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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

Design and Modeling of Energy Storage Systems Integrated with Solar Photovoltaic Energy

M.Sc. Thesis by

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ANKARA

Design and Modeling of Energy Storage Systems Integrated with Solar Photovoltaic Energy

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In Partial Fulfillment of the Requirements for the Degree of Master of Science in Energy Systems Engineering, Department of Energy Systems Engineering

by

Coşkun Özçelik

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M.Sc. THESIS EXAMINATION RESULT FORM

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First of all, I would like to state that I had the chance to continue my education while working to earn money in almost every period of my life. The biggest supporters of this habit, which has continued since primary school, have always been the teachers who have influenced my life.

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Date: **Coşkun ÖZÇELİK**

DESIGN AND MODELING OF ENERGY STORAGE SYSTEMS INTEGRATED WITH SOLAR PHOTOVOLTAIC ENERGY

ABSTRACT

Fossil energy resources on the world are rapidly being depleted. It is seen that the speed of energy consumption has increased with the developing technology in recent years. Therefore, it was ensured that the solar energy, which emerged with the researches for energy resources that can renew itself and never run out, was transformed into a usable energy source. However, with the day and night situation of the Earth around itself, the use of solar energy only during the day and other natural reasons have started to work to store the energy produced when there is no solar source. These studies, also called solar energy storage, will be more valuable and improved day by day and their efficiency will be maximized.

In this study, previous studies are reviewed and presented here in a comprehensive way. Many different methods for storing solar energy and increasing its efficiency are discussed with mathematical and experimental methods. The gaps in existing literature are identified and recommendations for future research are precisely outlined. Here, the output of the method chosen for the storage of solar energy in different geographical regions has been analyzed and analyzed.

Keywords: Energy storage systems, batteries , solar energy, renewable energy

SOLAR FOTOVOLTAİK ENERJİ İLE ENTEGRE ENERJİ DEPOLAMA SİSTEMLERİNİN TASARIMI VE MODELLENMESİ

ÖZET

Dünya üzerindeki fosil enerji kaynakları hızla tükenmektedir. Son yıllarda gelişen teknoloji ile birlikte enerji tüketim hızının arttığı görülmektedir. Bu nedenle kendini yenileyebilen ve asla tükenmeyen enerji kaynakları için yapılan araştırmalarla ortaya çıkan güneş enerjisinin kullanılabilir bir enerji kaynağına dönüştürülmesi sağlanmıştır. Ancak Dünya'nın kendi etrafındaki gündüz ve gece durumu ile güneş enerjisinin sadece gündüz kullanılması ve diğer doğal sebepler, güneş kaynağının olmadığı zamanlarda üretilen enerjiyi depolamak için çalışmaya başlamıştır. Güneş enerjisi depolama olarak da adlandırılan bu çalışmalar her geçen gün daha da değerlenecek ve geliştirilecek ve verimleri maksimize edilecektir.

Bu çalışmada, daha önce yapılmış çalışmalar gözden geçirilmiş ve burada kapsamlı bir şekilde sunulmuştur. Güneş enerjisini depolamak ve verimini artırmak için birçok farklı yöntem matematiksel ve deneysel yöntemlerle tartışılmaktadır. Mevcut literatürdeki boşluklar belirlenir ve gelecekteki araştırmalar için öneriler tam olarak ana hatlarıyla belirtilir. Burada güneş enerjisinin farklı coğrafi bölgelerde depolanması için seçilen yöntemin çıktıları analiz edilmiş ve analiz edilmiştir.

Anahtar Kelimeler: Güneş enerjisi depolama sistemleri, güneş enerjisi, batarya, yenilenebilir enerji

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NOMENCLATURE

Roman Letter Symbols

A	Diode ideality
A_c	Collector area
C_p	Specific heat capacity
D	Outer diameter of tube
F_R	Heat removal factor
F	Standard fin efficiency
FF	Fill Factor
F'	Efficiency factor
G	Total solar irradiation
h_w	Convection heat transfer coefficient
h_{fi}	Heat transfer coefficient inside tube
I	Current
I_0	Saturation current
k_{edge}	Thermal conductivity of edge
k_{ins}	Thermal conductivity of insulator
L_{edge}	Thickness of the edge
L_{ins}	Thickness of the insulator
m	Mass flow rate
N_s	Number of PV cell in series
N	Glass cover number

p	Collector circumference
P	Power
PF	Packing factor
q	Charge of electron
Q_{th}	Useful heat
Q_u	Useful gain energy
T	Temperature
t	Absorber plate thickness
U_L	Overall heat loss coefficient
V_t	Thermal voltage
V	Voltage
V_{wind}	Wind velocity
W	Distance between the tube
x	Length of the tube

Greek Letter Symbols

η	Efficiency
β	Temperature coefficient of the PV module
ε_p	Emissivity of plate
ε_g	Emissivity of glass
α_{cell}	Absorptivity of photovoltaic cells
ρ_f	Density of the fluid
τ_g	Transmissivity of the glass cover

ΔP Pressure drops of the coolant

θ Collector tilt

Subscripts

d Diode

el Electric

f Fluid

in inlet

max Maximum

Out Output

oc Open Circuit

p Pump

ph Photovoltaic

r reference

sc Short Circuit

th Thermal

Acronyms

CPV Concentrated Photovoltaic

DNI Direct normal irradiance

HCPV High concentration photovoltaic

ICSSWH Integrated collector storage solar water heater

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CHAPTER 1

INTRODUCTION

Main Framework

The sun is one of the most important energy sources in the world, perhaps even the first. Solar energy is an abundant, continuous and renewable and free energy source. Oil, natural gas and coal reserves known as fossil resources are estimated to be depleted over time due to their scarce resources. As it is known, the use of fossil fuels in the world has brought global environmental problems with it. Harmful gases such as carbon dioxide emitted into the atmosphere as a result of industrialization cause global warming and climate change. In short, the rapid depletion of fossil fuels today, international measures such as the greenhouse gas effect and the Kyoto Protocol make the transition to renewable and clean energy sources such as solar, wind, hydroelectric and bioenergy mandatory for all countries. The greenhouse effect caused by carbon dioxide in the atmosphere has increased the average temperature of the world by 0.7 ° C in the last century. Increasing this temperature by 1 ° C, visible changes in the world climatic zones, rising at 3 ° C may cause melting glaciers at the poles, rising the seas, drying in lakes and agricultural drought. In this case, since the use of energy is indispensable, turning to natural and alternative sources such as the sun emerges as a necessity.

The operation of stand-alone PV systems is highly dependent on batteries to meet the required energy demands in a desired way. Generally, in these systems, the batteries are charged when the sun is at its strongest, and the stored energy is used when needed. In a study by Japanese scientists published in 2019, it is seen that the information about solar radiation changes throughout the day and this irregular radiation pattern affects PV power generation. (Performance analysis of PV panels based on different technologies after two years of outdoor exposure in Fukushima, Japan. renew. Energy 2019). In recent studies, different estimation methods have been developed to predict solar radiation. Rapidly changing charge/discharge patterns due to intermittent radiation conditions occurring on a day when a battery suffers. (Bruno, S.; Dellino, G.; La

Scala, M.; Meloni, C. A Microforecasting Module for Energy Management in Residential and Tertiary Buildings. Energies 2019) This affects battery performance, shortens lifespan, and increases battery replacement cost.

No fuel problem, ease of operation, no mechanical wear, modularity, commissioning in a very short time (maximum one year), smooth operation for many years, a clean energy source, etc. The use of photovoltaic electrical energy is constantly increasing worldwide. In Turkey, the highest solar energy potential due to its geographical location. Energy and Natural Resources, prepared by the Ministry, Turkey Solar Energy Potential Atlas to (GEPA) by our country, annual sunshine time of 2,741 hours (daily average of 7.5 hours), the annual total coming from the sun energy is 1.527 kWh / m² (daily average 4.18 kWh / m²). In this study, it is planned to investigate energy storage and energy storage methods theoretically. It is desirable that the energy is ready to be used at anytime and anywhere. Storing it so that you can use it whenever we want is called storing. There are many methods of storing energy in different forms. With energy storage, it aims to store the waste energy generated in the areas where energy is used, on the other hand, to eliminate the difference between energy supply time and demand by storing the energy of renewable energy sources that can only supply energy at certain times. As a result of the limited and gradually decreasing energy resources in our country and in the world, renewable energy sources and storage of the produced energy are of great importance. There are many different forms of energy storage methods. For example, biological storage, chemical storage, thermal storage, electrical storage, potential energy, gravitational potential energy, kinetic energy, etc. In this study, chemical, mechanical, thermal and electrical energy storage methods which are the main energy storage methods are discussed. It is thought that this study will contribute to the literature in terms of previous studies and standards.

Aim of the thesis

The aim of this project is to integrate a 1 MW PV power station in 3 different cities with grid connection with a 1 MWh battery, realize the design and discuss the results. Size of batteries needed to power the system when the solar source is not going to be used determined to be available. Also, in case of energy reserves, the system is connected to the grid. The size of the batteries will be enough to store energy from day to night, but not for more than one day, so seasonal storage will not be examined in this article. To do the sizing, self-consumption will be the main switch, as less electricity will be sold. the network will be better for system economy. The size of the system will be smaller and can be easily amortized. Comparisons will be made in terms of Urfa, İzmir and Konya cities.

Limitations

The information obtained to make the relevant simulations was taken daily in the energy data of the cities in the construction of the thesis. Since these data are made according to the data that the program pulls from the virtual environment, there is a possibility of some deviation. Since there are different meteorological data provided by the PVSYST program, it is necessary to make sure that these data are received correctly. The received data is taken directly from the program. This deviation needs to be taken into account, as the interface of the program may differ from the actual understanding. Finally, the simulations carried out through PVSYST are quite different from the ones that we could obtain in the reality due to limitations of the program, and certain approximations within it.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 Energy

Energy has a great impact on the evolution of humanity. Since inception of humaninty, it has required energy to survive and progress. But what is energy and why is it so important? Energy, doing business and the ability of the body to produce changes in themselves or in other bodies.That is, the concept of energy is defined as the quality of doing things. The unit of measure we use to measure energy is the joule (J), in honor of British physicist James Prescott Joule.

2.2 Energy self-consumption

Self-consumption can be defined as the amount consumed by the producing energy source during the production phase. When the system produces more energy than it needs to produce, this excess energy must be stored and sold to the national system. One of the most common ways of domestic energy production is solar energy systems.

With the decrease in solar photovoltaic (PV) panel prices, there has been a large increase in the number of such renewable energy systems. When supply is high, prices are expected to fall. This will increase demand along with more incentives. The latest report of the International Energy Agency's Photovoltaic Power System Program found that 75 GW of solar power was installed globally in 2016, with installed global photovoltaic capacity reaching at least 303 GW."

2.3 The case of Turkey

Turkey has a high potential in terms of solar energy due to its geographical location. Although Turkey's sunshine duration varies throughout the year, it is approximately 2,738 hours annually. With an average of 7.5 hours of sunshine per day, Turkey has the opportunity to benefit from 60 percent more sunlight than Germany. However, in terms of the increase in installed power capacity in 2015, an improvement of 6 per thousand of Germany was achieved.[2]

Turkey's solar power generation potential is estimated at least 500 thousand MW according to calculations. Compared to other renewable energy sources, the sun is the energy source with the highest potential in Turkey. [3] Considering that as of the end of 2016, the total installed power of electrical energy is approximately 79 thousand MW, the importance of converting the potential in solar energy into production is understood once again.[4]

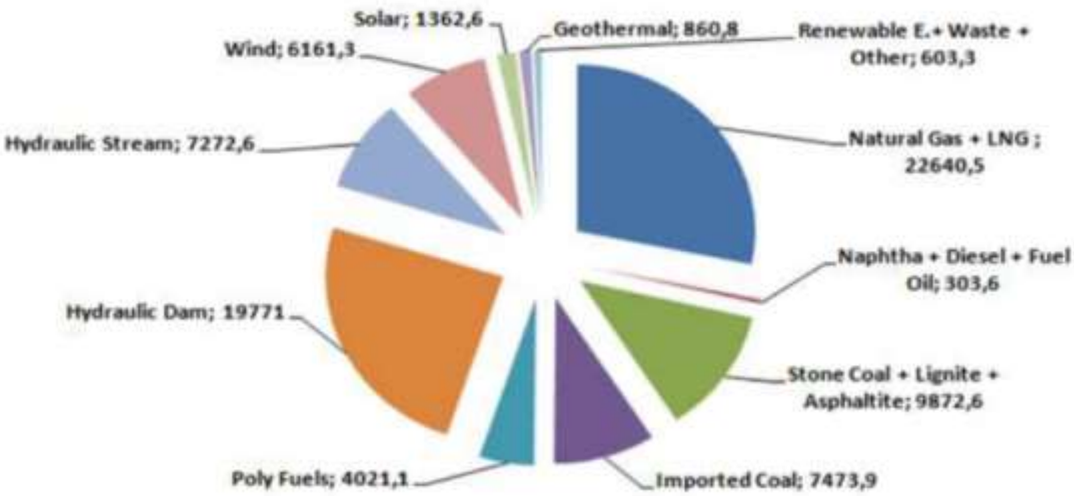

Figure 2.1 The distribution of installed power by sources in Turkey (MW)[3]

2.4 Solar Energy Storage

Energy storage is presented as a major challenge in order to have a continuous supply of energy, since solar energy cannot be generated at night. Rechargeable batteries have traditionally been used to store excess electricity in isolated systems. With the appearance of grid-connected systems, excess electricity can be transported via the grid to consumption points. When renewable energy production accounts for a small fraction of demand, other energy sources can adjust their production appropriately to support the variability of renewable sources, but with the growth of renewable sources, control is necessary best suited for balancing the network.

