MARMARA UNIVERSITY
FACULTY OF ENGINEERING

Analysis and Design to Meet the Energy Needs of a House on Istanbul Adalar with Renewable Energy Sources

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GRADUATION PROJECT REPORT

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Analysis and Design to Meet the Energy Needs of a House on Istanbul Adalar with Renewable Energy Sources

by

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January 2024 **Sezer Aktaşlı, Ekrem Doruk, Oğuzhan Duyar**

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ABSTRACT

Analysis and Design to Meet the Energy Needs of a House on Istanbul Adalar with a Solar-Wind Turbine Hybrid System

Aiming to meet the heating, cooling, and electrical energy needs of a four-member family's house on Adalar with solar and wind energy, the intention is to fulfill the energy requirements through an off-grid and hybrid system at the most affordable price while preserving the environment. The system's design, analysis, optimization, and cost analysis were conducted, revealing economic gains observed in the long term compared to a conventional home meeting its energy needs from the grid. Moreover, our hybrid system, with its environmentally friendly structure, will provide a healthier atmosphere for future generations. Optimization is performed to design the optimal number of solar panels, wind turbines, batteries, and inverters at the most favorable cost. These values are input manually based on pricing and energy quantities. For our hybrid system, we considered the average wind speed, sunlight durations, and the average solar energy on Adalar. If there is an energy input above the average, we opted for a battery to store the excess energy. In cases where the energy input is below average, our goal is to use energy from the storage.

ABBREVIATIONS

MGM: Meteoroloji Genel Müd.

TS-825 : Thermal Insulation Rules in Buildings

SYMBOLS

Q_1 = Convection Heat Load (kW)
U = Heat Transfer Coefficient (W/m^2K)
A = Wall Surface, Roof Surface, Floor Surface Area (m^2)
ΔT = Outdoor Temperature – Indoor Temperature
Q_2 = Internal Heat Load (kW)
N = Number of Person
C = Heat Loss per hour per person
Q_3 = Air Heat load (kW)
m = Mass of Air (kg)
Cp = Specific heat (J/kgK)
V_p = Air Volume for four people (m^3/h)
$\dot{V}_t$ = Volume flow rate (m^3/h)
ρ = Density of air (kg/m^3)
$\dot{m}$= Mass flow rate (kg/h)
Q_{Air} = Air Load (kW/h)
Q_{SR}= Solar Radiation Heat Load (kW)
Q_W= Walls Heating Load (kW)
Q_R= Roof Heating Load (kW)
Q_F= Floor Heating Load (kW)
$Q_{W,D}$= Windows and Doors Heating Load (kW)
Q_P= People Heating Load (kW)
Q_G= Gadget Heating Load (kW)
Q_T= Total Heating Load (kW)

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2 INTRODUCTION

As the demand for energy sources increases in today's world, the growing awareness of the limited and harmful nature of fossil fuels has led to an increasing interest and investment in green energy sources. In this context, European countries, especially, have been pioneers in the field of photovoltaic and wind energy systems. These sources are of great importance for environmental preservation due to their sustainability, renewability, and eco-friendly nature.

This study will examine the green energy potential and feasibility of Adalar. The applications of photovoltaic and wind energy systems in European countries, as well as the incentive mechanisms, will be integral parts of this research. Additionally, the practices and incentive mechanisms in Turkey in this field will also be addressed.

Photovoltaic and wind energy systems are expected to play a significant role among future energy sources. This study is designed to enhance the understanding of Adalar's green energy potential and create awareness about the feasibility of sustainable energy sources.

2.1 General Information

2.1.1 Photovoltaic Energy Systems

Photovoltaic systems can be divided into several different types. Here are the most common types of photovoltaic systems:

1. Grid-Connected Photovoltaic Systems
2. Stand-Alone Photovoltaic Systems
3. Hybrid Photovoltaic Systems
4. Portable Photovoltaic Systems

These are just a few examples of photovoltaic systems and there are many different systems available in different sizes and capacities.

Grid-Connected Photovoltaic Systems

Grid-connected photovoltaic systems are used to provide solar energy to buildings such as homes and businesses. These systems use solar energy generated to meet the electricity needs of homes or businesses and can also draw electricity from the grid when needed. Since these systems are connected to the grid, they can also function as a production system that can sell excess electricity back to energy companies.

Figure 1-Grid Connected Photovoltaic System Application Example

Grid-connected systems have several advantages such as helping homeowners or business owners reduce their electricity bills, benefiting from a sustainable energy source by using solar energy, causing less harm to the environment, and being able to provide electricity even in case of power outages. However, the disadvantages of these systems include that they may become unusable in case of power outages since they are connected to the grid and that there may be high costs for system installation and maintenance.

GCPS consists of photovoltaic (PV) panels. PV panels are devices that directly convert sunlight into electrical energy. The photovoltaic cells on these panels release electrons when exposed to sunlight. These electrons produce current by passing through a series of connections.

GCPS is connected to electrical grids used in homes or businesses using this electrical current. These networks combine with electrical currents from other sources in the electrical grid. Thus, homes or businesses can also receive electricity from the grid along with solar energy or return excess energy to the grid if there is excess energy in the grid. An inverter is generally used in GCPS. This device converts DC electrical current into AC current used in homes or businesses. The inverter also performs electronic control operations required for the system to receive or give energy from/to the grid.

GCPS provides an economic and environmentally friendly way to produce electricity using solar energy in homes and businesses. In addition, GCPS can contribute to energy savings by feeding back into the energy grid when it produces excess energy.

Stand-Alone Photovoltaic Systems

Independent photovoltaic systems are systems that operate independently of the grid. They are generally used in rural or remote areas and are used to meet the electricity needs of people who live without electricity grids. These systems help users meet their energy needs by loading energy produced by solar energy panels into storage devices such as batteries.

The advantages of independent photovoltaic systems include that they are not affected by power outages since they are not connected to the grid, that they are an environmentally friendly energy source, and that they allow energy to be loaded into storage devices such as batteries to meet users’ energy needs. The disadvantages of these systems may include high installation costs, limited battery life, battery maintenance requirements, and limited energy storage capacity.

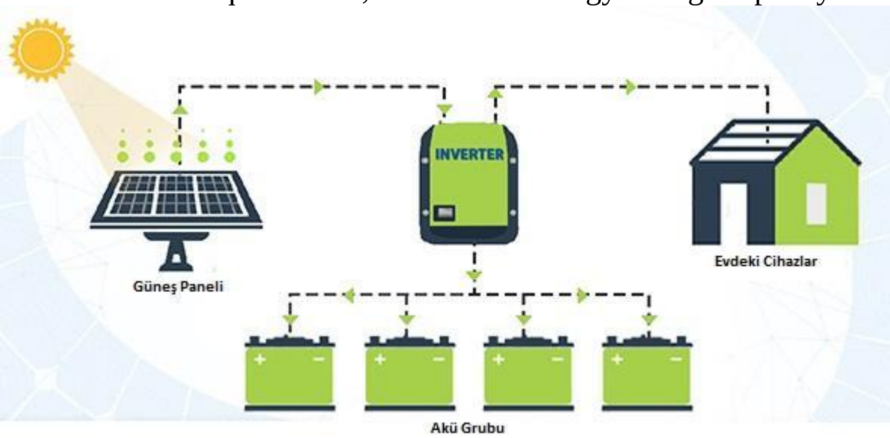


Figure 2-Standalone Photovoltaic System Application Example

A SAPS consists of photovoltaic (PV) panels, batteries, and a controller. PV panels are devices that directly convert sunlight into electrical energy. The photovoltaic cells on these panels release electrons when exposed to sunlight. These electrons produce current by passing through a series of connections.

Batteries are used to store the electricity produced. Thus, when enough energy is collected from sunlight, it can be stored on the batteries. This energy can then be used for storage purposes for later use.

Controllers are used to prevent batteries from overcharging or discharging while the energy from PV panels is stored in batteries. Controllers also ensure that the energy produced by PV panels while charging the batteries is safely stored by monitoring the charging status of the batteries.

Inverters can be used in SAPSs to convert DC current into AC current used in homes or businesses and to perform electronic control operations required for the system to be used in homes or businesses without being connected to grid electricity.

Independent photovoltaic systems provide an economic and environmentally friendly way to produce electricity using solar energy in homes and businesses. They also offer an ideal solution for meeting the electricity needs of people living in remote or rural areas.

Hybrid Photovoltaic Systems

Hybrid photovoltaic systems are used to take advantage of other renewable energy sources such as solar energy and wind energy. These systems allow for more stable energy production by combining both sources. These systems help meet energy needs by combining energy produced by solar energy panels and wind turbines when needed.

The advantages of hybrid photovoltaic systems include providing more stable energy production by taking advantage of different renewable energy sources, being environmentally friendly, and providing energy independence. However, the disadvantages of these systems may include high installation and maintenance costs, system complexity, and energy storage problems.

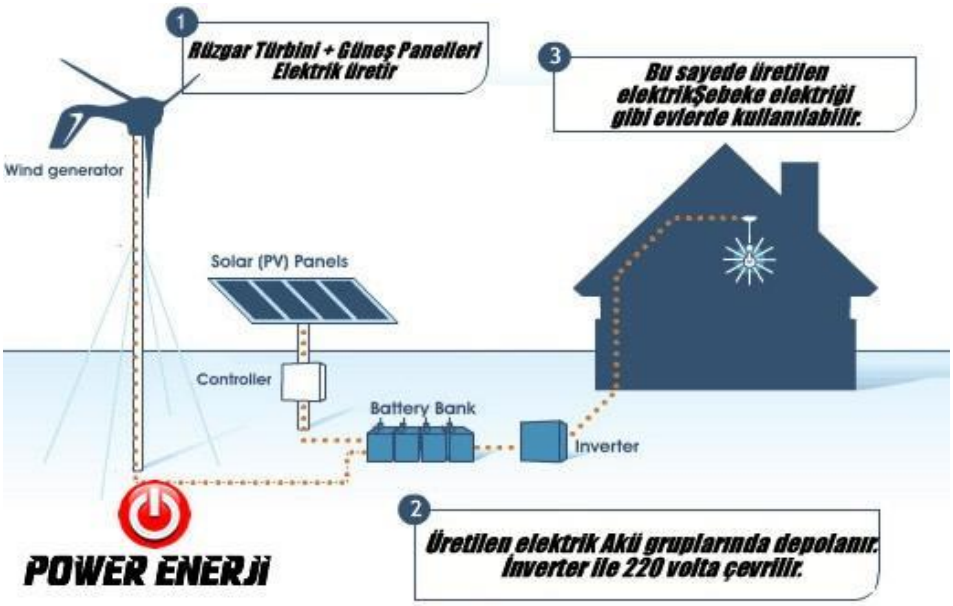


Figure 3-Hybrid Photovoltaic System Example

A hybrid photovoltaic system consists of photovoltaic (PV) panels, a wind turbine or hydraulic turbine, batteries, and a controller. PV panels are devices that directly convert sunlight into electrical energy. Wind or hydraulic turbines convert the kinetic energy of wind or water flow into electrical energy.

