REPUBLIC OF TÜRKİYE
ARTVİN ÇORUH UNIVERSITY
GRADUATE EDUCATION INSTITUTE
DEPARTMENT OF NATURAL RESOURCE MANAGEMENT

ANALYSIS OF ARTVİN ÇORUH UNIVERSITY ANG BOTANICAL GARDEN ENERGY NEEDS TO BE MET FROM RENEWABLE ENERGY SOURCES

MASTER’S THESIS

Adalet KESKİN

Advisor
Assoc. Prof. Dr. Elanur ADAR YAZAR

ARTVİN-2024

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THESIS DECLARATION

I have completed this study titled "Analysis of Artvin Çoruh University ANG Botanical Garden Energy Needs to be Met from Renewable Energy Sources" which I presented as a Master's Thesis to Artvin Çoruh University Graduate Education Institute under the supervision of my advisor Assoc. Prof. Dr. Elanur ADAR YAZAR, that I have collected the data myself, had the experiments and analyzes done in the relevant laboratories, that I have fully cited the information I have received from other sources in the text and bibliography, that I have acted in accordance with scientific research and ethical rules during the study process, and that I accept all kinds of legal consequences in case the contrary occurs.

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Artvin - 2024

TABLE OF CONTENTS

ABSTRACT

ANALYSIS OF ARTVİN ÇORUH UNIVERSITY ANG BOTANICAL GARDEN ENERGY NEEDS TO BE MET FROM RENEWABLE ENERGY SOURCES

Historically, the work done with primitive and physical labor and the primary energy sources used have brought the necessity of using energy by transforming it into different forms with the development of technology today. Undoubtedly, where there is technology, electrical energy or primary energy sources that mobilize this technology come into play. The largest share among primary energy sources belongs to fossil fuels. Fossil fuels are also the main actors in electrical energy production. However, since they are non-renewable resources, their reserves are gradually decreasing. For this reason, alternative and renewable energy sources have become a priority agenda of governments around the world.

In this study, within the scope of renewable energy use, Artvin Çoruh University ANG Botanical Garden campus, alternative, renewable resources for energy needs are discussed. In the study, three separate resource evaluations were made as wind energy, solar energy and the use of pruning waste as an energy source. It is aimed to create awareness for the evaluation of local and domestic resources as energy sources and to make investments in this direction.

In the study, the electrical energy to be obtained from wind energy for Artvin province remained at very low levels with a value of 0,0845 kW per hour. The solar energy project was prepared in PVSOL simulation program. With the grid-connected system, a project that produces 1.218.340 kWh of energy annually to meet the energy needs of the center and pays for itself in 8,8 years has been obtained. Finally, elemental analysis was carried out for a mixed sample of pruning waste from various trees in the center. It was suggested that the annual tree pruning waste of around 3.500 kg could be utilized by incineration, and as an alternative, the 27 tons of annual food waste generated after lunch in all campuses could be used together to generate biogas energy by anaerobic digestion.

Keywords: Renewable energy, wind energy, solar energy, biomass energy, Weibull distribution function, PVSOL programme.

ÖZET

ARTVİN ÇORUH ÜNİVERSİTESİ ANG BOTANİK BAHÇESİ ENERJİ İHTİYACININ YENİLENEBİLİR ENERJİ KAYNAKLARINDAN KARŞILANABİLMESİ ANALİZİ

Tarihsel olarak değerlendirme yapıldığında ilkel ve bedensel iş gücü ile yapılan işler ve kullanılan birincil enerji kaynakları, günümüzde teknolojinin gelişmesiyle enerjinin farklı formlara dönüştürülerek kullanılması gerekliliğini getirmiştir. Kuşkusuz teknolojinin olduğu yerde bu teknolojiyi harekete geçiren elektrik enerjisi ya da birincil enerji kaynakları devreye girmektedir. Birincil enerji kaynakları içerisinde en büyük pay ise fosil yakıtlara aittir. Fosil yakıtlar elektrik enerjisi üretiminde de baş aktör rolündedirler. Ancak yenilenemeyen kaynaklar oldukları için rezervleri giderek azalmaktadır. Bu nedenle dünya genelinde alternatif ve yenilenebilir enerji kaynakları hükümetlerin öncelikli gündemi haline gelmiştir.

Bu çalışmada, yenilenebilir enerji kullanımı kapsamında Artvin Çoruh Üniversitesi ANG Botanik Bahçesi yerleşkesi, enerji ihtiyacı için alternatif, yenilenebilir kaynaklar konu alınmıştır. Çalışmada rüzgar enerjisi, güneş enerjisi ve budama atıklarının enerji kaynağı olarak kullanılması şeklinde üç ayrı kaynak değerlendirmesi yapılmıştır. Yerel ve yerli kaynakların enerji kaynağı olarak değerlendirilebilmesi ve bu yönde yatırımlar yapılması için bir farkındalık oluşturması amaçlanmıştır.

Çalışmada Artvin ili için rüzgar enerjisinden elde edilecek elektrik enerjisi saatlik 0,0845 kW değerinde çok düşük seviyelerde kalmıştır. Güneş enerjisi projesi PVSOL simülasyon programında hazırlanmıştır. Şebeke bağlantılı sistemle merkezin enerji ihtiyacını karşılayabilecek yıllık 1.218.340 kWh enerji üreten ve 8,8 yılda kendini amorti eden bir proje elde edilmiştir. Son olarak merkezde bulunan çeşitli ağaçların budama atıklarından oluşan karışık bir numune için elementel analiz yapılmıştır. Yıllık 3.500 kg civarında olan ağaç budama atıklarının yakılarak değerlendirilebileceği, alternatif olarak tüm yerleşkelerde öğle yemeği sonrası oluşan 27 ton civarındaki yıllık yemek atıklarının da birlikte kullanılarak anaerobik çürütme ile biyogaz enerjisi elde edilebileceği görüşü sunulmuştur.

Anahtar Kelimeler: Yenilenebilir enerji, rüzgar enerjisi, güneş enerjisi, biyokütle enerjisi, Weibull dağılım fonksiyonu, PVSOL programı.

LIST OF TABLES

Page Number

TABLE OF FIGURES

Page Number

LIST OF ABBREVIATIONS

AC : Alternative current
AÇU : Artvin Çoruh University
ANG : Ali Nihat Gökyiğit
As : Arsenide
BC : Before christ
BP : British Petrol
CdTe : Cadmium Telluride
CF : Capacity Factor
CH_4 : Methane
cm : Centi meter
cm^2 : Centi square meter
C/N : Carbon / Nitrogen
CO : Carbon monoxide
CO_2 : Carbon dioxide
CSP : Concentrated solar power
$CuInSe_2$: Copper indium diselenide
ÇEDAŞ : Çoruh Electricity Distribution Corporation
DC : Direct current
EPDK : Republic of Türkiye Energy Market Regulatory Authority
ETKB : Republic of Türkiye Ministry of Energy and Natural Resources
EÜAŞ : The Electricity Generation Corporation
FF : Filling factor
GaAs : Gallium arsenide
GCal : Giga calorie
GJ : Giga joule
gr : Gram
GW : Giga watt
GWh : Giga watt hour
h : Hour
H_2 : Hydrogen
H_2S : Hydrogen sulphur
HHV : Higher Heating Value

HOMER	: Hybrid Optimization of Multiple Energy Resources
hz	: Hertz
IEA	: International Energy Agency
IRENA	: International Renewable Energy Agency
I-V	: Current - Voltage
J/K	: Joule / Kelvin
K	: Kelvin
kg	: Kilo gram
km	: Kio meter
kW	: Kilo watt
kWh	: Kilo watt hour
kW_p	: Kilo watt power
kW/m	: Kilo watt / meter
kWh/m^2	: Kilo watt hour / square meter
LPG	: Liquefied petroleum gas
LV	: Low voltage
m	: Meter
m^2	: Square meter
m^3	: Cubic meter
m/s	: Meter / second
MJ/kg	: Mega Joules / kilogram
MPP	: Maximum Power Point
MPPT	: Maximum Power Point Tracking
MSW	: Municipal Solid Waste
MTOE	: Million tons of oil equivalent
MV	: Middle voltage
MW	: Mega watt
MWh	: Mega watt hour
mW/m^2	: Milli watt / square meter
N_2	: Nitrogen
NO	: Nitrogen monoxide
O_2	: Oxygen
OC	: Open circuit
OWC	: Oscillating Water Column

ppm : Particles per million
PSEM : Potential Solar Energy Map
PV : Photo Voltaic
PWEM : Potential Wind Energy Map
R&D : Research & Development
SC : Short circuit
SO_2 : Sulphur dioxide
STE : Solar Thermal Energy
T : Temperature
TBMM : Grand National Assembly of Türkiye
TEDAŞ : Türkiye Electricity Distribution Corporation
TEİAŞ : Türkiye Electricity Transmission Corporation
TL : Turkish Lira
TPAO : Türkiye Petroleum Corporation
TÜİK : Turkish Statictical Institute
TWh : Tera watt hour
UK : United Kingdom
USA : United States of America
USD : United States Dollar
ÜFE : Services producers price
V : Voltage
V : Velocity
W/m^2 : Watt / square meter
WEC : World Energy Council
WEC : Wave Energy Converter
WEO : World Energy Outlook
WTE : Waste to Energy

1. INTRODUCTION

Energy has become an indispensable resource needed at every stage of daily life. The need for energy and the amount of energy use have gradually increased due to reasons such as the increase in population, the development of technology, the need for machine power rather than manpower in industry. Since existing energy resources are inadequate to satisfy this rising energy demand, policies are being developed for the utilisation of all alternative and potential energy resources and energy management.

The main sources of energy demand worldwide and in Türkiye are primarily fossil fuels and hydroelectric power plants from which electricity is generated. Fossil fuels are also the primary source of electricity supply. Fossil fuels are non-renewable energy sources. Their reserves will be exhausted after certain periods of time. For this reason, efforts to utilize potential renewable energy resources and convert them into electrical energy have accelerated. As of the 2000s, the shares of wind and solar energy in electricity generation have increased in addition to hydroelectric energy.

Electric energy consumption takes place today in homes, workplaces, industry and every moment of daily life. Although alternative and renewable sources of electrical energy are increasing in production, fossil fuels are still the primary sources as the amount of consumption is rising day by day in living conditions.

While the development of technology increases the amount of electrical energy consumption on the one hand, it also develops technologies on the efficient and economical use of electricity. For this reason, today, in homes and workplaces, installations are made to use electrical energy in the most efficient way and in the least amount, and more efficient electrical devices with less electrical energy consumption are preferred. In this context, energy commissions are established in institutions and decisions are taken and implemented for the most efficient use of energy resources. Action plans are also drawn up to use other resources and minimise costs.

In this thesis, a detailed literature research and analysis for wind, solar and biomass energy sources were carried out to meet the energy needs of Artvin Çoruh University Ali Nihat Gökyiğit Botanical Garden from renewable energy sources. In the first project of the botanical garden, solar energy panels were installed in two different areas, including an area where solar panels will be installed and a solar panel on the parking lot, and a grid-connected system was designed. In addition, the installation and performance analysis of a 5 kW wind turbine was carried out in the area. As a third renewable resource, an analysis was made on the amount of biogas and energy equivalent that can be obtained by incineration / anaerobic digestion method from grass, plant, tree pruning etc. wastes of the botanical garden.

1.1. Definition and Importance of Energy

Energy, in basic terms, is the ability of matter to do work. In thermodynamics, energy is defined as the capacity to produce an effect. Energy is a resource that exists in matter and is a property of matter. The stored energy in matter is released by certain methods and a work is obtained by using the energy. With the use of energy, a benefit and production occurs for humanity and life.

Energy sources are readily available in nature. Some of them are used directly. Some of them are used by converting them into other types of energy by certain methods. In daily life, energy appears in the form of resources used for the work done. For example, in physical work, mechanical energy is produced and a production or work is created in return. Another example is the work done by a machine. If this machine is a machine that works with electrical energy, it produces work in return for the electrical energy given and enables the energy to be transformed into a different useful form.

The first law of thermodynamics is known “as the law of conservation of energy”. Matter has energy. Energy cannot disappear. However, it transforms from one form to another and the total energy is conserved. Thermodynamics explains the relationship between matter and energy and deals with the creation and utilization of energy and its transformation into other forms. Energy can be stored in matter in chemical form. The first sources that come to mind as chemical energy are fossil fuels. It is known that fossil fuels were used by the ancient Babylonians, Chinese and Egyptians in prehistoric times. In the 18th century, with the industrial revolution, usage of coal became more common, and in the following century, usage of oil and natural gas increased. The use of fossil fuels increased continuously as of the 19th century, and this increase gained momentum after 1940. Today, fossil fuels are the main actors in meeting energy needs.

Energy resources are classified as renewable energy resources and non-renewable energy resources according to their usage. They are classified as primary energy sources by obtaining energy as a natural resource and using it as such, or as secondary energy sources by converting it into different types of energy. (Figure 1).

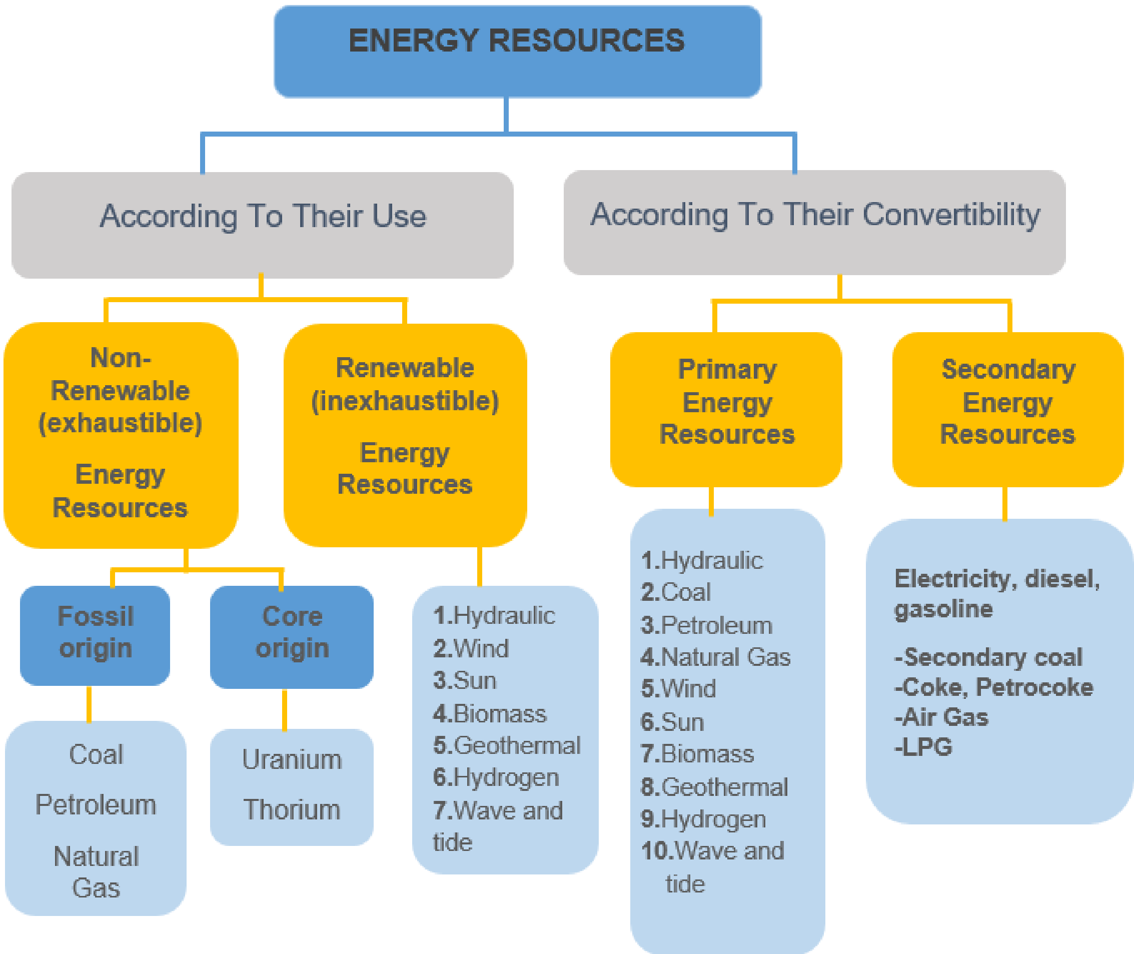


Figure 1. Classification of the energy resources (Koç et al., 2018)

Fossil-based energy sources consisting of coal, oil and natural gas are the most produced and consumed energy sources in the world. Fossil fuels provide about 85% of the world's energy consumption. Therefore, fossil fuels have a more critical place in global energy markets compared to other energy sources. However, the reserve life of fossil fuels is gradually decreasing as they are non-renewable energy resources and have limited reserves in the world. From a general perspective, fossil fuel reserves in the world will be depleted in the near future. In 2018, as a result of research and estimates, it was calculated that the world's oil reserves have a lifespan of approximately 50 years, natural gas reserves 53 years and coal reserves 134 years. The consumption of fossil fuels, which have a major share in world energy production and consumption, will be depleted in the near future, which will create energy security and energy deficit in energy markets (Zohrap, 2022).