With the decline in prices, photovoltaic plants begin to have batteries to control the output power or store excess energy so that it can be used during the hours when renewable plants cannot generate directly. This type of batteries allows to stabilize the electrical network by smoothing the peaks in demand for minutes or hours. These batteries are expected to play an important role in the electricity grid in the future, as they can be charged during periods when generation exceeds demand and pour such energy into the grid when demand is greater than generation.

Our country is lucky compared to many countries in terms of solar energy potential. The annual average sunshine duration is 2,640 hours (7.2 hours per day), and the average radiation intensity is 1311 KWh/m²-year (3.6 KWh/m² per day).

Turkey's gross solar energy potential is stated as 87.5 MTEP (million tons of oil equivalent). 26.5 MTEP of this amount is suitable for heat production and 8.75 MTEP is suitable for electricity generation.

In 2008, Turkey's use of solar energy accounted for 418 thousand TOE and a share of less than 1.5% in the domestic resource production of 28.3 MTEP. Solar energy use does not have a significant share in the energy consumption of 107 MTEP in 2008.

Two per hundred thousand of the solar radiation coming to Turkey is utilized and it is estimated that only 3.5-4 million houses out of 22 million houses have solar hot water systems. With the dissemination of systems with an energy return of approximately 500-600 million dollars in the current situation, an additional 3–3.5 billion dollars of thermal energy contribution can be realized.

Solar-based electricity generation capacity, whose technical capacity is estimated as 405 billion kWh and economic potential as 380 billion kWh by EIEI, is waiting to be fully utilized.[5]

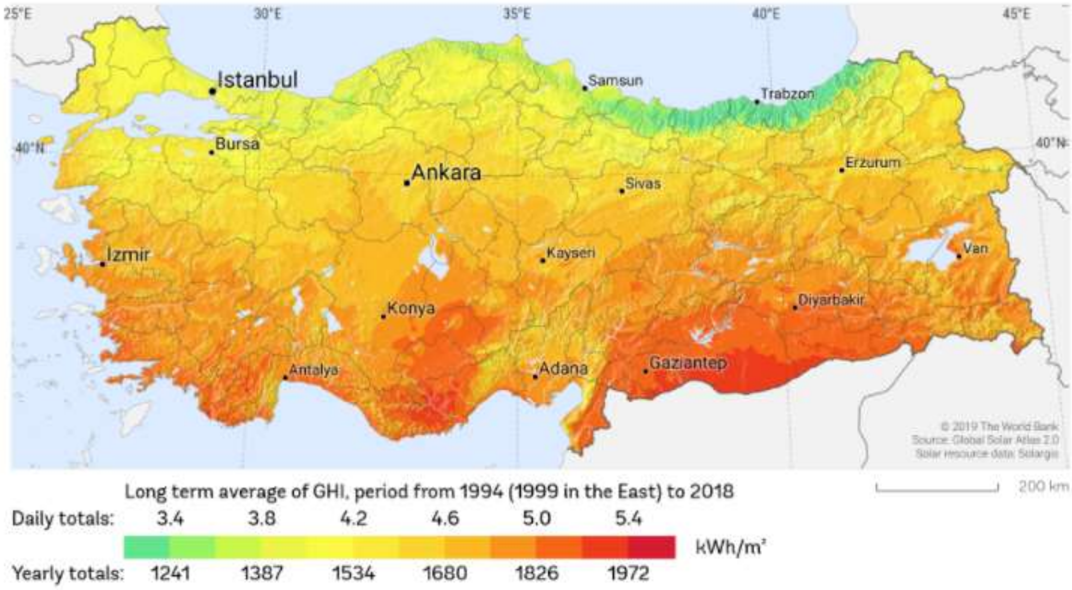

Figure 2.2 Turkey's solar energy potential [1]

2.5 Electrical Energy Storage (EES)

Electrical Energy Storage (EES) refers to the storage of electrical energy in order to use it again as electrical energy when needed. With the integration of battery storage of PV systems, the efficiency can be increased to much higher amounts. With the battery system, PV electricity can be stored in sunlight and used later. In this way, the houses using the systems can be self-sufficient by reducing the amount of electricity drawn from the grid.6]. Thus, PV battery systems can reduce the dependency on the central grid, while at the same time achieving the desired levels in terms of carbon emissions.

A battery that stores electrical energy in chemical form, each cell having a positive electrode (anode) and a negative electrode (cathode) together with a liquid, which comprises one or more electrochemical cells consisting of a paste or a solid electrolyte. During discharge, the two electrodes forming an electron flow through an external circuit electrochemical reactions occur. The reactions are reversible and provides an external voltage applied to the electrodes to recharge the battery over (Chen et al, 2009). batteries are used for a variety of applications with PV systems currently.

Flow batteries (ZnBr, VRB and PSB)

- ✓ Sodium–sulfur batteries (NaS)

- ✓ Lithium–ion batteries (Li–ion)
- ✓ Nickel–cadmium batteries (Ni–Cd)
- ✓ Lead–acid batteries
- ✓ Metal–air batteries

Flow batteries

A flow cell or redox flow battery (after reduction-oxidation), the system of fluid to be pumped from separate sides of a membrane electrochemical cell is a kind of chemical energy is provided by two chemical components dissolved. Ion exchange (with flow of electrical current), the two fluids takes place through the membrane while browsing through its cavity. The cell voltage is determined by the equation chemically and in practical applications vary from 1.0 volts to about 2:43. [7]

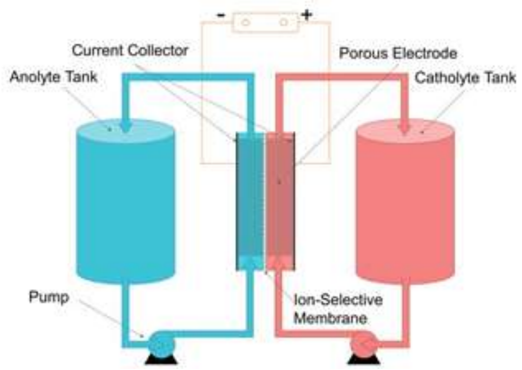

Figure 2.3 A typical flow battery consists of two tanks of liquids which are pumped past a membrane held between two electrodes[7]

Sodium–sulfur batteries

Sodium-sulfur battery, liquid sodium (Na) and sulfur (S) is made of a type of molten salt batteries. [8] [9] This type of battery, a high energy density, high charge / discharge efficiency [10] and has a long cycle life and is made of cheap materials. highly abrasive nature of the operating temperature between 300 to 350 ° C and sodium polysulphide, makes them primarily suitable for stationary energy storage applications. The cell grows, it becomes more economical.

Lithium–ion batteries

Lithium-ion batteries or Li-ion batteries are a type of rechargeable battery. Lithium-ion batteries are widely used for portable electronic and electric vehicles in military and aerospace applications and is increasing in popularity. [11] A prototype was developed by Akira Yoshino in 1985, by John Goodenough, M. Stanley Whittingham, Rachid Yazami, and Koichi Mizushima in the 1970s-1980s[12], and then a commercial Li-ion battery was developed. In 1991 Yoshio was developed by a team at Sony and Asahi Kasei Nishi leadership. [13] The Nobel Prize in Chemistry in 2019 "for the development of lithium-ion battery" Yoshino was given to the Goodenough and Whittingham.

Nickel–cadmium batteries

Nickel cadmium batteries (Ni-Cd batteries or NiCad batteries), nickel oxide hydroxide and metallic cadmium as using the rechargeable battery type electrodes. Ni-Cd abbreviations, nickel (Ni) and cadmium (Cd) is derived from the chemical symbols: NiCad acronym SAFT Company registered trademark, but the brand names is commonly used to describe all Ni-Cd battery.

Wet cell nickel-cadmium batteries were invented in 1899. Rechargeable Ni-Cd battery technology in the 1990s, has lost market share rapidly with NiMH and Li-ion battery; Its market share fell by 80%. A Ni-Cd battery has a terminal voltage of about 1.2 volts during discharge and this voltage is slightly reduced almost to the end of discharge. Provided by a Ni-Cd cell is 1,3v maximum electromotive force. Ni-Cd batteries, carbon-zinc dry cells which may be modified by the portable closed type, several sizes to large ventilated cells used for standby power and motive power and is generated in capacity. Compared with other rechargeable battery types in a reasonable capacity with low temperature good cycle life performance and offer, but the important advantages of high discharge rate (one hour or less at discharge) in practice is the ability to offer their full capacity. However, it is costly materials than lead-acid batteries and high self-discharge rate of the cells.

Lead-Acid Batteries

The lead-acid battery was invented by the French physicist Gaston Plante. Although a very low energy to weight ratio and having a lower volume ratio energy, high pulse current ability to provide a means to have a relatively large power to weight ratio of the cells. These features, combined with lower costs, to provide high current needed by the starter motor makes it attractive for use in motor vehicles.[14]

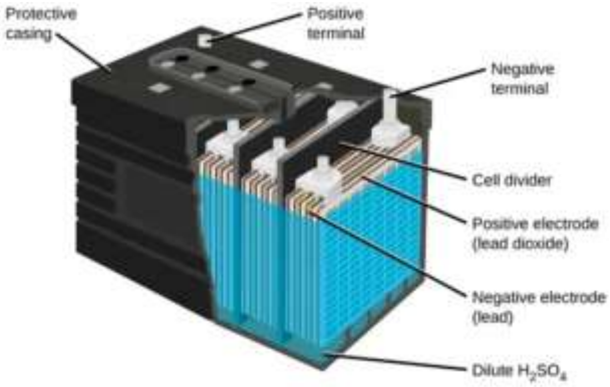

Figure 2.4 Lead-Acid battteries components[14]

Metal–air batteries

Metal-air electrochemical cell, an anode made of pure metal, typically an aqueous medium comprising air or aprotic electrolyte electrochemical cell using an external cathode. [12] Ambient air during the discharge of a metal-air electrochemical cell oxidizes a metal anode cathode reduction reaction occurs. specific capacity of the metal-air electrochemical cell and the energy density of lithium ion is higher than Piller, which makes them prime candidates for use in electric vehicles. However metal anodes, and electrolytes complications associated with catalysts have revented the development and implementation of metal-air batteries. [15] [16]

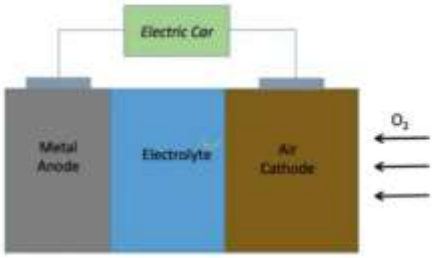

Figure 2.5 Metal-Air Baterries on cars (Metal-air batteries)[16]

CHAPTER 3

PREVIOUS RESEARCH STUDIES

The use of solar energy systems, PV systems is growing, especially in the last few years. Residential energy storage market was worth US $ 5.99 billion in 2018 and 2027 during the forecast period up to 2019 is expected to grow at a 16% cagri. Government support along with financial incentives for renewable energy worldwide will enhance the market growth globally.[15] Tend to produce appropriate policies to reduce energy dependence of many countries. It may be necessary to start from the basic work with energy storage houses in order to be successful. Many applications have been made about it in recent years. this kind of work for the community's welfare, especially for developing countries is to implement policies that can enforce the law.

After a short time ago to allow the UK government, one of the world's largest battery storage project, to be built on the banks of the Thames River in Essex. When it is completed in 2024, the battery will eventually store 1.3 gigawatt hours of electricity – enough to to supply more than 300 homes for a year.[17] Renewable, but generating electricity as permitted by the natural and climatic conditions due to the rapid growth of solar and wind energy, more efficient ways to use this kind of storage will be explored. Can be stored, the energy produced in solar or wind farm can then be used at night or when no wind blows.

Lithium battery technology has also seen an incredible rise and has become the type sought in the energy storage industry. Unfortunately, these batteries are not at the desired level of both capacity and recycling. Many studies are being done on this subject. Battery technology, large increases in storage capacity and a decrease in lithium ion proving surprisingly 85% of the cost of the battery proceeded immeasurably last decade. [18]

These industry achievements are largely bright Elon Musk and Tesla technology as the pioneer, was obtained thanks to innovation and advanced manufacturing processes. In fact, at Tesla's Battery Day in September, Musk made comments on the future of lithium-ion batteries, stating that they would be more efficient, cheaper, and be 56% cheaper to be exact. [19]

Although the most widely adopted and most lib referred to in the art that other storage systems approaching the market in different speeds. Redox flow batteries (RFID) are one of them. Due to the flow of electroactive species such cell lower energy density but is characterized by higher cycle life. Also, rfbU are safer use of the active ingredients lib, so the fire risk is not a concern for these systems.

