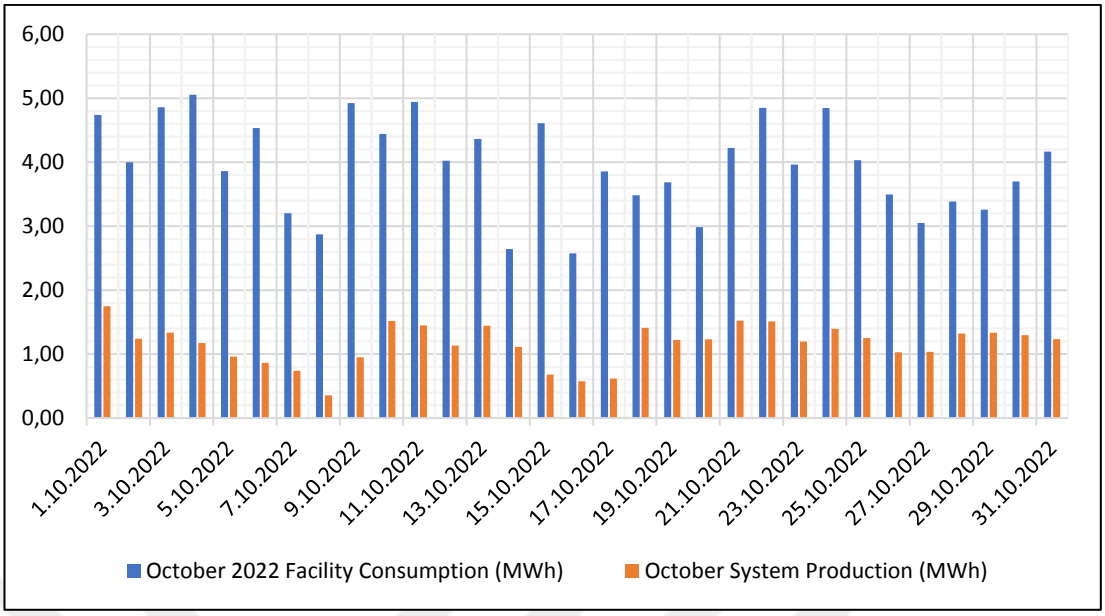


Figure 3.11 October 2022 Solar PV Production and Facility Consumption (MWh)

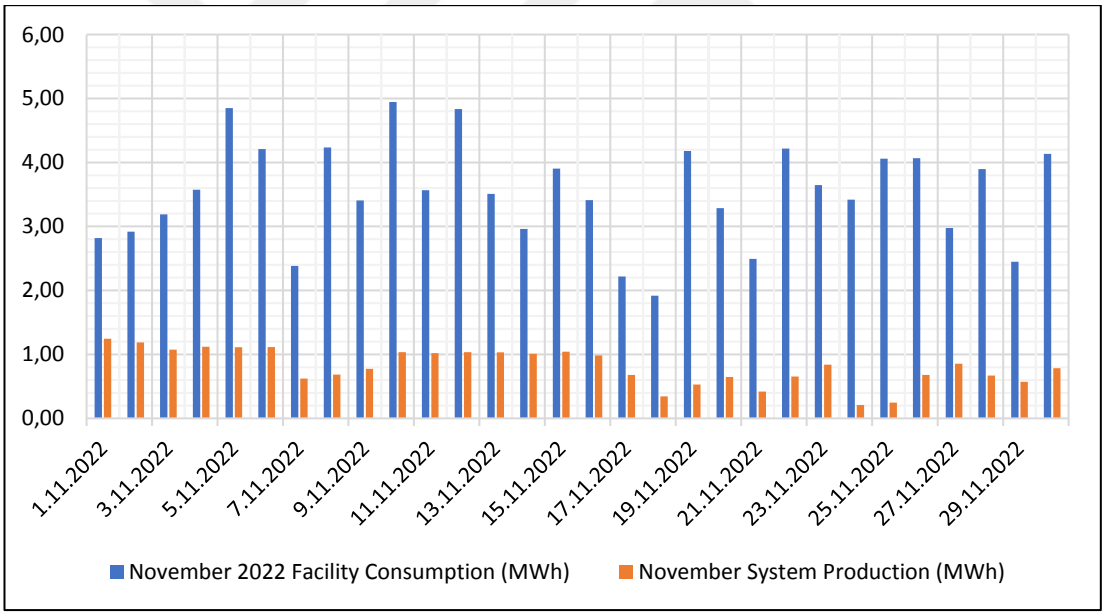


Figure 3.12 November 2022 Solar PV Production and Facility Consumption (MWh)

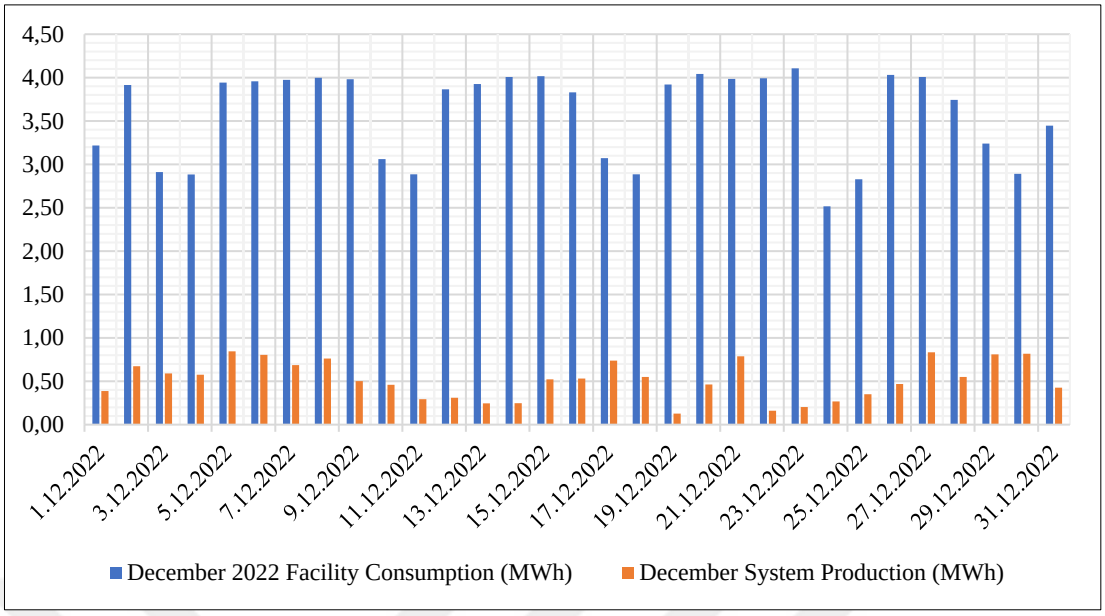


Figure 3.13 December 2022 Solar PV Production and Facility Consumption (MWh)

In the Figure 3.14 below, the percentage distribution of the monthly solar energy (MWh) during the working year is given. The amount of energy production, which accelerated positively due to sunshine in April, started to decrease with a negative acceleration depending on the season as of September of the same year. In other words, it is understood from the Figure 3.14 that energy production can be achieved at least 10% of the total production in six months of the year (from April to October).