Energy is essential for production activities and the use of equipment. For this reason, energy demand in the world is constantly on the rise. The increase in individual and general demand for goods and services, driven by the world's population growth, leads to a rapid consumption of global energy resources. Developed countries have to consume more energy in order to maintain their level of development and standards and to develop further; underdeveloped and developing countries have to consume more energy to ensure their development. Even agricultural activities, the main actor in food production, consume significant amounts of energy (Marion and Roush, 1982).

Energy has become the main focus of states with the industrial revolution. Thus, a fierce competition started among the countries in the energy market. This situation led to energy-related political wars such as the Yom Kippur War, the Iranian revolution, the invasion of Kuwait, the invasion of Iraq and the Arab Spring (Sevim, 2012). In early 2022, Russia's invasion of Ukraine led to high costs and sales figures in the energy markets, especially in fossil energy resources, and the world was caught in the middle of a complex energy crisis.

Even before Russia's invasion of Ukraine, markets were under pressure, especially due to the Covid-19 pandemic. However, Russia's action in Ukraine further triggered this situation and turned it into an additional supply chain and energy supply chaos in the post-pandemic economic recovery period. Russia is the world's largest exporter of fossil fuels. Russia's cuts in natural gas supplies to Europe and Europe's sanctions on oil and coal imports to Russia have caused a significant blow to global energy trade. This has affected all fuels and energy resources markets (WEO, 2022).

As of the 2000s, serious changes have emerged in international energy markets. The rapid increase in energy consumption and the possibility of depletion of fossil fuels have led global energy suppliers to turn to alternative energy sources. The squeeze on renewable energy resources in the international energy markets, the gradual expansion of energy investment capacities and the high growth rates achieved in developing countries have shifted the outlook in the energy markets in a different direction. In the same process, the use of unconventional energy sources accelerated along with favorable technological developments in energy resources. These developments have led to lower prices in international energy markets and increased greenhouse gas emissions while enabling economic growth. Many countries have taken advantage of this technological progress and have gained access to more diverse energy sources through the evolution of microgrids (WEC, 2016).

Energy is the most fundamental and driving requirement for a country's economic and social development. In this respect, "Energy Security" is the main issue of economic security and national security. Energy is “an indispensable resource for almost all areas necessary for sustaining social life; it is the lifeblood of sub-sectors such as industry, transportation, housing and commerce”. The energy consumed in the world today is derived from a variety of energy sources, and fossil resources rank first among these sources with 82.3 % (Figure 2) (TPAO, 2023).

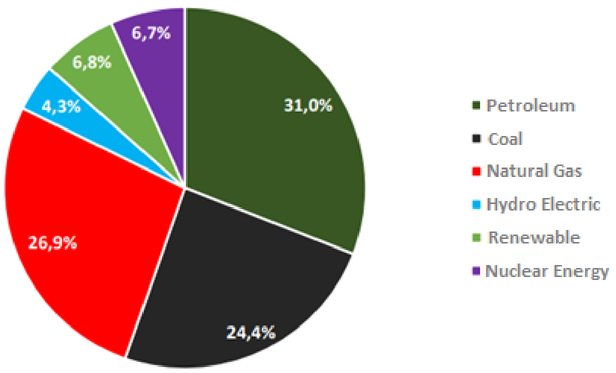


Figure 2. 2021 global primary energy consumption rates (BP, 2022)

Looking at the energy utilisation rates worldwide, almost all of the energy need is provided from fossil fuels. Fossil fuels have a large share in electrical energy due to their ease of use in thermal power plants in energy production, accessibility and availability. On the other hand, they are also the main source of energy in industry and transportation. Fossil fuels are composed of carbon and hydrogen in terms of their chemical structure. Their chemical names are also known as hydrocarbons. Heat energy is obtained from hydrocarbons as a result of combustion and this heat energy is converted into different useful forms. As a result of combustion of hydrocarbons, especially carbon dioxide and carbon monoxide, toxic and polluting harmful gases are released into the air.

The use of fossil fuels causes significant environmental problems. For this reason, carbon emission limits are set for countries by international agreements. In addition, filtering and disposal systems are made compulsory in thermal power plants and industry to minimize harmful gas emissions. Although necessary measures are taken and inspections are carried out by the relevant ministries, the increasing need for energy and the leading role of fossil fuels cannot reduce these emission rates to the expected levels. Figure 3 shows the share of low-carbon sources and coal in other sources by years in the last 50 years worldwide.

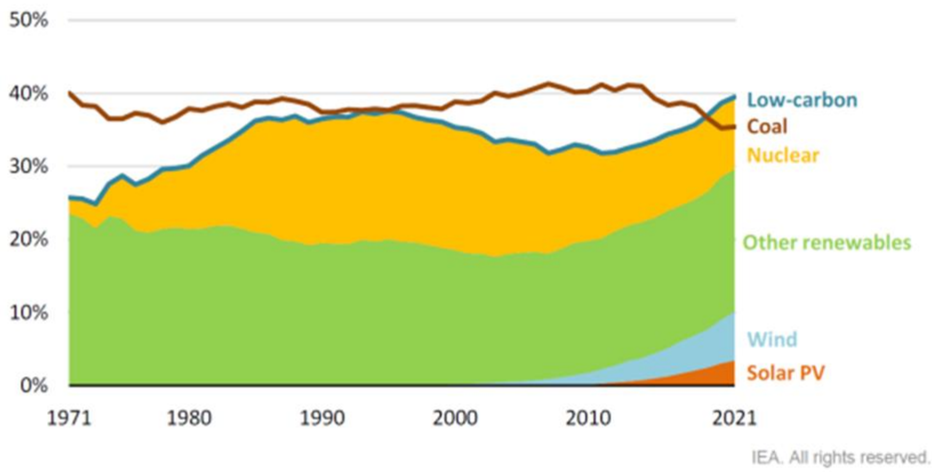


Figure 3. Share of low-carbon sources and coal in world electricity generation (WEC, 2021)

From past to present, the ratio of fossil fuels to meet the global energy supply has been at the same level on average. In the following years, with the technology development and population growth, the need for energy has increased and alternative and renewable energy sources have come into play. However, fossil fuels have always been the primary sources. With the excessive use of fossil fuels worldwide, environmental pollution, greenhouse effect, global warming and climate changes have occurred. Figure 4 shows energy production and fossil fuel coverage ratio by years, while Figure

5 shows global warming and temperature changes by years. Accordingly, the situation is not quite at the expected level and therefore, it is necessary for governments to raise awareness of all societies on energy use and environmental issues and to take the necessary measures.

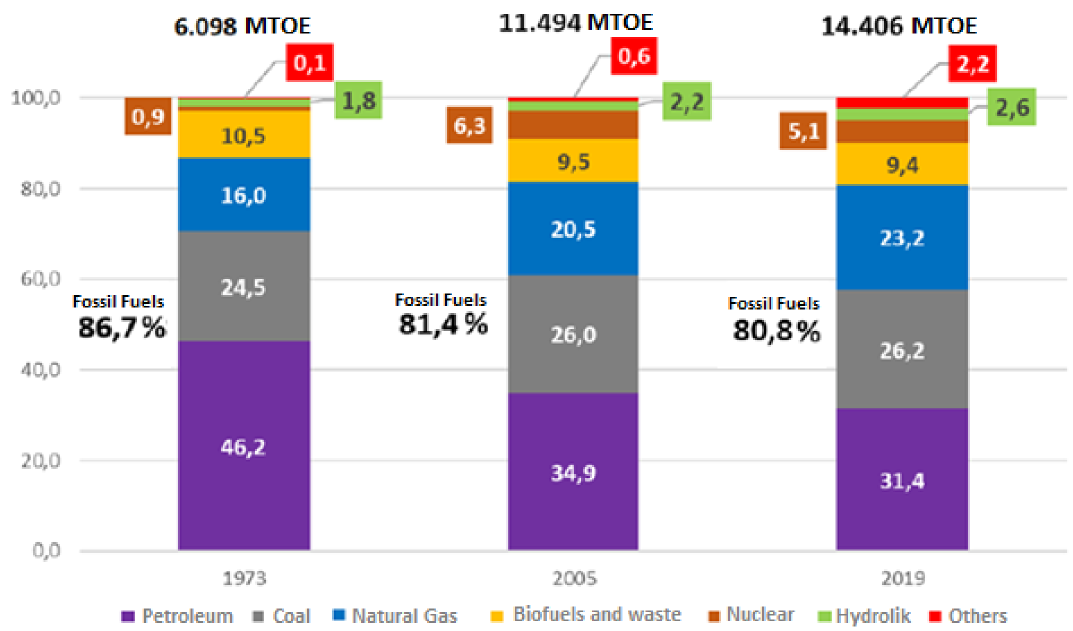


Figure 4. Primary energy supply by source (MTOE and %) (IEA, 2020)

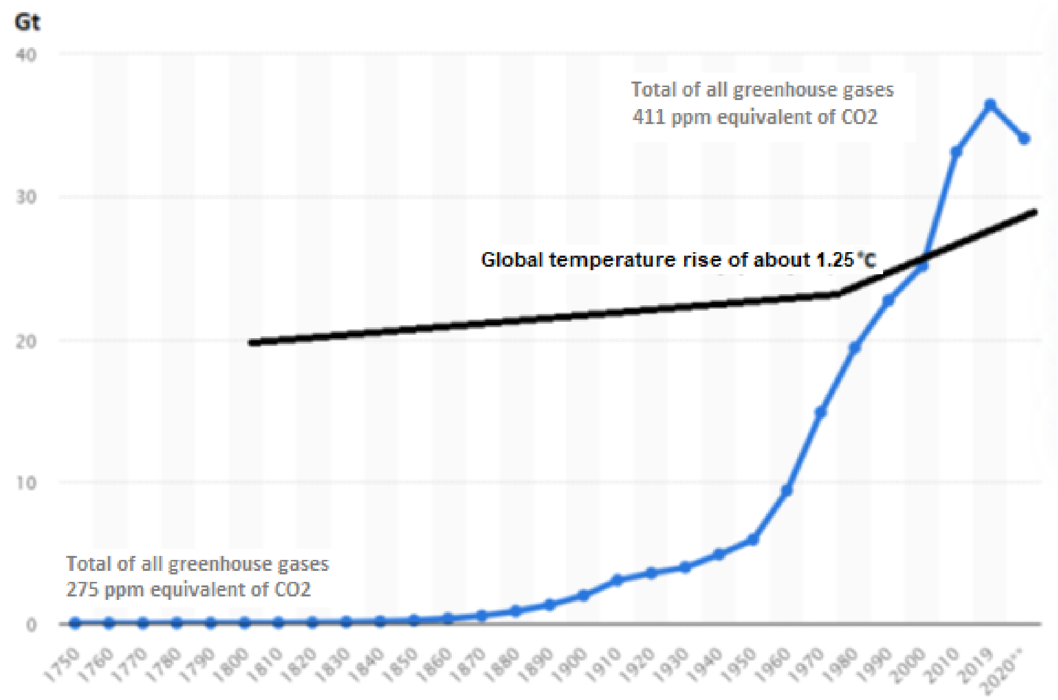


Figure 5. CO_2 emissions and temperature rise since the industrial revolution (URL-1)

1.2. Renewable Energy Resources

The energy demand of the world's growing population and expanding industry cannot be utilised with the limited resources available and the gap is increasing between energy production and consumption. Global energy consumption is expected to double the quantity of energy consumed in 1998 by 2035 and triple by 2055. On the other hand, ‘non-renewable’ traditional energy sources such as fossil fuels and nuclear energy are gradually threatening the environment and human health. The extensive usage of traditional energy sources, especially in the transport, housing and industrial sectors, carries the problem to even more important dimensions. In this context, 95% of energy consumption in the transportation sector comes from oil. It is estimated that this rate will increase by 1.5% per year in developed countries and 3.6% in developing countries in the next five years (URL-2).

With this active progress in the energy sector and the prediction that oil will run out of reserves in 50 years and natural gas in 200 years, mankind has been in search of nature-friendly, clean and cheaper energy sources. With this in mind, steps are being taken to make more use of renewable energy sources, which are sustainable and have the ability to exist in nature in every region of the world. Renewable energy source is defined as an energy source that can exist in the next day or in the future within the natural cycle of the world and life. The most important features of renewable energy sources are that they are environmentally friendly by decreasing carbon emissions, they are contributing to the decline of foreign dependency in energy and employment, and they are preferred and supported by the public and governments. In short, renewable energy sources have all the characteristics of accessibility and acceptability (URL-2).

Renewable energy sources are natural resources that exist spontaneously in nature, can constantly renew themselves and have energy potential. The main source of all renewable energy sources and the reason for the formation of other non-renewable energy sources is solar energy. The main renewable energy sources are listed from largest to smallest according to their electrical energy generation potential: hydraulic, wind, solar and other sources. The capacity of these resources to produce energy varies from region to region according to geographical conditions.

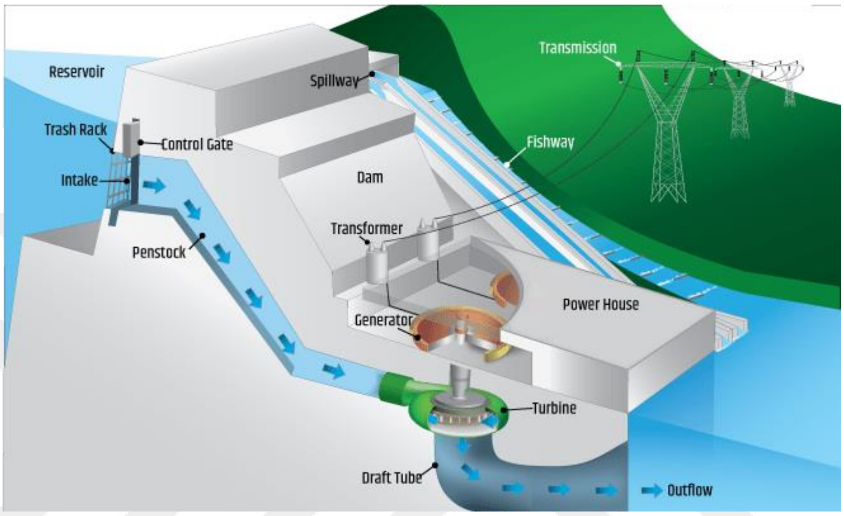
Renewable energy sources consist of hydraulic, geothermal, solar, wind, biomass and biogas, tidal and wave energies, which are the main sources applied and used in the world. In the next section, general information about these energy sources is given. In addition, all the technical information used in the conversion of wind, solar and biomass energy sources into electrical energy is explained in detail, that are studied in the thesis.