California, in the high-capacity battery with efforts to balance the discontinuity of renewable energy in the electricity grid is currently the world leader. However, most of the world is following the event quickly. Recently announced plans range from a 409 megawatt system in South Florida to a 320 megawatt plant near London, England, a 200 megawatt plant in Lithuania and a 112 megawatt unit in Chile.[19]

One of the greatest obstacles to the low penetration of renewable energy, large storage systems. Radiation is too much or too strong wind, solar or wind lower than the supply available is very low, which means that a major shortcoming. When people reduce the imbalance between supply and demand will be further away from fossil fuels. Experts think storage is the key to making renewable energy much more common.

Spain's IREC Catalonia Energy Research Institute and scientists from Finland's Aalto University, vanadium redox flow batteries (vrfb's) copper, indium, gallium and selenium (CIGS) combined based on technology with mini solar modules in a single device. This is the advantage of high energy density.

According to the research group, the open circuit voltage values obtained for the mini panels were high enough to make the device neutral photocharge. However, the potential change in battery cell voltage determined a photocurrent I drop. It reached 21% in the 4CM panel and 59% in the 3CM module. "Whether this is the optimal point of operation in this system, so possibly photocharging vrfb could be limited," the researchers say.

It has achieved neutral photocharging under full illumination with four series connected mini modules 1 Solar, this 77% higher energy efficiency and a 7.5% total round trip energy conversion efficiency of 5.0% with solar battery charger. According to the scientists, these values exceeded all values reported in the literature for solar vrfb cost. [20]

CHAPTER 4

METHOD

After seeing the current state of the literature and technology, we will continue with the method section, which is the main point of the thesis.

4.1 Location

As earlier said, Three systems will be studied in this thesis, the case in İzmir, Konya and Adıyaman. The difference between the weather and location are going affect to this analysis.

- Our first region is located in İzmir Gaziemir district. (38.317774062179424, 27.143491661385852) is a solar power plant with a capacity of 1MW.
- Secondly, there is a 1MW solar power plant (37.46197037097927, 31.84681687887908) in the Seydişehir district of Konya
- Our last point is in Adıyaman (37.793163211221504, 38.61572097366446) with a capacity of 1 MW, located in the East of Turkey.

As it can be seen, the production capacity of our 3 power plants is the same. In this case, environmental conditions will also determine the result of our thesis.

Figure 4.1 Location of the system to study

This study consists of sizing the addition of the battery to the system while evaluating whether the economic and structural energy to be spent on a PV system to be designed is worth the output.

4.2 Electricity Sale price

With the President's decision published in the Official Gazette on January 30, 2021, the purchase prices to be applied after July 1, 2021 within the scope of YEKDEM have been determined.

Accordingly, the purchase price of YEKDEM to be applied for RES certified generation facilities that will be in operation from July 1, 2021 to December 31, 2025, is 40 Kuruş per kilowatt-hour for a hydroelectric generation facility, 32 Kuruş for a wind or solar power generation facility, and a production facility based on geothermal energy. and 32 Kuruş for resources obtained from by-products resulting from the processing of landfill gas or waste tires in biomass-based production facilities, 54 Kuruş for biomethanization, and 50 Kuruş for thermal disposal.[21]

In the study to be carried out within the scope of this situation, we can accept the electricity price as 32 Kurus per kWh and do our work.

4.3 Estimation of PV and battery

4.3.1 PV System

Before work on PVSYST software for system design, it is necessary to understand the operation logic of the system. So it is necessary to know the load amount of the system, then the size of the PV system will be calculated by covering the consumption as follows:

$$P_{PV}(kWp) = \frac{E_{Load}}{P_{Output}} \quad \textbf{(4.1)}$$

- $Load$ is the monthly average determined load.
- $POutput$ is the power production from 1kWp of PV-modules during a months in kWh/month, kWp

4.3.2 Battery

While designing a battery, it is necessary to follow a certain way to do it in the most optimal way. The load of the system is one of the terms that determines the amount of capacity as well as efficiency. The depth of discharge is an important factor, as the relevant battery will never be discharged to the bottom.

The battery capacity in Ampere hours is going to be calculated as follows:

$$C_{Bat}(Ah) = \frac{E_{Load}}{U_b} \cdot \frac{d}{DoD} \tag{4.2}$$

Where:

- $ELoad$ is the daily average load in a months
- Ub is the battery bus voltage - d are the number of days of autonomy
- DoD is the depth of discharge

For a good charge balance, it is necessary to reduce the number of parallel connections of the batteries. however, it is said that the maximum recommended index is 4.[22]

4.4 PVSYST

The PVSYST program will be used for modeling and analysis of the system. It is a program that provides analysis and modeling of all data of photovoltaic systems. In the program interface, cost analysis, investment study, current and future studies are also available in the program. This program was developed and made available by the University of Geneva. There is an interface in the program where data that can be consumed while producing such as self-consumption can be entered. In addition, the sizing of the system battery provides ease of selection with pre-defined brands and data belonging to those brands. All modeling work simulation will be done with this program.

4.5 Simulation

4.5.1 Geographical Site Parameters

Although PVSYST has a large meteorological database from which we can add data from other stations, it may not have data for some cities. However, with the coordinate system we used, we had the chance to access the data easily.

Monthly meteo values for each of our cities are given below Table 1-2-3.

Table 4.1 Monthly Meteo values of İzmir Dokuz Eylül Region (PVSYST)

Geographical Site
Dokuz Eylül
Turkey

Situation
Latitude 38.32 °N
Longitude 27.14 °E
Altitude 121 m
Time zone UTC+3

Monthly Meteo Values

Source Meteonorm 8.0 (2005-2013), Sat=26%

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	68.2	78.3	131.2	168.8	213.4	232.4	242.8	217.9	169.1	120.8	77.9	58.7	1779.3	kWh/m²
Horizontal diffuse	34.4	37.1	56.7	64.8	77.8	69.7	59.6	55.4	39.4	43.6	30.0	28.7	597.3	kWh/m²
Extraterrestrial	141.3	170.0	244.3	293.2	342.8	347.7	351.9	320.1	259.3	208.0	149.2	127.9	2955.6	kWh/m²
Clearness Index	0.482	0.461	0.537	0.576	0.623	0.668	0.690	0.681	0.652	0.581	0.522	0.459	0.602	ratio
Ambient Temper.	6.5	7.7	10.9	14.7	20.0	25.3	29.1	28.9	23.3	18.2	12.4	8.0	17.1	°C
Wind Velocity	4.0	4.2	4.1	3.9	3.9	5.0	6.1	6.0	4.7	4.1	3.4	3.8	4.4	m/s

Table 4.2 Monthly Meteo values of Konya Seydişehir Region (PVSYST)

Geographical Site
Kara Bulak
Turkey

Situation
Latitude 37.46 °N
Longitude 31.85 °E
Altitude 1121 m
Time zone UTC+3

Monthly Meteo Values

Source Meteonorm 8.0 (2003-2013), Sat=100%

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	68.4	86.0	130.7	165.3	211.0	227.3	235.6	209.1	167.7	116.8	79.9	62.4	1760.2	kWh/m²
Horizontal diffuse	31.7	39.1	48.0	64.4	66.2	59.6	59.3	52.5	47.4	42.7	31.1	28.6	570.7	kWh/m²
Extraterrestrial	145.8	173.6	247.5	294.9	343.2	347.4	351.9	321.3	261.8	211.8	153.4	132.5	2985.1	kWh/m²
Clearness Index	0.469	0.495	0.528	0.561	0.615	0.654	0.669	0.651	0.640	0.552	0.521	0.471	0.590	ratio
Ambient Temper.	0.4	2.2	6.8	10.9	15.9	20.6	24.9	24.6	19.3	13.4	6.8	2.0	12.3	°C
Wind Velocity	2.6	2.9	3.2	3.1	2.9	3.3	3.7	3.5	2.9	2.6	2.3	2.3	2.9	m/s

Table 4.3 Monthly Meteo values of Adıyaman Kahta Region (PVSYST)

Geographical Site
Kâhta
Turkey

Situation

Latitude	37.79 °N
Longitude	38.62 °E
Altitude	718 m
Time zone	UTC+3

Monthly Meteo Values

Source Meteonorm 8.0 (2006-2013), Sat=100%

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	72.2	85.2	139.1	177.8	212.0	246.2	249.2	223.2	179.9	126.7	86.4	69.9	1867.9	kWh/m²
Horizontal diffuse	29.0	41.9	54.2	65.9	74.4	52.9	54.1	48.9	39.9	39.3	31.2	26.8	558.5	kWh/m²
Extraterrestrial	144.1	172.2	246.2	294.2	343.0	347.5	351.9	320.8	260.8	210.3	151.8	130.7	2973.7	kWh/m²
Clearness Index	0.501	0.495	0.565	0.604	0.618	0.709	0.708	0.696	0.690	0.602	0.569	0.535	0.628	ratio
Ambient Temper.	2.9	4.7	9.9	14.7	20.4	26.8	31.5	31.0	24.9	18.1	9.8	4.6	16.6	°C
Wind Velocity	1.8	1.9	2.4	2.4	2.4	3.0	3.0	2.6	2.4	1.9	1.6	1.7	2.3	m/s

Three different orientations selected will be analyzed. The orientation of the solar panels will face south and the inclination angles from the horizontal plane will be 30º, 45º and 70º inclined. Optimization of the angle of inclination of the solar panel surface at a given site will provide the maximum output power throughout the year[23]. Therefore, the optimization will be calculated for an annual irradiation efficiency for Adıyaman, Konya and İzmir. The azimuth is set to 0º and the modules are fixed so tracking is not used.The data showing plane inclination and other factors are shown in Figure 12.

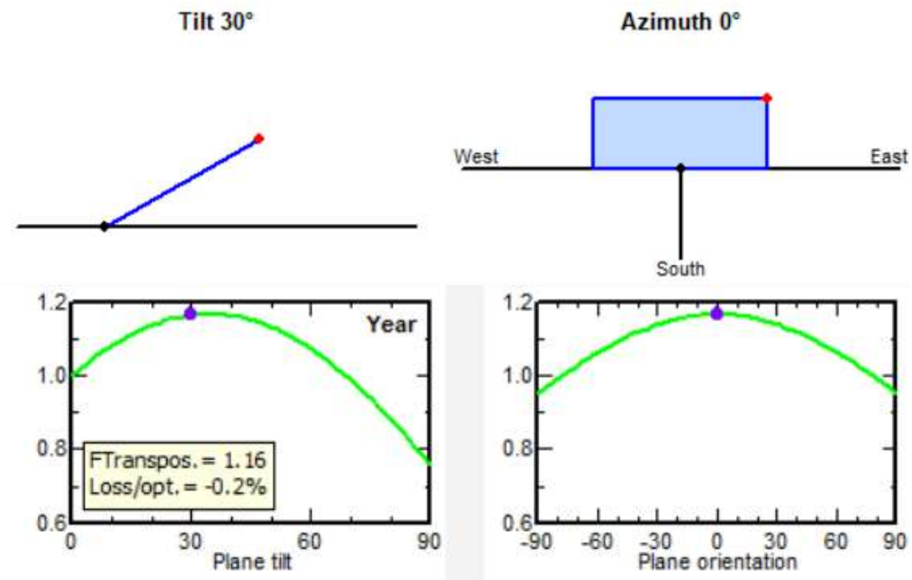

Figure 4.2 Orientation and inclination opt. of solar modules in the Adıyaman (PVSYST)

4.5.2 Horizon

This scope simulates the horizon line that signals the amount of useful radiation in the system. The visible red line corresponds to obstacles around the sun field, while the blue line represents automatic shading due to modules. The higher the slope, the larger this line will be. There will be no automatic shading in this project.

4.5.3 System

In the system part of the program, it allows the user to take the load curve or select the peak power needed in the system. The panel type to be selected, the inverter selection and your automatic work arising from their selection are performed.

In addition, it is possible to see the data of the parameters we selected earlier. In short, the main parameters of our system appear on this page.

Solar module

It is assumed that domestic production is preferred in the use of solar panels. In this context, Jurawatt Solar panel of Desiba company was chosen. The characteristic features of the JWP 60-260 solar panel are as follows.

Table 3.4 Characterıstıcs of the solar modüle

Technology	Si-Poly
Maximum power	260 Wp
Vmpp	30.95 V
Impp	8.400 A
Length	1640 mm
Width	990 mm

Inverter

The inverter converts the electricity DC generation into AC to supply this energy to the system or discharge it to the grid. The inverter chosen to simulate the system is an SMA inverter, Sunny Boy SWR 2500 U, whose characteristics are shown in Table 4. It has been chosen to follow the Maximum Power Point each time.