In addition to PV panels, energy produced by wind or hydraulic turbines can also be stored in batteries. Thus, when enough energy is collected from energy sources such as sunlight or wind, it can be stored on the batteries. This energy can then be used for storage purposes for later use.

Controllers are used to prevent batteries from overcharging or discharging while the energy from PV panels and wind or hydraulic turbines is stored in batteries. Controllers also ensure that the energy produced by PV panels and wind or hydraulic turbines is safely stored by monitoring the charging status of the batteries.

Inverters can be used in hybrid photovoltaic systems to convert DC current into AC current used in homes or businesses and to perform electronic control operations required for the system to operate connected or disconnected from grid electricity.

Hybrid photovoltaic systems provide a more reliable and sustainable energy source by taking advantage of multiple renewable energy sources such as solar, wind, or hydraulic energy. In addition, using these systems reduces electricity costs and provides an environmentally friendly energy source.

Portable Photovoltaic Systems

Portable photovoltaic systems are used to meet the electricity needs of people who travel or spend time outdoors. These systems include portable components such as small-sized solar panels, batteries, and other electronic devices. Portable photovoltaic systems are a suitable energy source for outdoor activities such as camping, caravans, boats, and RVs.

The advantages of portable photovoltaic systems include being portable and meeting energy needs while traveling, being environmentally friendly, and having low maintenance costs. Disadvantages may include limited energy storage capacity, limited energy production due to their small size, and the need for sufficient sunlight to produce enough energy.

Figure 4-A Portable Battery Charged by Solar Energy

These systems are a few examples of solar energy-based energy production technologies. Each system is designed for different needs and offers different advantages and disadvantages. Which system to use may vary depending on the application and needs.

Portable photovoltaic systems consist of several basic components: photovoltaic (PV) panels, a charge controller, batteries, and an inverter. PV panels produce electrical energy from sunlight. The charge controller manages the storage of energy from PV panels in batteries and is used to prevent batteries from overcharging or discharging. Batteries store energy from PV panels or charge controllers and provide electrical energy. The inverter converts DC current into AC current used in homes or businesses.

Portable photovoltaic systems can be used for many different purposes due to their small size and portability. You can charge devices by using them for camping, caravans, or boats or provide direct electrical energy. They can also be used in emergency or disaster situations.

2.1.2 Wind Energy Systems

Wind energy is a renewable source used to generate electricity and is typically collected using wind turbines or wind generators. Wind turbines are devices that convert wind energy into mechanical energy. Wind generators work with alternators that convert mechanical energy into electrical energy.

The systems used in wind energy are as follows:

1. Horizontal Axis Wind Turbines
2. Vertical Axis Wind Turbines
3. Wind Farms
4. Air Compressors
5. Wind Pumps

<u>Horitzonal Axis Wind Turbines</u>

Horizontal axis wind turbines are the most common wind turbines. These types of turbines consist of three main components: rotor (blades), generator and body.

The rotor consists of many blades stacked on top of each other and generates mechanical energy by rotating around the wind. This mechanical energy is transferred to the generator through a transmission.

Figure 5-Horizontal Axis Wind Turbines

The generator is like a motor that produces electrical energy. Magnetic fields are created as the rotor rotates, and these magnetic fields produce electrical power in the stator surrounded by a series of coils.

The body is the structure that holds the rotor and generator and is the basis of the wind turbine. The body also includes tail and direction control mechanisms that adjust the direction and angle of the turbine.

Wind turbines work most efficiently with the right wind speed and direction. As wind speed increases, the turbine produces more energy, and production decreases as speed decreases. Wind turbines are considered a clean energy source that does not harm the environment to produce electricity.

<u>Vertical Axis Wind Turbines</u>

Vertical axis wind turbines are a different type of turbine than horizontal axis turbines, where the blades rotate around the vertical axis instead of the horizontal axis. These types of turbines usually have blades placed at right angles to each other.

Vertical axis wind turbines may be less efficient than horizontal axis turbines, but they also have advantages. For example, they can work with less wind energy and perform better as the wind direction changes.

They may also be more suitable for some applications due to lower construction costs and less space requirements.

Vertical axis wind turbines typically consist of three main components: rotor, generator, and pole. The rotor consists of many blades mounted perpendicular to each other on a vertical shaft. The wind causes the blades to rotate, and this rotational motion is transferred to the generator on the vertical shaft.

Figure 6-Vertical Axis Wind Turbines

The generator is like a motor that produces electrical energy. Magnetic fields are created as the rotor rotates, and these magnetic fields produce electrical power in the stator surrounded by a series of coils.

The pole is a structure that determines the height of the turbine and holds the rotor and generator. It also includes direction control mechanisms that allow the turbine to rotate according to the wind direction.

The production efficiency of vertical axis wind turbines varies depending on wind speed and direction. Higher wind speeds produce more energy while lower wind speeds produce less energy. Wind turbines are considered a clean and sustainable energy source and can be used to produce electricity without harming the environment.

Wind Farms

Wind farms are wind energy plant created by large groups of wind turbines. Wind energy plants are used for electricity production and typically consist of turbines with capacities ranging from 100 kW to 7.5 MW. These fields are usually located in places where the wind blows frequently, such as coastal areas or open land.

Wind farms use horizontal axis wind turbines where energy is mechanically generated by wind hitting the turbine blades. The turbines in wind farms are equipped with a rotor with rotating blades affected by the wind. The rotor rotates a generator attached to a shaft, and this generator produces electricity. This electricity is usually transported from the grid to a remote location through a transformer connected to the grid.

Figure 7-Wind Farms

Wind turbines work if the wind speed is above a certain threshold. This threshold is usually a low wind speed such as 3-4 m/s. As the wind speed increases, the turbine blades rotate faster and produce more electricity. However, very high wind speeds can also damage the turbine, so wind turbines are usually stopped at very high wind speeds.

Wind farms are a highly effective and efficient method for generating electricity. Wind energy is a sustainable resource, so wind farms can produce electricity without harming the environment. However, the location of wind energy plants can also bring some environmental and social issues, so these issues should be considered during the planning and implementation of wind energy projects.

Air Compressors

Air compressors can be used as an option between electrical energy storage systems in wind energy production. Air compressors compress air using the energy produced by wind turbines and store it in high-pressure air storage tanks. Later, this high-pressure air stored can be used to produce electrical energy.

Air compressors are available in various designs, but the most common design used in wind energy production is a piston compressor. Piston compressors compress air using a piston driven by an engine. Wind turbines compress air by directly connecting to piston compressors and using the energy obtained from the rotational motion of rotors. The compressed air is then transferred to high-pressure air storage tanks and stored there. Later, stored air is used to produce electrical energy. The air in high-pressure air storage tanks flows towards pressure air turbines used to rotate turbines. These turbines capture the flow of high-pressure air and transfer it to a generator to produce electrical energy.

Wind Pumps

Wind pumps are mechanical devices used to lift or pump water using wind energy. They are usually used for extracting water from wells or other water sources. Wind pumps are available in various designs, but the most common design is a typical design where a rotor rotating with wind power is combined with a pump cylinder.

Wind pumps convert wind energy into mechanical energy and this mechanical energy is used by a pump that pushes water upwards. The working principle of wind pumps is quite simple. When the wind hits the blades of the turbine, the turbine starts to rotate and moves a shaft. This movement is combined with a pump cylinder and this cylinder converts the movement into vertical movement. This vertical movement is used by a piston to push the water.


Figure 8-Wind Pumps

The piston moves inside the pump cylinder and pushes the water upwards. The water is transported through a pipe or another channel and directed to a reservoir or water well. Later, the water can be used for an area that needs it. Wind pumps are a reliable method for extracting and pumping water using only wind energy without solar energy or electrical energy. This is a useful solution for accessing water sources, especially in remote areas or where the electrical energy infrastructure is weak. However, wind pumps can be limited in terms of efficiency since wind is not constant. Wind pumps can only work when there is wind and sometimes an alternative method may be needed to pump water when there is not enough wind.

3 MATHERIAL AND METHOD

Due to the fast-growing industry and the increasing population, the use of longer-lasting renewable energies has increased to provide the increasing energy need. The possibility of running out of fossil fuel, which is non-renewable energy, and increasing environmental pollution also increase the need for renewable energy. Wind and photovoltaic energies are also examples of inexhaustible renewable energy.

3.1 Photovoltaic Applications

Photovoltaic energy systems are becoming increasingly popular due to their low maintenance costs, environmental friendliness, and long life. Photovoltaic energy systems can be used in homes, businesses, and industrial facilities. Photovoltaic energy applications are quite common around the world. For instance, Germany, China, USA, Japan, and Italy are among the largest producers of photovoltaic energy in the world. Photovoltaic energy systems are also used in space research, traffic signaling and communication systems, tents, jackets, textile materials and concentrators.

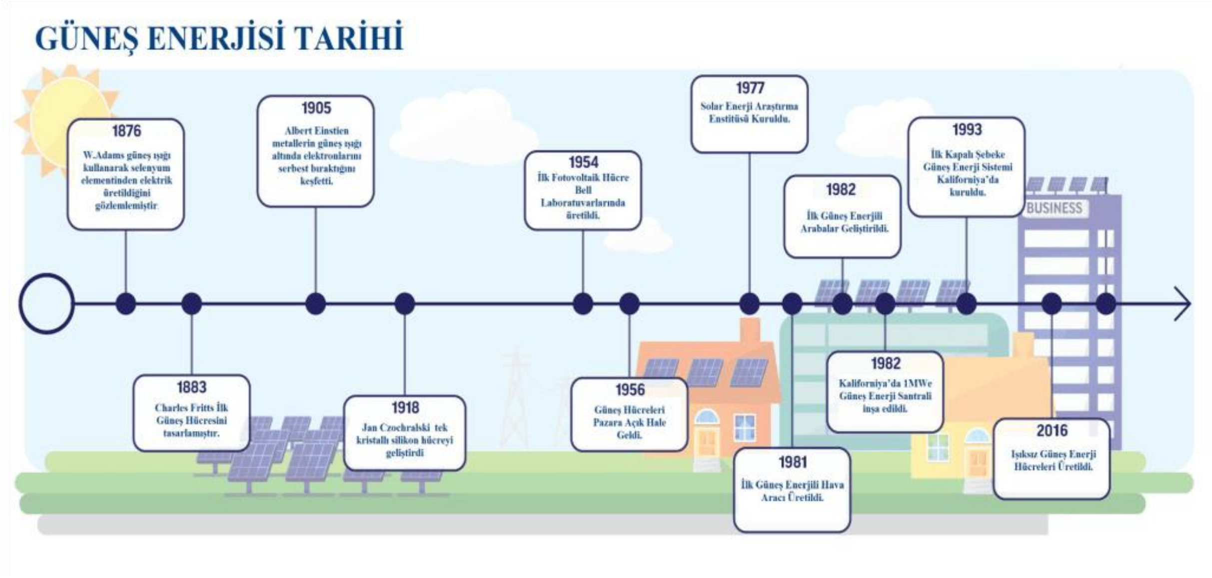
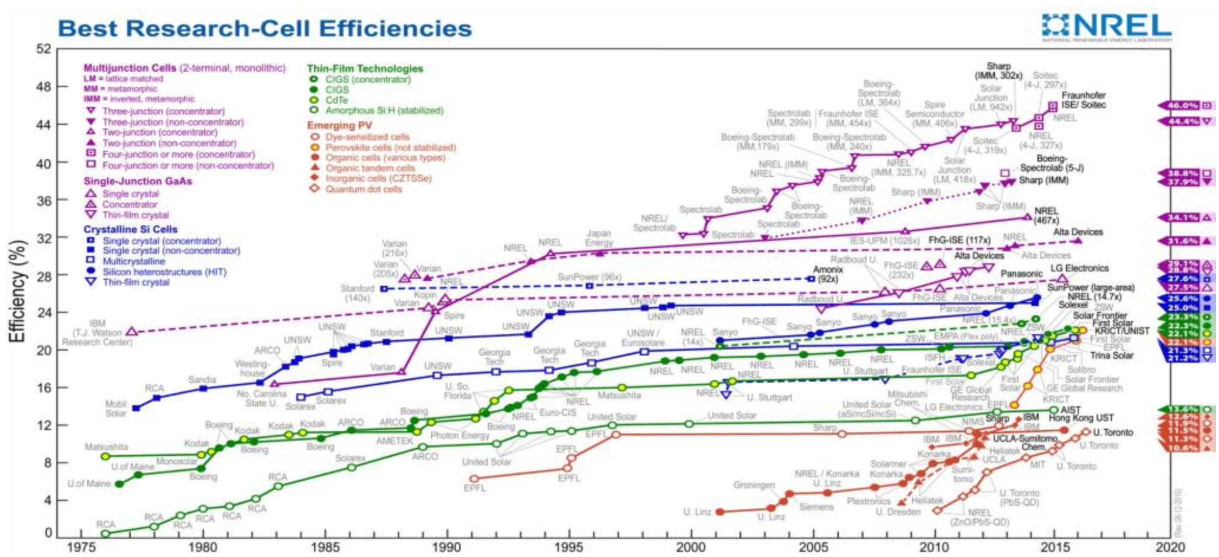