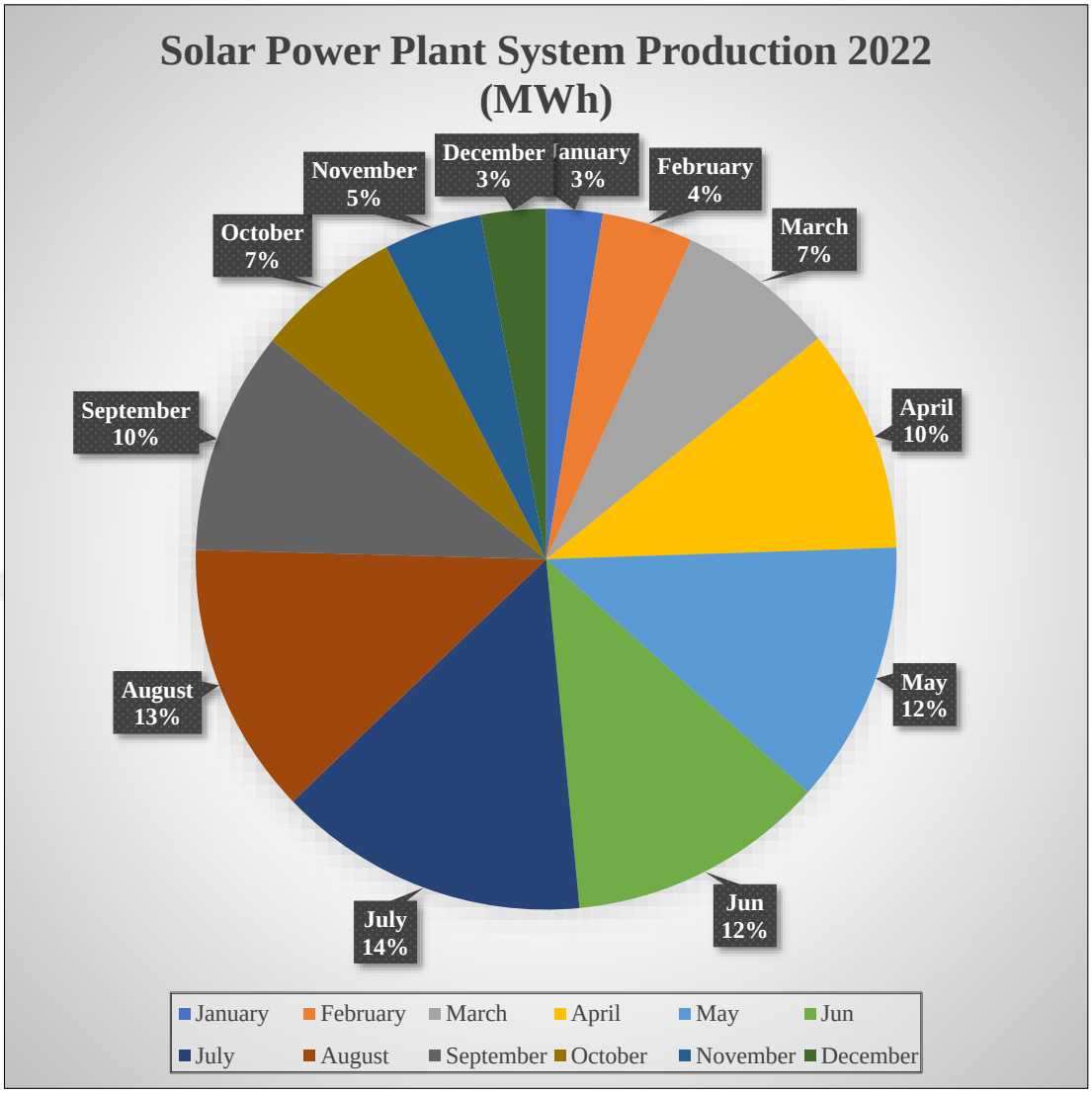


Figure 3.14 The situation of production in terms of total production by months in 2022

As can be seen in Figure 3.15, it can be clearly stated that the Thermal Battery production facility has a balanced load and consumption profile. The battery production facility has shared the annual total energy consumption almost equally every month. Production continued by consuming energy at the rate of approximately 9% of the total consumption each month of the year.

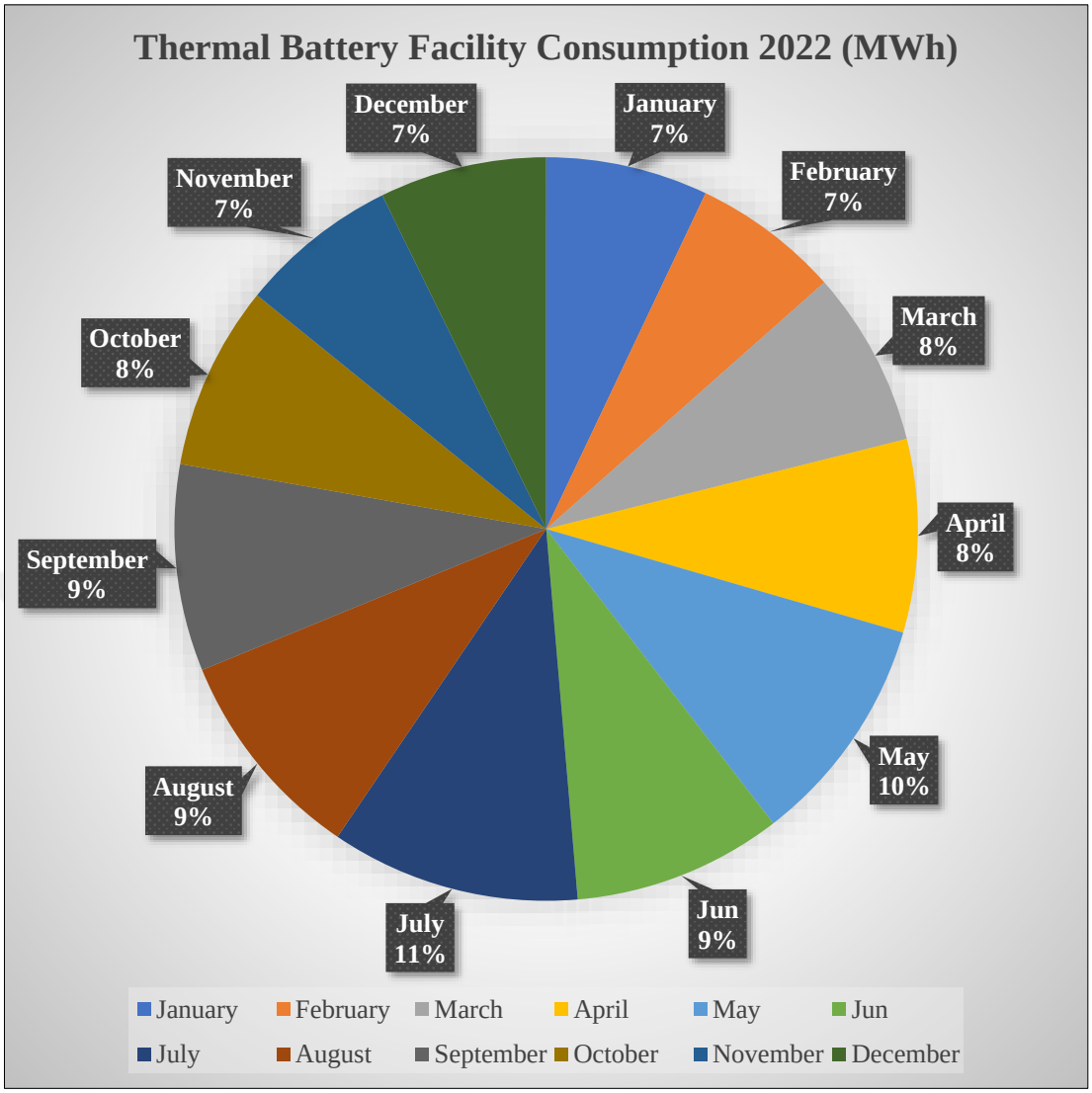


Figure 3.15 Percentage distribution of monthly consumption data 2022

3.3 Determining The Maximum Consumption - Production Days in The Month

Table 3.1 Maximum production and consumption days for January 2022

Date	January 2022 Plant Consumption (MWh)	January System Production (MWh)
01-01-22	2,0575	0,4535
02-01-22	3,0279	0,6112
03-01-22	3,4720	0,8442
04-01-22	3,4352	0,3261
05-01-22	3,5487	0,8961
06-01-22	3,5950	0,7659
07-01-22	3,5352	0,4756
08-01-22	2,6968	0,6761
09-01-22	3,0755	0,9484
10-01-22	3,6974	0,4270
11-01-22	3,7403	0,3214
12-01-22	3,7904	0,1488
13-01-22	3,6891	0,6725
14-01-22	3,6609	0,9977
15-01-22	3,2359	0,4928
16-01-22	3,4114	0,8009
17-01-22	3,8281	1,0349
18-01-22	3,8045	0,4064
19-01-22	3,8490	0,9012
20-01-22	3,9411	1,1168
21-01-22	3,8512	0,2676
22-01-22	2,8081	0,0541
23-01-22	2,8633	-
24-01-22	3,7463	-
25-01-22	4,0667	-
26-01-22	3,8920	0,0015
27-01-22	3,8388	0,0033
28-01-22	4,0334	0,0062
29-01-22	3,0169	0,0528
30-01-22	3,0257	0,1076
31-01-22	3,6619	0,0344

As can be seen from the Table 3.1, while the maximum energy consumption day of the facility is 25.01.2022, the day the solar power plant achieves maximum production is 20.01.2022.

Table 3.2 Maximum production and consumption days for February 2022

Date	February 2022 Plant Consumption (MWh)	February 2022 System Production (MWh)
01-02-22	3,7146	0,1164
02-02-22	3,8281	0,0622
03-02-22	3,6036	0,4001
04-02-22	3,8337	0,7098
05-02-22	3,1970	1,3282
06-02-22	2,1083	1,1594
07-02-22	4,7940	1,3894
08-02-22	3,5532	0,3610
09-02-22	3,6320	0,3178
10-02-22	4,1113	1,3673
11-02-22	4,0587	1,4246
12-02-22	1,8983	1,4225
13-02-22	4,4824	1,2388
14-02-22	3,5945	0,3170
15-02-22	3,6689	0,3695
16-02-22	3,9244	1,3935
17-02-22	3,6530	1,3243
18-02-22	3,7228	0,7673
19-02-22	2,7950	0,6842
20-02-22	3,0445	0,8749
21-02-22	3,5954	1,3366
22-02-22	3,4212	0,1611
23-02-22	3,6662	1,2747
24-02-22	3,4161	0,4051
25-02-22	3,5441	0,1601
26-02-22	2,6711	0,6911
27-02-22	2,8635	1,0490
28-02-22	3,4203	0,2619

As can be seen from the Table 3.2, while the maximum energy consumption day of the facility is 07.02.2022, the day the solar power plant achieves maximum production is 11.02.2022.