Table 3.5 Characterıstıcs of the inverter

Input voltaje, MPP range	234-550 V
Max open circuit voltage	≤ 600 V DC
Max input current	13 A DC
Max DC power	2710 W DC

Storage

Peak Shaving:

When the injection power is limited by the grid manager, the overload energy could be stored in batteries.

This will have the advantages:

- for the PV plant owner, recovering the energy which would otherwise be lost (at the the price of an additional cost of the stored energy).

- for the grid (large scale): regulate the renewable energy production.

For doing this, we need a battery pack able to store the overpower produced during one day, of higher power than the specified limit.

In practice, if the limit is rather high the storage will only be used episodically, representing a high investment for a low benefit.

For being significant for the grid management, the limit should be rather low, this will require a very big storage system. The price of stored energy (especially due to cycling) becomes crucial for the PV plant profitability. [40]

Simulation

In this study, we need to discuss a few scenarios so that we can analyze the system better and obtain more accurate results. As said before, the example of İzmir, Adıyaman and Konya will be represented and compared. All scenarios to be implemented will be run on a common parameter. PV is lower than that produced by the system, more energy will be stored and will be used to charge batteries. Production is even higher and batteries are already full, it will be discharged over the power grid. On the other hand, demand is greater than the energy production of the energy stored in the battery system to be used, the demand will be met even if the excess over the network.

System connected to the grid

The type and placement of solar modules will be the same in all scenarios. Since the electricity production will be constant, the battery usage times will give us the most accurate usage conditions. The usage scheme of the system is given below.

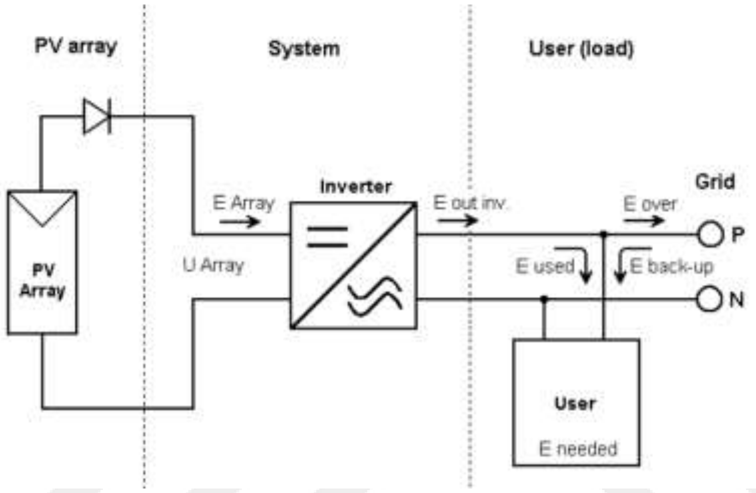

Figure 3.3 Scheme of the pv system connected to the grıd

The system will be in the form of simulating 3 different types of battery usage in connection with the grid. The scenarios to be applied are given in the table below.

Table 3.6 Scenarıos of the sımulatıons

	Adıyaman	**Konya**	**İzmir**
Orientation	30°	30°	30°
	45°	45°	45°
	70°	70°	70°
Only PV	X	X	X
Operating Conditions	Power needed	Power needed	Power needed
	After sunset	After sunset	After sunset

4.6 Economic evaluation

One of the most important criteria for a system to be applicable is the economic criteria it has. Sometimes projects that seem very interesting and feasible will reveal that this work should stop for the day after the current situation is analyzed from an economic point of view. For this reason, it can be seen as an important output in revealing at least the developmental aspects of the studies by making an economic analysis.

Radiation emitted by the sun is one of the main items in such systems. Figure 3.4 shows that PV systems located in lower latitude areas have higher irradiation and shorter energy payback time. The payback period for the investments made in the system is also shorter

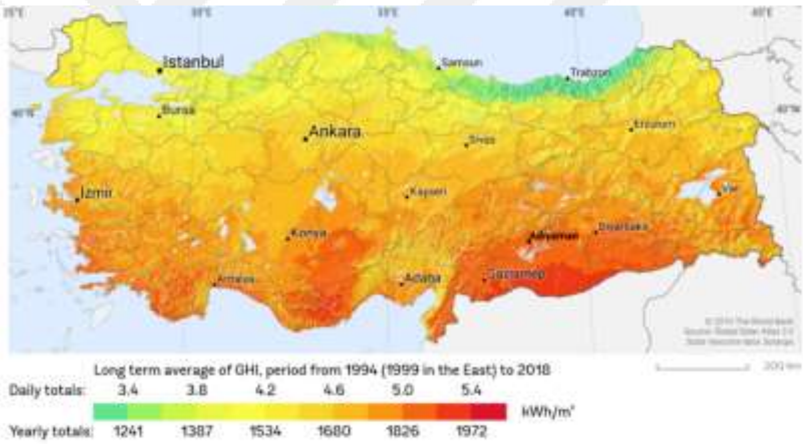

Figure 4.4 Energy pay-back tıme of pv roof systems. geographıcal comparıson for Turkey

Figure 3.4 shows the row Energy Reimbursement (EPBT) with annual solar radiation on horizontal surfaces in Turkey. The EPBT indicates how long it takes the PV module to recover the cost after the system is installed. The lower the latitude, the less this refund. If the payback is low, the project will be more likely to happen since it is larger. Adıyaman has a clear advantage over location. On the other hand, the geographical conditions of Konya make it more attractive. In order to make an economic analysis, the calculation will be made by taking into account the price of the battery system of the PV system and the purchase price of electricity due to the PV system not producing enough energy, and subtracting the savings gained due to overproduction. The rest of the installation of energy produced by the solar source will be considered equal in any case.

4.6.1 Analysis of the battery prices

Battery technology is developing day by day in the world. Therefore, there are many different battery manufacturers. The quantity and size of the batteries change and the price changes according to their capacities. Price research has been done in the table below [25].

Table 4.7 Price of different products and its warranty capacity

Product Name	Total Warranted kWh(1 cycle Per day)	Energy Storage (kWh)	Price ($)	Price Per kWh
Genz	8200	3	3300	1100
Growatt	22000	6	4500	750
Huawei	16500	5	6000	1200
LG Chem	16000	6,5	5300	815
Powerplus Energy	9500	3,3	3550	1076
Pylontech	4500	2,4	2000	833
Redflow	36500	10	12600	1260
SimpliPhi	11000	3,4	4700	1382
Photonic Universe	8750	12	1500	125
SunGrow	47000	12,8	8200	641
SolarWatt	4500	2,4	2000	833
Tesla Powerwall w	38000	14	13303	950
ABB REACT 2	14000	4	8350	2088
Redback SH5000+BE13200	-	13,2	18000	1364
RedEarth Sunrise	19000	6,5	9625	1481

When the table is examined, it is seen that Photonic Universe brand will be the most advantageous choice. Both the price per kW and the capacity it guarantees will facilitate the selection.

4.6.2 The case of Turkey

The mechanism related to renewable energy in Turkey is called YEKDEM. YEKDEM is a support mechanism applied to wind, solar, geothermal, biomass, biomass gas (including landfill gas), wave current energy, tidal energy, canal, river and hydroelectric generation facilities with reservoir area less than fifteen square kilometers.[26] There is a table of distribution of electricity sales price in Turkey by years.

Table 4.8 2011-2021 YEKDEM Price Development [26]

	USD/MWh												
YEKDEM	Ocak	Şubat	Mart	Nisan	Mayıs	Haziran	Temmuz	Ağustos	Eylül	Ekim	Kasım	Aralık	Tümü
2011												0,09	0,09
2012	0,00	-0,53	0,29	0,93	-0,02	-0,02	-0,29	-0,08	-0,02	0,17	0,16	0,03	0,05
2013	0,19	0,32	0,44	0,26	0,36	0,29	0,23	0,27	0,29	0,44	0,40	0,19	0,31
2014	0,62	0,49	1,16	0,62	0,63	0,67	0,38	0,37	0,65	0,82	0,52	0,85	0,63
2015	0,92	2,55	3,59	5,36	4,94	3,71	3,37	2,32	2,09	3,33	3,60	2,70	3,21
2016	6,17	11,01	12,96	11,43	11,66	7,95	8,33	5,26	6,73	6,83	6,70	3,30	8,19
2017	7,09	7,87	11,99	14,72	14,61	11,11	7,53	7,25	5,60	7,95	7,20	10,79	9,48
2018	9,32	10,45	17,07	13,76	13,69	15,83	11,89	11,80	8,81	8,48	8,75	9,60	11,79
2019	15,21	13,30	16,70	24,77	25,67	19,15	10,94	11,92	10,65	10,20	9,10	8,83	14,76
2020	9,98	12,80	22,17	34,27	33,26	16,46	15,18	13,99	12,56	11,76	13,97	11,91	17,36
2021	14,55	16,71											

The studies, which started in December 2011, continued to develop as the years passed. When we look at the values of 2020, we see that the average value of 1 MWh energy is 17.36 dollars. When we look at the same period of the previous year, a great change is seen in 2021. At the end of the year, it can be said that this situation will increase the average selling price.

CHAPTER 5

RESULT AND DISCUSSION

In this section, simulations of various scenarios were made using the PVSYST software and some results were presented. These results will determine the conclusions we will form for this thesis.

5.1 Correct orientation

Installing the system in the east is one of the first and most important steps of the efficiency to be achieved.

Tilt 30° South

Table 5.1 Results for a tılt of 30°

Design of the PV-System	Adıyaman	Konya	İzmir
N modules	3780 Units	3780 Units	3780 Units
PV Installation	983 kWp	983 kWp	983 kWp
Produced Energy	1753 MWh/year	1652 MWh/year	1664 MWh/year

Tilt 45° South

Table 5.2 Results for a tılt of 45°

Design of the PV-System	Adıyaman	Konya	İzmir
N modules	3780 Units	3780 Units	3780 Units
PV Installation	983 kWp	983 kWp	983 kWp
Produced Energy	1730 MWh/year	1614 MWh/year	1632 MWh/year

Tilt 70° South

Table 5.3 Results for a tilt of 70°

Design of the PV-System	Adıyaman	Konya	İzmir
N modules	3780 Units	3780 Units	3780 Units
PV Installation	983 kWp	983 kWp	983 kWp
Produced Energy	1490 MWh/year	1383 MWh/year	1395 /year

5.2 Solar Panel Without Battery

In case there is no battery in the system, the energy data obtained are as follows.

Table 5.4 In case there is no battery in the system

	GlobHor (kWh/m²/year)	Specific prod (MWh/MWp/year)	E_Grid (MWh/year)	PR (%)
Adıyaman	1867,9	1509	1726,8	70,3
Konya	1759,1	1420	1624,6	71,3
İzmir	1792,3	1444	1652,4	71,4

5.3 Operation Conditions

In this area, various simulations have been run to learn more about the behavior of the system and the conditions under which it will be performed. The battery systems shown in the following tables are described in the method section. The optimum angle at which the maximum amount of energy is reached was selected for each location. Obtained thanks to PVsyst software.

As soon as power is needed

The battery will be systematically discharged when energy is needed.

Table 5.5 Result when battery operated as soon as power is needed

	GlobHor (kWh/m²/year)	Specific prod (MWh/MWp/year)	E_Grid (MWh/year	Capacity (Ah)	EBatDis MWh/year	PR (%)
Adıyaman	1867,9	1770	2062,6	2964 Ah	168,59	82,2
Konya	1760,2	1666	1948,7	2964 Ah	174,11	83,6
İzmir	1792,3	1680	1965,2	2964 Ah	152,10	83,0

Where:

- Available energy is the amount of energy that are able to get in each system.
- Global Horizontal Radiation (GHI) is the total solar radiation falling on a horizontal surface. Direct Normal Radiation (DNI) is the sum of Scattered Horizontal Radiation and reflected radiation from the ground.
- The specific generation is the annual electrical power generation from a 1 kWp PV system.

- Capacity indicates the total size of the battery system.
- Grid-tied means your solar system is connected to your local grid's GRID. This is what most systems will use, as this should be used if your solar system under- or over-produces according to your changing energy needs.
- The battery discharge cycle is the term that describes the time it takes for the energy contained in the Charger battery to be consumed. It can also be used to describe the life of the battery.
- PR (Performance Ratio) is the relationship between the actual and nominal efficiency of the system.

In the study conducted for Adıyaman province, the graph of the profiles that emerge when the energy produced by the battery is stored over 600 kW limit for the first four months of the year and discharged during the day when it is lower than the limit is as given below.