Figure 9-History of Solar Energy 1876-2016



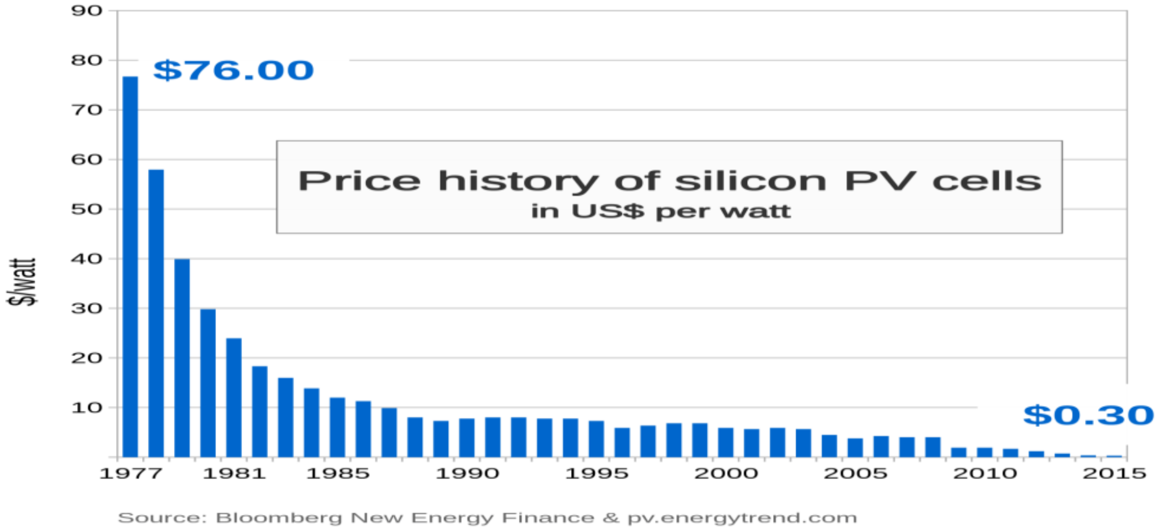
Graph 1-Efficiency of Solar Cells-Photovoltaic (PV) Between 1976-2020

Installed solar capacity in the world reached 509 GW as of the end of 2018; 34% of this capacity is in China (173 GW); 12% at USD (61GW); 11% in Japan (56GW); 9% in Germany (46GW); 5% is in India (26GW).

More than 100GW of new capacity is added to this installed capacity every year; It will be added in 2023; It is expected that the top 10 countries in 2023 will be listed as follows:

1. China 448GW
2. USA 132GW
3. India 116GW
4. Japan 82GW
5. Germany 72GW
6. Australia 45GW
7. Italy 29GW
8. Spain 25GW
9. South Korea 24GW
10. France 22GW

Turkey is expected to reach 10.5GW capacity in 2023. As of the end of July 2019, the installed capacity in Turkey reached 5.4GW; Of the 5 GW capacity to be added in 4 years, 2GW will be land applications; It is expected that 3GW will be from rooftop solar systems.



Graph 2-Cost Change of Solar Cells-Photovoltaic (PV) 1977-2015

FIGURE 15 TOP GLOBAL SOLAR PV MARKETS' PROSPECTS

	2018 Total Capacity (MW)	2023 Total Capacity Medium Scenario by 2023 (MW)	2019 - 2023 New Capacity (MW)	2019 - 2023 Compound Annual Growth Rate (%)	Political support prospects
China	175 131	448 131	273 000	21%	
India	27 347	116 106	88 759	34%	
United States	62 127	132 426	70 299	16%	
Australia	12 560	45 236	32 676	29%	
Germany	45 920	72 611	26 692	10%	
Japan	55 851	82 351	26 500	8%	
Spain	5 915	25 367	19 452	34%	
South Korea	7 742	24 768	17 026	26%	
Netherlands	4 181	20 059	15 878	37%	
Mexico	3 580	19 010	15 430	40%	
France	8 920	22 259	13 339	20%	
Saudi Arabia	19	11 412	11 393	260%	
Brazil	2 346	12 505	10 159	40%	
Italy	19 877	29 498	9 621	8%	
Taiwan	2 739	12 074	9 335	35%	
Pakistan	1 720	8 381	6 660	37%	
Ukraine	2 004	7 963	5 959	32%	
Turkey	5 062	10 562	5 500	16%	
United Arab Emirates	720	6 132	5 412	53%	

Figure 10-Development of Solar Energy - Photovoltaic (PV) Systems in the World

3.1.1 Photovoltaic Applications in Turkey

Photovoltaic applications in Turkey have been developing rapidly in recent years. Especially in the last five years, the number and capacity of photovoltaic power plants have increased significantly.

Turkey’s solar radiation intensity is quite high, and this provides an ideal environment for photovoltaic energy systems. Throughout the country, especially the Marmara, Aegean, Mediterranean and Southeastern Anatolia regions stand out in terms of solar energy potential.

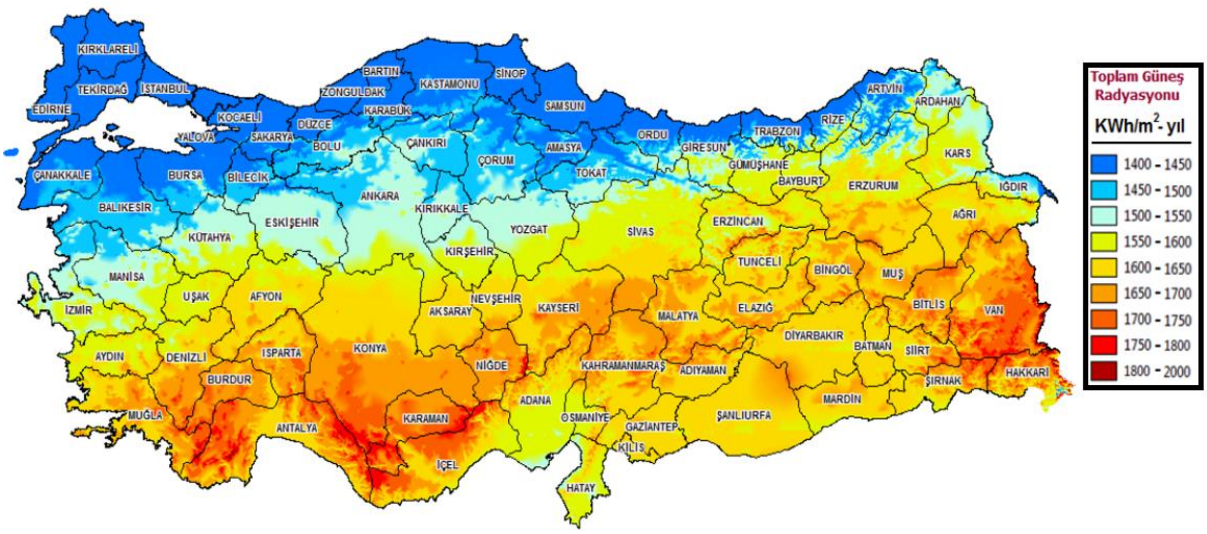
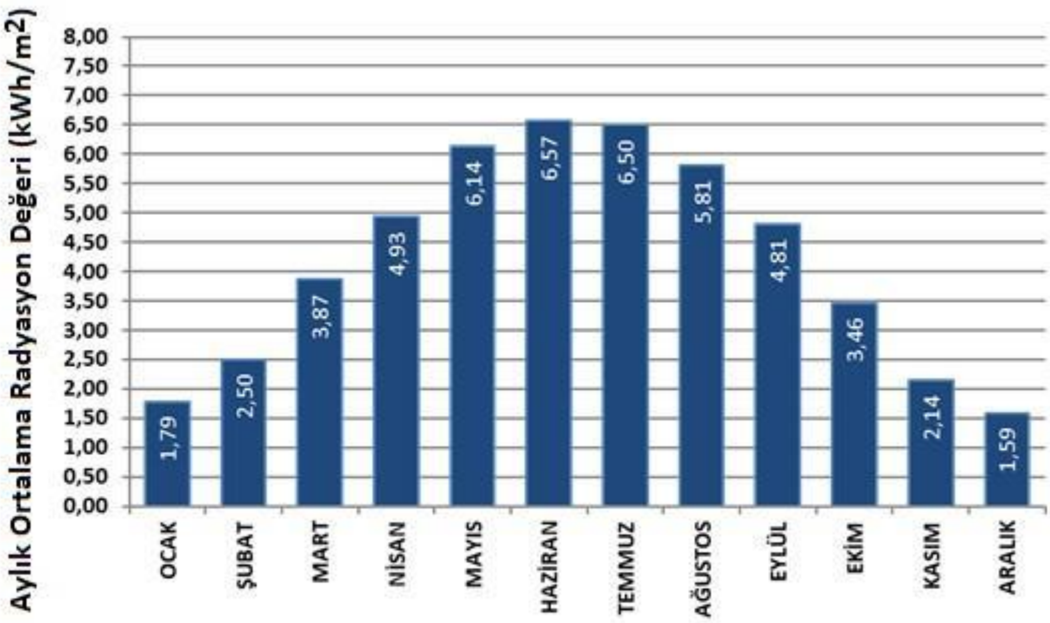