1.2.1. Hydroelectric Energy

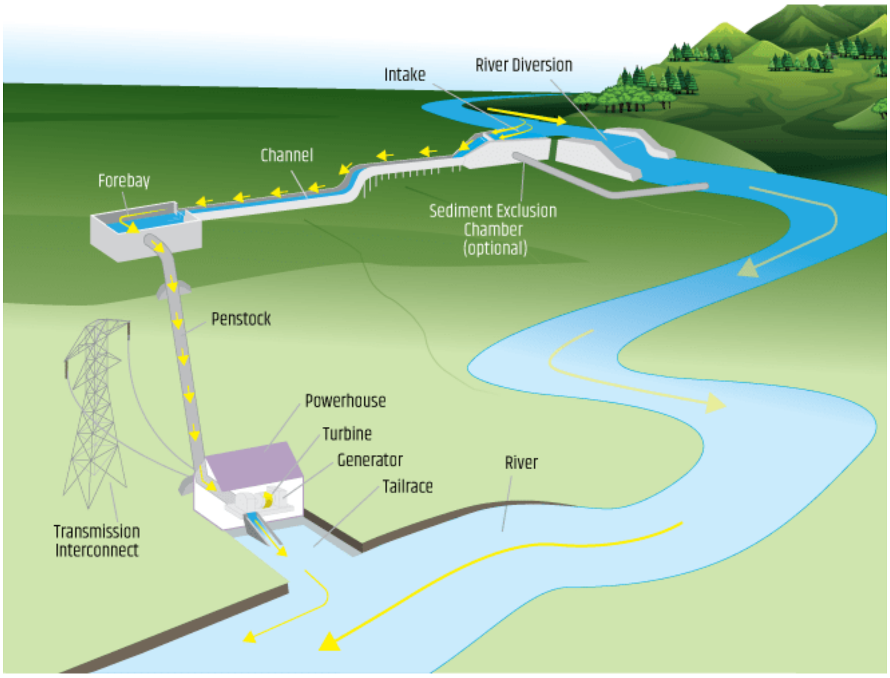
Hydraulic power or water power (Greek: hydro→water) is defined as "the power derived from the energy of falling or fast-flowing water that can be used for a useful purpose". The energy derived from this power is hydraulic energy. Since ancient times, hydraulic power has been used as a renewable energy source in many types of water mills, irrigation, and to drive different types of mechanical devices: "wheat mills, sawmills, weaving mills, harbor cranes, ore crushers, large power hammers, elevators, industrial rollers and drums" (Nijman, 2020).

Although the potential of hydraulic power was discovered long ago, it was not until the 19th century that it was used to generate electricity. The first studies in this field were carried out on the Wey River in October 1881 and the first hydroelectric power plant named "Central Power Station" was commissioned (Dinçer et al., 2017). The first hydroelectric power generation in Türkiye started in 1902 with a 2kW water turbine built in Tarsus. The first large hydroelectric power plant was the 15 MW power plant established in Silahtarağa, İstanbul in 1913. In the 1950s, power plants were started to be built with the cooperation of the state and the private sector. In 1950, the installed capacity reached 407.8 MW and generation reached 789.5GWh (URL-3).

Hydroelectric power plants are power generation plants where electrical energy is produced by converting the potential energy of water into kinetic energy. Water has a stored potential energy due to its elevation position. This potential energy of the water is released downward with its own fluidity through appropriate water diversion structures, creating a water velocity and a maximum kinetic energy at the lowest level. This kinetic energy is converted into rotational motion by turbine structures with blades and rotation capability and a rotating mechanical energy is obtained. With the rotation of the turbine, a generator coupled to the turbine operates to generate electrical energy. The water flow and the water elevation can be done with embankments / dams, as well as by changing the water beds of rivers, streams, rivers, etc. and raising them to a certain high level (Dinçer et al., 2017). These structures have two groups as hydroelectric power plants with dams and hydroelectric power plants without dams (Figure 6).



(a)



(b)

Figure 6. (a) Hydroelectric power plant constructed with dam (URL-4), (b) Hydroelectric power plant without dam (URL-4)

The fact that 90% of the total national electricity generation in 24 countries and 50% in 63 countries worldwide is met by hydroelectric power plants reveals the importance of these structures in providing energy. The advantages of hydroelectric energy over other renewable energy sources are that it is reliable, energy can be easily stored in storage hydroelectric power plants and used when needed, and its capacity can be increased in a few seconds (Bozkurt and Tür, 2015).

By the end of 2021, China ranks first with 370 GW of the world's 1,330 GW of installed hydroelectric capacity, Brazil ranks second with 109GW, and the USA ranks third with 102 GW. Canada ranks in the top five with 82GW, India with 50 GW, and Türkiye ranks ninth with 31 GW of installed capacity, behind Japan, Russia and Norway with 33 GW (WEC, 2021).

Hydroelectricity installed capacity in Türkiye ranks first with 31,490 MW as of the end of 2021, with a share of 31,73% of the total installed capacity. 55,550 GWh of the total electricity generation of 330,806 GWh in 2021 was provided by hydroelectric generation. Due to the dry winter and spring months of 2020-2021 in Türkiye, our hydroelectricity generation remained at 16.79% during this period. Electricity generation from natural gas ranked first with a value of 32,40% (EÜAŞ, 2021).

Türkiye is a developing country in terms of hydroelectric installed capacity and generation. In this context, studies are ongoing for the establishment of hydroelectric power plants in all potential resources. There are operational, ongoing and projected hydroelectric power plant constructions on all rivers. Figure 7 reveals the development of hydroelectric installed capacity in the last 15 years.

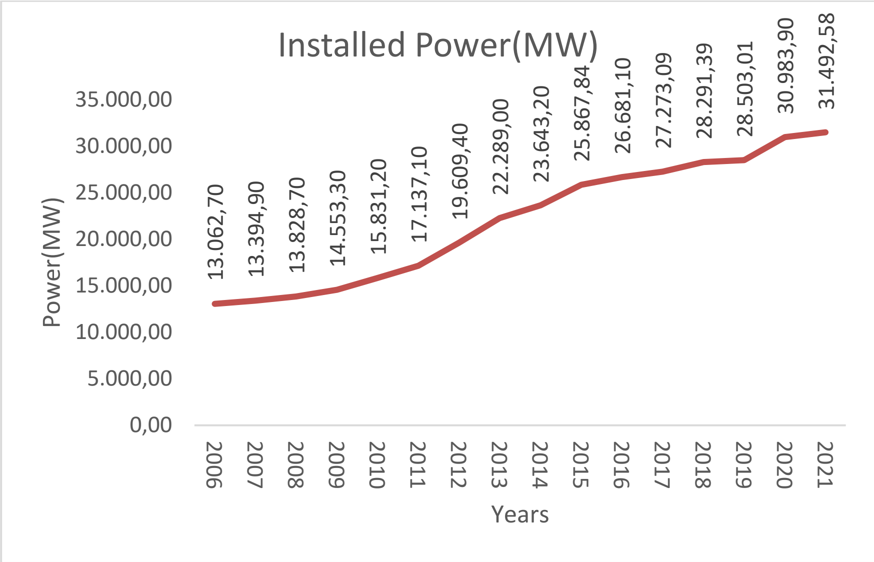


Figure 7. Yearly hydropower development in Türkiye (TEİAŞ, 2021)

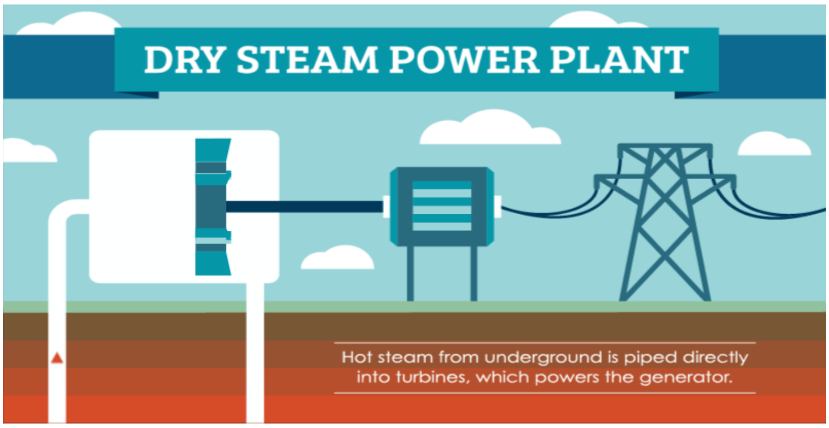
1.2.2. Geothermal Energy

Geothermal energy is defined as “a type of heat energy that is carried to the surface by hot water, steam and gases, which can contain more dissolved minerals, various salts and gases than the surrounding groundwater and surface water, and which is above the atmospheric average temperature in the region where it is located” (Erkul, 2012). It is a heat energy source with an average heat production of 87mW/m^2 and an annual global heat flow of 31-44 TeraWatt (10^{12}Watt). Heat is generated by tectonic movements underground and by the decay of radioactive isotopes of uranium, thorium and potassium in the earth (Satman, 2013).

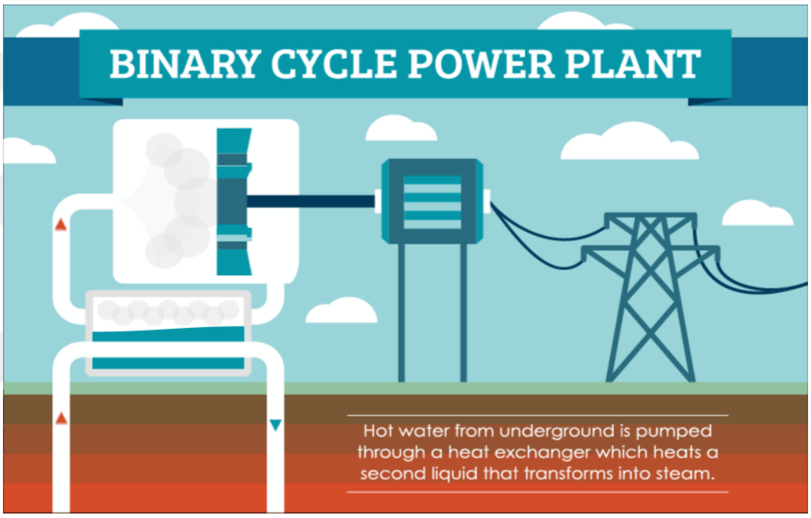
Geothermal energy dates back to ancient times. The first use of geothermal energy in history was as an energy source in the production of pottery, glass, textiles and creams in the Mediterranean Region. In 1500 BC, the Romans and Chinese used natural geothermal resources for bathing, heating and cooking. In 630, the hot spring tradition became widespread in Japan, and in 1200, it was discovered that space and water heating could be done with geothermal energy in Europe. By the 1800s, spa tourism became widespread in the USA. In 1841, geothermal wells were started to be drilled in Larderello, Italy using new techniques. In 1904, electricity was generated from geothermal energy for the first time in Larderello. In 1943, electricity generation from the geothermal field in Larderello reached a capacity of 132 MW. In 1963, the first geothermal borehole in Türkiye was drilled in Balçova, İzmir. In 1968, the Denizli-Kızıldere geothermal field was discovered and the first geothermal well construction for electricity generation was started in this region (URL-5).

The use of geothermal energy is divided into two as direct and indirect use. In direct use, the heat energy provided by geothermal energy is used directly in processes that require heat energy. Indirect use is the conversion into electrical energy. Electrical energy can be generated by steam turbines by separating the steam from the high-temperature steam of geothermal energy or high-temperature water and steam mixture.

Under 150 degrees celsius, thermal energy obtained from geothermal resources is used directly in greenhouses, district heating needs, irrigated agriculture and industrial processes (Külekçi, 2009). Geothermal fields with a reservoir temperature of more than 150 degrees can produce electricity conventionally. With a system developed in recent years and called binary cycle, electricity can also be generated from the fluid at temperatures between 80-150 degrees by using gases with low vaporization points. There are various systems for converting steam and liquid dense systems into electrical energy. The easiest sites to use are dry steam sites. Here steam is used directly in steam turbines. In liquid-dominated systems, the principle is that the liquid vapor mixture is first passed through a separator to separate the vapor and liquid. While the steam obtained is used in steam turbines, the released liquid is either injected directly in the source or the efficiency increases by maximising the use of heat energy using different technologies. These technologies are conventional steam turbines with atmospheric exhaust (back pressure), condensing conventional steam turbines, binary stage evaporation, multi-flash, binary cycle power plants, hybrid fossil-geothermal systems, batch flow (Figure 8) (Kaymakçıoğlu et al., 2005).



(a)



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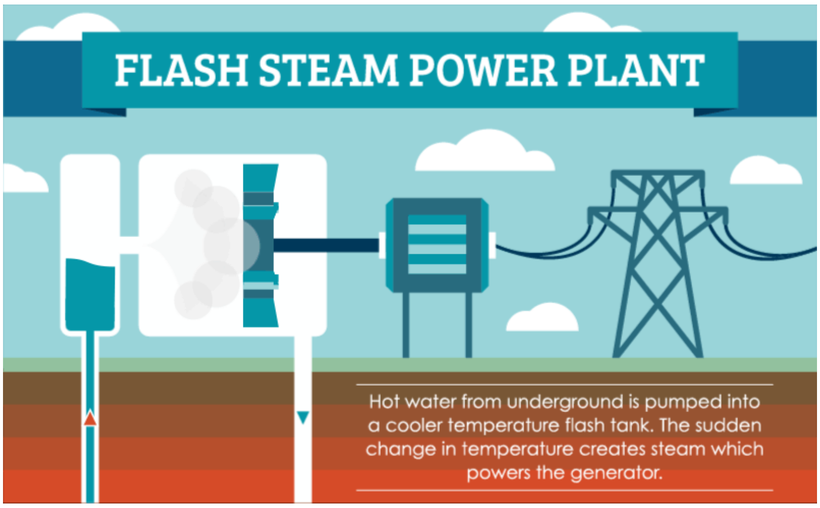


(c)

Figure 8. Types of geothermal power plants (URL-6) (a): Dry steam power plant, (b): Binary cycle power plant, (c): Flash steam power plant

Since geothermal energy is an underground natural resource like fossil resources, the regions where it is found consist of only certain regions in the world. The American continent, Central American countries, the Aegean Region in Türkiye and Italy in Europe are the geographical regions with the highest number of geothermal power plants. Looking at the installed capacity of geothermal power plants by country, the USA is by far the leader. The US is followed by the Philippines, Indonesia and Türkiye, where many new geothermal power plants have recently been commissioned. The total installed capacity of geothermal energy in the world is 15.416 MW (URL-7).

Table 1. Leading countries in geothermal energy and their installed powers

Country	**Installed Power (MW)**
USA	3.714
Indonesia	2.133
Philippines	1.918
Türkiye	1.679
New Zeland	1.005
Mexico	963

Geothermal energy development in Türkiye started with Denizli Kızıldere. As of 1980, the geothermal installed capacity remained at the level of 17 MW in a 20-year period. As of 2007, with the commissioning of new power plants, the installed capacity development gained acceleration and reached 1.679 MW today (Figure 9) (TEİAŞ, 2021).

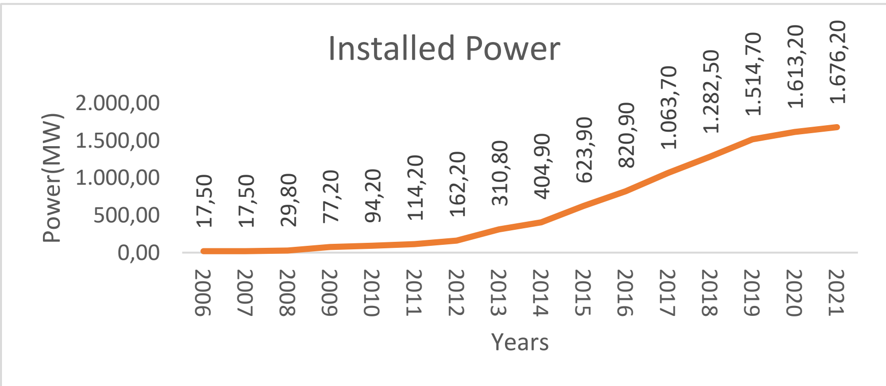


Figure 9. Yearly geothermal power development in Türkiye (TEİAŞ, 2021)

1.2.3. Solar Energy

Solar energy can be defined as “radiant energy from the sun's core, released by the fusion of hydrogen gas into helium (the fusion process)”. The sun is a clean, renewable energy that emits about $3,9x10^{26}$ W of power and will not run out as long as life on earth continues. Very little of this energy emitted by the sun reaches the earth. On average, 1.367 W of power falls on each square meter on the outer surface of the atmosphere. Some of this radiation coming into the atmosphere, usually X-rays and ultraviolet rays, is absorbed and some is reflected back (Figure 10) (URL-8).