Table 3.3 Maximum production and consumption days for March 2022

Date	March 2022 Plant Consumption (MWh)	March System Production (MWh)
01-03-22	3,5040	0,3357
02-03-22	3,6450	0,1665
03-03-22	3,6170	0,0492
04-03-22	3,7683	0,3722
05-03-22	2,9928	0,4824
06-03-22	2,9516	1,0989
07-03-22	3,6107	0,9096
08-03-22	4,1006	1,3090
09-03-22	3,7614	0,9028
10-03-22	3,9267	1,0558
11-03-22	4,1250	1,2435
12-03-22	4,2318	1,5304
13-03-22	3,6232	1,2340
14-03-22	4,0387	1,7220
15-03-22	3,7732	1,1125
16-03-22	4,0094	1,9771
17-03-22	3,6705	1,1646
18-03-22	3,9990	1,4854
19-03-22	3,9642	1,9059
20-03-22	3,4133	0,9809
21-03-22	3,9389	1,9050
22-03-22	3,6538	1,1041
23-03-22	4,0524	1,8151
24-03-22	3,7799	1,2448
25-03-22	3,8010	1,6921
26-03-22	3,7572	1,3095
27-03-22	3,7690	2,2734
28-03-22	4,1496	2,2625
29-03-22	3,6067	1,1085
30-03-22	4,0375	1,9592
31-03-22	3,6557	1,5373

As can be seen from the Table 3.3, while the maximum energy consumption day of the facility is 12.03.2022, the day the solar power plant achieves maximum production is 27.03.2022.

Table 3.4 Maximum production and consumption days for April 2022

Date	April 2022 Plant Consumption (MWh)	April System Production (MWh)
01-04-22	3,8249	1,4621
02-04-22	3,6979	1,9342
03-04-22	3,5819	1,8970
04-04-22	4,1874	2,1999
05-04-22	3,6253	1,1844
06-04-22	4,1710	2,2680
07-04-22	3,7863	1,4089
08-04-22	3,9680	1,6807
09-04-22	3,9221	2,4119
10-04-22	3,7277	2,2140
11-04-22	3,9013	1,6284
12-04-22	3,9682	1,7087
13-04-22	4,0693	1,8321
14-04-22	4,2749	2,1991
15-04-22	4,2944	2,2326
16-04-22	3,1118	0,7575
17-04-22	2,8781	0,7271
18-04-22	4,0331	2,2192
19-04-22	3,7137	1,5130
20-04-22	6,2888	2,4608
21-04-22	5,8034	2,0074
22-04-22	5,2695	1,9585
23-04-22	5,9386	1,9956
24-04-22	5,6461	2,3671
25-04-22	4,0737	2,4107
26-04-22	4,3883	2,3253
27-04-22	6,1090	2,1070
28-04-22	3,5397	1,5477
29-04-22	3,2441	1,0961
30-04-22	5,2537	1,2527

As can be seen from the Table 3.4, the day the facility consumes maximum energy and the day the solar power plant achieves maximum production are the same date as 20.04.2022.

Table 3.5 Maximum production and consumption days for May 2022

Date	May 2022 Plant Consumption (MWh)	May System Production (MWh)
01-05-22	2,1777	0,6737
02-05-22	6,0852	2,2232
03-05-22	4,1806	1,2946
04-05-22	2,8405	0,6715
05-05-22	3,3516	1,5026
06-05-22	3,0657	1,5257
07-05-22	4,5634	1,7654
08-05-22	5,3528	2,1998
09-05-22	6,4497	2,4937
10-05-22	5,5965	2,7895
11-05-22	3,6132	2,0482
12-05-22	5,7561	2,5791
13-05-22	4,9987	2,7797
14-05-22	5,2390	2,7040
15-05-22	3,4215	0,9785
16-05-22	5,2090	1,9270
17-05-22	5,9887	2,0137
18-05-22	5,0278	2,6688
19-05-22	4,0014	1,8434
20-05-22	6,1942	2,9532
21-05-22	6,5889	2,9089
22-05-22	4,3266	0,3876
23-05-22	4,2382	1,5422
24-05-22	4,6673	2,4943
25-05-22	5,7786	2,4566
26-05-22	5,9452	2,7242
27-05-22	6,0867	2,3107
28-05-22	5,2727	2,6847
29-05-22	6,3182	2,6762
30-05-22	6,1683	2,5913
31-05-22	5,0152	2,1352

As can be seen from the Table 3.5, while the maximum energy consumption day of the facility is 21.05.2022, the day the solar power plant achieves maximum production is 20.05.2022.

Table 3.6 Maximum production and consumption days for Jun 2022

Date	Jun 2022 Plant Consumption (MWh)	Jun System Production (MWh)
01-06-22	5,9256	2,5966
02-06-22	5,3847	2,5607
03-06-22	5,1296	2,0106
04-06-22	5,2884	2,4124
05-06-22	4,4719	2,6719
06-06-22	3,9257	2,2937
07-06-22	4,9089	1,7119
08-06-22	3,8684	2,1714
09-06-22	4,6720	2,6440
10-06-22	4,8548	2,0368
11-06-22	4,9979	1,5729
12-06-22	5,0774	1,8934
13-06-22	3,6813	1,3603
14-06-22	3,1997	1,2827
15-06-22	4,0482	2,2382
16-06-22	5,4513	2,5933
17-06-22	3,6350	1,9890
18-06-22	5,5346	2,6956
19-06-22	5,0012	2,3292
20-06-22	6,7651	2,9011
21-06-22	5,2535	2,0315
22-06-22	4,5437	2,4257
23-06-22	4,6747	2,8897
24-06-22	4,2524	2,3114
25-06-22	4,1874	1,8944
26-06-22	3,5339	1,7929
27-06-22	3,8983	1,1373
28-06-22	3,0126	1,1996
29-06-22	5,6227	1,9847
30-06-22	4,4575	1,8265

As can be seen from the Table 3.6, the day the facility consumes maximum energy and the day the solar power plant achieves maximum production are the same date as 20.06.2022.

Table 3.7 Maximum production and consumption days for July 2022

Date	July 2022 Plant Consumption (MWh)	July System Production (MWh)
01-07-22	3,9855	1,6745
02-07-22	6,6123	2,9583
03-07-22	5,7031	2,8841
04-07-22	6,0885	3,0305
05-07-22	5,8391	2,9821
06-07-22	4,5690	2,9270
07-07-22	5,4961	2,4671
08-07-22	3,7779	2,2269
09-07-22	6,1937	2,2637
10-07-22	4,8851	2,2861
11-07-22	4,7332	2,6212
12-07-22	5,6524	2,3624
13-07-22	5,2742	2,2612
14-07-22	6,0655	2,3815
15-07-22	5,5361	2,1061
16-07-22	1,8026	0,2196
17-07-22	5,9147	2,1237
18-07-22	4,7211	1,6691
19-07-22	6,4321	2,5381
20-07-22	6,6679	2,8149
21-07-22	5,0093	2,8173
22-07-22	4,4283	2,7323
23-07-22	4,8384	2,8544
24-07-22	6,0632	2,7832
25-07-22	6,2188	2,7818
26-07-22	4,2796	2,5856
27-07-22	6,2756	2,7016
28-07-22	6,3903	2,6993
29-07-22	5,3220	2,7340
30-07-22	4,8317	2,5577
31-07-22	6,0846	2,6046

As can be seen from the Table 3.7, while the maximum energy consumption day of the facility is 20.07.2022, the day the solar power plant achieves maximum production is 04.07.2022.

Table 3.8 Maximum production and consumption days for August 2022

Date	August 2022 Plant Consumption (MWh)	August System Production (MWh)
01-08-22	5,2316	2,3686
02-08-22	6,3618	2,3898
03-08-22	4,2551	2,4781
04-08-22	4,9123	2,3693
05-08-22	4,5702	2,2932
06-08-22	4,2687	2,1357
07-08-22	3,8134	2,1734
08-08-22	5,3722	2,5122
09-08-22	5,3485	2,4015
10-08-22	5,1336	1,8236
11-08-22	3,9694	2,3604
12-08-22	4,2695	2,2845
13-08-22	3,9169	2,1579
14-08-22	5,6428	1,9708
15-08-22	4,8720	2,0650
16-08-22	4,4145	2,4645
17-08-22	5,5415	2,3435
18-08-22	5,4006	2,2786
19-08-22	3,3974	1,8524
20-08-22	4,2299	2,1469
21-08-22	4,0144	1,7644
22-08-22	4,0893	2,1443
23-08-22	3,9820	2,2630
24-08-22	4,3974	2,0864
25-08-22	4,3617	2,1337
26-08-22	4,3930	1,6210
27-08-22	4,5205	1,9735
28-08-22	4,4816	1,4906
29-08-22	4,7610	2,1050
30-08-22	4,4026	2,2886
31-08-22	4,3230	2,2610

As can be seen from the Table 3.8, while the maximum energy consumption day of the facility is 02.08.2022, the day the solar power plant achieves maximum production is 08.08.2022.