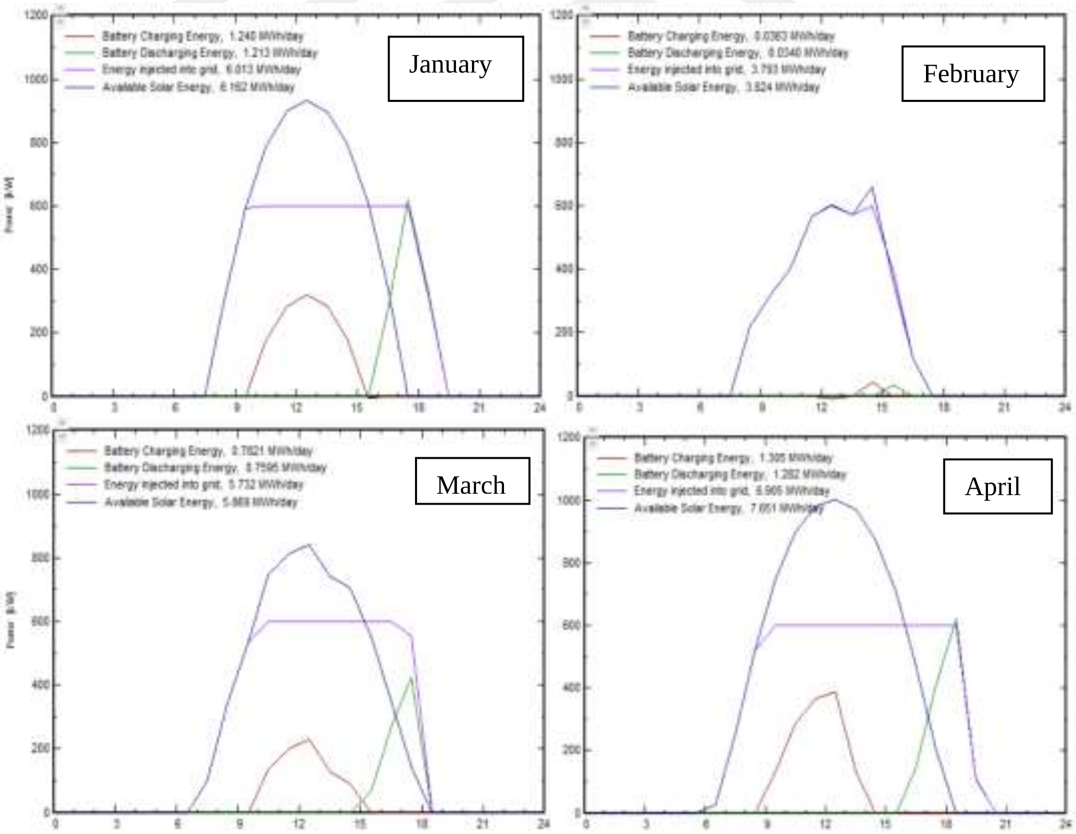

Figure 5.1 Battery charge and discharge profiles for the first 4 months of the year in Adıyaman

In the study conducted for Adıyaman province, the graph of the profiles that emerge when the energy produced by the battery is stored over 600 kW limit for the second four months of the year and discharged during the day when it is lower than the limit is as given below.

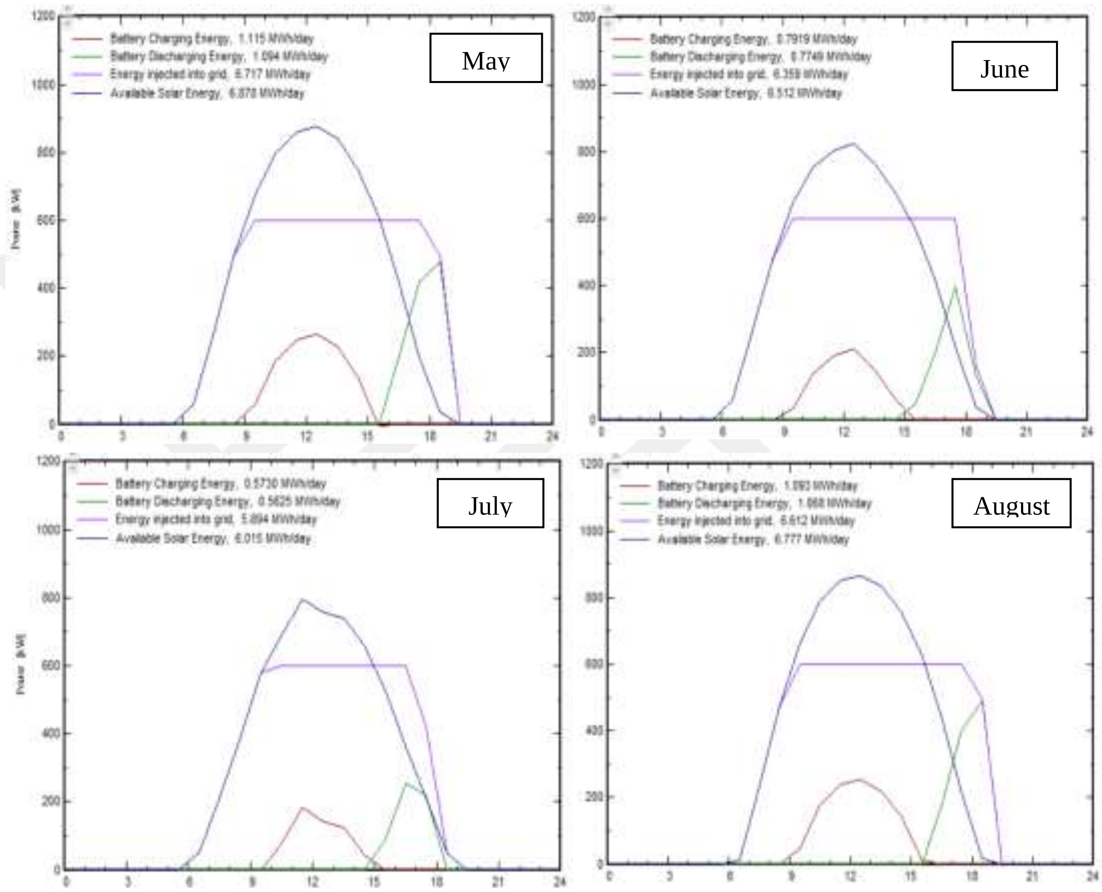

Figure 5.2 Battery charge and discharge profiles for the second 4 months of the year in Adıyaman

In the study conducted for Adıyaman province, the graph of the profiles that emerge when the energy produced by the battery is stored over 600 kW limit for the last four months of the year and discharged during the day when it is lower than the limit is as given below.

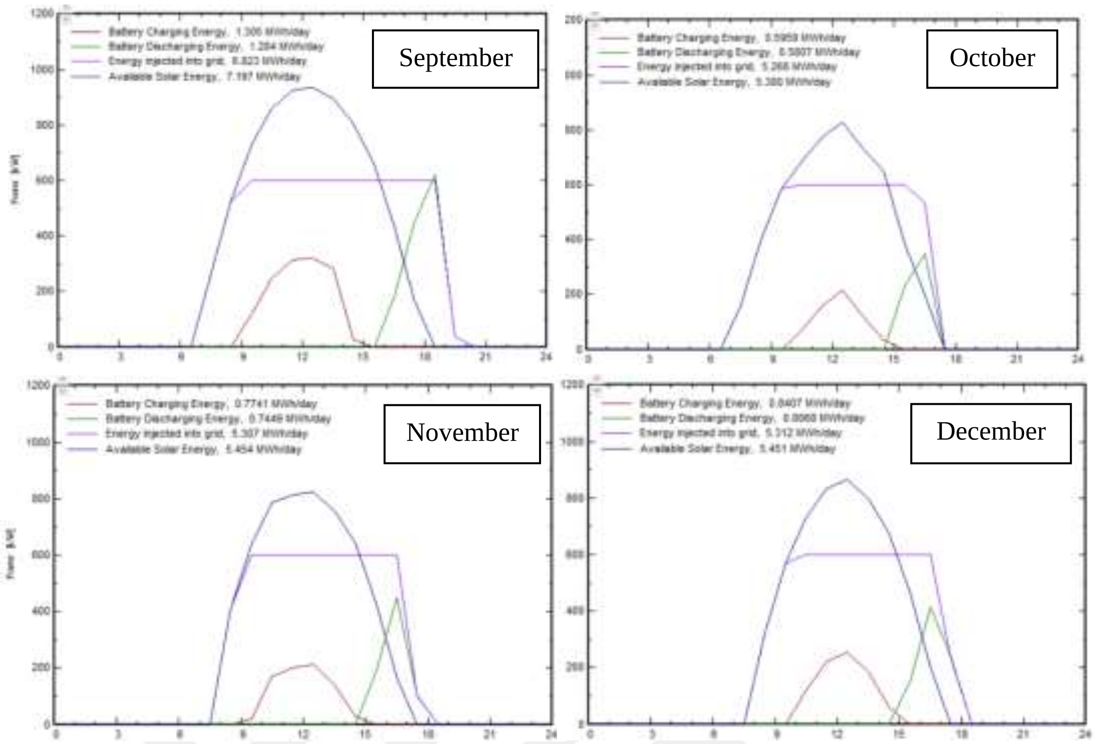

Figure 5.3 Battery charge and discharge profiles for the last 4 months of the year in Adıyaman

In the study conducted for Konya province, the graph of the profiles that emerge when the energy produced by the battery is stored over 600 kW limit. It is known that there are 4 seasons in a year in Turkey. The chart below shows the profiles for the 2nd month of each season of the year.

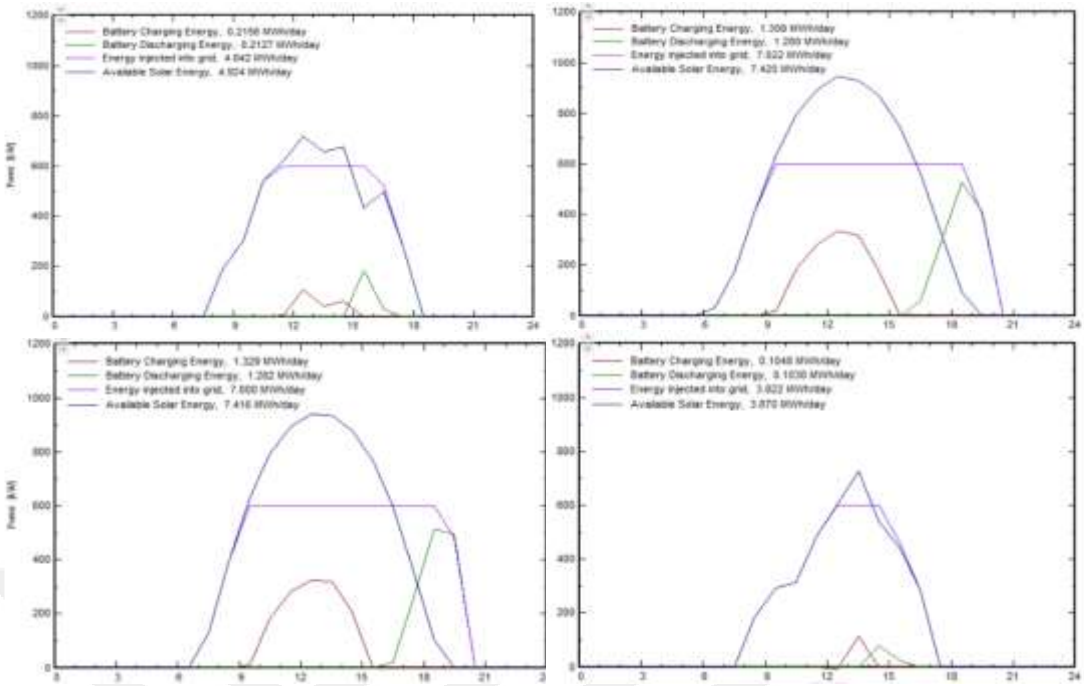

Figure 5.4 Battery charge and discharge profiles of the 2nd month of each season in Konya province

In the study conducted for İzmir province, the graph of the profiles that emerge when the energy produced by the battery is stored over 600 kW limit. The chart below shows the profiles for the 2nd month of each season of the year.

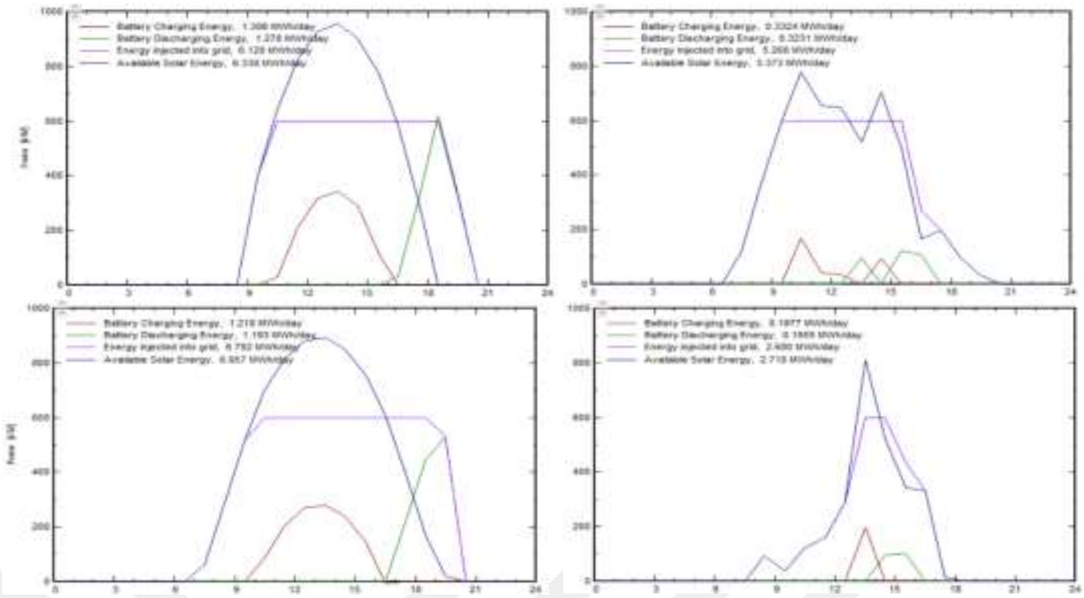

Figure 5.5 Battery charge and discharge profiles of the 2nd month of each season in Izmir province

After sunset

The battery will be systematically discharged when the sun goes down.