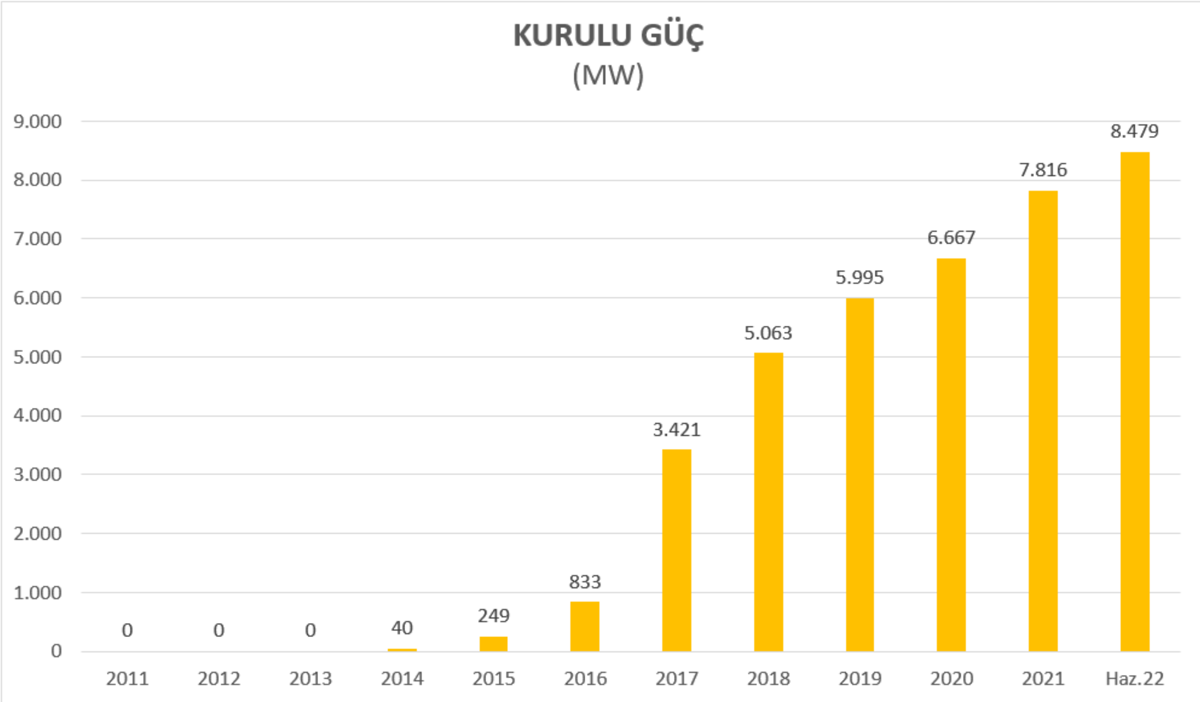
Figure 11-General potential outlook of Turkey and monthly average global radiation distribution

Today, there are photovoltaic power plants in many cities in Turkey. Most of these are large-scale power plants established with the support of the state. Approximately 4% of Turkey's installed power is obtained from photovoltaic energy. Turkey's photovoltaic energy capacity is over 8.5 GW, and it is aimed to increase this figure to 34 GW by 2030.

In Turkey, small-scale photovoltaic systems designed for individual use are also becoming widespread. Small-scale photovoltaic systems used in homes, workplaces, schools, and hospitals both reduce energy costs and encourage the use of an environmentally friendly energy source.



Graph 3-Turkey's monthly average radiation value



Graph 4-Turkey's installed power obtained from total solar energy.

In conclusion, photovoltaic applications in Turkey are developing rapidly and considering the country's solar energy potential, it can be said that it has significant potential in terms of photovoltaic energy production.

3.2 Wind Energy Applications

Wind energy is an increasingly popular energy source around the world. Wind energy systems can be used in homes, businesses, and industrial facilities due to their low maintenance costs, environmental friendliness, and long life. Wind energy applications are quite common around the world.

For example, China, USA , Germany, Spain, India, UK, France, Italy, Canada, and Denmark are among the largest producers of wind energy in the world.

The potential for using wind energy in the world is quite high and is approximately 53000 TWh. This value is equivalent to approximately 53000000000000 kWh. Some of the leading regions in the world in wind energy use are: We can list them as Oceania, North America, Africa, Asia, Eastern Europe, and Russia. According to research, it has been observed that among these regions, Eastern Europe, Russia, Africa, and North America have more than half of the world's wind energy potential. Although research shows that Eastern Europe, Russia, Africa, and North America have the highest wind energy potential, later research has shown that this is not the case. The reason is the industry level in countries is not the same. According to the data and research conducted, the countries with the most wind energy power in the world, according to July 2014 data, can be listed as follows: China, USA, Germany, Spain, India. Afterwards, it varies according to the values of countries such as England, France, Italy, Canada, and Denmark.

3.2.1 Wind Energy Applications in Turkey

Wind energy applications in Turkey have also increased significantly in recent years. Our country's geographical structure provides an ideal environment for wind energy. Especially in the Aegean, Mediterranean and Marmara regions, the wind energy potential is quite high.

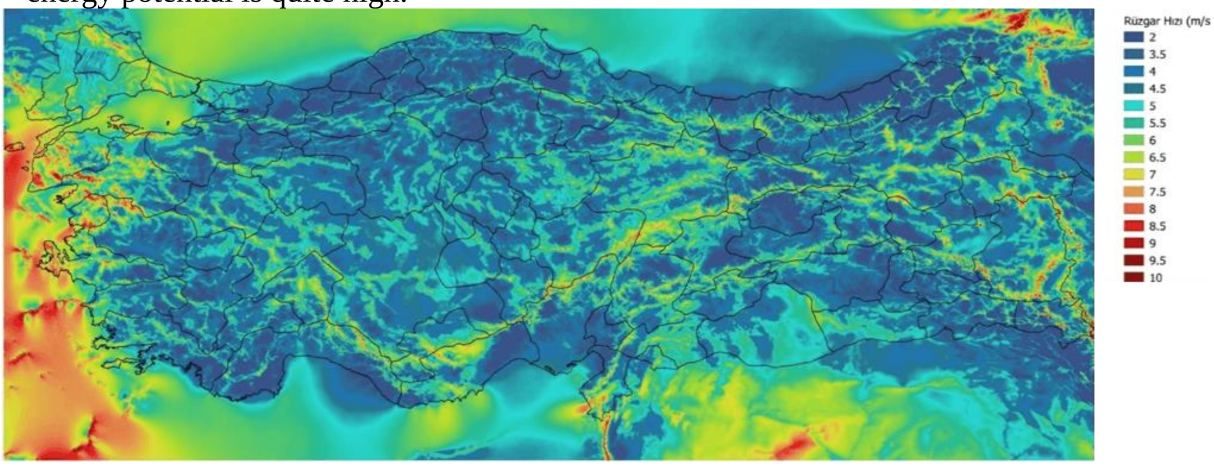
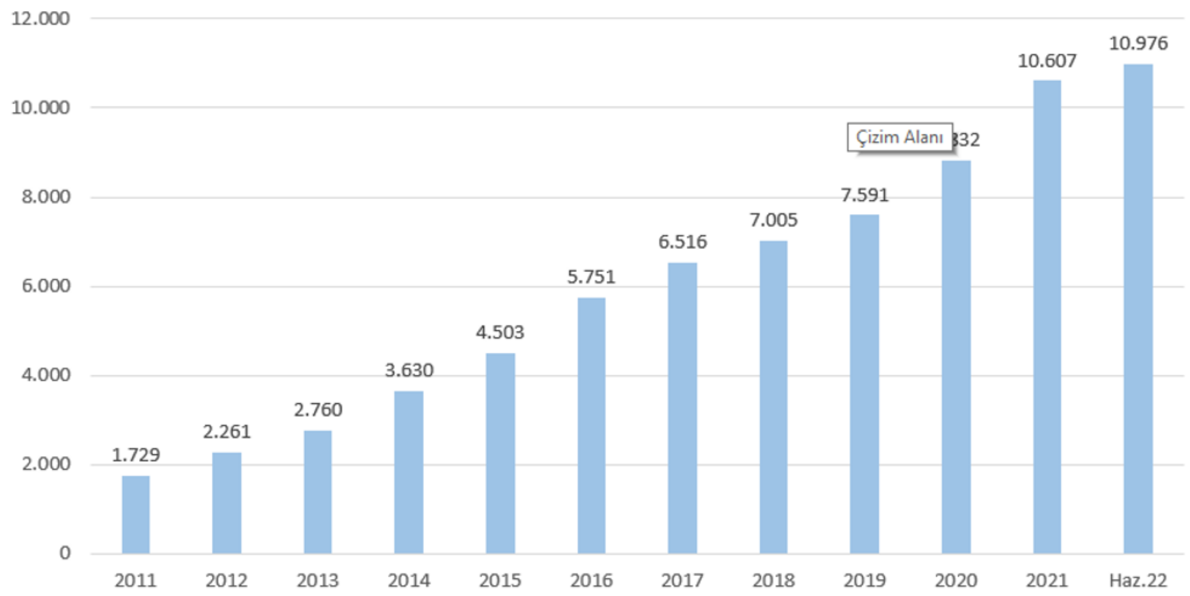


Figure 12-Map of Turkey's average wind speed

The wind energy sector in Turkey started to develop rapidly with the Renewable Energy Resources Support Mechanism (YEKDEM), which came into effect in 1998. YEKDEM is a mechanism that supports the production of renewable energy sources. Thanks to this mechanism, significant incentives are given by the state for wind energy investments and the growth of the sector is supported.

As of today, there are more than 90 wind energy power plants in Turkey and their total capacity is over 10 GW. Turkey ranks among the top 10 countries in Europe in terms of wind energy production.



Graph 5-Turkey's installed power based on wind energy (MW))

The wind energy sector in Turkey has been developing rapidly in recent years. Especially in 2020, 1.5 GW of wind energy capacity was commissioned. Turkey aims to increase its wind energy capacity to 20 GW by 2023.

In conclusion, the wind energy sector in Turkey is growing rapidly and the country's geographical structure provides a high potential for wind energy. With the support of investors and the state, the growth of the sector and sustainable energy production are aimed.