Table 3.9 Maximum production and consumption days for September 2022

Date	September 2022 Plant Consumption (MWh)	September System Production (MWh)
01-09-22	3,7348	2,1878
02-09-22	4,8051	2,0841
03-09-22	4,5841	2,1121
04-09-22	5,8261	2,0671
05-09-22	3,4978	1,5598
06-09-22	5,0940	1,4230
07-09-22	4,8894	2,2554
08-09-22	4,9800	2,1920
09-09-22	4,6074	2,1114
10-09-22	4,8429	2,0689
11-09-22	3,7204	2,0184
12-09-22	5,6559	1,7199
13-09-22	4,9336	2,0886
14-09-22	5,3545	2,0735
15-09-22	3,8369	2,0039
16-09-22	5,5070	1,8860
17-09-22	5,2823	1,8703
18-09-22	4,1598	1,8818
19-09-22	4,4588	1,6428
20-09-22	5,1846	1,5886
21-09-22	3,9208	0,7928
22-09-22	3,4554	1,0294
23-09-22	4,9823	1,9813
24-09-22	5,2470	1,9970
25-09-22	3,9263	1,9333
26-09-22	4,6836	1,8546
27-09-22	3,9168	1,7268
28-09-22	3,0766	1,3686
29-09-22	4,0777	1,6777
30-09-22	5,2062	1,7272

As can be seen from the Table 3.9, while the maximum energy consumption day of the facility is 04.09.2022, the day the solar power plant achieves maximum production is 07.09.2022.

Table 3.10 Maximum production and consumption days for October 2022

Date	October 2022 Plant Consumption (MWh)	October System Production (MWh)
01-10-22	4,7390	1,7500
02-10-22	3,9987	1,2417
03-10-22	4,8598	1,3358
04-10-22	5,0535	1,1745
05-10-22	3,8602	0,9612
06-10-22	4,5346	0,8626
07-10-22	3,2013	0,7393
08-10-22	2,8714	0,3544
09-10-22	4,9239	0,9519
10-10-22	4,4408	1,5178
11-10-22	4,9419	1,4489
12-10-22	4,0225	1,1335
13-10-22	4,3644	1,4444
14-10-22	2,6426	1,1126
15-10-22	4,6076	0,6816
16-10-22	2,5751	0,5751
17-10-22	3,8562	0,6182
18-10-22	3,4831	1,4121
19-10-22	3,6861	1,2221
20-10-22	2,9857	1,2317
21-10-22	4,2195	1,5225
22-10-22	4,8495	1,5115
23-10-22	3,9639	1,1949
24-10-22	4,8464	1,3964
25-10-22	4,0303	1,2513
26-10-22	3,4962	1,0292
27-10-22	3,0486	1,0346
28-10-22	3,3847	1,3217
29-10-22	3,2563	1,3323
30-10-22	3,6975	1,2965
31-10-22	4,1665	1,2335

As can be seen from the Table 3.10, while the maximum energy consumption day of the facility is 04.10.2022, the day the solar power plant achieves maximum production is 01.10.2022.

Table 3.11 Maximum production and consumption days for November 2022

Date	November 2022 Plant Consumption (MWh)	November System Production (MWh)
01-11-22	2,8181	1,2441
02-11-22	2,9172	1,1862
03-11-22	3,1893	1,0743
04-11-22	3,5736	1,1206
05-11-22	4,8491	1,1131
06-11-22	4,2106	1,1146
07-11-22	2,3822	0,6212
08-11-22	4,2346	0,6836
09-11-22	3,4064	0,7734
10-11-22	4,9459	1,0349
11-11-22	3,5671	1,0191
12-11-22	4,8336	1,0356
13-11-22	3,5094	1,0324
14-11-22	2,9615	1,0085
15-11-22	3,9042	1,0412
16-11-22	3,4116	0,9836
17-11-22	2,2181	0,6791
18-11-22	1,9165	0,3435
19-11-22	4,1802	0,5282
20-11-22	3,2858	0,6478
21-11-22	2,4936	0,4186
22-11-22	4,2179	0,6549
23-11-22	3,6464	0,8384
24-11-22	3,4186	0,2086
25-11-22	4,0603	0,2453
26-11-22	4,0673	0,6803
27-11-22	2,9747	0,8537
28-11-22	3,8960	0,6680
29-11-22	2,4481	0,5711
30-11-22	4,1350	0,7840

As can be seen from the Table 3.11, while the maximum energy consumption day of the facility is 10.11.2022, the day the solar power plant achieves maximum production is 01.11.2022.

Table 3.12 Maximum production and consumption days for December 2022

Date	December 2022 Plant Consumption (MWh)	December System Production (MWh)
01-12-22	3,2177	0,3867
02-12-22	3,9146	0,6730
03-12-22	2,9107	0,5912
04-12-22	2,8835	0,5750
05-12-22	3,9431	0,8443
06-12-22	3,9570	0,8051
07-12-22	3,9742	0,6867
08-12-22	3,9978	0,7623
09-12-22	3,9814	0,5022
10-12-22	3,0599	0,4595
11-12-22	2,8846	0,2931
12-12-22	3,8643	0,3104
13-12-22	3,9261	0,2448
14-12-22	4,0070	0,2473
15-12-22	4,0156	0,5227
16-12-22	3,8308	0,5314
17-12-22	3,0724	0,7385
18-12-22	2,8853	0,5503
19-12-22	3,9203	0,1272
20-12-22	4,0413	0,4639
21-12-22	3,9842	0,7887
22-12-22	3,9931	0,1601
23-12-22	4,1075	0,2036
24-12-22	2,5161	0,2680
25-12-22	2,8287	0,3498
26-12-22	4,0317	0,4683
27-12-22	4,0064	0,8332
28-12-22	3,7438	0,5496
29-12-22	3,2392	0,8106
30-12-22	2,8917	0,8174
31-12-22	3,4472	0,4272

As can be seen from the Table 3.12, while the maximum energy consumption day of the facility is 23.12.2022, the day the solar power plant achieves maximum production is 05.12.2022.

After determining the days of maximum production and consumption obtained from the data in the tables in this title, the 24-hour production and consumption values of these days are evaluated in the title below.

The consumption curve of the battery production facility will be compared against the maximum energy (MWh) obtained from the solar plant.

3.4 Comparison of Maximum Production and Consumption

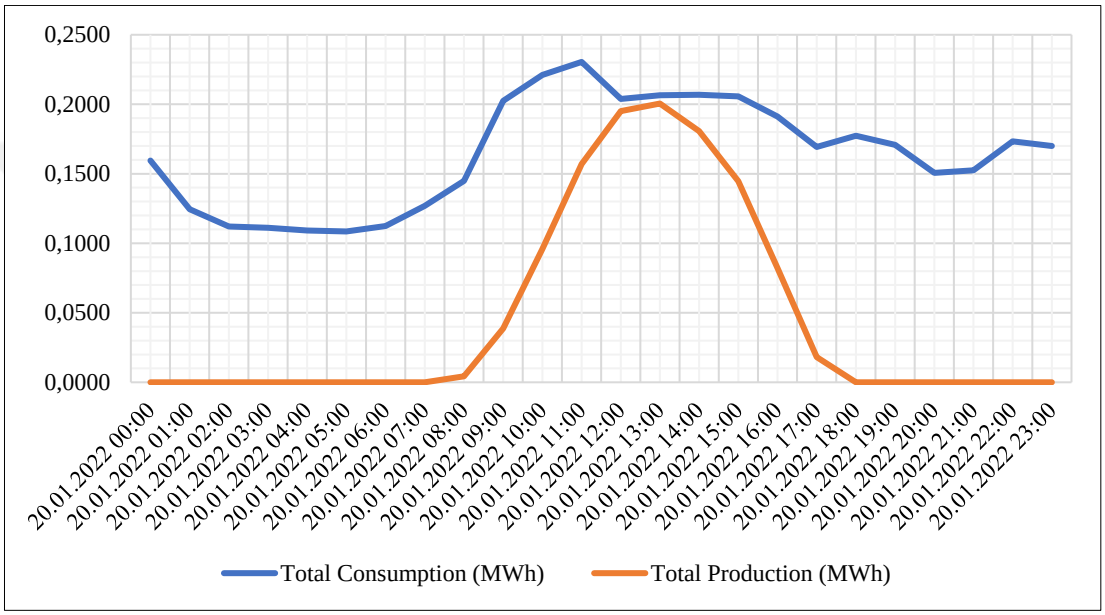


Figure 3.16 Production-consumption graph on the maximum production date realized on 20.01.2022

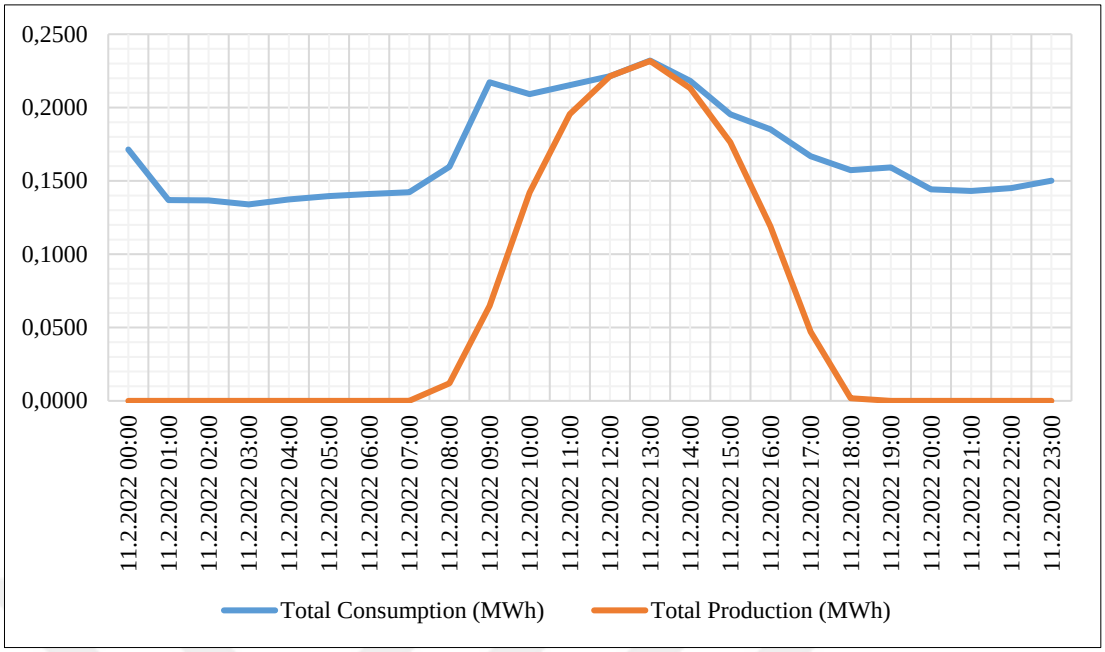


Figure 3.17 Production-consumption graph on the maximum production date realized on 11.02.2022