Table 5.5 Result when battery operated after sunset

	GlobHor (kWh/m²/year)	Specific prod (MWh/MWp/year)	E_Grid (MWh/year	Capacity (Ah)	EBatDis MWh/year	PR (%)
Adıyaman	1867,9	1764	2063,9	2964 Ah	169,11	82,2
Konya	1760,2	1666	1949,2	2964 Ah	145,93	83,6
İzmir	1405,6	1653	1891	2964 Ah	246,8	81,7

Where:

- Available energy is the amount of energy that are able to get in each system.
- Global Horizontal Radiation (GHI) is the total solar radiation falling on a horizontal surface. Direct Normal Radiation (DNI) is the sum of Scattered Horizontal Radiation and reflected radiation from the ground.
- The specific generation is the annual electrical power generation from a 1 kWp PV system.
- Capacity indicates the total size of the battery system.

- Grid-tied means your solar system is connected to your local grid's GRID. This is what most systems will use, as this should be used if your solar system under- or over-produces according to your changing energy needs.
- The battery discharge cycle is the term that describes the time it takes for the energy contained in the Charger battery to be consumed. It can also be used to describe the life of the battery.
- PR (Performance Ratio) is the relationship between the actual and nominal efficiency of the system.

In addition to these, data for each day of each month for a year for Adıyaman province are given below. In addition, for İzmir and Konya Provinces 4 months a year, provided that the battery works in a way to keep the efficiency of the system high and that it is charged when there is no sun.

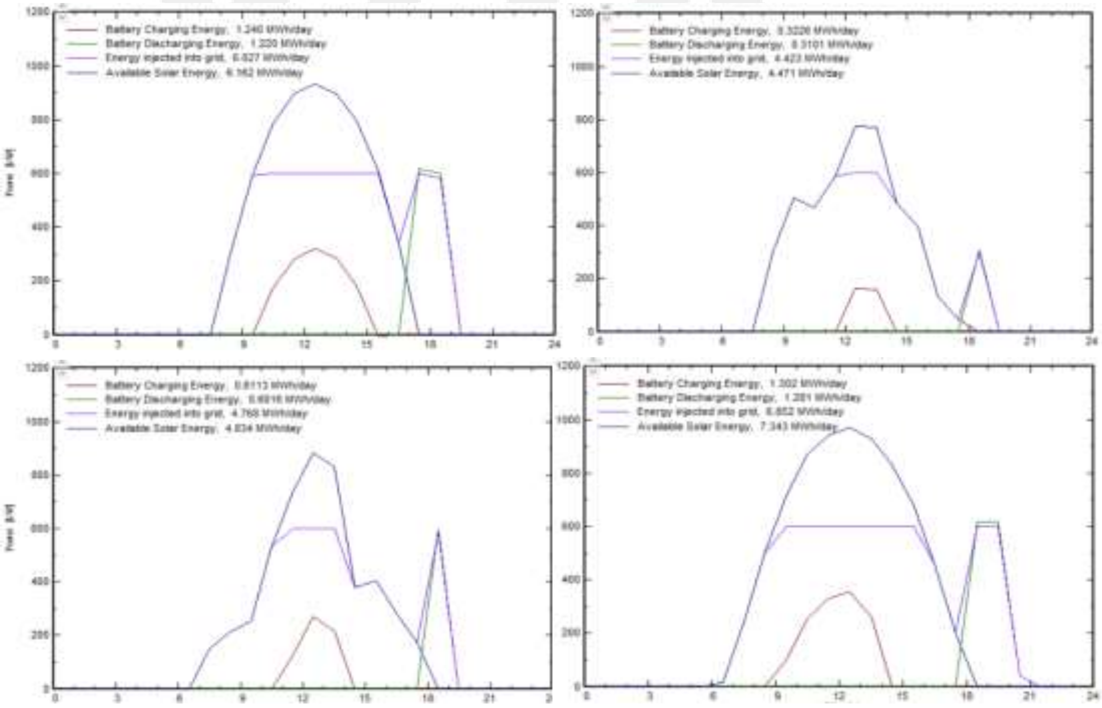

Figure 5.6 Battery charge and discharge profiles for the first 4 months of the year in Adıyaman

In the study conducted for Adıyaman province, the graph of the profiles that emerge when the energy produced by the battery is stored over 600 kW limit for the second four months of the provided that the battery works in a way to keep the efficiency of the system high and that it is charged when there is no sun.

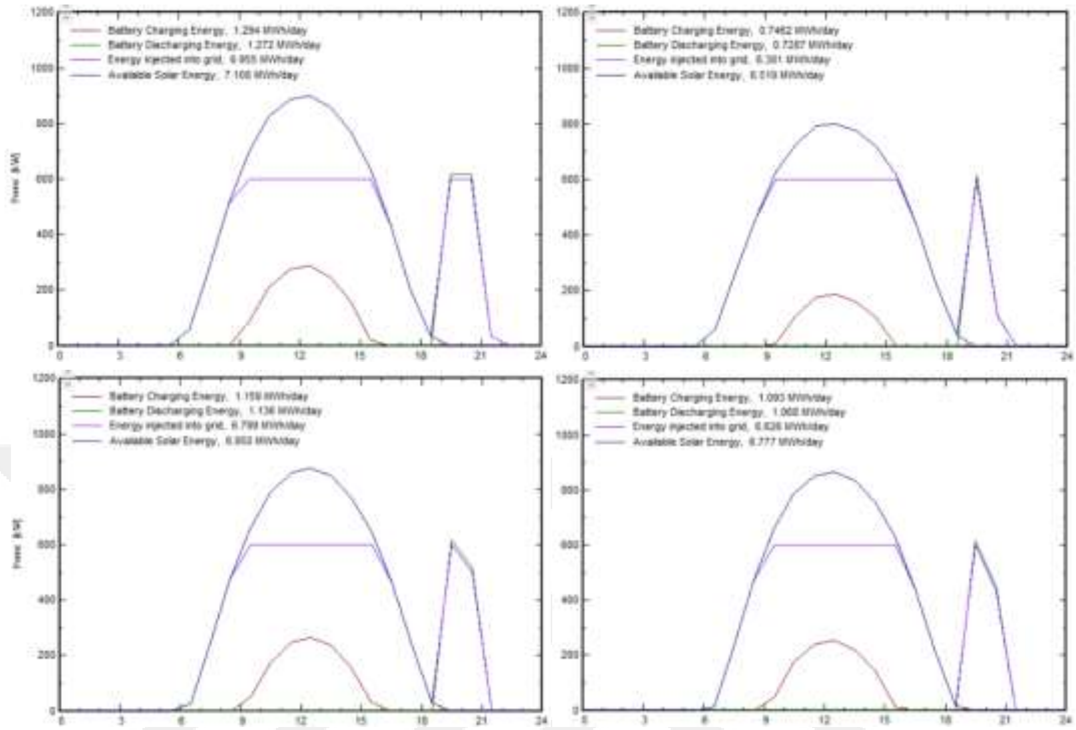

Figure 5.7 Battery charge and discharge profiles for the second 4 months of the year in Adıyaman

In the study conducted for Adıyaman province, the graph of the profiles that emerge when the energy produced by the battery is stored over 600 kW limit for the last four months of the provided that the battery works in a way to keep the efficiency of the system high and that it is charged when there is no sun.

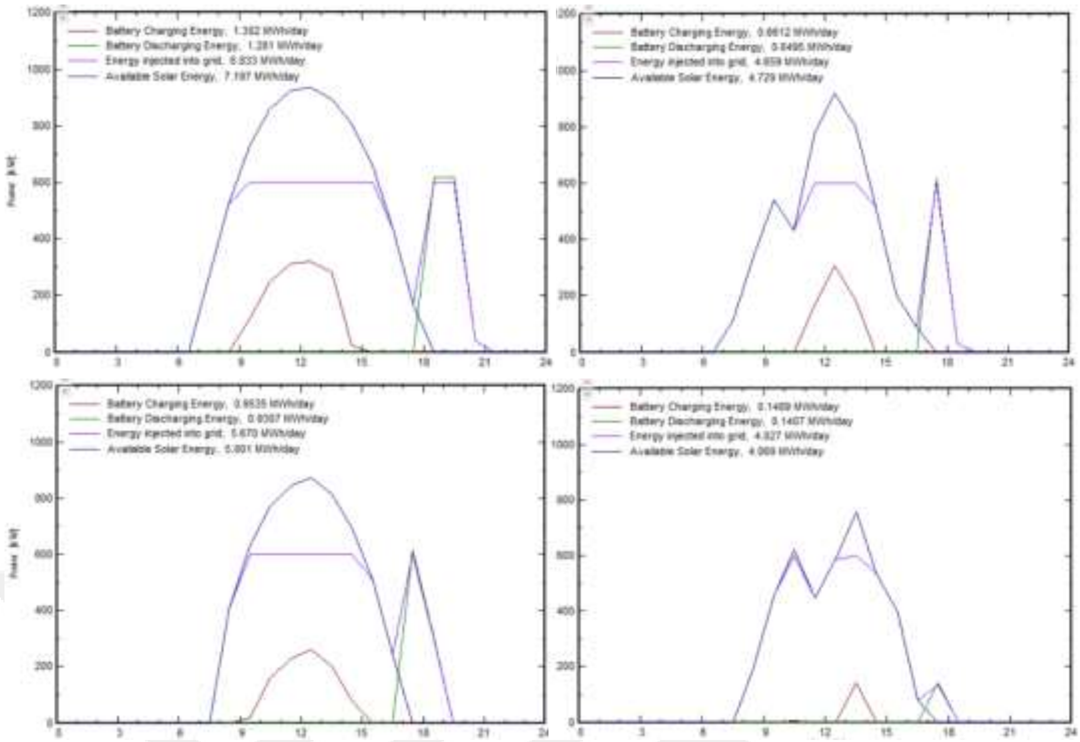

Figure 5.8 Battery charge and discharge profiles for the last 4 months of the year in Adıyaman

In the study conducted for Konya province, the graph of the profiles that emerge when the energy produced by the battery is stored over 600 kW limit. It is known that there are 4 seasons in a year in Turkey. The chart below shows the profiles for the 2nd month of each season of the year.

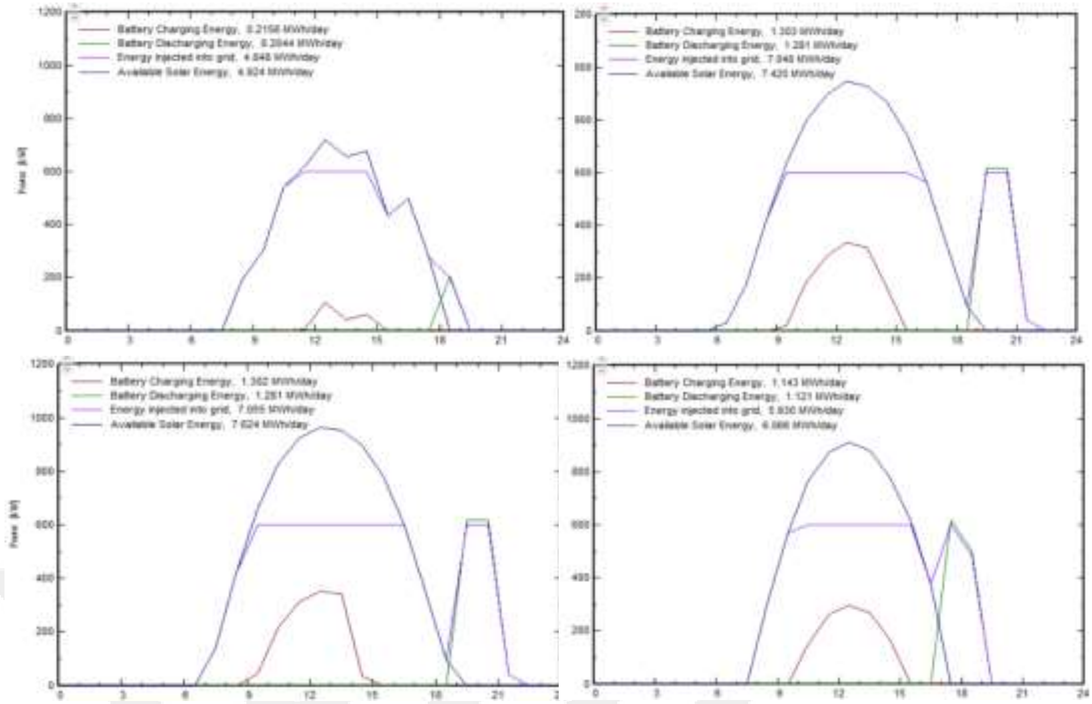

Figure 5.9 Battery charge and discharge profiles of the 2nd month of each season in Konya province

In the study conducted for İzmir province, the graph of the profiles that emerge when the energy produced by the battery is stored over 600 kW limit. The chart below shows the profiles for the 2nd month of each season of the year.