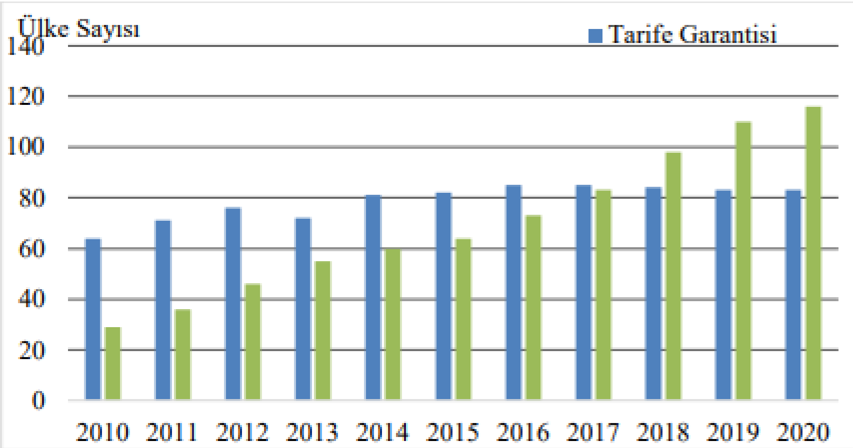
3.3 Incentives for Solar and Wind Energy Systems

There are various incentives for renewable energy systems, including photovoltaic, and wind energy systems, around the world. However, the specific incentives vary by country and region. For example, in the United States, the federal government offers tax credits for residential and commercial solar installations, as well as wind and geothermal systems. In Indonesia, fiscal incentives such as tax reduction, tax holiday, tax allowance, value-added tax reduction, and subsidy policy are used to support renewable energy deployment. Cyprus is also offering incentives for foreign businesses interested in investing in renewable energy.

Countries have adopted various incentive models in renewable energy policies in recent years. These incentives have positive effects on economic development, national income, social welfare, and the environment. Financial incentives, such as low-interest and long-term loans, environmental tax exemptions, value-added tax exemptions, and accelerated depreciation, are among the economic supports provided by lawmakers to practitioners in the production and consumption of renewable energy. Tax subsidies are a key component of these financial incentives and generally include carbon taxes, energy taxes, environmental tax exemptions, property tax exemptions, value-added tax exemptions, customs duty exemptions, withholding tax support, and corporate tax exemptions.

Studies conducted in the United States have observed that tax incentives and credit support have particularly increased the adoption of solar-powered renewable energy applications. Similarly, research in China has noted that tax incentive policies have accelerated the country's renewable energy industry. Finland became the world's first country to implement a carbon tax, followed by countries such as the Netherlands, Norway, Sweden, and Denmark. Other significant applications of incentive mechanisms include fixed guaranteed tariffs and premium guarantee incentives.

A purchase guarantee is provided for energy produced over 10-25 years with a fixed guaranteed tariff. On the other hand, a premium guarantee involves selling the produced energy to the market, with the price difference between the selling price and the market price taken as a premium. Different countries have implemented various tariffs and premium guarantee incentives. Additionally, investors are given the opportunity to sell excess electricity produced at a fixed guaranteed tariff.



Graph 6-The Number of Countries Implementing Tariff Guarantees and Auctions in Renewable Energy Between 2010 and 2020

Especially the number of countries participating in auctions in the field of renewable energy has shown a linear increase over the past decade. In 2020, the number of countries implementing tariff guarantees in renewable energy reached 83, while the number of countries participating in auctions was 116.

Germany, which holds a significant position in the field of renewable energy, generally implements financial incentives for renewable energy sources, classified as tax subsidies, tariff and premium guarantees, and tax regulations. Tax exemptions are also available for photovoltaic systems in Germany, with a 19% VAT exemption for commercial investors. Additionally, various investment incentives are applied in different regions. In Germany, a fixed purchase guarantee for solar energy systems is implemented at 9.23–13.50 € cents/kWh. The United States is the third-largest investor in renewable energy applications, following China and Germany. Renewable energy incentives in the U.S. can be broadly categorized as production tax credits, investment tax credits, operational and grant subsidies, and portfolio standards. One of the most significant incentives in the U.S. is the state tax exemptions, covering 30% of the installed system's costs.

India is one of the fastest-growing countries in the field of renewable energy, particularly in solar-powered systems. Financial incentives implemented in India include income tax deductions, accelerated depreciation, customs duty exemptions, capital benefits, tariff guarantees, obligations for renewable energy procurement, and tax advantages. Additionally, incentives are provided to produce photovoltaic panels and efforts to increase installed capacity for photovoltaic systems.

Brazil holds a significant position globally, particularly in the production of biodiesel and ethanol. Reduced value-added tax (VAT) is applied to the production and distribution of ethanol and biodiesel. There is a mandatory requirement for a minimum of 5% blending of biodiesel with diesel.

Algeria is the first African country to implement a tariff guarantee to promote the development of renewable energy technologies. Since 2014, a 20-year tariff guarantee has been initiated for solar photovoltaic systems and wind-powered renewable energy projects in Algeria.

3.3.1 Incentives in Turkey

The following information is available about incentives for Turkey's photovoltaic, and wind energy systems applications:

Law on the Use of Renewable Energy Sources for the Purpose of Generating Electricity (YEK Law)

The Law on the Use of Renewable Energy Sources for the Purpose of Generating Electricity is a law enacted in 2005 to encourage the generation of electricity from renewable energy sources in Turkey. The law aims to increase the use of renewable energy sources in the country, ensure energy supply security, support environmental protection, and reduce energy imports.

Under the law, electricity generation from renewable energy sources such as solar, wind, hydro, geothermal, biomass, sea wave and sea current is encouraged. These incentives include purchase guarantees, tax exemptions, investment deductions, credit facilities and license fee exemptions.

This law is an important step towards increasing the use of renewable energy sources in the country and meeting part of Turkey's energy needs from domestic sources. As a result, Turkey's energy supply security will increase, environmental pollution will decrease, and energy costs will decrease.

Renewable Energy Resources Support Mechanism (YEKDEM)

The Renewable Energy Resources Support Mechanism (YEKDEM) is a support mechanism created to encourage the use of renewable energy sources for electricity generation in Turkey.

YEKDEM was implemented with the "Law on the Use of Renewable Energy Sources for Electricity Generation" which came into force in 2011. Under the mechanism, electricity generated from renewable energy sources is purchased from producers at a special price tariff. This price tariff is determined based on the electricity generation costs of renewable energy sources.

The aim of YEKDEM is to increase energy supply security by encouraging the use of renewable energy sources, especially wind and solar energy, to reduce negative impacts on the environment, to increase the use of domestic resources and to reduce the foreign trade deficit in energy.

With the implementation of YEKDEM, there has been a significant increase in electricity production from renewable energy sources in Turkey. It has been announced that YEKDEM will be implemented by the end of 2020.

Renewable Energy Resources Areas (YEKA)

Renewable Energy Resources Areas (YEKA) are special areas opened for renewable energy production in Turkey. These areas are selected by considering certain criteria to ensure the most efficient use of renewable energy sources.

YEKAs are opened by the Ministry of Energy and Natural Resources and are generally used for large-scale projects. Different renewable energy sources such as wind, solar, and hydroelectric can be used in YEKAs. There are also various incentive mechanisms to support investments made in these areas.

Turkey’s first YEKA was opened in the field of wind energy in 2017. Since then, many renewable energy projects have been implemented through YEKAs.

Tax Exemption

There are certain tax exemptions for renewable energy investments in Turkey. With the "Law on the Use of Renewable Energy Sources for Electricity Generation" enacted in 2005, certain tax exemptions are provided to investors who generate electricity from renewable energy sources.

In this context, the VAT rate has been reduced to zero for the purchase of land and immovable properties required for the installation of photovoltaic and wind energy systems. In addition, 85% of the income generated after these investments are put into operation is exempt from tax.

Again, for renewable energy investments made with domestic production in Turkey, a VAT exemption of up to 50% of the investment amount is provided. In addition, certain tax exemptions are applied in the import of machinery and equipment used during the investment process.

All these tax exemptions have been regulated to make renewable energy investments more attractive and to encourage more investment in this field.

4 RESULTS

The main purpose of our research was to meet the energy required for electricity and heating-cooling of four families living on Adalar. Our first step in our research was to simulate a house and a prototype house. The simulation was performed for a residential single-family building made in traditional (brick) technology, which means that the walls are made of cellular concrete blocks. The area of the building was set as 225 m2(15x15), while the cubature was calculated at about 675 m3 (15x15x3).

The object included: living room with kitchen, two rooms, bathroom, and hall, and consisted of only ground floor. It was intended for the living of three or four people. The glazed surface of the building envelope (windows, balcony doors) was estimated at 24 m2. The technical parameters of the analyzed object meet all the necessary requirements. The building model and the plan is presented below.

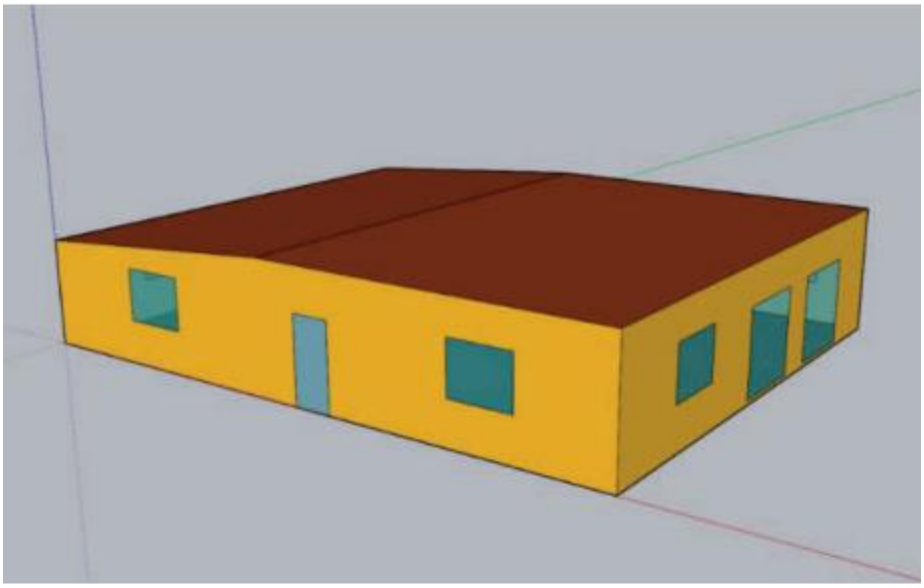


Figure 13-SketchUp model of the building.