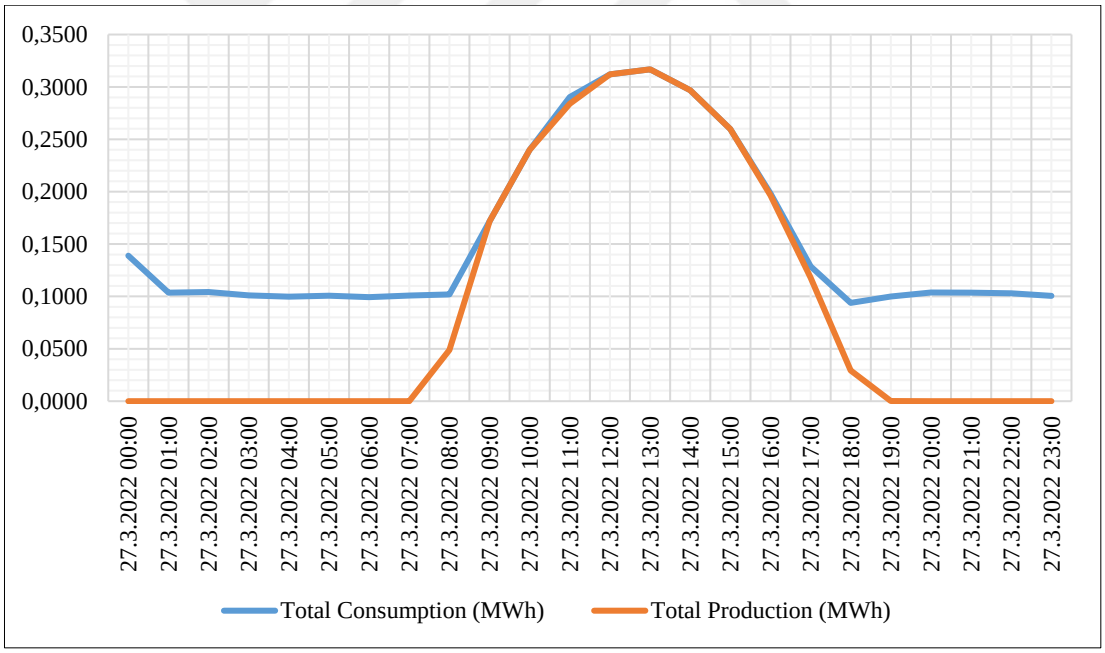


Figure 3.18 Production-consumption graph on the maximum production date realized on 27.03.2022

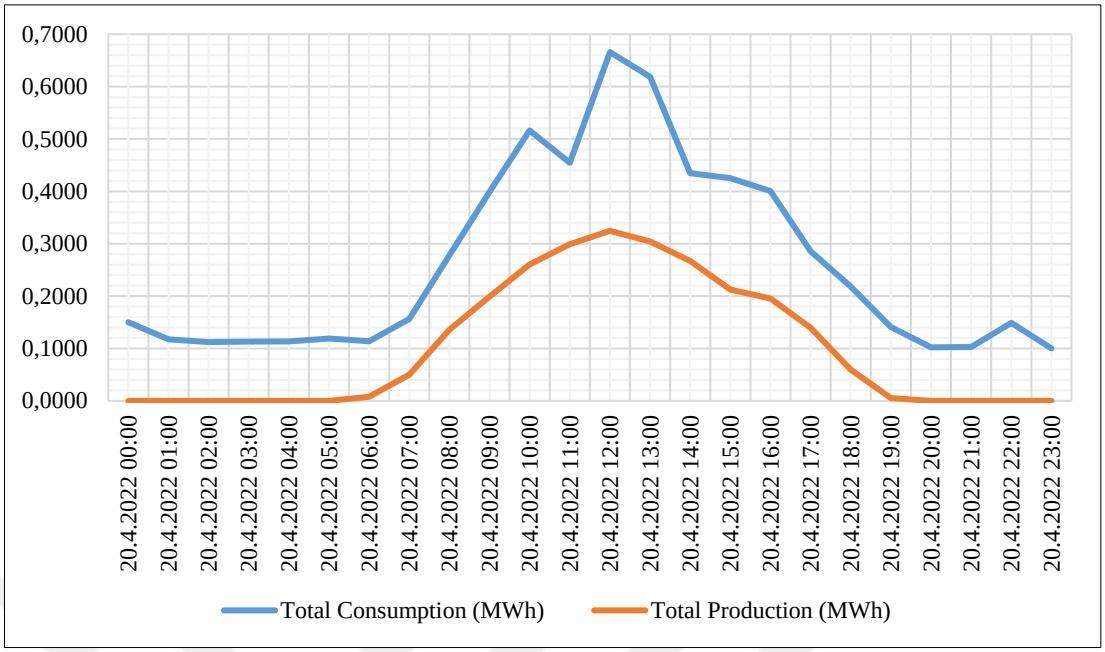


Figure 3.19 Production-consumption graph on the maximum production date realized on 20.04.2022

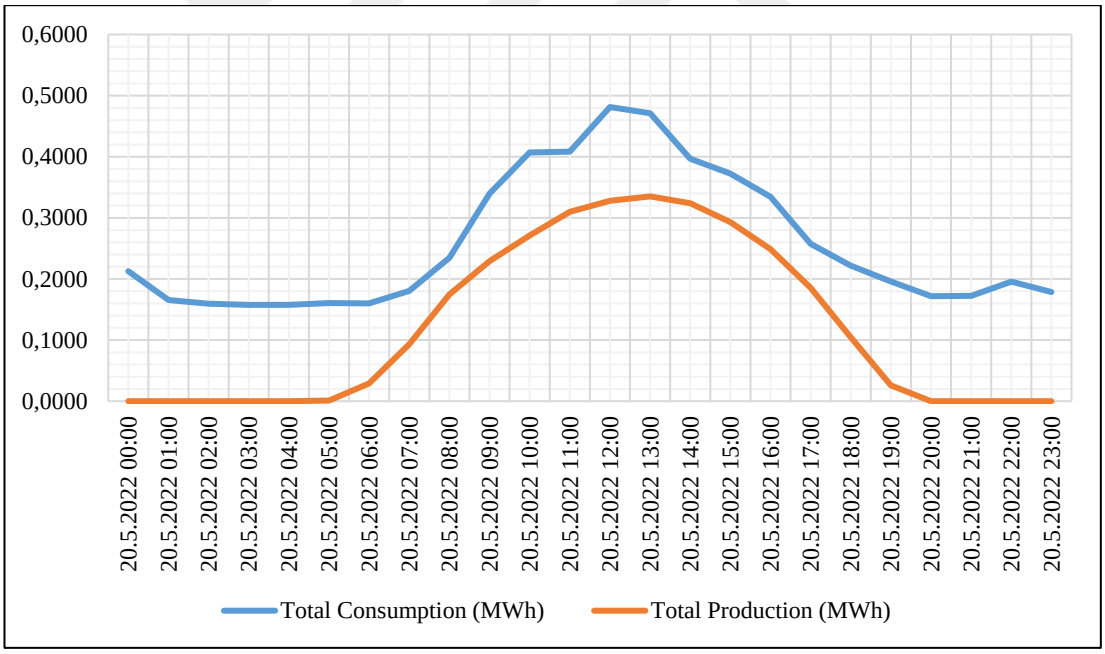


Figure 3.20 Production-consumption graph on the maximum production date realized on 20.05.2022