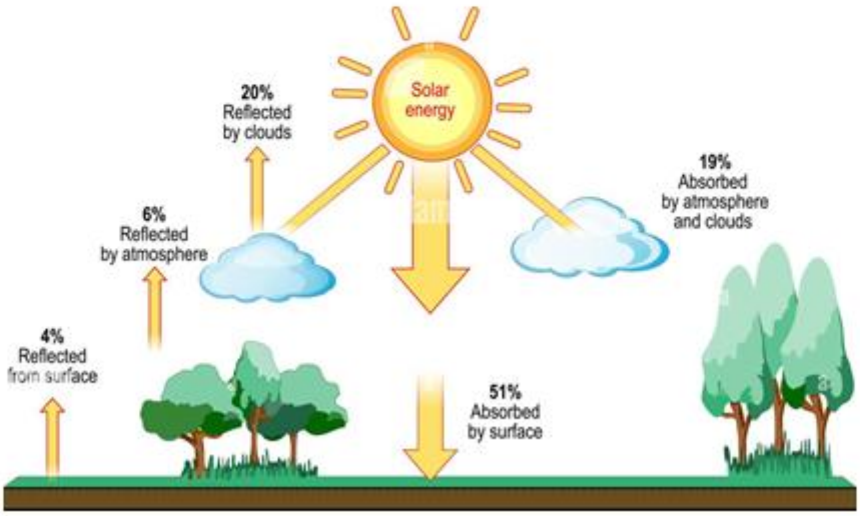


Figure 10. Solar radiation (URL-9)

Since the sun is the main source of life on earth, all kinds of energy are directly or indirectly composed of solar energy. Solar energy is the most ancient known primary energy source and is a clean, renewable and continuously available energy source all over the world (Akova, 2008).

Studies to utilize solar energy date back to ancient times. According to documents, Socrates stated for the first time in 400 BC that if more windows were placed on the south side of the houses, solar radiation would be taken more into the house and benefit in terms of heat and light. In 250 BC, Archimedes succeeded in burning the ships besieging Syracuse by focusing solar radiation with concave mirrors. In the 1600s, studies developed with Galilee's discovery of the lens. A solar-powered water pump was first developed by Belidor in 1725. In 1860, the French scientist Mohuchok worked on a small steam engine by focusing solar radiation with the help of parabolic mirrors and experimented on solar pumps and solar cookers. As oil gained importance during the First World War, studies on solar energy decreased. Since 1930, studies have increased, but have not found much application area. Studies did not go beyond research institutions. But in the 1960s, the emergence of the oil crisis forced people to work on alternative energy sources. Initially, studies mainly focused on solar energy, which is a clean and cheap energy source (URL-10).

Since solar energy is diffuse energy, it needs to be concentrated to achieve high degrees of heat compared to other energy sources. It is possible to convert solar energy into other forms of energy, such as mechanical and electrical energy, with appropriate efficiency. In addition, solar energy has the properties needed to initiate photosynthetic and photochemical reactions. Using photoelectric and thermoelectric effects in semiconductors, solar energy can be directly converted into electrical energy (Akova, 2008).

Solar energy is the cause of the formation of all other resources. It is the most important natural resource that is necessary for the survival of living things and whose energy is infinite. The electrical energy equivalent of the energy coming from the sun on Earth is worth 1.080.000.000.000 TWh, which is 60.000 times the world's annual electricity consumption. However, converting solar energy into other energy sources is unfortunately not affordable today. If energy conversion technologies and costs are reduced to appropriate values, perhaps there will be no need for other types of energy (Eldem, 2017).

There are several different technologies in the use of solar energy. These are technologies including primary solar energy utilization, photovoltaic (PV) technology, concentrated solar energy and solar heating and cooling systems (Balat, 2006).

The direct use of solar energy as a primary energy source, as the main source of natural events and the food chain, as a source of heat and light in daily life, and as the basic starting point for other fossil energy sources, especially wind, water and biomass formation.

The traditional and most common use of solar energy is for domestic hot water. In general terms, its applications can be classified as: “air conditioning (heating-cooling), cooking, hot water supply and swimming pool heating in residential and workplaces; in agricultural technology, greenhouse heating and drying of agricultural products; in industry, solar cookers, solar ovens, solar ovens, solar cookers, salt and fresh water production from seawater, solar pumps, solar cells, solar pools, heat pipe applications; in transportation-communication vehicles, signaling and automation, electricity generation”. Although solar energy technologies differ greatly regarding method, material and technological level, they can be analysed in two main categories: thermal solar technologies and solar cells (Figure 11). In thermal technology, heat energy is first obtained from solar energy and this heat energy is either used directly as heat energy or converted into different secondary energy sources. Solar cells are known by the general term photovoltaic cells. Photovoltaic cells are made of semiconductor materials and convert sunlight directly into electrical energy (Varınca and Gönüllü, 2006).

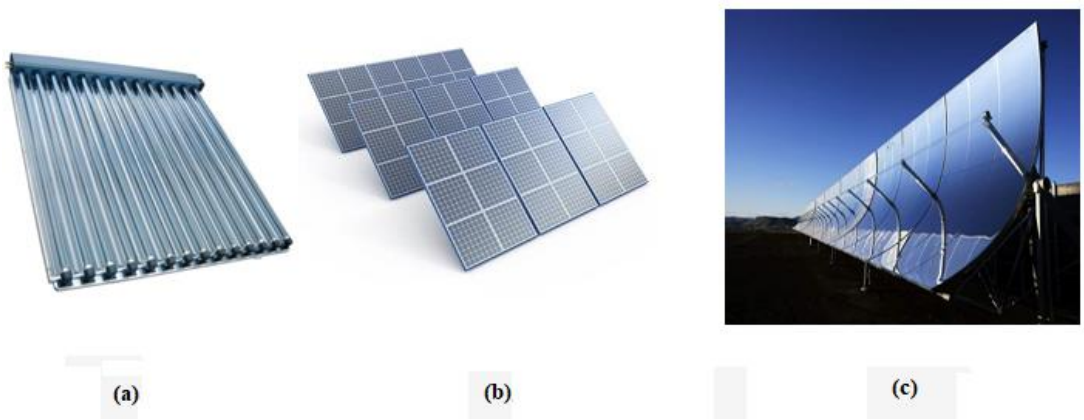


Figure 11. (a): Solar thermal panel, (b): Solar PV panel, (c): Solar thermo-electric panel (URL-11).

Solar cells generally consist of two groups: thin film and crystalline silicon. Crystalline Silicon, Gallium Arsenide (GaAs), Amorphous Silicon, Cadmium Telluride (CdTe), Copper Indium Diselenide ($CuInSe_2$) compounds are mostly used in the production of these cells today (Kapluhan, 2014a). Solar cells are produced in two forms: crystalline and amorphous. Commonly used crystalline cells are produced as monocrystalline and polycrystalline. The area of the solar cell, whose surfaces are shaped as square, rectangular and circular, is around 100 cm² on average and its thickness varies between 0,2-0,4 mm (URL-12). The efficiency comparison of monocrystalline, polycrystalline and amorphous solar cells is given in Table 2.

Table 2. Comparison of the solar cell types (Salah, 2019)

Material	**Efficiency %**
Monocrystalline silicon	14 - 17
Polycrystalline silicon	13 - 15
Amorphous silicon	5 - 7

A photovoltaic cell consists of an N-conductor layer on a P-conductor base material. The back side of the cell is coated with a metallic contact, while the irradiation side is fabricated with a finger-type contact system to minimize shadowing losses. The surface is also covered with transparent conductive layers. An anti-reflective coating can be applied to the cell surface to reduce reflection losses. Silicon solar cells are usually blue in color. Reflection losses are reduced in cells assembled in an reverse pyramid shape. Sunlight is completely absorbed by these cells, creating a black colored appearance of the cells (Kaltschmitt et al., 2007).

Solar cells are the backbone of photovoltaic technology. They are two-terminal devices that conduct like diodes in the dark and produce a photovoltage when exposed to sunlight. Thin slices of semiconductor are joined together to form 100 cm2 panels. Panels are produced in dark blue or black color to reflect the least amount of light. For electrical conductivity between cells, a pattern of conductive material is patterned on the surface (Figure 12(a)) (Nelson, 2003).

When the solar cells are charged, the base unit produces a DC photovoltage of 0,5 to 1 volt and a photocurrent of tens of milliamps per cm^2. While the current is sufficient, the voltage is too low for many applications. Therefore, for a useful voltage value, cells are connected in series and formed into modules. To obtain a DC output voltage of 12V under normal bright weather conditions from a module, 28 to 36 cells are connected in series (Figure 12(b)). 12 volt modules can be used as single modules or they can be connected in parallel or in series to produce high current and voltage depending on the need. Series connected modules form arrays and parallel connected modules form strings (Figure 12(c)) (Nelson, 2003).

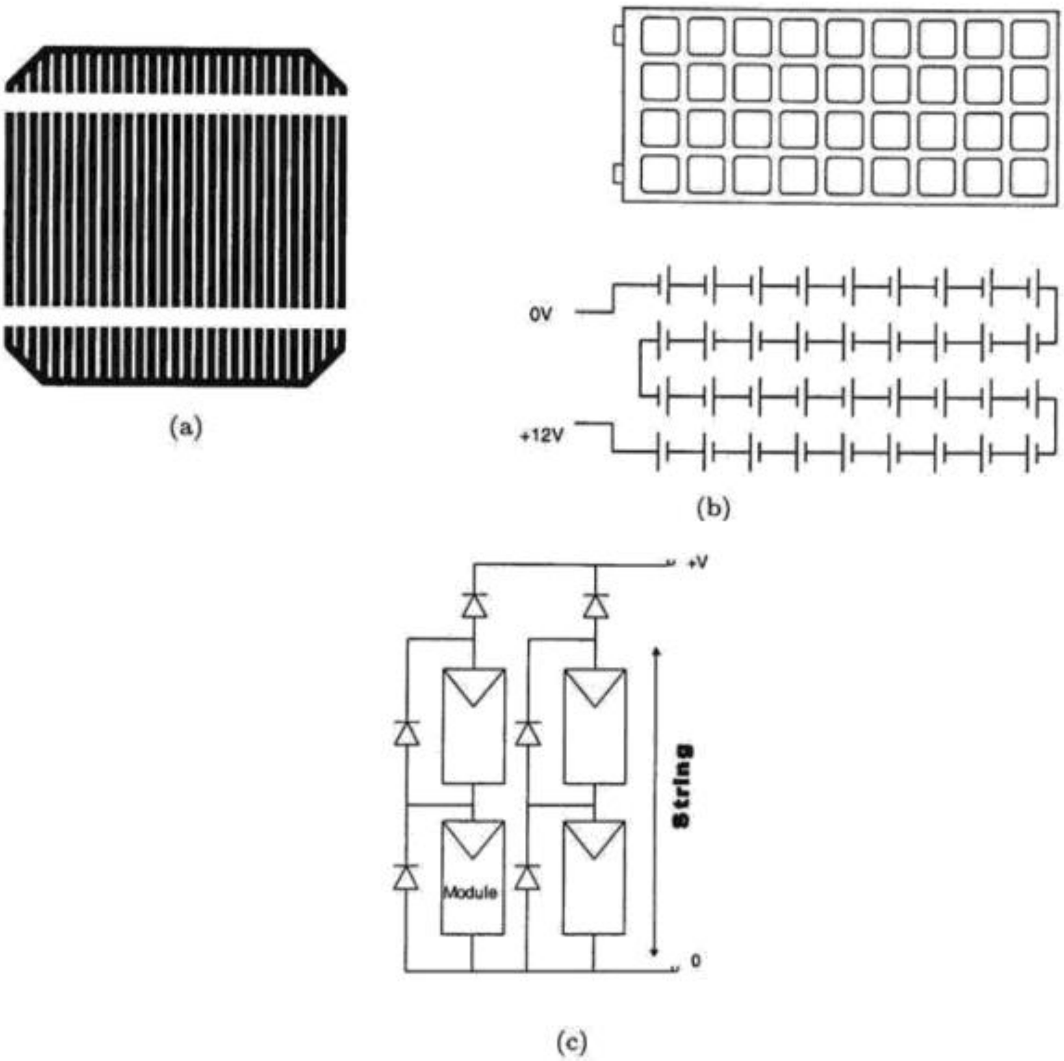


Figure 12. (a) Photovoltaic cell surface contact patterns, (b) Serial connected cells in a module (c) For any application serial connection into string or parallel connection into array (Nelson 2003).

In these photovoltaic panels, which are generally produced in the form of quadrilateral panels, a direct current electrical energy is generated at the edges of the panel by moving the electrons of the semiconductor materials inside under the impact of the sun's rays. This direct current electrical energy can be used directly in direct current devices or it can be converted into alternating current and used as a grid-connected or off-grid system with storage. In both cases, inverters are used in conjunction with inverters since most of the devices operating with electrical energy in daily life operate with alternating current.

A solar cell irradiated with solar radiation can ideally be considered as a current source supplied from a parallel diode (Figure 13). The light current (I_{Ph}) is the proportional to the photon flux incident on the cell. Shockley's equation for ideal diodes (Equations 1-2) gives the current-voltage characteristic of a solar cell (Kaltschmitt et al., 2007).

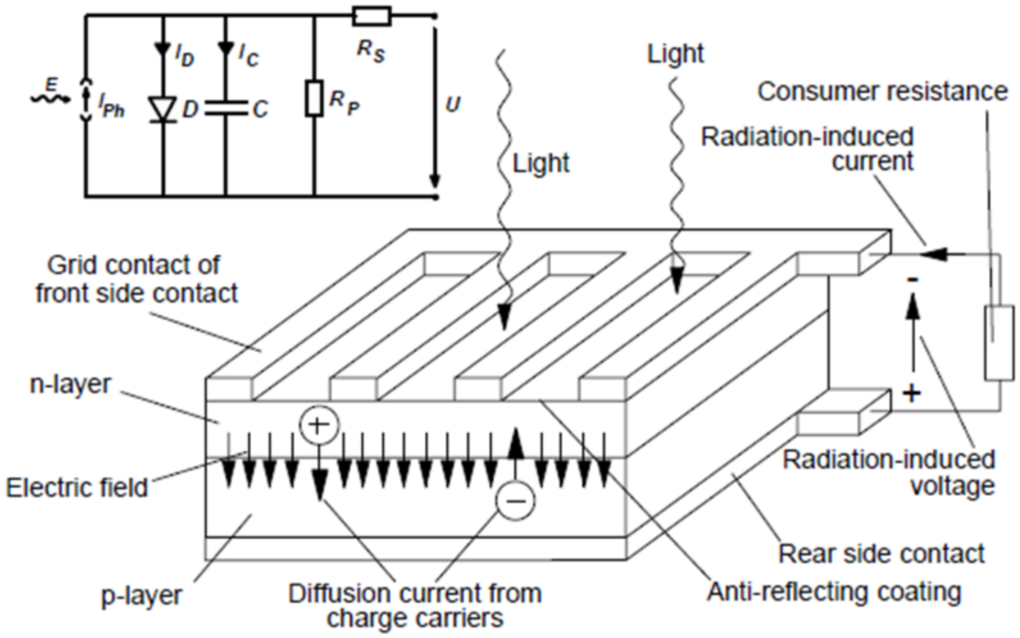


Figure 13. Structure of a typical solar cell and an equivalent circuit diagram (Kaltschmitt et al., 2007)

$$I = I_{Ph} - I_0 \left(e^{\frac{e_0 U}{kT}} - 1 \right) \quad (1)$$

$$U = \frac{k}{e_0}.T.\ln\left(1 - \frac{I - I_{Ph}}{I_0}\right) \quad (2)$$

I: current flowing through the terminals

I_{Ph}: photocurrent

I_0: saturation current of thr diode

e_0: elementary charge (1,6021x10^{-19}As)

U: cell voltage

k: Boltzmann constant (1,3806x10^{-23}J/K)

T: temperature

Figure 14 shows the current-voltage curve for varying irradiance and temperature values. At the intersection points of the curve and the axes, the short circuit current (I_{SC}) is determined at U = 0 and the open circuit voltage (U_{OC}) at I = 0. Starting from the short-circuit current, the cell current initially decreases slightly and continuously increases the cell voltage, while it suddenly drops shortly before reaching the open-circuit voltage. The filling factor FF of the cells is found by the formula given in Equation 3 (Kaltschmitt et al., 2007).