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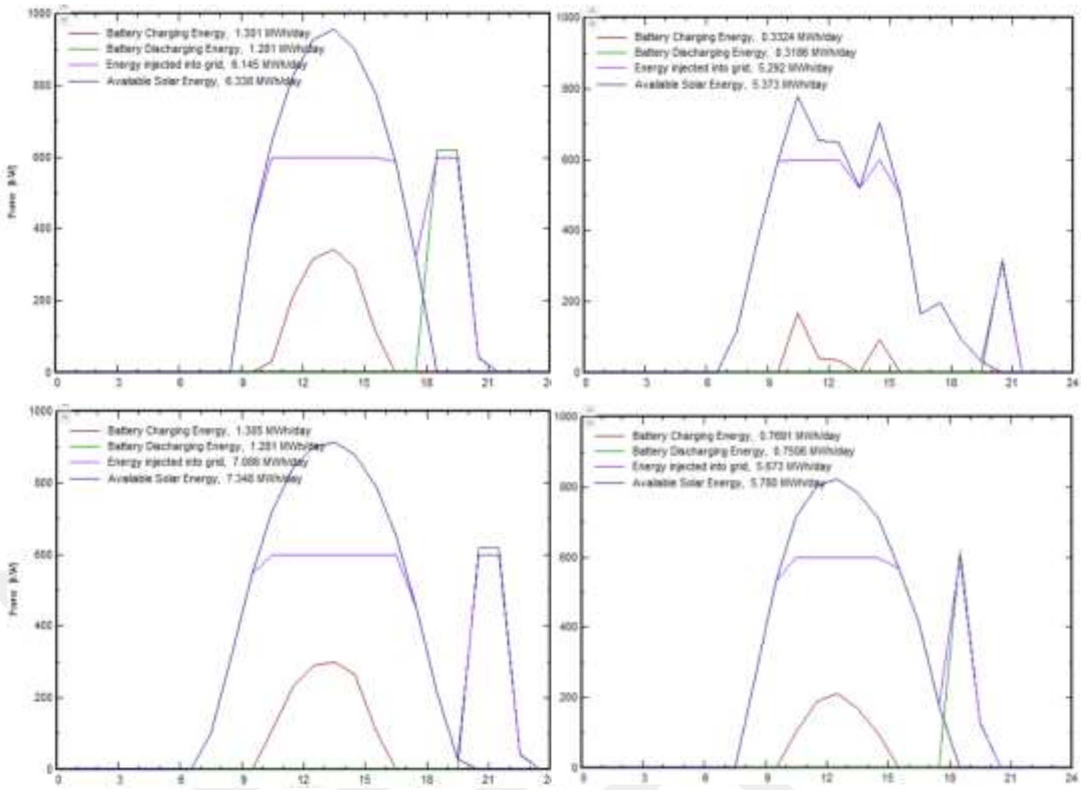

Figure 5.10 Battery charge and discharge profiles of the 2nd month of each season in Izmir province

5.4 Economical study

One of the biggest points to be considered regarding the economic results is the return period of the investment and the state of the income to be obtained at the end of the project. The economic work has been examined in two main themes as the work done after the sun goes down and the feeding of the system as the energy need arises.

Solar Panel Without Battery

The table showing the economic results in cases where the battery is not used in the solar panel system is as follows.

As seen in Table 5.7, the return on investment is 6.2 years for İzmir.

Table 5.7 Results of the economic study without battery in İzmir in $

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2022	165'240	3'000	0	162'240	29'203	133'037	-691'233	16.1%
2023	165'240	3'000	0	162'240	29'203	133'037	-558'196	32.3%
2024	165'240	3'000	0	162'240	29'203	133'037	-425'159	48.4%
2025	165'240	3'000	0	162'240	29'203	133'037	-292'123	64.6%
2026	165'240	3'000	0	162'240	29'203	133'037	-159'086	80.7%
2027	165'240	3'000	0	162'240	29'203	133'037	-26'049	96.8%
2028	165'240	3'000	0	162'240	29'203	133'037	106'987	113.0%
2029	165'240	3'000	0	162'240	29'203	133'037	240'024	129.1%
2030	165'240	3'000	0	162'240	29'203	133'037	373'061	145.3%
2031	165'240	3'000	0	162'240	29'203	133'037	506'097	161.4%
2032	165'240	3'000	0	162'240	29'203	133'037	639'134	177.5%
2033	165'240	3'000	0	162'240	29'203	133'037	772'171	193.7%
2034	165'240	3'000	0	162'240	29'203	133'037	905'208	209.8%
2035	165'240	3'000	0	162'240	29'203	133'037	1'038'244	226.0%
2036	165'240	3'000	0	162'240	29'203	133'037	1'171'281	242.1%
2037	165'240	3'000	0	162'240	29'203	133'037	1'304'318	258.2%
2038	165'240	3'000	0	162'240	29'203	133'037	1'437'354	274.4%
2039	165'240	3'000	0	162'240	29'203	133'037	1'570'391	290.5%
2040	165'240	3'000	0	162'240	29'203	133'037	1'703'428	306.7%
2041	165'240	3'000	0	162'240	29'203	133'037	1'836'464	322.8%
Total	3'304'797	60'000	0	3'244'797	584'063	2'660'733	1'836'464	322.8%

As seen in Table 5.8, the return on investment is 5.2 years for Konya.

Table 5.8 Results of the economic study without battery in Konya in $

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2022	162'460	3'000	0	159'460	0	159'460	-664'909	19.3%
2023	162'460	3'000	0	159'460	0	159'460	-505'349	38.7%
2024	162'460	3'000	0	159'460	0	159'460	-345'889	58.0%
2025	162'460	3'000	0	159'460	0	159'460	-186'429	77.4%
2026	162'460	3'000	0	159'460	0	159'460	-26'969	96.7%
2027	162'460	3'000	0	159'460	0	159'460	132'490	116.1%
2028	162'460	3'000	0	159'460	0	159'460	291'950	135.4%
2029	162'460	3'000	0	159'460	0	159'460	451'410	154.8%
2030	162'460	3'000	0	159'460	0	159'460	610'870	174.1%
2031	162'460	3'000	0	159'460	0	159'460	770'330	193.5%
2032	162'460	3'000	0	159'460	0	159'460	929'790	212.8%
2033	162'460	3'000	0	159'460	0	159'460	1'089'250	232.1%
2034	162'460	3'000	0	159'460	0	159'460	1'248'710	251.5%
2035	162'460	3'000	0	159'460	0	159'460	1'408'170	270.8%
2036	162'460	3'000	0	159'460	0	159'460	1'567'630	290.2%
2037	162'460	3'000	0	159'460	0	159'460	1'727'090	309.5%
2038	162'460	3'000	0	159'460	0	159'460	1'886'550	328.9%
2039	162'460	3'000	0	159'460	0	159'460	2'046'010	348.2%
2040	162'460	3'000	0	159'460	0	159'460	2'205'470	367.6%
2041	162'460	3'000	0	159'460	0	159'460	2'364'930	386.9%
Total	3'249'199	60'000	0	3'189'199	0	3'189'199	2'364'930	386.9%

As seen in Table 5.9, the return on investment is 4.9 years for Adıyaman.

Table 5.9 Results of the economic study without battery in Adıyaman in $

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2022	172'679	3'000	0	169'679	0	169'679	-654'591	20.6%
2023	172'679	3'000	0	169'679	0	169'679	-484'912	41.2%
2024	172'679	3'000	0	169'679	0	169'679	-315'234	61.8%
2025	172'679	3'000	0	169'679	0	169'679	-145'555	82.3%
2026	172'679	3'000	0	169'679	0	169'679	24'123	102.9%
2027	172'679	3'000	0	169'679	0	169'679	193'802	123.5%
2028	172'679	3'000	0	169'679	0	169'679	363'480	144.1%
2029	172'679	3'000	0	169'679	0	169'679	533'159	164.7%
2030	172'679	3'000	0	169'679	0	169'679	702'837	185.3%
2031	172'679	3'000	0	169'679	0	169'679	872'516	205.9%
2032	172'679	3'000	0	169'679	0	169'679	1'042'194	226.4%
2033	172'679	3'000	0	169'679	0	169'679	1'211'873	247.0%
2034	172'679	3'000	0	169'679	0	169'679	1'381'551	267.6%
2035	172'679	3'000	0	169'679	0	169'679	1'551'230	288.2%
2036	172'679	3'000	0	169'679	0	169'679	1'720'908	308.8%
2037	172'679	3'000	0	169'679	0	169'679	1'890'587	329.4%
2038	172'679	3'000	0	169'679	0	169'679	2'060'265	350.0%
2039	172'679	3'000	0	169'679	0	169'679	2'229'944	370.6%
2040	172'679	3'000	0	169'679	0	169'679	2'399'622	391.1%
2041	172'679	3'000	0	169'679	0	169'679	2'569'301	411.7%
Total	**3'453'570**	**60'000**	**0**	**3'393'570**	**0**	**3'393'570**	**2'569'301**	**411.7%**

After Sunset

The economic study table for the situation that the system starts to discharge after the sun goes down is as follows.

The return on investment for Adıyaman province is 7.5 years.

Table 5.7 Results of the economic study in Adıyaman in $

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2022	96'483	10'000	0	86'483	15'567	70'916	-490'084	12.6%
2023	96'483	10'000	0	86'483	15'567	70'916	-419'168	25.3%
2024	96'483	10'000	0	86'483	15'567	70'916	-348'252	37.9%
2025	96'483	10'000	0	86'483	15'567	70'916	-277'336	50.6%
2026	96'483	10'000	0	86'483	15'567	70'916	-206'420	63.2%
2027	96'483	10'000	0	86'483	15'567	70'916	-135'504	75.8%
2028	96'483	10'000	0	86'483	15'567	70'916	-64'588	88.5%
2029	96'483	10'000	0	86'483	15'567	70'916	6'327	101.1%
2030	96'483	10'000	0	86'483	15'567	70'916	77'243	113.8%
2031	96'483	10'000	0	86'483	15'567	70'916	148'159	126.4%
2032	96'483	10'000	0	86'483	15'567	70'916	219'075	139.1%
2033	96'483	10'000	0	86'483	15'567	70'916	289'991	151.7%
2034	96'483	10'000	0	86'483	15'567	70'916	360'907	164.3%
2035	96'483	10'000	0	86'483	15'567	70'916	431'823	177.0%
2036	96'483	10'000	0	86'483	15'567	70'916	502'739	189.6%
2037	96'483	10'000	0	86'483	15'567	70'916	573'655	202.3%
2038	96'483	10'000	0	86'483	15'567	70'916	644'571	214.9%
2039	96'483	10'000	0	86'483	15'567	70'916	715'487	227.6%
2040	96'483	10'000	0	86'483	15'567	70'916	786'402	240.2%
2041	96'483	10'000	0	86'483	15'567	70'916	857'318	252.8%
Total	**1'929'657**	**200'000**	**0**	**1'729'657**	**311'338**	**1'418'318**	**857'318**	**252.8%**

The return on investment for Konya province is 7.9 years.