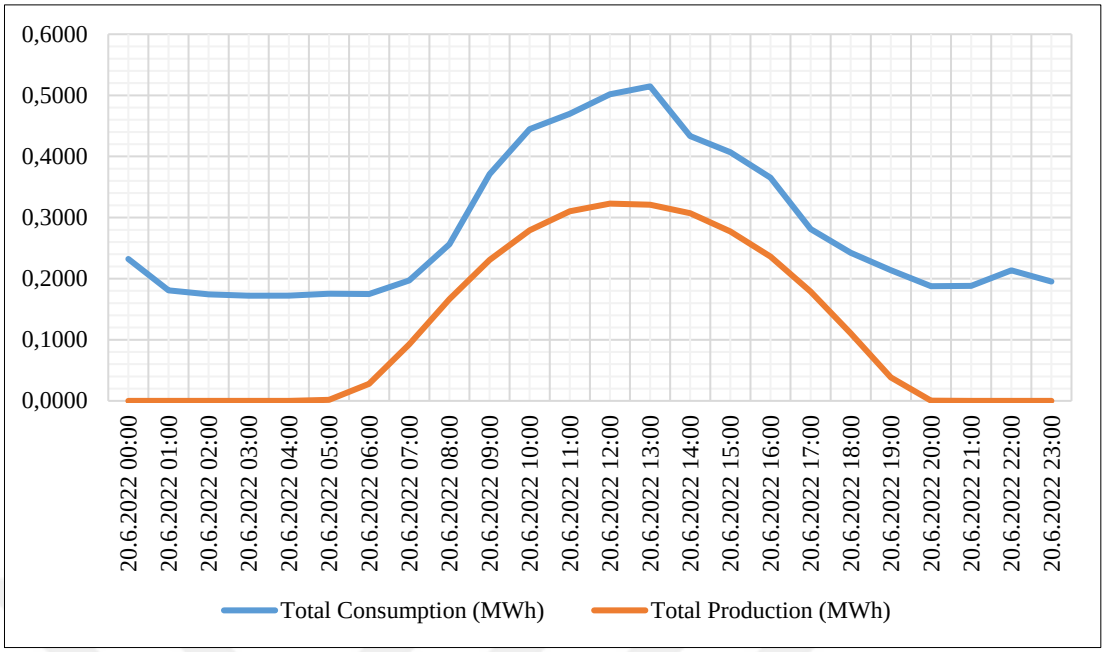


Figure 3.21 Production-consumption graph on the maximum production date realized on 20.06.2022

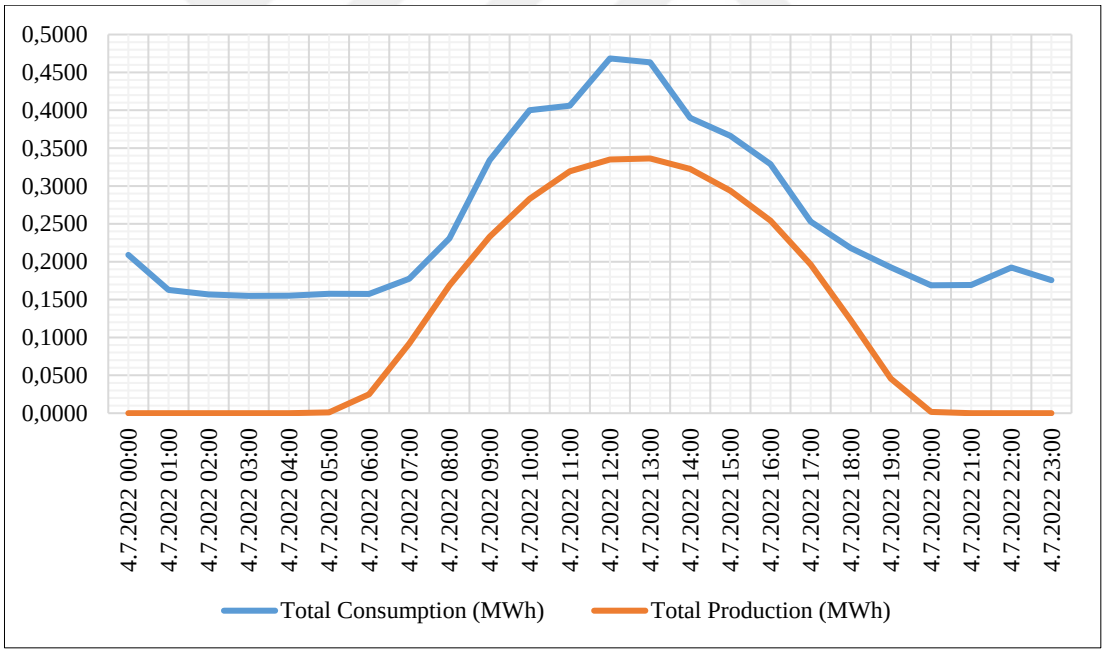


Figure 3.22 Production-consumption graph on the maximum production date realized on 04.07.2022

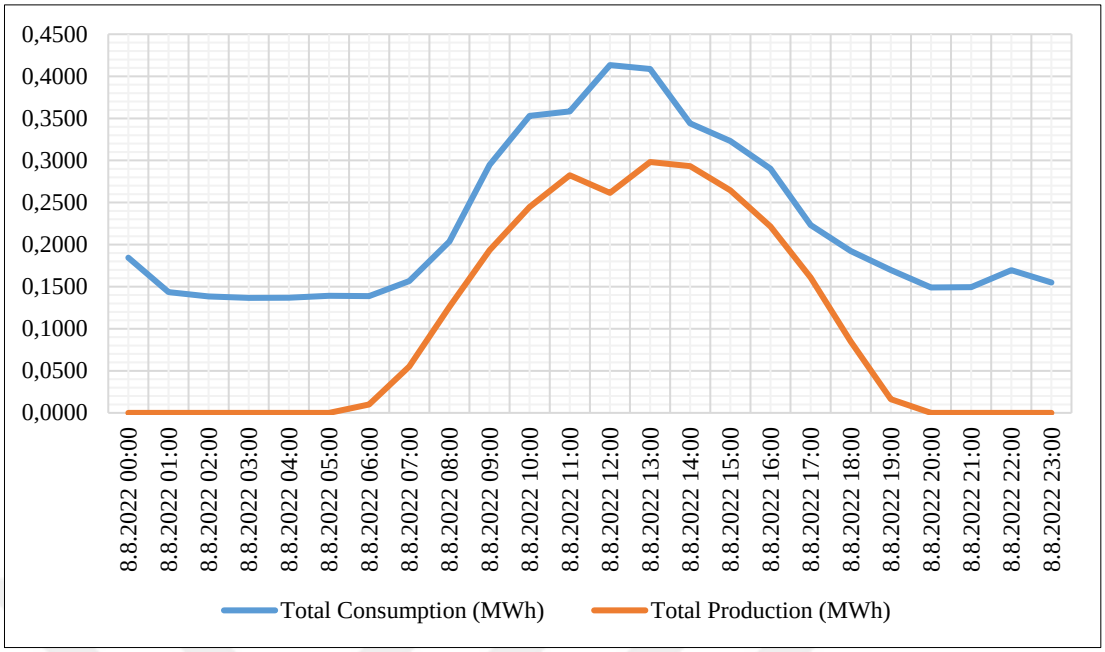


Figure 3.23 Production-consumption graph on the maximum production date realized on 08.08.2022

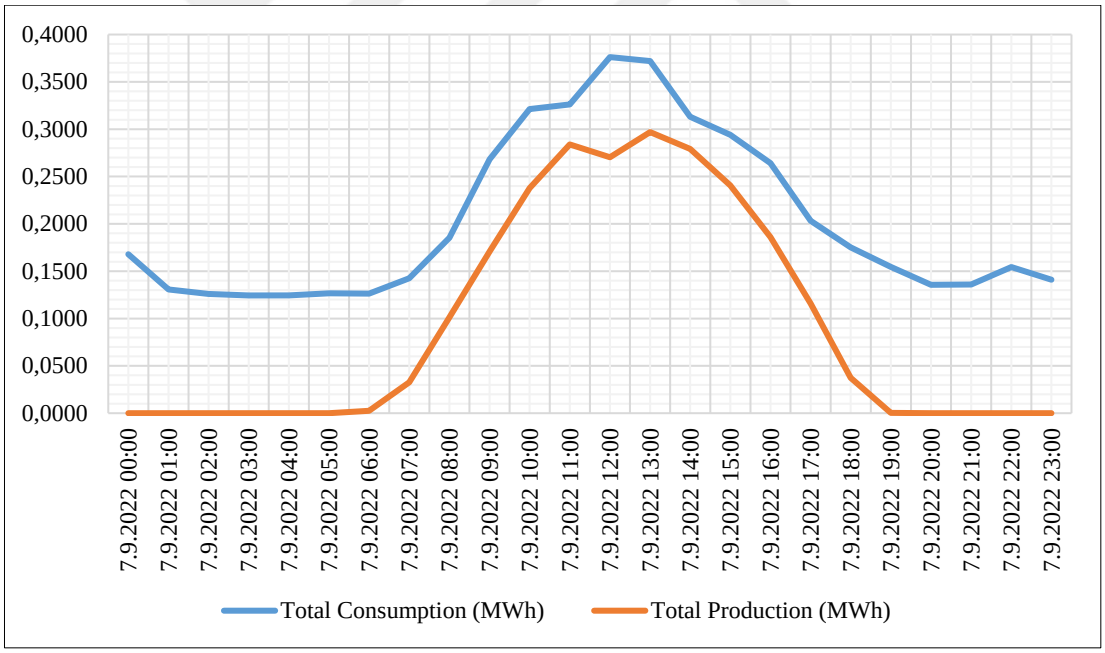


Figure 3.24 Production-consumption graph on the maximum production date realized on 07.09.2022