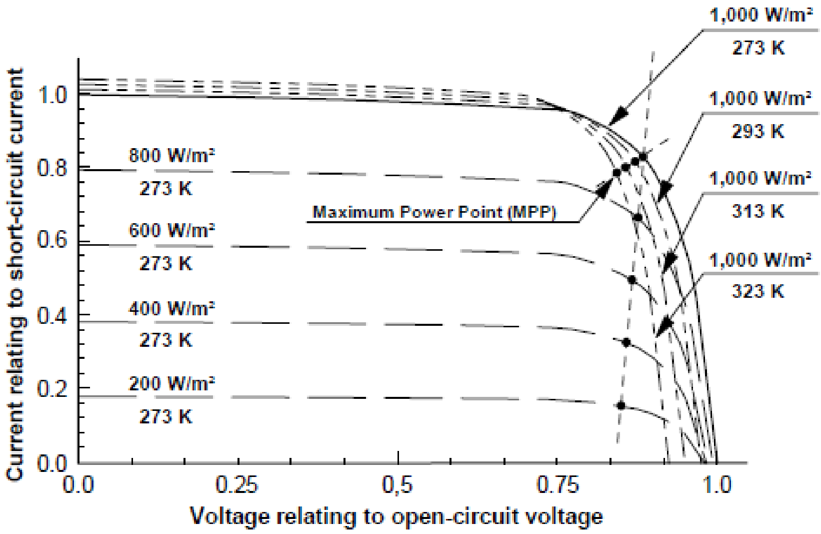


Figure 14. Influence of radiation and temperature on the characteristic current-voltage curve assuming standard test conditions (Kaltschmitt et al., 2007)

$$FF = \frac{I_{MPP} . U_{MPP}}{I_{SC} . U_{OC}} \quad (3)$$

Photovoltaic means the generation of electricity from photons. This production is realized by means of photovoltaic panels. Photovoltaic systems generally generate electrical energy from the sun. These systems consist of many components. These are some basic components such as solar panels, battery, inverter and charge controller (Figure 15). The charge controller regulates and stabilizes the DC energy from the solar panel and converts it into a constant DC electrical energy for charging the batteries. Inverters are the devices that convert DC electrical energy into AC electrical energy. The quality of the battery pack and batteries is an important issue for off-grid storage systems (Akcan and Minaz, 2020).

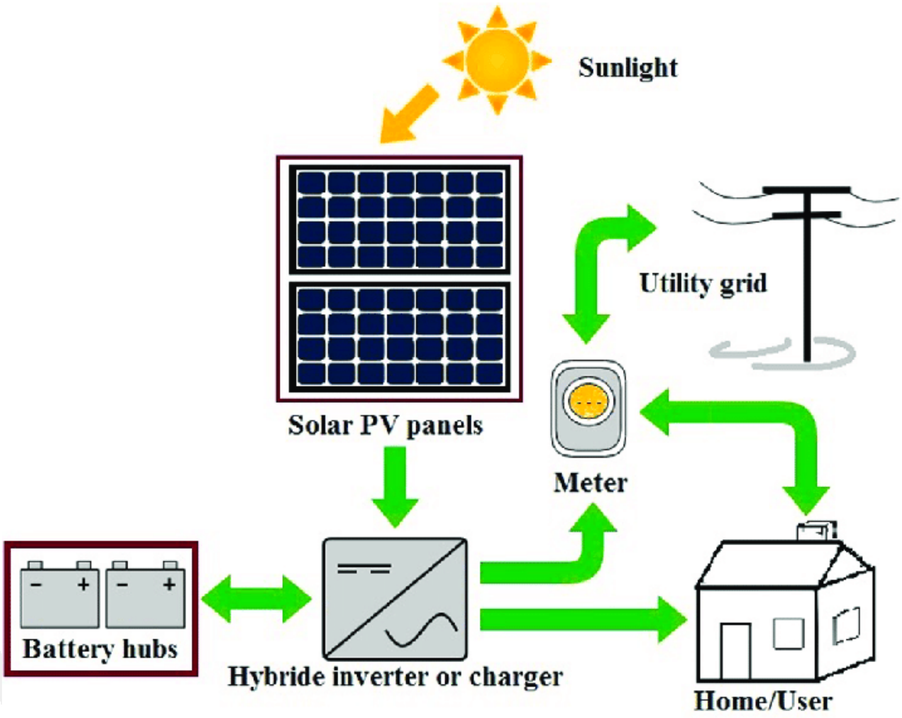


Figure 15. Schematic diagram of a typical solar PV system (Behura et al., 2021).

In photovoltaic solar technologies, a photovoltaic conversion takes place. In the first stage of this two-stage conversion, charge pairs, which are positive-negative current carriers, are formed, and in the second stage, the pairs are separated from each other by an electric field. The P-N junction is formed by the interconnection of an N-type semiconductor with an excess of electrons and a P-type semiconductor with an excess of positive charges. An electric field is structurally formed in the P-N junction and energy conversion takes place in this region. Solar photons arriving in this region give their energy to the electrons here and the negative-positive charges formed with this energy are separated from each other by the existing electrical field and produce direct current. This direct current is stored in batteries and used as DC or converted to AC with inverters and used in connection with the grid (URL-12).

The output of photovoltaic panels is direct current and direct voltage. Variable direct voltage is generated according to the intensity of solar radiation. In storage systems that are not connected to the grid, this direct voltage can be regulated with a regulator and used directly in devices operating with direct voltage or stored in batteries. The direct voltage stored in batteries is converted to alternating voltage by an inverter when there is no solar radiation. Since battery storage systems without grid connection do not offer sufficient utilization advantages both technically and economically, grid-connected systems are generally preferred. In grid-connected systems, the DC voltage produced is converted to AC voltage in the grid conditions to be connected with the inverter without a storage system. Since the panel output can be variable, a regulator device must be installed before the inverter. In photovoltaic power generation plants that are connected to the grid for the needs of a specific facility or house, the energy produced is sold to the grid when the energy produced is more than the need, and energy is taken from the grid when there is no production. Offsets are made with production and consumption meters.

Since solar radiation is a source that can change instantaneously, photovoltaic panel outputs are not constant. MPPT (Maximum Power Point Tracking) devices are used to optimize panel outputs. MPPT devices are electronic devices that track the maximum value of the power generated at certain intervals in wind and solar energy technologies where power generation may change instantaneously and transfer it to the load. MPPT devices compare the solar panel power output value with the battery power or inverter power and provide the optimum voltage value output for the battery or inverter. In the structure of the MPPT, there are power regulation elements such as diodes, inductors and capacitors, as well as a data logger that reads and records current and voltage information from the solar panel and information from the load side. There is also a specially programmed microcontroller system inside the device that provides and controls system security by using all this information (URL-13).

PV modules give an output that is essentially determined by the level of incoming radiation. For certain external conditions, the I - V curve in Figure 16 is formed. The power, I-V, depends on the operating point and the maximum power point (MPP) takes its maximum value at the operating state close to the knee of the curve. The quality of a cell depends on the quadrature of the I - V characteristic. This is calculated as the ratio of the open circuit voltage to the closed circuit current divided by the power value at the MPP. This ratio is the filling factor (Infield and Freris, 2020).

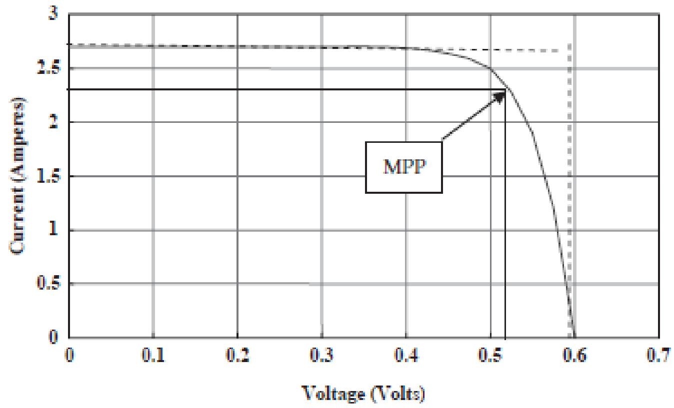


Figure 16. I – V curve of the PV systems (Infield and Freris, 2020).

As shown in Figure 17(a), the variation of irradiance and temperature changes the I - V curve and the voltage value at which the MPP occurs. The power electronic converter is used to bring the operating voltage as close as possible to the MPP value and to keep it under control for the smallest irradiance and temperature variations. Usually these power electronics functions are combined with inverters for grid connection. PV modules store negligible energy. However, in the case of a power system, their output varies with the instantaneous change in irradiance. Therefore, as shown in the curve example in Figure 17(b), a cloud shading the PV system before 18:00 h caused a sudden drop. As with wind turbines, positioning PV systems with such geographical effects in mind can avoid such short-term effects (Infield and Freris, 2020).

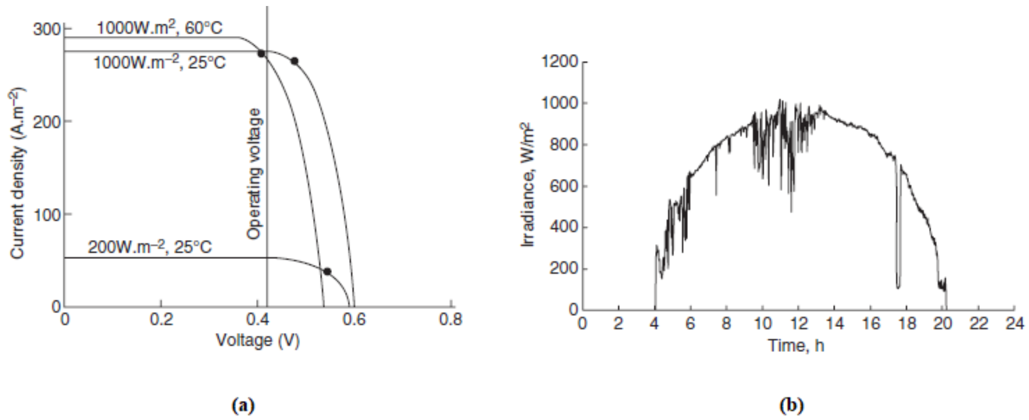


Figure 17. (a) Impact of radiation and temperature on the I – V characteristic, (b) Time variation of radiation through a summer's day in Loughborough, UK (Infield and Freris, 2020).

Solar energy is made useful and usable through solar panels. These solar panels should be positioned in a way to obtain maximum efficiency from solar energy. For this, the installation direction and installation angles of the panels are important. In the universe, the earth, sun and moon move in accordance with certain rules. As a result of these movements, day-night events and seasons are formed. Night-day durations, the formation and duration of seasons also vary from region to region. In line with all these variable natural phenomena, several engineering calculations related to the installation of solar panels have become mandatory. A few of these are listed below.

Solar radiation has two important terms. These are peak sundials, which refer to the time it takes for a day's total solar radiation to accumulate unconditionally at the peak, and *zenith and zenith angle*, which refer to the point directly above a given position in the sky (Figure 18(a))(URL-11).

The **solar window** is the area of sky between the summer equinox and the winter equinox formed by the path of the sun in a given region (Figure 18(b)) (URL-11).

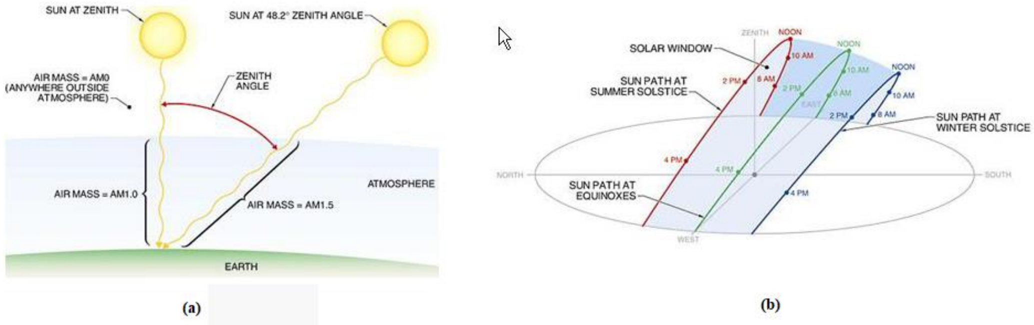


Figure 18. (a) Solar radiation, (b) Solar window

The **incidence angle** is "*the angle value between the direction of direct solar radiation and the line drawn exactly perpendicular to the panel*". The position and direction of the arrays are determined by the tilt angle and azimuth angle (Figure 19). The array positions for the maximum energy that can be obtained from the arrays according to the annual summer and winter conditions are given in Figure 20 (URL-11).

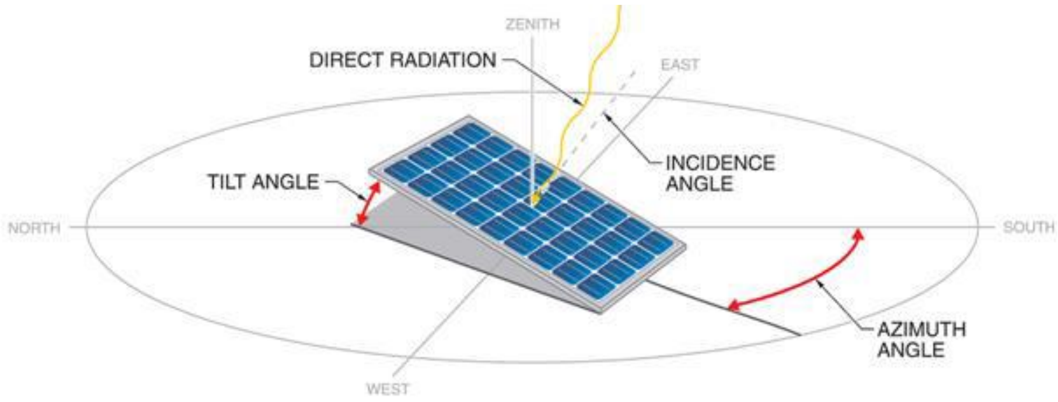


Figure 19. Incidence angle and the other radiation angles.

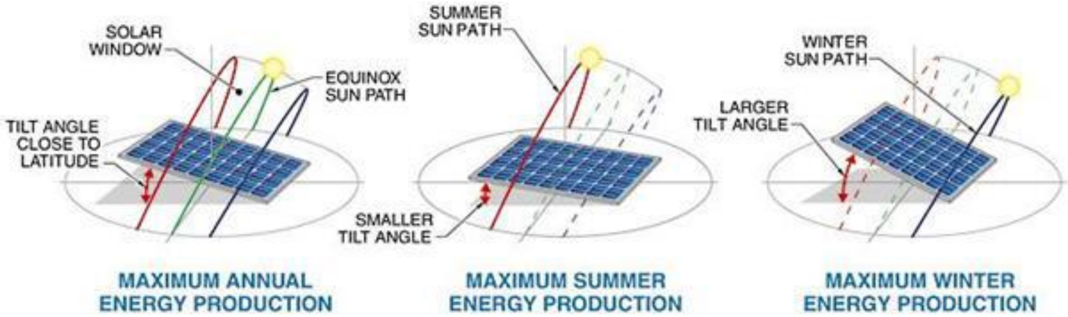


Figure 20. Variation of the tilt angle according to seasonal conditions

Simulation programs provide the opportunity to calculate and report the planning and investment stages of solar energy projects by entering the geographical characteristics of the installation location in the computer environment, together with the current equipment costs registered in the program. With simulation programs, the limit values and operating conditions of the systems can be adjusted and the project can be designed in many different ways and the results can be reported. Simulation programs are used for accurate yield estimates and forecast reports during the investment phase. Equipment manufacturers keep their newly developed, improved or optimized products in the database of simulation programs. Simulation programs facilitate engineers in shadow calculations, maximum power point (MPP) determination, and selection of suitable panels and inverters. When searching for the most efficient component or the most economically beneficial solution, or when making detailed planning of complex PV plants, simulation programs can make designs in a shorter time, apart from the known rules and information. Simulation programs are also used for educational purposes other than investment and planning projects (Kınalı, 2019).