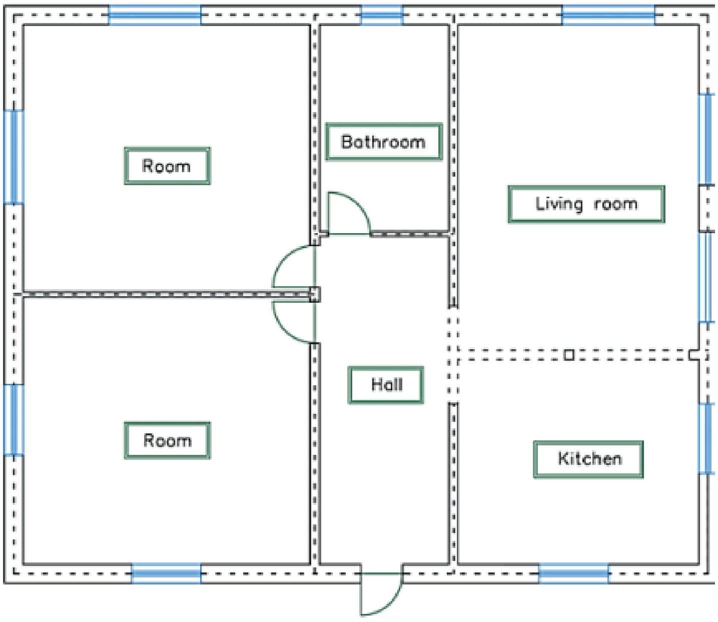
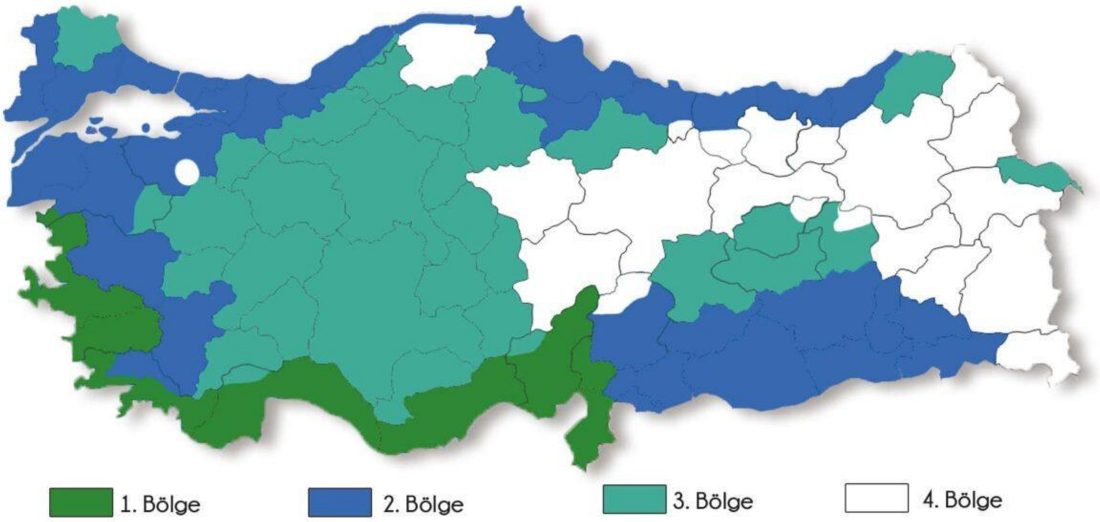


Figure 14-Ground floor plan of the building.

The building model was prepared in SketchUp and then applied to TRNBuild. The heat transfer coefficients (U) of the building, assuming that the walls and roof are insulated with 100mm of polyurethane, are accepted as follows:

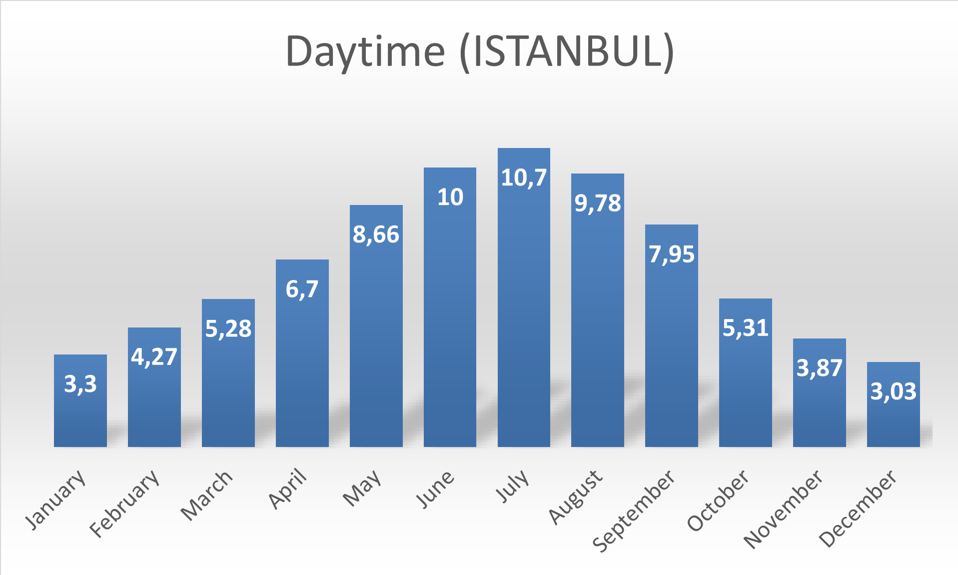


	U_{duvar} (W/m^2K)	U_{tavan} (W/m^2K)	U_{taban} (W/m^2K)	$U_{pencere}$ (W/m^2K)
1. Bölge	0,70	0,45	0,70	2,4
2. Bölge	0,60	0,40	0,60	2,4
3. Bölge	0,50	0,30	0,45	2,4
4. Bölge	0,40	0,25	0,40	2,4

Table 1-U-value requirements according to TS 825

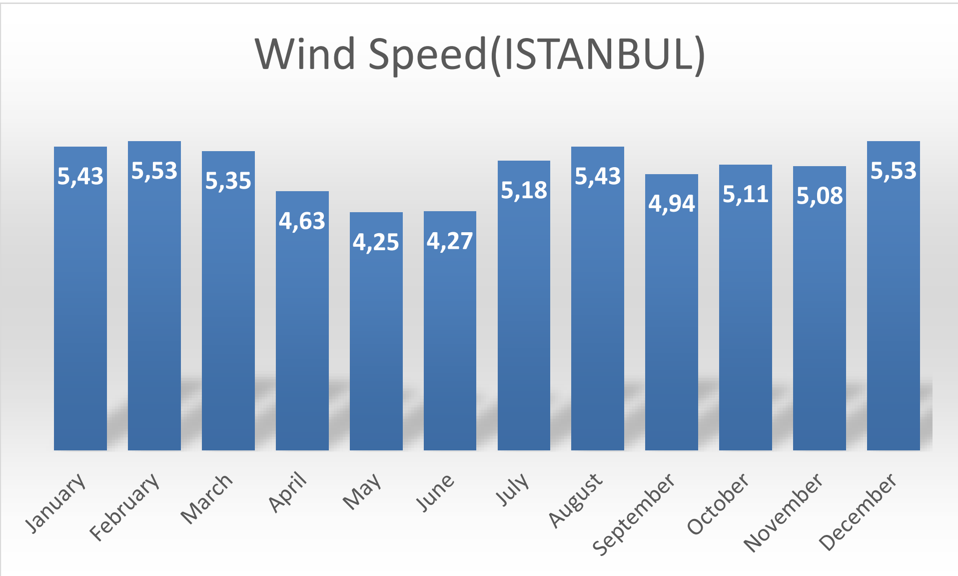
Since Istanbul is in the second region, the values number 2 in the table are taken as basis. The selected U values have been determined according to the TS 825 standard. The TS 825 standard defines calculation rules aimed at determining the heating energy requirements in buildings and comparing them with allowable limit values. It specifies minimum requirements for U values related to building roofs, facades, windows, and floor slabs based on different regions.

We, on the other hand, utilized these values to calculate the heating and cooling energy requirements from all aspects of our residence located in Zone 2, thereby determining the necessary energy quantity for our heat pump.



Graph 7-Daytime Time in Istanbul (hours)

The graph depicting solar exposure duration for our region is based on data from the Turkish State Meteorological Service. According to the Meteorological General Directorate, if solar radiation exceeds 120 W/m^2, solar exposure duration is measured using a device called a heliograph. This value is crucial for us, as the average measured solar exposure duration over a month allows us to estimate the average energy production of our solar panels during that period.



Graph 8-Wind Speed in Istanbul (m/s)

The graph above represents the wind energy data according to the General Directorate of Meteorology for our region. The speed of wind energy determines the rotation speed of wind turbines. Each wind turbine has a required wind speed for rotation, typically ranging between 1.5 m/s and 2.5 m/s.

There are specific speeds at which each wind turbine rotates optimally, generating maximum energy; this speed is usually around 12.5 m/s on average. When wind turbines generally exceed the optimum wind speed, some turbines may produce a constant amount of energy, while others may cease to generate energy.

For our region, the monthly average wind speed is crucial for selecting the appropriate wind turbine and calculating the amount of energy we can obtain from the wind turbine. Based on the monthly average data, all wind turbines should be able to rotate and generate energy in this region each month.

İSTANBUL	Ocak	Şubat	Mart	Nisan	Mayıs	Haziran	Temmuz	Ağustos	Eylül	Ekim	Kasım	Aralık	Yıllık
	Ölçüm Periyodu (1950 - 2022)												
Ortalama Sıcaklık (°C)	6.7	6.9	8.4	12.8	17.6	22.2	24.6	24.6	21.1	16.6	12.5	8.9	15.2
Ortalama En Yüksek Sıcaklık (°C)	9.5	10.2	12.2	17.3	22.3	26.9	29.5	29.6	25.8	20.6	16.0	11.7	19.3
Ortalama En Düşük Sıcaklık (°C)	4.1	4.2	5.4	9.2	13.6	18.0	20.4	20.7	17.6	13.7	9.8	6.4	11.9
Ortalama Güneşlenme Süresi (saat)	0.9	0.5	1.2	1.5	1.2	1.3	1.3	1.6	1.1	0.3	0.5	0.7	1.0
Ortalama Yağışlı Gün Sayısı	16.61	14.17	12.72	10.22	7.65	5.54	3.54	3.65	5.59	9.61	11.39	15.74	116.4
Aylık Toplam Yağış Miktarı Ortalaması (mm)	89.7	70.5	63.1	47.5	32.6	27.9	22.5	24.6	40.5	66.7	76.0	99.3	660.9
	Ölçüm Periyodu (1950 - 2022)												
En Yüksek Sıcaklık (°C)	22.4	23.4	28.6	33.3	36.4	38.9	40.6	40.1	39.6	33.5	27.2	25.0	40.6
En Düşük Sıcaklık (°C)	-6.8	-9.0	-5.6	0.2	4.8	9.8	13.6	14.3	7.7	2.5	-2.0	-4.2	-9.0

Table 2-MGM Seasonal Statistical Table for Istanbul (1950-2022)

The official temperature and maximum-minimum average values shared on the website of the Turkish State Meteorological Service (MGM) for Istanbul for the years 1950-2022 have been considered in our calculations.

4.1 General Load Formulas

We have chosen to meet the heating and cooling needs of our home using a heat pump. The reason for this choice is its economic efficiency and environmental friendliness, as it can maintain room temperature throughout all four seasons. Other heating sources, due to carbon dioxide emissions, and high-cost, high-electricity-consuming devices like electric heaters, which aim to save electricity while heating the entire house, are not suitable for our project.

We aim to maintain a room temperature of 21 degrees Celsius in our home. Our heating and cooling formulas are the same; the only difference is that the calculations are based on a temperature of -3 degrees Celsius for heating and 30 degrees Celsius for cooling. Another difference in the calculations is that the energy emitted by the people and devices in the house will contribute to heating the environment, resulting in negative work for our required heating energy. Therefore, the sign of the total required heating energy in our formula is written as negative due to the people heating and gadget heating load.