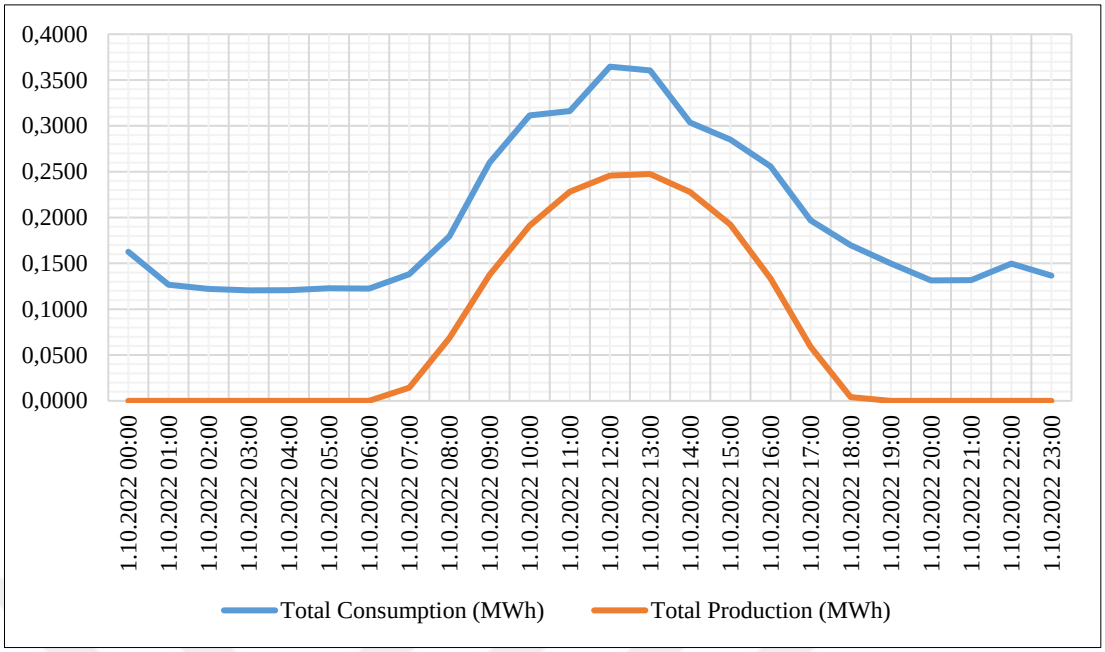


Figure 3.25 Production-consumption graph on the maximum production date realized on 01.10.2022

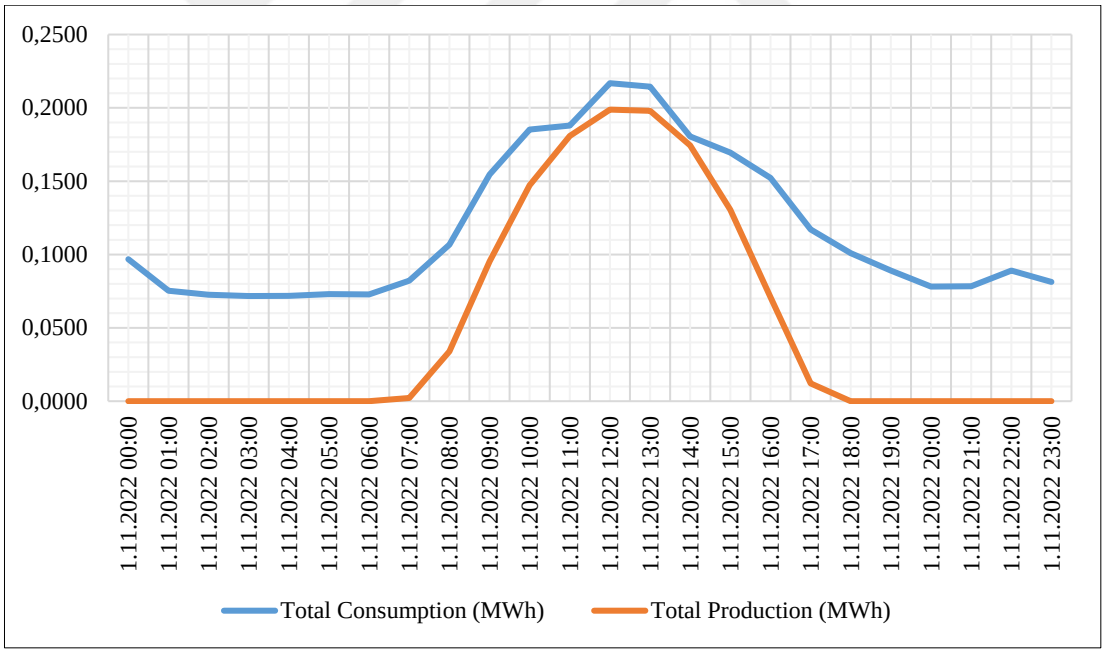


Figure 3.26 Production-consumption graph on the maximum production date realized on 01.11.2022

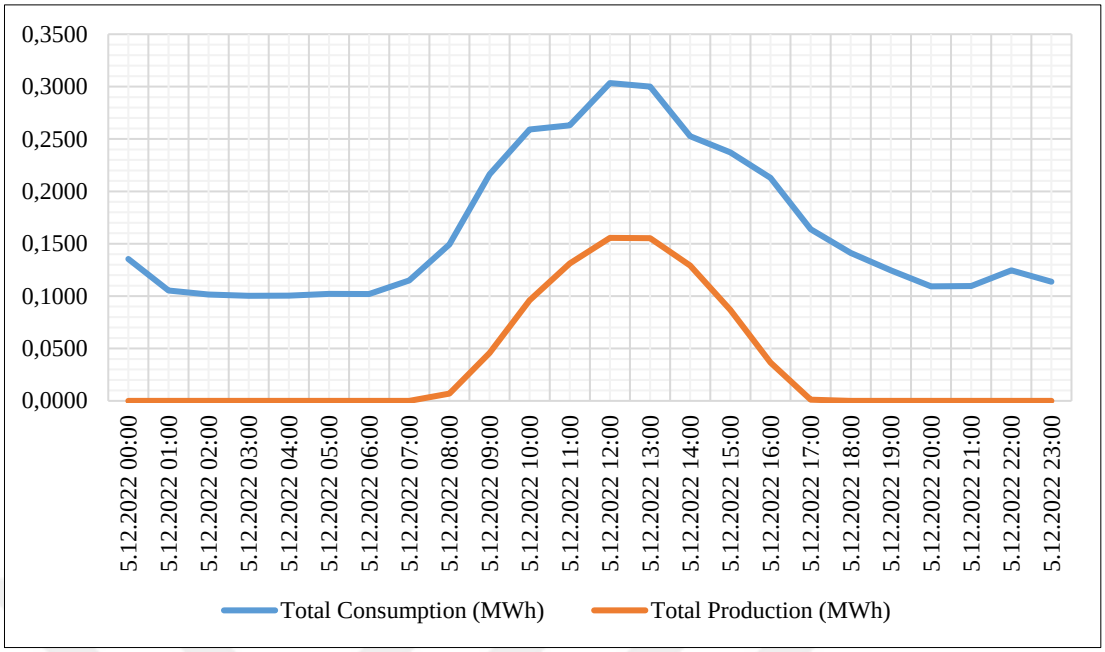


Figure 3.27 Production-consumption graph on the maximum production date realized on 05.12.2022

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

In this thesis, the production data of a selected rooftop solar power plant and the consumption data of the industrial facility to which it is connected are analyzed in monthly, daily and yearly periods.

With the Siemens Sentron PAC4200 energy analyzers built into the system of the consumption facility, consumption data were obtained in targeted periods (daily-monthly-yearly) via the siemens powermanager web interface.

The generation data of the rooftop solar power plant were also taken from the power management application SolarEdge web interface of the plant at targeted periods.

In line with all these data obtained, it has been determined that the consumption amount (kWh) and the production amount (kWh) are above all of the daily, monthly and annual periods.

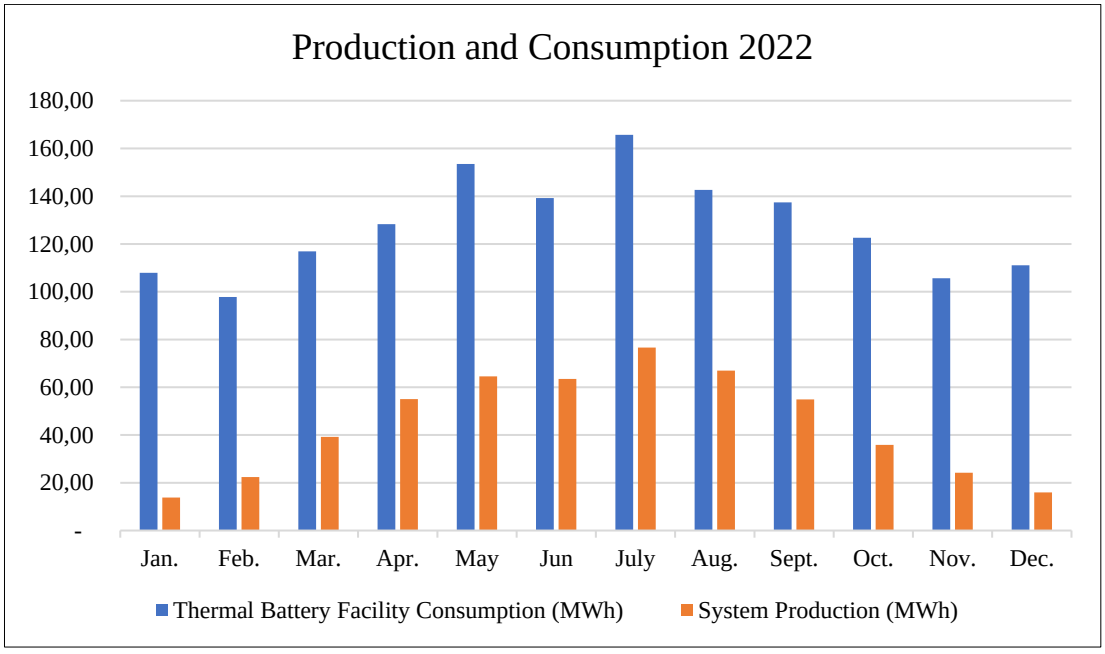


Figure 4.1 Production consumption situation in 2022

In order to balance production and consumption, the following solutions were suggested.