These simulation programs, which assist investors and the engineers who plan the facilities in which investors work, can generate the facility diagram, parameters, data sheets, facility-specific calculations, product quantity lists, circuit diagrams, assembly and installation warnings, and the documents required for the grid distribution company in the form of a report ready for printing and presentation (Haselhuhn and Hemmerle, 2012).

The shading factor is one of the most complex issues in the planning and simulation phase of PV installations. On flat roofs or open areas, module series cast shadows on each other. This is natural shading. Partial or complete shading by nearby objects such as trees, buildings, poles, etc. is defined as direct shadow or near shadow. The horizon line elevations of mountains and forests also cast shadows on modules in the form of horizontal or far shading. Shadows negatively affect the efficiency and operation of the plant. In these PV plants, simulation programs are used to determine the losses due to shading and to optimize the system. Therefore, the shading factor is very important for the simulation of PV plants (Kınalı, 2019).

The main goal of the simulation is to generate a shadowing detection with the help of horizon images based on one or more partial modules (Greenius, Polysun, PVSOL, etc.). In this way, shadowing factors due to the large area are adequately taken into account. HorizOn, HORIcatcher and Suneve simulation programs can convert digital photographs into horizon lines for simulation, which can help in shading analysis. Meteonorm and PVGIS programs allow the creation of horizon images for the whole region with the help of a digital terrain model. In case of complex shadowing or close shadows, a detailed shadowing detection cannot be done with the help of 3D simulation. However, PVSOL, PVSYST and SolarPro have input features for 3D parameterization. In PVSOL, shadows are taken into account in the form of modules by utilizing the bypass diode circuit and their effects on current and voltage curves. In PVSYST, shading is considered on predefined sequences, on an area basis or on the basis of the entire area of the PV module. Module row definition and row shading calculation can be successfully simulated in PVSYST (Haselhuhn and Hemmerle, 2012).

The importance of renewable energy is rising day by day. In this context, plans and investments are being made worldwide to utilize potential renewable resources in energy production. Among these, solar power plants have been preferred and encouraged by governments in recent years as their technology has reached appropriate levels. Simulation programs are used in the planning, project and investment stages of solar power plants. Information on the main simulation programs used extensively around the world is given in Table 3.

Table 3. PV Simulation programmes commonly used in the global market (Jacques et al., 2014).

Name of the PV software tool	Software developer	Cost	Aim	Advantages	Drawbacks	Target users
Archelios	University of Savoie, France	Free of charge	Solar system sizing, solar irradiation calculation	Easy to use	Flexibility	General Public
Calsol	INES, Lyon, France	Free of charge	Solar system sizing	Meteorological data from an official source	Flexibility	General Public
Homer	National Renewable Energy Laboratory, USA	Free of charge	Solar system sizing and financial studies	Hybrid system sizing	Accuracy of calculations	Laboratories and companies
Tecsol	Languedoc-Roussill on region, France	Free of charge	Solar system sizing	Easy to use, environmental and financial studies	Flexibility	General Public
Pv f-chart	University of Wisconsin, USA	Commercial program	Solar system sizing	Complete	Accuracy of calculations	Companies
Pvgis	European Commission	Free of charge	Solar system sizing	Easy to use, climate data mapping	Flexibility	General Public
PVSOL	Valentin company, Germany	Commercial program	Solar system sizing	Complete, graphical tools	Accuracy of calculations	Laboratories and companies
Pvsyst	University of Geneva, Switzerland	Commercial program	Complete solar system sizing	Flexible, graphical tools, shadowing	Graphical tools	Laboratories and companies
Pvwatts	National Renewable Energy Laboratory, USA	Free of charge	Solar system sizing	Accurate calculations	Grid-connected system sizing	Laboratories and companies
Retscreen	Natural Resources, Canada	Free of charge	Environmental and financial studies	Meteorological database from NASA	Flexibility, PV tool	Laboratories and companies
Sam	National Renewable Energy Laboratory, USA	Free of charge	Solar system sizing and financial studies	Complete and accurate calculations	Inverter database	Laboratories and companies

Similar to photovoltaic technology, solar panels and solar collectors are used in thermal solar technology. In the solar collector, the sun's rays are absorbed and converted into thermal energy and heat is transferred to a fluid. The fluid used has various types depending on the construction and method. The task of the solar collector is to transfer solar radiation to a secondary circuit as useful heat energy. The part called absorber realizes this transfer inside the collector. Absorber is an element of the system that absorbs the energy received through radiation. The absorber surface is coated to absorb the radiation and reflect the minimum possible radiation and the heat generated is transferred to the heat carrier fluid through pipes (Karakoç et al., 2012).

Another area of use in thermal solar energy applications is in power generation plants. Its use in power plants is based on the use of parabolic trough collectors, parabolic dish collectors or central receiver type systems (solar concentrators). Depending on the geometry of the concentrator collectors, temperatures of up to 400°C can be reached in direct concentration, i.e. parabolic trough collectors, and up to 1400°C in three-dimensional, i.e. dish collectors. With focused solar collectors, superheated water, saturated steam and superheated steam are obtained at high temperatures. The superheated water or steam energy obtained in this way can be used in energy production in industrial plants. Today, there are many thermal power plants operating with superheated steam obtained from solar energy in various places around the world, and research and development studies are still ongoing (Kılınç, 2015).

Solar thermal energy is currently used conventionally for hot water supply. A more efficient use of solar thermal energy at higher temperatures is called Concentrated Solar Power (CSP) or Solar Thermal Energy Electricity (STE). In this system, electrical energy is generated by concentrating solar radiation to heat a material (typically a liquid). The heated material, called “the Heat Transfer Fluid or Heat Transfer Medium”, then produces steam to drive a turbine-generator set in the power block. A typical CSP system structure is given in the figure below (Figure 21) (Fereres, 2018).

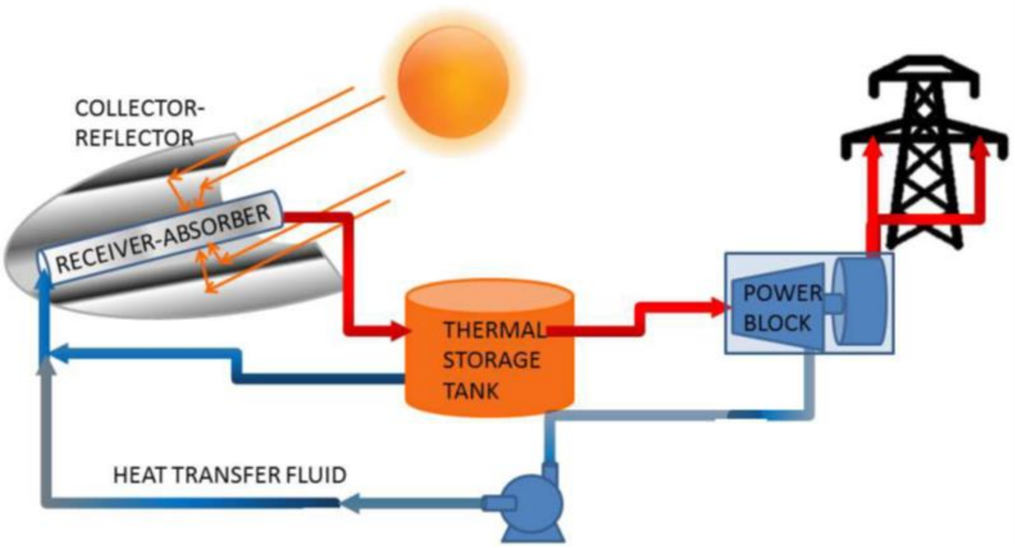


Figure 21. General schematic of a CSP system with its main components: collector/reflector, receiver/absorber, heat transfer fluid, thermal energy storage, and power block.

Electricity generation with solar energy should be preferred and evaluated because it is more environmentally friendly and continuous compared to other conventional generation techniques. Other advantages include low maintenance and operating costs. However, the disadvantages of solar energy are that it requires a large area for the panels, there is no or little sunshine during night hours and winter months when the need for electrical energy is higher, and storage techniques are not yet economical enough.

In almost all countries in the world, solar energy is used to generate electricity to a greater or lesser extent. But in official statistics, power plants that are not connected to the interconnected system of the countries, in other words off-grid power plants, are generally not included in the statistics. Looking at the distribution of grid-connected systems by country in the world, China is the leader with an installed solar power capacity of approximately 255.000 MW. Türkiye ranks 14th among the world countries with an installed capacity of 8.275 MW. The Public Republic of China is followed by Japan, Germany, the USA, Italy, the United Kingdom (UK and other countries affiliated to the UK) and India (URL-11).

The development of electricity generation from solar energy in Türkiye has gained acceleration as of 2010. The development of solar energy installed capacity by years is given in Figure 22.

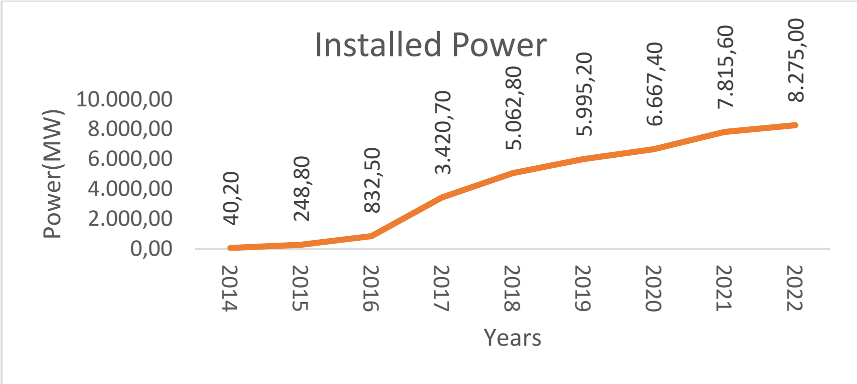


Figure 22. Yearly photovoltaik power development in Türkiye (TEİAŞ, 2021)

1.2.4. Wind Energy

Wind is created by the differential heating of the earth's surface by solar radiation. The different heating of the Earth's surface leads to different temperature, humidity and pressure of the air, and this different pressure results in the movement of the air. Approximately 2 per cent of the solar energy arriving on Earth is converted into wind energy. The properties of wind vary temporally and regionally depending on local geographical differences and inhomogeneous heating of the earth. Wind is represented by two parameters: speed and direction. Wind speed generally increases with height and its theoretical strength varies as a function of the cube of its speed (Equation 4) (URL-14).

$$P_W = \frac{1}{2}\rho A V^3 \tag{4}$$

ρ : Density (kg/m^3) Small changes with elevation & temperature
A: Area (m^2) Squared effect of changes in Radius
V: Velocity (m/s) Cubic effect of changes in wind speed

Winds are classified into two groups (Table 4) according to their continuity as continuous winds blowing all year round and winds blowing at certain times. Alize winds blow every season from the high pressure zone above 30^o latitude in the northern and southern hemispheres to the low pressure zone above the equator. Contralized winds, on the other hand, blow in the opposite direction of the trade winds at the heights of the atmosphere and the reason for their formation is the rise of the air masses heated at the equator and their movement away from the equator. Breeze winds occur when the land warms and cools faster than the seas and the mountains cool faster than the valleys, affecting the air masses above them. At night, land breezes blow from the rapidly cooling land to the seas, and during the day, sea breezes blow from the seas to the rapidly warming land (Özdamar, 2000).

Table 4. Generally classification of wind kinds

Continuous Winds						Discontinuos Winds	
			Breeze Wind				
Alize Winds	Contralized Winds	Monsoon Winds	Land and sea breeze	Mountain and valley breeze	Foehn Winds	Cyclone Winds	Anticyclone Winds

Wind energy was first used in the Middle East around 2800 BC. It was used for irrigation purposes in Mesopotamia in the 17th century BC during the reign of the Babylonian king Hammurabi and it is known that it was also used in China during the same period. The first windmills were built near Alexandria. Europeans first encountered windmills during the Crusades. The use of windmills in France and England started in the 12th century (Başaran, 2019).

The windmill in Seistan on the Iran-Afghanistan border is the first officially recorded windmill dating back to the year 644. In China, windmills were used to irrigate rice fields in the years 750-850. Windmills with vertical axes, which were first used in the east, were developed by westerners and turned into horizontal axis windmills. The first example of a horizontal axis windmill was found in 1180 during the Kingdom of Normandy. The next historical development of horizontal axis windmills are: "*the free-standing windmill (Germany), the tower-type windmill (Mediterranean Countries, Alacati), the Dutch windmill with a rotating roof (Netherlands) and the multi-blade American windmill with a wind direction director installed by Daniel Halladay in 1850*". In 1891, Danish Professor Paul La Cour was the first to generate electricity from wind energy. In the following 50 years, the production of electrical energy from wind energy remained stagnant due to the cheapness of fuel in diesel power plants. The Smidth wind turbine with 17.5 m propeller diameter and 50 kW rated power produced in 1942 and the Gedser wind turbine with 24 m propeller diameter and 200 kW rated power produced in 1957 can be shown in the ongoing historical development (Hau, 1996).

The generation of electrical energy from wind energy consists of converting the kinetic energy of the wind into rotary motion by means of a bladed turbine and transmitting this motion to a generator. Today, the concept stereotyped as "wind turbine" is an integrated structure consisting of tower, generator, speed converters (gearbox), electrical and electronic elements and blades. The shaft to which the rotating parts are connected is called the rotor shaft. The rotary motion of the rotating rotor shaft is accelerated in the gearbox and transferred to the generator in the body and the electrical energy obtained from the generator is stored and used by means of batteries or transmitted directly to the grid (Elibüyük and Üçgül, 2014).

Wind turbines are classified into three different types according to their axis of rotation: horizontal axis, vertical axis and inclined axis wind turbines (Figure 23). According to the number of blades in horizontal axis turbines, there are single-blade, double-blade, triple-blade and multi-blade turbines. Vertical axis turbines are of three types: Savonious, Darrieus and H-Darrieus wind turbines. Inclined axis wind turbines are described as " the turbines whose axes of rotation make an angle with the vertical in the direction of the wind" (Nurbay and Çınar, 2005).

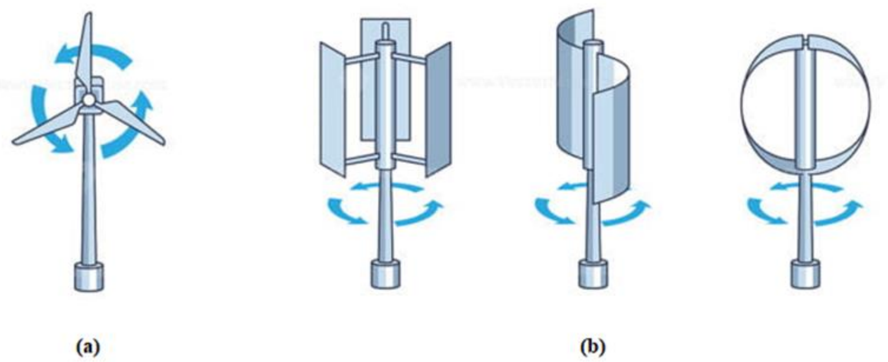


Figure 23. (a): 3 bladed horizontal axis wind turbine, (b): Some vertical axis wind turbine (URL-15)

Due to the oil crisis and rising fuel prices in the 1970s, wind energy came back to the world agenda and investments started to be made in this field (Heier, 1996). As a consequence of improvements in the 1980s, serial and massive production of wind turbines with nominal powers of 600 kW, 750 kW, 1000 kW, 1500 kW and 2000 kW was started (Figure 24) (Anonim, 1997). Today, wind turbines with a power of 10 MW can be produced. In 2025, 15 MW turbines are expected to be produced (Pisanò, 2019).