Table 5.8 Results of the economic study in Konya in $

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2022	96'483	10'000	0	86'483	15'567	70'916	-490'084	12.6%
2023	96'483	10'000	0	86'483	15'567	70'916	-419'168	25.3%
2024	96'483	10'000	0	86'483	15'567	70'916	-348'252	37.9%
2025	96'483	10'000	0	86'483	15'567	70'916	-277'336	50.6%
2026	96'483	10'000	0	86'483	15'567	70'916	-206'420	63.2%
2027	96'483	10'000	0	86'483	15'567	70'916	-135'504	75.8%
2028	96'483	10'000	0	86'483	15'567	70'916	-64'589	88.5%
2029	96'483	10'000	0	86'483	15'567	70'916	6'327	101.1%
2030	96'483	10'000	0	86'483	15'567	70'916	77'243	113.8%
2031	96'483	10'000	0	86'483	15'567	70'916	148'159	126.4%
2032	96'483	10'000	0	86'483	15'567	70'916	219'075	139.1%
2033	96'483	10'000	0	86'483	15'567	70'916	289'991	151.7%
2034	96'483	10'000	0	86'483	15'567	70'916	360'907	164.3%
2035	96'483	10'000	0	86'483	15'567	70'916	431'823	177.0%
2036	96'483	10'000	0	86'483	15'567	70'916	502'739	189.6%
2037	96'483	10'000	0	86'483	15'567	70'916	573'655	202.3%
2038	96'483	10'000	0	86'483	15'567	70'916	644'571	214.9%
2039	96'483	10'000	0	86'483	15'567	70'916	715'487	227.5%
2040	96'483	10'000	0	86'483	15'567	70'916	786'402	240.2%
2041	96'483	10'000	0	86'483	15'567	70'916	857'318	252.8%
Total	**1'929'657**	**200'000**	**0**	**1'729'657**	**311'338**	**1'418'318**	**857'318**	**252.8%**

The return on investment for İzmir province is 7.9 years

Table 5.9 Results of the economic study in İzmir in $

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2022	96'483	10'000	0	86'483	15'567	70'916	-490'084	12.6%
2023	96'483	10'000	0	86'483	15'567	70'916	-419'168	25.3%
2024	96'483	10'000	0	86'483	15'567	70'916	-348'252	37.9%
2025	96'483	10'000	0	86'483	15'567	70'916	-277'336	50.6%
2026	96'483	10'000	0	86'483	15'567	70'916	-206'420	63.2%
2027	96'483	10'000	0	86'483	15'567	70'916	-135'504	75.8%
2028	96'483	10'000	0	86'483	15'567	70'916	-64'589	88.5%
2029	96'483	10'000	0	86'483	15'567	70'916	6'327	101.1%
2030	96'483	10'000	0	86'483	15'567	70'916	77'243	113.8%
2031	96'483	10'000	0	86'483	15'567	70'916	148'159	126.4%
2032	96'483	10'000	0	86'483	15'567	70'916	219'075	139.1%
2033	96'483	10'000	0	86'483	15'567	70'916	289'991	151.7%
2034	96'483	10'000	0	86'483	15'567	70'916	360'907	164.3%
2035	96'483	10'000	0	86'483	15'567	70'916	431'823	177.0%
2036	96'483	10'000	0	86'483	15'567	70'916	502'739	189.6%
2037	96'483	10'000	0	86'483	15'567	70'916	573'655	202.3%
2038	96'483	10'000	0	86'483	15'567	70'916	644'571	214.9%
2039	96'483	10'000	0	86'483	15'567	70'916	715'487	227.5%
2040	96'483	10'000	0	86'483	15'567	70'916	786'402	240.2%
2041	96'483	10'000	0	86'483	15'567	70'916	857'318	252.8%
Total	**1'929'657**	**200'000**	**0**	**1'729'657**	**311'338**	**1'418'318**	**857'318**	**252.8%**

Battery prices simply mean the price of each battery multiplied by the number of batteries in each system. Total electricity is the result of money earned due to the discharge of excess energy generated by the different operating system into the grid.

As soon as power is needed

The economic study table for the situation that the system starts to discharge as soon as power is needed is as follows.

The return on investment for Adıyaman province is 7.7 years.

Table 5.10 Results of the economic study in Adıyaman in $

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2022	99'340	10'000	0	89'340	16'081	73'259	-487'742	13.1%
2023	99'340	10'000	0	89'340	16'081	73'259	-414'483	26.1%
2024	99'340	10'000	0	89'340	16'081	73'259	-341'225	39.2%
2025	99'340	10'000	0	89'340	16'081	73'259	-267'966	52.2%
2026	99'340	10'000	0	89'340	16'081	73'259	-194'708	65.3%
2027	99'340	10'000	0	89'340	16'081	73'259	-121'449	78.4%
2028	99'340	10'000	0	89'340	16'081	73'259	-48'191	91.4%
2029	99'340	10'000	0	89'340	16'081	73'259	25'068	104.5%
2030	99'340	10'000	0	89'340	16'081	73'259	98'326	117.5%
2031	99'340	10'000	0	89'340	16'081	73'259	171'584	130.6%
2032	99'340	10'000	0	89'340	16'081	73'259	244'843	143.6%
2033	99'340	10'000	0	89'340	16'081	73'259	318'101	156.7%
2034	99'340	10'000	0	89'340	16'081	73'259	391'360	169.8%
2035	99'340	10'000	0	89'340	16'081	73'259	464'618	182.8%
2036	99'340	10'000	0	89'340	16'081	73'259	537'877	195.9%
2037	99'340	10'000	0	89'340	16'081	73'259	611'135	208.9%
2038	99'340	10'000	0	89'340	16'081	73'259	684'393	222.0%
2039	99'340	10'000	0	89'340	16'081	73'259	757'652	235.1%
2040	99'340	10'000	0	89'340	16'081	73'259	830'910	248.1%
2041	99'340	10'000	0	89'340	16'081	73'259	904'169	261.2%
Total	1'986'791	200'000	0	1'786'791	321'622	1'465'169	904'169	261.2%

The return on investment for Konya province is 8.3 years.

Table 5.11 Results of the economic study in Konya in $

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2022	94'546	10'000	0	84'546	15'218	69'328	-491'672	12.4%
2023	94'546	10'000	0	84'546	15'218	69'328	-422'345	24.7%
2024	94'546	10'000	0	84'546	15'218	69'328	-353'017	37.1%
2025	94'546	10'000	0	84'546	15'218	69'328	-283'690	49.4%
2026	94'546	10'000	0	84'546	15'218	69'328	-214'362	61.8%
2027	94'546	10'000	0	84'546	15'218	69'328	-145'035	74.1%
2028	94'546	10'000	0	84'546	15'218	69'328	-75'707	86.5%
2029	94'546	10'000	0	84'546	15'218	69'328	-6'380	98.9%
2030	94'546	10'000	0	84'546	15'218	69'328	62'948	111.2%
2031	94'546	10'000	0	84'546	15'218	69'328	132'275	123.6%
2032	94'546	10'000	0	84'546	15'218	69'328	201'603	135.9%
2033	94'546	10'000	0	84'546	15'218	69'328	270'931	148.3%
2034	94'546	10'000	0	84'546	15'218	69'328	340'258	160.7%
2035	94'546	10'000	0	84'546	15'218	69'328	409'586	173.0%
2036	94'546	10'000	0	84'546	15'218	69'328	478'913	185.4%
2037	94'546	10'000	0	84'546	15'218	69'328	548'241	197.7%
2038	94'546	10'000	0	84'546	15'218	69'328	617'568	210.1%
2039	94'546	10'000	0	84'546	15'218	69'328	686'896	222.4%
2040	94'546	10'000	0	84'546	15'218	69'328	756'223	234.8%
2041	94'546	10'000	0	84'546	15'218	69'328	825'551	247.2%
Total	1'890'916	200'000	0	1'690'916	304'365	1'386'551	825'551	247.2%

The return on investment for İzmir province is 8.1 years.

Table 5.12 Results of the economic study in İzmir in $

	Electricity sale	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2022	92'225	10'000	0	82'225	14'801	67'425	-493'575	12.0%
2023	92'225	10'000	0	82'225	14'801	67'425	-426'151	24.0%
2024	92'225	10'000	0	82'225	14'801	67'425	-358'726	36.1%
2025	92'225	10'000	0	82'225	14'801	67'425	-291'301	48.1%
2026	92'225	10'000	0	82'225	14'801	67'425	-223'877	60.1%
2027	92'225	10'000	0	82'225	14'801	67'425	-156'452	72.1%
2028	92'225	10'000	0	82'225	14'801	67'425	-89'027	84.1%
2029	92'225	10'000	0	82'225	14'801	67'425	-21'603	96.1%
2030	92'225	10'000	0	82'225	14'801	67'425	45'822	108.2%
2031	92'225	10'000	0	82'225	14'801	67'425	113'246	120.2%
2032	92'225	10'000	0	82'225	14'801	67'425	180'671	132.2%
2033	92'225	10'000	0	82'225	14'801	67'425	248'096	144.2%
2034	92'225	10'000	0	82'225	14'801	67'425	315'520	156.2%
2035	92'225	10'000	0	82'225	14'801	67'425	382'945	168.3%
2036	92'225	10'000	0	82'225	14'801	67'425	450'370	180.3%
2037	92'225	10'000	0	82'225	14'801	67'425	517'794	192.3%
2038	92'225	10'000	0	82'225	14'801	67'425	585'219	204.3%
2039	92'225	10'000	0	82'225	14'801	67'425	652'644	216.3%
2040	92'225	10'000	0	82'225	14'801	67'425	720'068	228.4%
2041	92'225	10'000	0	82'225	14'801	67'425	787'493	240.4%
Total	**1'844'504**	**200'000**	**0**	**1'644'504**	**296'011**	**1'348'493**	**787'493**	**240.4%**

Although Although the sun is a worldwide available energy source, Earth latitude greatly affects the amount of energy collected by modules. The greater the latitude, the lower the amount of solar energy collected. When we look at the examination we made about the orientation of solar panels without using batteries, the table shows the highest production capacity in all three cities at 30° in the table from 10 to 13.

In addition, in the study, 2 different types of operation were compared for 3 different cities. If we discuss in order;

We can start by looking at the situation in which the battery will discharge as the energy need arises. With its geographical structure, Adıyaman city has transferred 2062.6 MWh of energy annually to the system. Having the same conditions, İzmir province produced 1965.2 MWh and Konya province 1948.7 MWh annual production. Here, the advantage brought by the battery was used with the continuous completion of the 600 kW limit. Again, when we look at the economy in the same operation, it is seen that the investment made after 7.7 years pays off for Adıyaman province, when the annual tax rate is deducted from the electricity sales of almost 100 thousand dollars per year. Again in the same parameters, İzmir shows 8.1 and Konya 8.3 years.

When we look at the situation where the battery is discharged after the sun goes down; Adıyaman province seems to be superior to the other 2 cities with an annual production of 1897 MWh. In the economic evaluation, the return on investment is seen as 7.5 years.

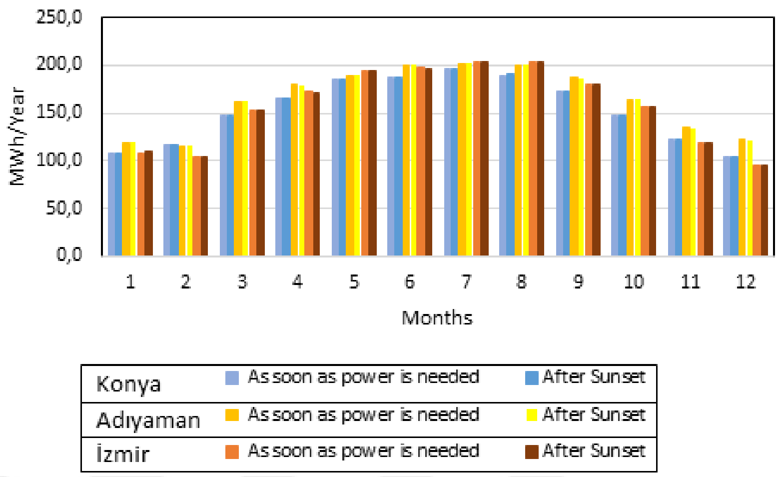

Figure 5.1 Change of annual energy production of 3 different cities by months with scenarios

The fact that the solar potential of Adıyaman is more in the study conducted here shows that this city is advantageous compared to the other two cities. In addition, if the peak tariff is used, it is seen that the battery discharge work is more efficient in the hours after the sun goes down. Therefore, when we examine the Figure 5.1, the choice of operation performed in Adıyaman province and after sunset seems to be the ideal choice

CHAPTER 6

CONCLUSIONS

One of the goals of the aforementioned future policies is to achieve near-zero energy systems, where energy from conventional sources accounts for approximately 30% of the total world energy. In the early days, reducing the need for energy from traditional sources such as fossil fuels can help achieve these goals. Thanks to this document, we can say that a future without a deep dependence on fossil fuels is possible, but the benefits of implanting these alternative technologies need to be increased.

In this context, battery simulations in the grid system were carried out by determining the number, type and characteristics of solar modules and compared the amount of energy obtained in each case. Another line of work would be to determine the amount of energy desired to be obtained and to calculate from it the number of modules and their size required to meet that demand. Results from the grid system, as might be expected. confirmed that the theoretical optimum 30° slope is the optimum slope for tree cities.

Table 4.4 and 4,5 previously show that Different battery operation in different cities may produce different results. In this case, the necessary work should be done by considering the geographical conditions of each city and the climatic conditions.

Hence, The work to be done in a facility to be established in the city of Konya should be the operation of the battery whenever power is needed. In addition, transferring the energy stored in Adıyaman and İzmir during the day to the system at night will create an efficient operation.

With the development of technology and the country's economy reaching the desired points, battery costs will come to much more attractive points. Especially in recent years, when air pollution, where the CO2 value has increased, causes climate change, the increase of such studies will be a great gain for our country. Considering this study, my preference is to establish a facility in Konya in terms of its geographical structure.

Finally, it can be said that our work can be used efficiently in studies to be carried out for self-consumption in a facility with an instantaneous energy consumption of 600 kW. In a country like Turkey, which has an efficient geographical structure in the field of sun, such studies should be expanded and their applications should be supported.

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