4.1 Increasing Production Capacity at the Same Consumption Facility Conditions

It has been determined from the studies that doubling the capacity of the solar power plant will provide a solution for approaching the production-consumption balance, provided that the consumption data of the industrial facility is not changed.

In the Table 4.1 below, the situation where the energy obtained from the solar power plant is doubled on 20.01.2022 and the normal situation are evaluated as the first situation production data and the second situation production data in the table. When the data in Table 4.1 is examined, it is seen that the difference between production and consumption decreased from 1.7073 MWh to 0.5904 MWh by doubling the production data on the selected date.

Table 4.1 Considering that twice the data produced on 20.01.2022 is produced

Time	Production 1.State (MWh)	Production 2.State (MWh)	Consumption (MWh)	Difference First State (MWh)	Difference Second State (MWh)	Production/Consumptio 1.State	Production/Consumption 2. State
20.01.2022 00:00	0	0,0000	0,1595	-0,1595	-0,1595	0,00	0,00
20.01.2022 01:00	0	0,0000	0,1245	-0,1245	-0,1245	0,00	0,00
20.01.2022 02:00	0	0,0000	0,1121	-0,1121	-0,1121	0,00	0,00
20.01.2022 03:00	0	0,0000	0,1112	-0,1112	-0,1112	0,00	0,00
20.01.2022 04:00	0	0,0000	0,1092	-0,1092	-0,1092	0,00	0,00
20.01.2022 05:00	0	0,0000	0,1085	-0,1085	-0,1085	0,00	0,00
20.01.2022 06:00	0,0000	0,0000	0,1124	-0,1124	-0,1124	0,00	0,00
20.01.2022 07:00	0,0000	0,0000	0,1269	-0,1269	-0,1269	0,00	0,00
20.01.2022 08:00	0,0043	0,0085	0,1407	-0,1364	-0,1322	0,03	0,06
20.01.2022 09:00	0,0388	0,0775	0,1637	-0,1250	-0,0862	0,24	0,47
20.01.2022 10:00	0,0959	0,1918	0,1252	-0,0293	0,0667	0,77	1,53

Table 4.1 (continued) Considering that twice the data produced on 20.01.2022 is produced

Time	Production 1.State (MWh)	Production 2.State (MWh)	Consumption (MWh)	Difference First State (MWh)	Difference Second State (MWh)	Production/Consumption 1.State	Production/Consumption 2. State
20.01.2022 11:00	0,1570	0,3139	0,0735	0,0834	0,2404	2,13	4,27
20.01.2022 12:00	0,1950	0,3901	0,0088	0,1863	0,3813	22,19	44,39
20.01.2022 13:00	0,2005	0,4011	0,0059	0,1946	0,3951	33,85	67,70
20.01.2022 14:00	0,1807	0,3613	0,0262	0,1545	0,3351	6,90	13,80
20.01.2022 15:00	0,1446	0,2892	0,0611	0,0835	0,2281	2,37	4,73
20.01.2022 16:00	0,0821	0,1643	0,1090	-0,0269	0,0552	0,75	1,51
20.01.2022 17:00	0,0181	0,0362	0,1513	-0,1332	-0,1151	0,12	0,24
20.01.2022 18:00	0,0000	0,0000	0,1773	-0,1773	-0,1773	0,00	0,00
20.01.2022 19:00	0,0000	0,0000	0,1708	-0,1708	-0,1708	0,00	0,00
20.01.2022 20:00	0,0000	0,0000	0,1506	-0,1506	-0,1506	0,00	0,00
20.01.2022 21:00	0,0000	0,0000	0,1525	-0,1525	-0,1525	0,00	0,00
20.01.2022 22:00	0,0000	0,0000	0,1733	-0,1733	-0,1733	0,00	0,00
20.01.2022 23:00	0,0000	0,0000	0,1700	-0,1700	-0,1700	0,00	0,00
				-1,7073	-0,5904		

According to the initial state production data in Table 4.1, the amount of production between 11:00 am and 3:00 pm is more than the amount of energy consumed by the facility. In the case of doubling the production capacity, that is, in the second case, it is seen that these clocks will shift one hour back at 10:00 in the morning and forward at 16:00 in the afternoon, so that more benefits will be gained from the facility.

4.2 Using More Efficient Consumption Equipment in the Facility

Waste heat released during energy production and consumption processes indirectly and directly damages the environment and living ecosystems, as well as hinders factors such as economic growth. Reducing energy consumption with high-efficiency equipment in production facilities such as factories helps institutions and organizations achieve their sustainability goals. not only that, but also efficient use of energy resources; helps to reduce costs. Thus, by consuming less, both operating costs are

reduced and environmental awareness occurs. By replacing the electrical equipment used in the industrial production facility with new generation, high-efficiency electrical equipment, savings in consumption values can be achieved and it can be helped to balance the production consumption. By reducing the installed power of the facility to acceptable limits with this method, it can be beneficial to approach the production-consumption balance.

4.3 Installing a Suitable Power Battery Storage System

The option of using a battery as an energy storage facility with a capacity equivalent to the power of the existing solar power plant, which will be obtained from solar energy on days when the industrial consumption facility does not work on weekly holidays and other public holidays such as these, will also be beneficial in order to maintain the production-consumption balance.

When the data in Table 4.2 are reviewed, it is seen that the energy obtained from the solar power plant is more than the total energy consumed by the facility, with the energy produced doubled. The hours in which this situation occurs are shown in the table as 11:00 in the morning and 15:00 in the afternoon.

Consumption-production balance can be achieved by storing the excess energy produced between 11:00 am and 15.00 pm in the morning by the energy storage system that can be installed in addition to the facility, and then fed to the system after the solar power plant production weakens in the afternoon.

It is seen in Table 4.2 that the energy produced with a yellow fill and a total surplus of 0.7023MWh can be used for storage purposes. Considering the days where the same situation repeats throughout the year, battery storage will make a significant contribution to the facility in order to ensure the production-consumption balance.

Table 4.2 The period when production is above consumption on 20.01.2022

Time	Total Production (MWh)	Total Consumption (MWh)	Difference Between Production and Consumption (MWh)	Production/Consumption Rate
20.01.2022 00:00	0	0,1595	-0,1595	0,00
20.01.2022 01:00	0	0,1245	-0,1245	0,00
20.01.2022 02:00	0	0,1121	-0,1121	0,00
20.01.2022 03:00	0	0,1112	-0,1112	0,00
20.01.2022 04:00	0	0,1092	-0,1092	0,00
20.01.2022 05:00	0	0,1085	-0,1085	0,00
20.01.2022 06:00	0,0000	0,1124	-0,1124	0,00
20.01.2022 07:00	0,0000	0,1269	-0,1269	0,00
20.01.2022 08:00	0,0043	0,1407	-0,1364	0,03
20.01.2022 09:00	0,0388	0,1637	-0,1250	0,24
20.01.2022 10:00	0,0959	0,1252	-0,0293	0,77
20.01.2022 11:00	0,1570	0,0735	0,0834	2,13
20.01.2022 12:00	0,1950	0,0088	0,1863	22,19
20.01.2022 13:00	0,2005	0,0059	0,1946	33,85
20.01.2022 14:00	0,1807	0,0262	0,1545	6,90
20.01.2022 15:00	0,1446	0,0611	0,0835	2,37
20.01.2022 16:00	0,0821	0,1090	-0,0269	0,75
20.01.2022 17:00	0,0181	0,1513	-0,1332	0,12
20.01.2022 18:00	0,0000	0,1773	-0,1773	0,00
20.01.2022 19:00	0,0000	0,1708	-0,1708	0,00
20.01.2022 20:00	0,0000	0,1506	-0,1506	0,00
20.01.2022 21:00	0,0000	0,1525	-0,1525	0,00
20.01.2022 22:00	0,0000	0,1733	-0,1733	0,00
20.01.2022 23:00	0,0000	0,1700	-0,1700	0,00

By maintaining the same consumption conditions of our facility; By doubling the solar energy production and establishing an additional battery storage facility with suitable power, it will be close to achieving the balance of production and consumption.

Our study will constitute an important step in ensuring the production-consumption balance in the new facilities to be designed from now on. Considering this study, the feasibility studies to be carried out will be on the agenda in new facility planning during the design phase. For example, the design of roofs with a structure and size suitable for the installation of solar power plants will be the best example of this work in order to ensure that the consumption of the new facilities will be provided from hybrid systems. Again, with the use of energy efficient equipment, which is included in our recommendations, it will be possible to be one step ahead by preventing excess consumption.

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