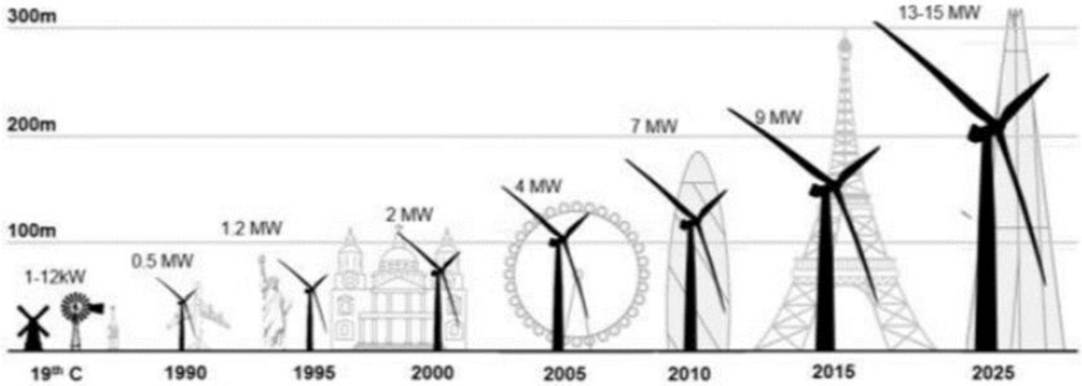


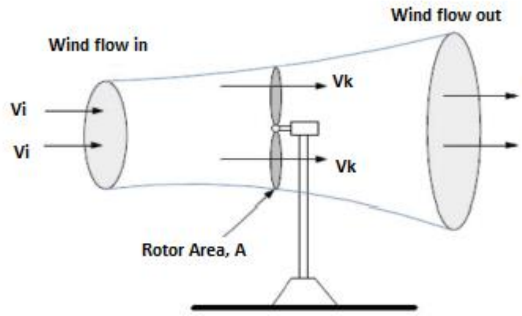
Figure 24. Evolution of wind turbine size and power output (Pisanò, 2019).

The power of wind energy is derived from the formula for the kinetic energy of the wind. In the kinetic energy formula, the mass m depends on the mass flow rate through the swept area swept by the blade (m = ρ.V) (Equation (4)). In the case of horizontal axis turbines, the parameters that affect the intensity of the wind and hence the strength of the wind are blade size, temperature and tower height. Blade size affects the "A" field in equation (4). Since a circle is formed in the rotation of the turbine, the area A is related to the square of the diameter of the blade (D: Diameter formed by the rotation of the blade) from the circle area formula $A = \frac{1}{4}\pi D^2$. Density changes with temperature change. As the temperature increases, the density decreases, which leads to a decrease in wind power (Equation (5)). Tower height affects the wind speed in direct proportion. As the friction force caused by the roughness of the landforms will decrease in higher towers, the wind speed increases, thus increasing the wind power (Terzioglu et al., 2019).

$$\rho = \frac{P.MW.10^{-3}}{R.T} \tag{5}$$

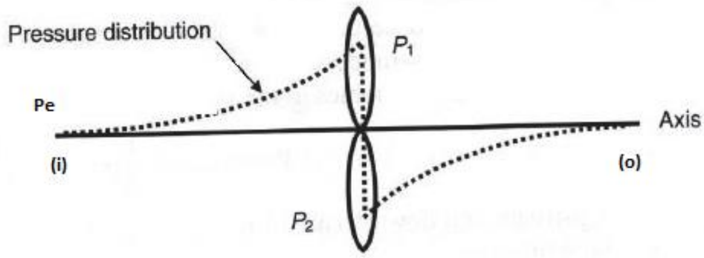
R: Ideal Gas Constant
P: Absolute Pressure (1 atm)
T: Absolute Temperature (K:Kelvin)
MW: Molecular Weight of Gas (g/mol)

The amount of power generated from the wind can be determined by the Betz theorem. Betz analysis applies the actuator disk approximation method. In the actuator theory, energy transfer takes place in the actuator plane and energy conversion occurs in front of and at the end of the actuator. Actuator disk analysis includes pressure, speed and cross-sectional area parameters in wind turbines as shown in Figure 25 below (Terzioglu et al., 2019).

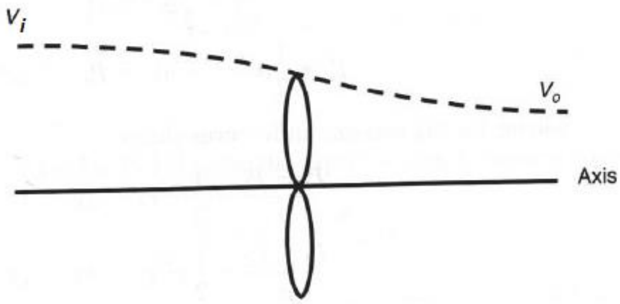


(a)

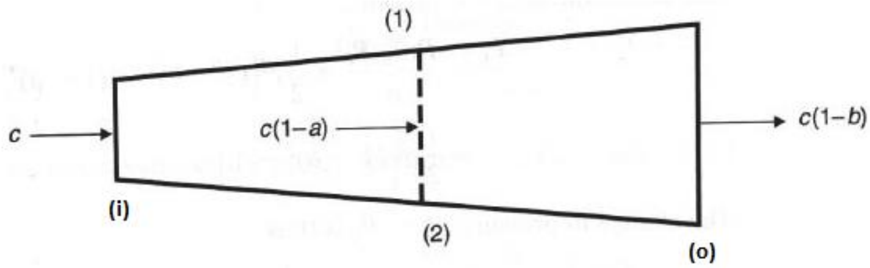
$$v_k = \frac{v_i + v_o}{2} \tag{6}$$



(b)



(c)



(d)

Figure 25. (a) Wind flow velocity, (b) Static pressure distribution, (c) Velocity distribution, (d) Cross sectional flow area distribution (Terzioğlu et al., 2019)

In wind turbines, the power depends on the average wind speed (V_k) applied to the turbine blade, which depends on the input and output wind speeds as shown in Figure 25(a). For the speed parameter V in equation (4), the average speed (V_k) value given in equation (6) is taken. When the V_k value is applied in equation (4), the following equations and power formulas are obtained respectively (Terzioglu et al., 2019).

$$P_W = \frac{1}{2}\rho A V_k^3 \tag{7}$$

$$P_W = \frac{1}{2}\rho A \left(\frac{v_i+v_o}{2}\right)^3 \tag{8}$$

$$P_W = \frac{1}{2}\left(\rho A \frac{v_i+v_o}{2}\right)(v_i^2 - v_o^2) \tag{9}$$

$$P_W = \frac{1}{2}(\rho A v_i^3)\frac{\left(1+\frac{v_o}{v_i}\right)\left(1-\frac{v_o^2}{v_i^2}\right)}{2} \tag{10}$$

$$\frac{v_o}{v_i} = \lambda \tag{11}$$

In wind turbines, the ratio of the output speed (V_o) to the input speed (V_i) is expressed by "λ". In the expression given in equation (12), the rotor efficiency is defined as C_p.

$$C_p = \frac{1}{2}(1+\lambda)(1-\lambda^2) \tag{12}$$

When equations 10, 11, 12 are combined, the wind turbine power formula (P_w) equation (13) is finally obtained.

$$P_W = \frac{1}{2}\rho A v_i^3 C_p \tag{13}$$

Wind energy has shown a significant development in the last 20 years and the installation of wind power plants has accelerated in the world and in Türkiye. In order to make maximum use of wind energy and to convert this energy into electrical energy, some wind data are needed for the regions where wind turbines will be installed. Since wind is a natural resource that changes hourly, daily, monthly and seasonally, some probabilistic approaches are used to calculate electrical energy production and to install appropriate facilities. The most widely used of these probabilistic approaches are Weibull, Rayleigh, Gamma and Lognormal functions.

- **Weibull Distribution Function:**

Among the distribution functions used in the evaluation of wind speed data, the most widely used one is the Weibull distribution function. This function makes a more accurate estimation than the other distribution functions. There are two parameters in the Weibull distribution function, the dimensionless shape parameter (k) and the scale parameter (c), which has the same unit as the wind speed. The shape parameter (k) expresses the frequency of the wind blowing. If there is no fluctuation in wind speed in a region, that is, if the wind is blowing at a constant speed, k takes a large value. If there is a large variation between wind speeds, then k takes a small value. The scale parameter (c) varies depending on the average speed. That is, if the average velocity is high, then c is also high. The c parameter also expresses the frequency of the cumulative wind speed. The expressions of shape and scale parameters are given in equation (14) and equation (15) below.

$$k = \left(\frac{\sum_{i=1}^{n} V_i^k \ln(V_i)}{\sum_{i=1}^{n} V_i^k} - \frac{\sum_{i=1}^{n} ln(V_i)}{n}\right)^{-1} \tag{14}$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} V_i^k\right)^{\frac{1}{k}} \tag{15}$$

Depending on the wind speed (v), shape (k) and scale (c) parameters, the equation of the weibull distribution function is given in equation (16) below (Doğanşahin et al., 2019).

$$f(V,k,c) = \frac{k}{c}.\left(\frac{V}{c}\right)^{k-1}.e^{-\left(\frac{V}{c}\right)^k} \tag{16}$$

- **Rayleigh Distribution:**

The Rayleigh Distribution is a distribution function used when the average wind speed in an area is known. With the Rayleigh distribution, the wind speed blowing hour percentage was found. The shape parameter (k) used for the Weibull distribution in the Rayleigh distribution is accepted as 2. In this case, the expression of the Rayleigh distribution function is as in equation (17).

$$f(V,c) = \frac{2V}{c^2}.e^{-\left(\frac{v}{c}\right)^2} \tag{17}$$

The expression of the Rayleigh cumulative distribution function is:

$$F(V,c) = 1 - \ e^{-\left(\frac{v}{c}\right)^2} \tag{18}$$

The only advantage of the Rayleigh distribution function is the determination of the distribution by the mean wind speed (Arslan et al., 2014).

- **Gamma Distribution:**

The gamma distribution function is expressed by the gamma function. In mathematics, the gamma function is "*a generalization of the factorial function to complex numbers and non-integer real numbers*". Indicated by the Γ icon. The gamma function is expressed as in equation (19).

$$\Gamma(z) \int_0^{\infty} t^{z-1}.e^{-t}.dt \tag{19}$$

The expression of the gamma distribution function depending on the gamma function and the parameters k(shape) and c(scale) is given in equation (20).

$$f(V,k,c) = \frac{V^{k-1}}{c^k.\Gamma(k)}.e^{\frac{-V}{c}} \tag{20}$$

The cumulative gamma distribution function is found by the ratio of the incomplete gamma function(γ) to the gamma function in the equation (21).

$$F(V,k,c) = \frac{\gamma\left(k,\frac{V}{c}\right)}{\Gamma(k)} \tag{21}$$

- **Lognormal Distribution:**

Expression of the probability density function of the lognormal distribution obtained with the normal distribution function is in the equation (22) shown in the below.

$$f(V,k,c) = \frac{exp\left(-\frac{ln\left(\frac{V}{c}\right)^2}{2k^2}\right)}{V.k.\sqrt{2\pi}}, \text{ c>0} \tag{22}$$

As in other distribution functions, here k represents shape and c represents scale parameter.

The cumulative density function of the lognormal distribution is expressed as "*equation (23), where Φ is the cumulative distribution function of the standard normal distribution*".

$$F(V,k,c) = \Phi\left(\frac{ln\left(\frac{V}{c}\right)}{k}\right) \tag{23}$$

The first electricity generated from wind energy for general use in Türkiye was generated from a Vestas wind turbine with a rated power of 55 kW installed at Çeşme Altınyunus Facilities in 1986. The first wind power plant on an international scale was established on February 21, 1998 in Germiyan Village of Çeşme after being purchased from a German company and consisting of 3 Enercon-40 wind turbines, each with a nominal power of 500 kW (Özdamar, 2000).

The fact that wind energy is clean, renewable, free of charge and a potential resource are positive features of wind energy, but it also has some negative aspects in terms of energy economics and technology. Due to the variability of wind, the electrical energy needs of a location cannot be met only from wind resources. In large electricity grids, 20% of the energy from wind is an achievable upper rate. For this reason, in periods when the wind does not blow at all or the wind speed is insufficient for production, the required energy must be met by a system such as accumulators, water pumping, compressed air, etc. or supplemented from different sources such as diesel generators (Başaran, 2019).

In the world, there are currently more than 100 countries that produce electricity from wind energy. Of these, China ranks first with an installed capacity of approximately 330.000 MW. The United States of America and Germany have also been in second and third place for a long time. Today, Türkiye ranks seventh in Europe and thirteenth in the world with an installed wind power capacity of 11.000 MW (URL-16).

Installed wind power capacity and electricity generation from wind energy in Türkiye started in 1998. The development of wind energy installed capacity over the years is given in Figure 26.

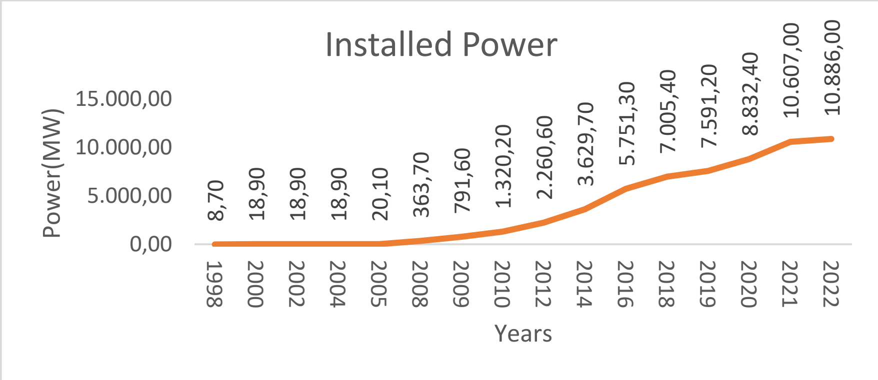


Figure 26. Yearly wind power development in Türkiye (TEİAŞ, 2021)

1.2.5. Biomass and Biogas Energy

Biomass consists of substances that are formed during the life cycles of plants, animals and humans in nature and are also referred to as waste. Wastes are formed by taking what is used and needed during the transition in the layers and processes that make up the life cycle of living things in nature and discarding the useless part. In other words, waste is what is used and can no longer be used, what is necessary and useful for life is taken and the useless part is formed, what is unwanted and left in the environment, and what is environmentally damaging. For example, when the peels of vegetables are peeled and discarded in a kitchen, these peels constitute waste. Or if part of a meal is consumed on the first day of cooking and after a few days it becomes unusable and is thrown away, that is, if it is an unwanted substance, it constitutes waste. The examples given are classified as food waste. Wastes are not only limited to the parts of food resources that are not consumed for human survival, but also include production wastes arising from agricultural, animal and industrial processes during the production of food and all products. Direct disposal of waste is the easiest method used by small local governments with underdeveloped economies. Here, waste is stored and disposed of in a way that does not harm the food chain by incinerating or covering it with soil away from living areas.

Wastes can be divided into two classes according to their recoverability: recyclable and non-recyclable wastes. Recyclable waste consists of materials such as metal, paper, plastic and glass, especially product packaging waste. Municipalities have a great responsibility for the recycling of these wastes. And people should consciously dispose of recyclable waste in the appropriate collection area. Non-recyclable wastes are mainly food, agricultural and animal wastes. Wastes can be classified as solid, liquid and gaseous wastes according to the way they are found in nature. In the classification according to the source of waste generation, it can be divided into three groups as domestic, industrial and agricultural wastes (Figure 27) (URL-17).