4.1.1 Heating and Cooling Load Calculations

Convection Heating Load

$$Q_1 = \frac{U * A * (\Delta T)}{1000} \tag{4.1}$$

Internal Heating Load - Heating Load from People

$$Q_2 = \frac{N * C}{1000} \tag{4.2}$$

Air Load and Ventilation

Air per person is 30 m^3/h, for 4 people it is 120 m^3/h. Since all people won't be stay inside all day, we can use correction factor of 0.25. The calculation will remain the same for both heating and cooling load calculations.

So,

$$\dot{V}_t = 4 * V_p = 4 * 120 * 0{,}25 = 120\ \frac{m^3}{h}$$

$$\dot{m} = \rho * \dot{V}_t = 1{,}293 * 795 = 1027{,}9\ \frac{kg}{h}\ or\ 1{,}03 * 10^3\,\frac{kg}{h} \tag{4.3}$$

$$c_p = 2{,}78 * 10^{-4}\ \frac{kWh}{(kg * K)}$$

$$Q_{Air} = \dot{m} * c_p * \Delta T = 1027{,}9 * 2{,}78 * 10^{-4} * 24 = 6{,}85\ kW \tag{4.4}$$

Solar Radiation Heating Load

$$Q_{SR} = Total\ Area\ Of\ Window * (Solar\ Radiation\ Absorbtion\ Coefficient) * Solar\ Radiation\ Heat\ Load$$

$$Q_{SR} = 23m^2 * \frac{438kcal}{m^2 h} * 0{,}8 = 9{,}37\ kW$$

4.1.2 Heating Load Results

Walls Heating Load

$$Q_W = \frac{0,6 * \big((15 * 3 * 4) - 23\big) * (24)}{1000} = 2,26\ kW$$

Roof Heating Load

$$Q_R = \frac{0,4\ x\ 225\ x\ (24)}{1000} = 2,16\ kW$$

Floor Heating Load

$$Q_F = \frac{0,6 * 225 * \ (24)}{1000} = 3,24\ kW$$

Windows and Doors Heating Load

$$Q_{W,D} = \frac{2,4 * \ 23 * (24)}{1000} = 1,32\ kW$$

People Heating

$$Q_P = \frac{4\ *\ 130}{1000} = 0,52\ kW$$

Gadget Heating Load

We can assume average heating value from electric gadgets is,

$$Q_G = 0,63\ kW$$

We found that total heating load as,

$$Q_W + Q_R + Q_F + Q_{W,D} - Q_P - Q_G + Q_{Air} = 14,7\ kW$$

4.1.3 Cooling Load Results

Walls Cooling Load

$$Q_W = \frac{0{,}6x\big((15*3*4)-23\big)x\ (10)}{1000} = 0{,}94\ kW$$

Roof Cooling Load

$$Q_R = \frac{0{,}4*\ 225*\ (10)}{1000} = 0{,}9\ kW$$

Floor Cooling Load

$$Q_F = \frac{0{,}6*\ 225*\ (10)}{1000} = 1{,}35\ kW$$

Windows and Doors Cooling Load

$$Q_{W,D} = \frac{2{,}4*\ 23*\ (10)}{1000} = 0{,}55\ kW$$

People Heating

$$Q_P = \frac{4\ *\ 130}{1000} = 0{,}52\ kW$$

Gadget Heating Load

We can assume average heating value from electric gadgets is

$$Q_G = 0{,}63\ kW$$

We found that total cooling load as,

$$Q_W + Q_R + Q_F + Q_{W,D} + Q_P + Q_G + Q_{Air} + Q_{SR} = 21{,}11\ kW$$

Since we are not going to climate whole building, we can calculate cooling capacity by multiplication the total cooling load with 0.7 correction factor. Correction factor is calculated by dividing rooms m^2 that are going to climate to house's m^2.

$$21.11 * 0.70 = 14\ kW$$

4.2 Heating Pump Selection

The selected heat pump is “Sigma SGM14INVAHTP Split Type Inverter Heat Pump”.

	Hourly	Daily	Monthly
Heat Pump Cooling Consumption(kWh)	3,80	30,40	912,00
Heat Pump Heating Consumption(kWh)	3,75	30,00	900,00

Table 3-Heat Pump Consumption Table

Heat Pump Cooling Capacity (kW)	13,50
Heat Pump Heating Capacity (kW)	14,00

Table 4-Heat Pump Cooling and Heating Capacity

The energy consumption and capacity of the selected heat pump are provided in Table 3 and Table 4, respectively. The heat pump will not operate at full performance for heating and cooling, so the electricity consumption has been assumed accordingly.

4.3 Monthly Energy Consumption

Table 5 displays the daily, weekly, and monthly energy consumption of household electrical appliances based on their power ratings and operating hours.

	Daily Working Hour(h)	Weekly Working Hour(h)	Monthly Working Hour (h)	Gadget Power(W)	Energy Usage per Day(kWh)	Energy Usage per Week(kWh)	Energy Usage per Month(kWh)
Television	3	21	84	98	0,29	2,06	8,23
Fridge	24	168	672	44	1,06	7,39	29,57
Washing Machine	-	4	16	300	0,17	1,20	4,80
Vacuum Cleaner	-	2	8	600	0,17	1,20	4,80
Dishwasher	1	7	28	510	0,51	3,57	14,28
Iron	-	1	3	2.600	0,28	1,95	7,80
Hair Dryer	0,1	1	3	2.000	0,20	1,40	5,60
Oven	-	3	12	3.300	1,41	9,90	39,60
Microwave	0,1	1	3	800	0,08	0,56	2,24
Laptop	6	42	168	150	0,90	6,30	25,20
Aspirator	-	3	12	280	0,12	0,84	3,36
Phone Charging	4	28	112	20	0,08	0,56	2,24
Kettle	0,1	1	3	2.400	0,24	1,68	6,72
Toast Machine	-	1	2	2.000	0,14	1,00	4,00
LED Bulb	5	35	140	6	0,03	0,21	0,84
Dryer	-	4	16	2.050	1,17	8,20	32,80
Total							192,08

Table 5-Gadget Power Consumption

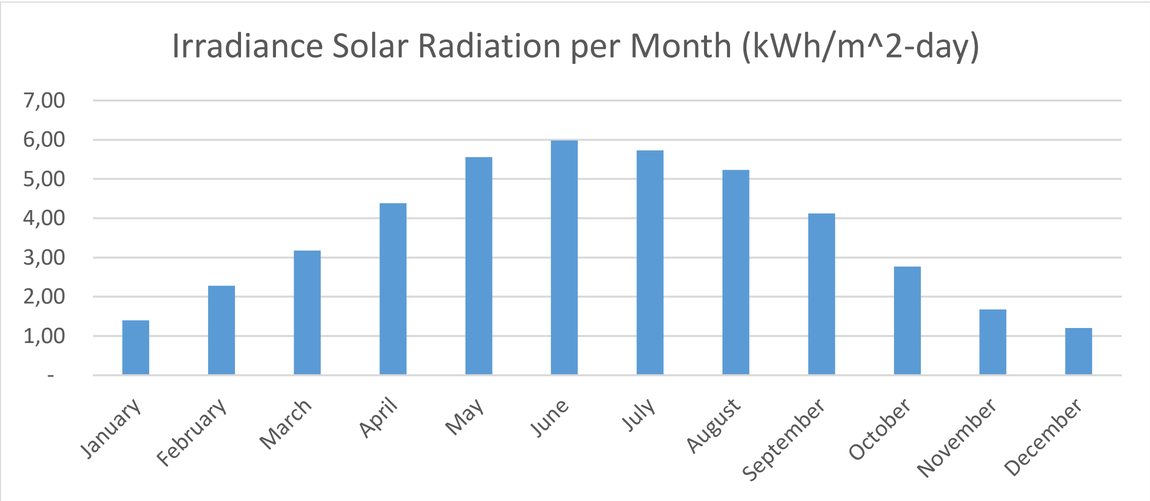
Table 6 presents the daily and monthly total energy consumption of the house, categorized by months.

Months	Daily Total Consumption (kWh)	Monthly Total Consumption (kWh)
January	27,5	825
February	27,4	822
March	22,2	664
April	16,4	492
May	16,4	492
June	24,1	723
July	31,9	957
August	32,2	966
September	16,4	492
October	16,4	492
November	23,7	709
December	24,7	739

Table 6-Daily and Monthly Total Consumption

4.4 Solar Panel Selection Scenarios

The monthly solar radiation capacity of the region where the house is located is shown in Graph 9. It can be observed from this graph that the winter months are the least favorable for harnessing solar energy. Additionally, based on this graph, the most suitable capacity for the solar panels for the system has been calculated as the TommaTech 550-Watt 144PMB10 M10 Solar Panel.'



Graph 9-Irradiance Solar Radiation per Monthly in Adalar ISTANBUL

	TommaTech 550 Watt 144PMB10 M10 Solar Panel	
	Single Panel Area(m^2)	Total Panel Area (m^2)
Only Solar System	2,58	72,24
Panel to Turbine System	2,58	38,70
On Grid System	2,58	38,70

Table 7-Total Solar Panel Areas for Each Scenarios

4.4.1 Only Solar Panel Scenario

The required number of panels, daily generated energy, monthly generated energy, and the surplus energy for a system created only using solar panels are shown in Table 8.

Months	Number of Panels	Daily Produced Energy (kWh)	Monthly Produced Energy (kWh)	Total Energy Left (kWh)
January	28	27,95	838	12
February	28	36,17	1.085	262
March	28	44,72	1.341	677
April	28	56,75	1.702	1.210
May	28	73,35	2.200	1.708
June	28	84,70	2.541	1.817
July	28	90,63	2.718	1.761
August	28	82,84	2.485	1.519
September	28	67,34	2.020	1.528
October	28	44,98	1.349	857
November	28	32,78	983	273
December	28	25,66	769	30
Total			20.031	11.660

Table 8-Using Only Solar Panel

4.4.2 Panel to Turbine Scenario

The required number of panels, along with the calculated number of turbines based on the number of panels, daily generated energy, monthly generated energy, and surplus energy for the system, are presented in Table 9.The remaining energy need will be met by wind turbines. The rest of the data can be examined in Table 13.

Months	Number of Panels	Daily Produced Energy (kWh)	Monthly Produced Energy (kWh)	Total Energy Left (kWh)
January	15	14,97	449	-376
February	15	19,38	581	-240
March	15	23,96	718	54
April	15	30,40	912	719
May	15	39,29	1.178	986
June	15	45,38	1.361	638
July	15	48,55	1.456	499
August	15	44,38	1.331	365
September	15	36,07	1.082	890
October	15	24,09	722	530
November	15	17,56	526	-182
December	15	13,75	412	-327
Total			10.730	3.560

Table 9-Using Panel to Turbine

4.4.3 On Grid Scenario

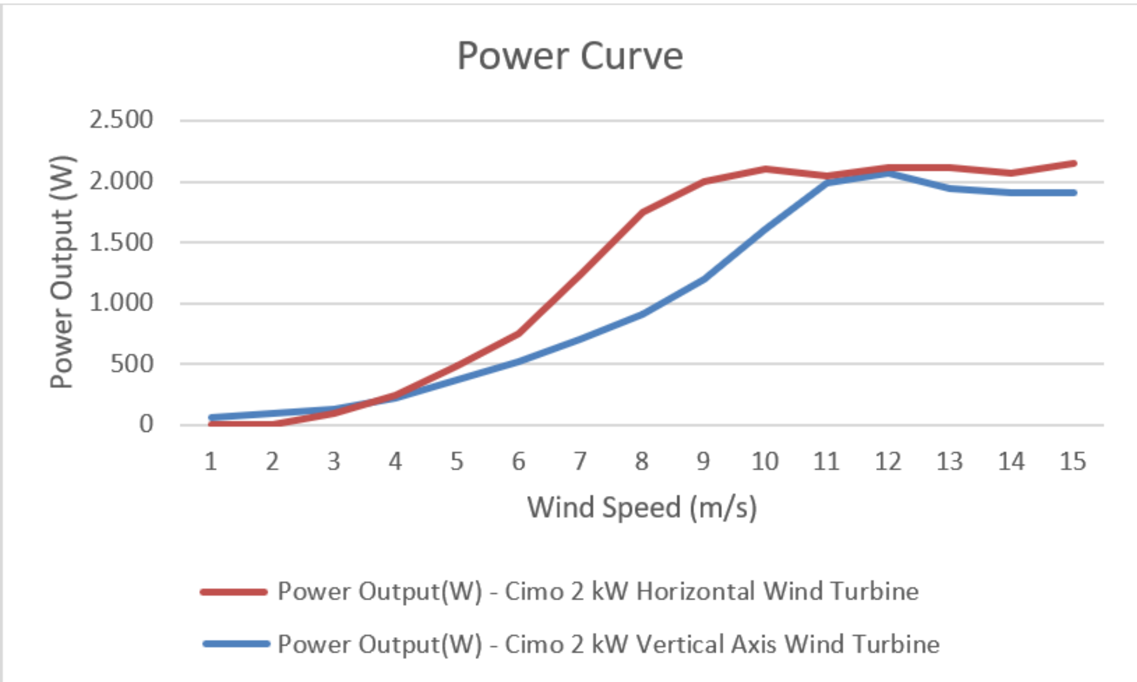
The number of panels chosen for the On-Grid system is based on the energy consumed during daylight hours. Table 10 shows the daily energy production, monthly energy production, and the surplus energy remaining from consumption for this system. Additionally, the daily values of the battery capacity to be added to the system for enhancing its stability are provided based on the months.

Months	Number of Panels	Daily Produced Energy (kWh)	Monthly Produced Energy (kWh)	Total Energy Left (kWh)	Excess Energy Storage Capacity (kWh)
January	15	14,97	449	272	9,10
February	15	19,38	581	277	9,24
March	15	23,96	718	422	14,09
April	15	30,40	912	636	21,21
May	15	39,29	1.178	878	29,28
June	15	45,38	1.361	947	31,60
July	15	48,55	1.456	923	30,78
August	15	44,38	1.331	823	27,46
September	15	36,07	1.082	790	26,36
October	15	24,09	722	464	15,48
November	15	17,56	526	251	8,38
December	15	13,75	412	151	5,04
Total			10.730	6.800	

Table 10-Using on Grid

4.5 Wind Turbine Selection Scenarios

Due to the low average wind speed in the region, the decision on the type of wind turbine to be selected was made based on the power curve of horizontal and vertical wind turbines with the same capacity (Graph 10).



Graph 10-Performance Graph of Both Turbines

Table 11 provides the specifications and model of the selected horizontal wind turbine. Average wind speeds and power outputs are given in Table 12.

Cimo 2 kW Horizontal Wind Turbine	
Rotor Dimater (m)	2,00
Air Density (kg/m^3)	1,23
Power Coefficient	0,59
Swept Area (m^2)	12,56
Constant	0,5

Table 11-Cimo 2 kW Horizontal Wind Turbine Specification

Months	Wind Speed (m/s)	Power Output (kW)
January	5,43	0,53
February	5,53	0,55
March	5,35	0,52
April	4,63	0,38
May	4,25	0,30
June	4,27	0,30
July	5,18	0,50
August	5,43	0,53
September	4,94	0,48
October	5,11	0,49
November	5,08	0,48
December	5,53	0,55

Table 12-Cimo 2 kW Horizontal Wind Turbine Power Output Values for Istanbul

4.5.1 1 Turbine for Panel to Turbine Scenario

The energy generations of the turbine in the system where the turbine is selected based on the panels are provided daily and monthly in Table 13.

Months	Daily Generated Energy (kWh)	Monthly Generated Energy (kWh)
January	12,7	381
February	13,2	396
March	12,3	370
April	9,0	270
May	7,2	216
June	7,2	216
July	12,0	360
August	12,7	381
September	11,4	342
October	11,7	352
November	11,5	345
December	13,2	396
Total		4.030

Table 13-Daily and Monthly Generated Power

4.5.2 4 Turbine for Only Turbine Scenario

The number of turbines used in the system, total generated energy, and surplus energy for the scenario created only using wind turbines are presented in Table 14.

Months	Number of Turbines	Total Energy Generated (kWh)	Total Energy Left (kWh)
January	4	1.526	700
February	4	1.584	761
March	4	1.483	818
April	4	1.080	587
May	4	864	371
June	4	864	140
July	4	1.440	482
August	4	1.526	560
September	4	1.368	875
October	4	1.411	919
November	4	1.382	672
December	4	1.584	844
Total		16.100	7.700

Table 14-Selection of the number of Turbines and Total Converted Energy Data

5 COST ANALYSIS

Table 15 displays the main components, quantities, and total costs of the components within the scenarios.

Starting Investment	Solar Panel	Wind Turbine	LiFePO4 Battery (50Ah-48V)	Inverter (16kW)	Inverter (9kW)	Prices ($)
Scenario 1 Panel to Turbine	15	1	10	0	1	15.682
Scenario 2 Only Panel	28	0	10	1	0	15.365
Scenario 3 Only Turbine	0	4	2	0	0	15.668
Scenario 4 Only Grid	0	0	0	0	0	-
Scenario 5 On Grid	16	0	2	0	1	6.640

Table 15-System Options and Initial Costs

The unit prices of the main system components used can be found in Table 16.

	Solar Panel	Wind Turbine	LifePO4 Battery (48V-50Ah)	Inverter (16kW)	Inverter (9kW)	Energy Cost ($/kWh)	Energy Price ($/kWh)
Prices ($)	145	3217	750	1665	1040	0,074	0,055

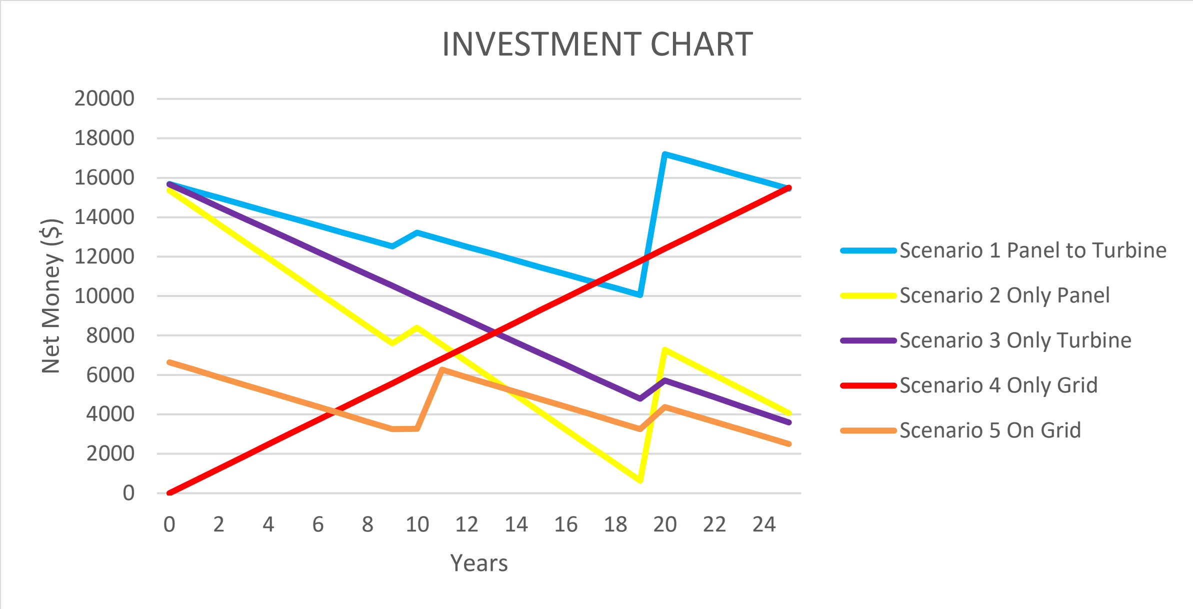
Table 16-Price Table

Table 17 provides the surplus or purchased amounts of energy from different scenarios.

	Buy or Sell	Net Energy(kWh)
Scenario 1 Panel to Turbine	Grid buys from system	6.385
Scenario 2 Only Panel	Grid buys from system	11.659
Scenario 3 Only Turbine	Grid buys from system	7.737
Scenario 4 Only Grid	Grid sells to system	8.376
Scenario 5 On Grid	Grid buys from system	6.840

Table 17-Net Energy Values for Each Scenarios

Graph 11 compares the net costs of all scenarios over the years, both at the beginning and annually, with the cost incurred when using only grid electricity.



Graph 11-Investment Chart

6 CONCLUSION

When comparing five different designed systems in terms of cost and performance, the most suitable system is the grid-connected system. The system amortizes itself financially over a period of 6.5 years. It generates the energy needed during the day from a solar system, while at night, when the solar system cannot produce energy, it draws the required electricity from the grid.

Among the off-grid systems, the most cost-effective and performance-oriented system in terms of cost and lifespan is the only solar system. Although a significant part of the system's cost consists of batteries, it can amortize itself in 11 years.

The least suitable off-grid system in terms of cost and performance lifespan is the only turbine system.

The reason why wind turbine systems are more costly and less efficient for Istanbul-Adalar is the low average wind speed in the region. Turbines do not operate efficiently with the average wind speeds in the region, and increasing the number of turbines raises the cost.

Surplus electricity generated by all systems is sold back to the grid as raw electricity, resulting in increased profit margins and reduced costs by saving on battery capacity.

One of the main reasons for the high cost of the systems is the excessiveness of battery prices. The grid-connected system's ability to be cost-effective and amortize itself in 6.5 years is primarily due to selling excess electricity to the grid in raw form and being able to draw electricity from the grid when no energy is being produced, instead of storing it.

In conclusion, it is possible to generate and use environmentally friendly electricity by using a grid-independent solar system that amortizes itself in 11 years or a less expensive grid-connected solar system. In addition, in our world where the impacts of global warming are increasingly evident each year, solar systems are of great importance for the future.

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