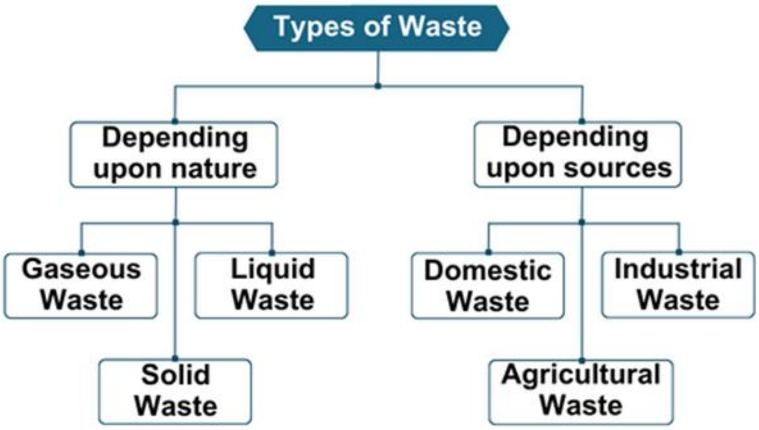
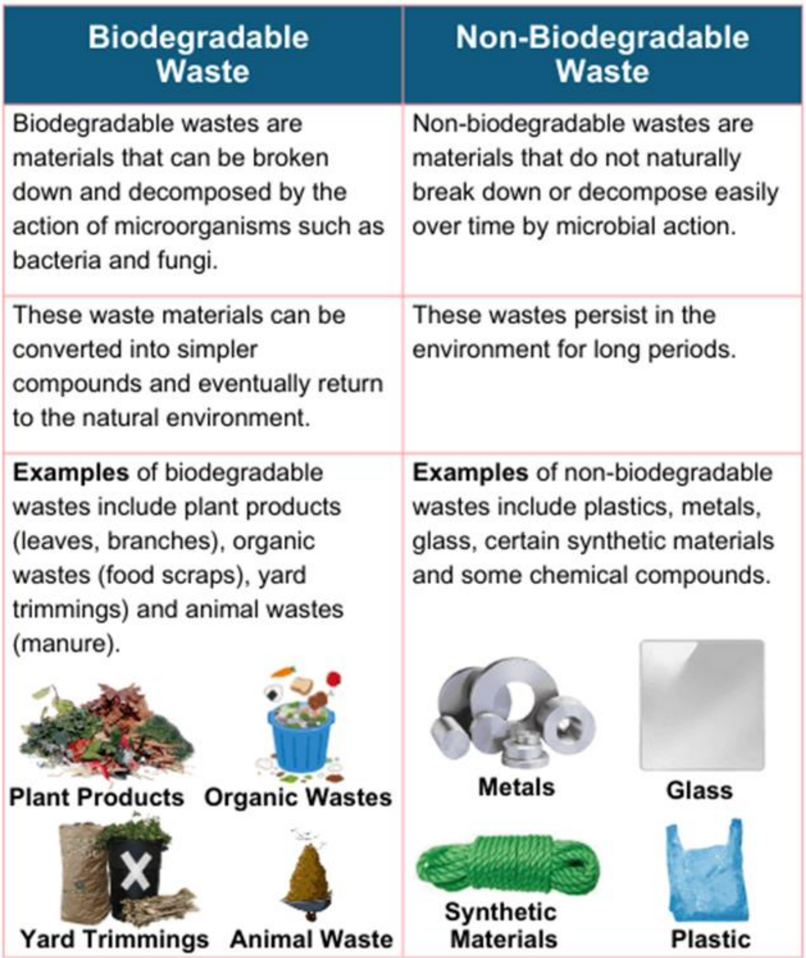


Figure 27. Basic classification of wastes (URL-17)

Gaseous and liquid wastes are generally defined as hazardous wastes that pollute air, soil and water. Gaseous wastes are wastes that are released into the air and cause air pollution. The most important gaseous waste is CO and CO_2 gases, which cause climate change with the greenhouse gas effect, which has become the biggest problem globally today. NO and SO_2 gases are also harmful gaseous wastes. Liquid wastes are harmful and toxic wastes such as domestic sewage and sewage wastes known as gray water, chemical liquid wastes of factories, and liquid harmful and toxic wastes formed by the mixing of pesticides and fertilizers used in agriculture with water. Solid wastes are divided into several classes according to their composition and source. They can be utilized and managed. Proper management of solid waste is an important approach to reduce landfill, recycling or other sustainable disposal methods. Solid wastes can be defined according to their biodegradability as follows (Figure 28) (URL-17).



Biodegradable Waste	Non-Biodegradable Waste
Biodegradable wastes are materials that can be broken down and decomposed by the action of microorganisms such as bacteria and fungi.	Non-biodegradable wastes are materials that do not naturally break down or decompose easily over time by microbial action.
These waste materials can be converted into simpler compounds and eventually return to the natural environment.	These wastes persist in the environment for long periods.
Examples of biodegradable wastes include plant products (leaves, branches), organic wastes (food scraps), yard trimmings) and animal wastes (manure).	**Examples** of non-biodegradable wastes include plastics, metals, glass, certain synthetic materials and some chemical compounds.

Figure 28. Biodegradable and non-biodegradable solid wastes (URL-17)

Biomass is most commonly described as the material produced by living organisms. The main examples of biomass can be classified into four categories (URL-18):

1. Agricultural biomass sources (oilseed crops, sugar and starch crops, fiber crops, crop waste),

2. Forest and forestry products biomass sources "*forest and forestry industry waste and residues, energy forests and energy crops*",

3. Animal biomass sources "*feces of cattle, sheep and poultry, slaughterhouse wastes and wastes generated during the processing of animal products*",

4. Biomass resources obtained from urban and industrial wastes, "*industrial wastes of biological origin, municipal wastes, sewage sludge*" can be classified as.

Waste or biomass consists of garbage and unsightly deposits in daily life. However, with appropriate transformation technologies, wastes contain products that are beneficial to humanity in their chemistry. Waste management systems were developed to get these products. There is a hierarchical structure in waste management. This hierarchy is a systematic order created to manage waste according to what is best and right for the environment. The waste management hierarchy consists of conceptual steps designed to guide and sequence individual or organizational waste management decisions. The highest priority is to prevent waste from occurring. After that, there is reduce, reuse, recycling, recovery and, in the last step, disposal (Figure 29) (URL-19).

Figure 29. Hierarchic scheme of the waste management (URL-19)

An important approach in waste management today is waste to energy (WTE). WTE approaches can be divided into three main classes: thermal treatment, biological treatment and landfilling, as shown in Figure 30. Incineration and gasification techniques are applied in thermal treatment to generate electrical energy and heat energy. In biological treatment, anaerobic digestion is used for biogas production. In the landfill method, CH_4 gas can be produced to generate electricity and heat energy in thermal power plants (Tan et al., 2015).

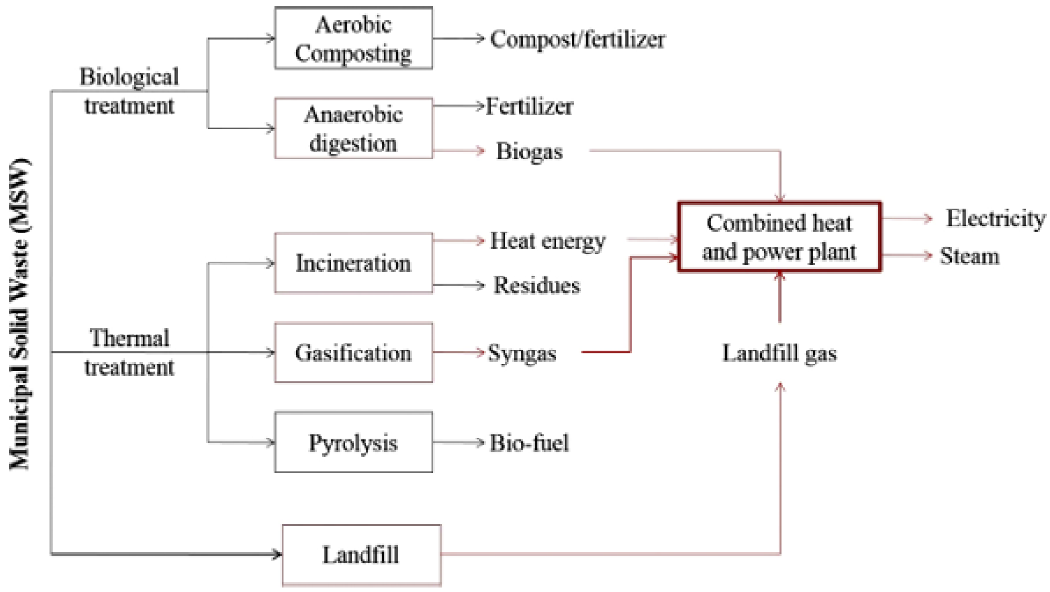


Figure 30. Waste-to-energy technologies and other manufactured products (Tan et al., 2015).

Traditionally, biomass is a known energy source that has already been used naturally for several millennia. As of the 21st century, the use of biomass in a new form is to increase its energy density and use it as liquid fuel. Modern energy forms of biomass can be classified as solid (wood, pellets, etc.), liquid (ethanol, biodiesel, etc.) and gas (biogas, hydrogen, etc.). Biomass can be transformed into several sources of energy such as hydrogen, ethanol, methanol or methane by thermal, biological and physical processes through a wide range of techniques. Biogas technology is the conversion of biomass into liquid and gaseous fuel forms by gasification and pyrolysis (Üçgül, 2010).

Various energy products can be obtained from biomass in solid, liquid and gaseous forms as a result of certain processes. The fact that biomass energy can be easily stored provides a more advantageous situation compared to other renewable energy sources (Şenol et al., 2017). The main methods of obtaining energy from biomass-forming wastes are listed below.

Aerobic composting is the conversion of organic waste into compost or fertilizer in the presence of air. In this conversion, aerobic microorganisms break down organic matter and produce carbon dioxide, ammonia, water, heat and the relatively stable organic end product humus. This creates important conditions for growing agricultural crops. It also offers the ability to destroy many microorganisms that are human or plant pathogens, as well as weed seeds. Although more nutrients are removed from the material in aerobic composting, it is more useful in agricultural production than anaerobic composting and increases yields (URL-20).

In **anaerobic digestion**, in the absence of oxygen and in the presence of microorganisms, other products and by-products are produced from waste by microorganisms. Anaerobic processes have been used worldwide for many years to produce energy from biomass or waste. In developing countries, agricultural and animal wastes are incinerated and heat energy is obtained by conventional methods. In developed countries, on the other hand, significant amounts of energy are produced by obtaining methane gas from wastes in biogas production facilities by anaerobic digestion method (Ardıç et al., 2005).al., 2005).

Incineration is a priority technology for converting biomass into electrical energy. The waste feedstock usually contains the organic matter of the waste to be reacted. Incineration is carried out in a furnace or boiler under high pressure with intense oxygen. The end products of combustion are N_2, CO_2, O_2, water as waste and flue gas and unburned residues (Tchobanoglous et al., 1993).

The net energy yield after incineration varies according to the density and composition of the waste. These are the moisture that causes heat loss, the proportion of inert materials, the ignition temperature, the size and shape of the components, the design of the incineration system, etc. In practice, about 65 to 80% of the energy content of organic matter is released as heat energy, which can be used directly for thermal applications or for power and energy generation with the help of steam turbine-generators (Patil et al., 2015).

The combustion temperature of conventional incinerators is 760^{o}C and the secondary combustion chamber temperatures are above 870^{o}C. The reason for this high temperature value is to prevent odor caused by incomplete combustion. However, it is not enough to burn and melt some of the inorganic contents such as glass. Some modern furnaces use auxiliary fuel to burn up to 1650^{o}C. This high temperature reduces the volume of waste by 97% and allows materials such as inorganic metals and glass to be converted into inert ash. If the purpose of incineration is only to reduce the volume, no additional fuel is needed beyond the initial incineration process. When there is a need for high heat energy, such as for steam generation, incineration should be carried out with pulverized garbage as an auxiliary fuel due to the variable energy content of the waste or if the amount of waste available is small. The flow chart of a typical incineration process is as follows (Figure 31) (Patil et al., 2015).

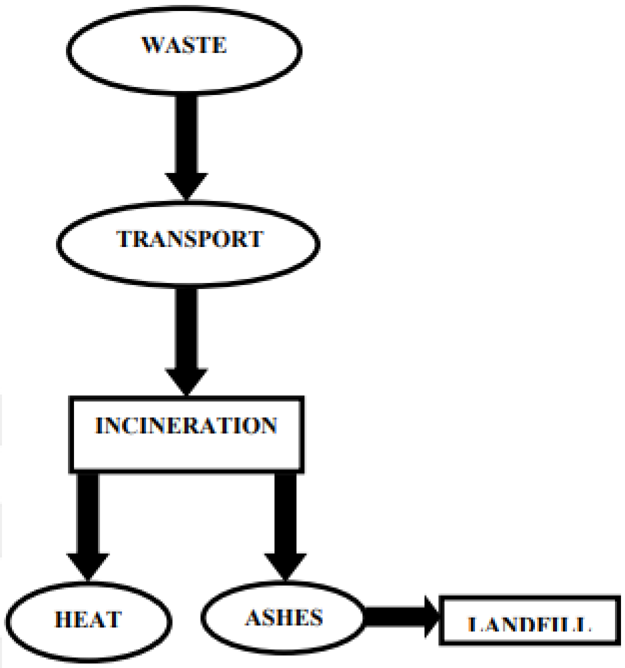


Figure 31. Typical incineration system flow chart (Patil et al., 2015)

Incineration has the advantages of reducing the volume of waste and thus reducing landfill space, and reducing transportation costs by locating incineration plants where waste is concentrated. Disadvantages include: the installation and cost of the incineration plant and the need for skilled personnel, and if flue gas residues are not disposed of properly, their leaks can enter groundwater and surface water and cause water pollution (Rand et al., 2000).

Gasification, also known as "indirect combustion", is "*the production of fuels or synthesis materials from solid waste through gas formation reactions*". Another definition is "*the partial oxidation of waste in the presence of a lower amount of oxidant than required for stoichiometric combustion*". In the gasification process, part of the combustible material is burned to obtain the heat necessary to gasify the remaining part (autothermal gasification). In the case of air gasification, heat energy can also be provided by an external source (allo-thermal gasification), e.g. using a plasma torch. As a result of gasification, not a hot noxious flue gas, as in the traditional direct combustion of waste, but a large amount of hot fuel gas is formed ('producergas' or 'syngas'), which contains completely unoxidized products with a sufficient calorific value that can be used in different places (Arena, 2012).

Pyrolysis is defined as “a thermo-chemical waste utilization process in which organic matter, such as biomass, is converted into a carbon-rich solid and volatile substance by heating in the absence of oxygen”. The solid product of this process is biochar or coal with a high carbon content. The volatile substance in the pyrolysis process is a liquid oil called tar or bio-oil, together with a mixture of non-condensable gases. This is called bio-oil or biofuel. The bio-oil can be stored and later used as fuel in energy production. The gases can be used to provide heat energy to the pyrolysis reactor. An important advantage of pyrolysis is that the process can take place at lower temperatures than those required for combustion and gasification (Sharma et al., 2015).

In a **landfill**, solid waste is disposed of in the traditional way by landfilling. Incineration or composting is the least costly method among other waste management systems. For this reason, small local governments use this method more often. Solid waste accumulated in landfills undergoes biological, chemical and physical changes. As a result of these changes, the accumulated waste water has negative aspects such as mixing with groundwater and causing environmental pollution. The use of methane gas in the production of electrical energy is a positive result of the landfill (URL-21). Landfill is an effective method in waste management. However, it is not preferred as a rational method due to its negative consequences. The fact that waste can only be stored for a limited period of time, landfill reclamation can take hundreds of years, biogas and leachate can seriously affect the environment, and in many countries, garbage is stored in these areas without any sorting makes it a non-preferred method (Vaverková, 2019).

The fact that biogas can be obtained from many biomasses makes it possible to produce it from various organic materials or organic wastes. The gas produced as a result of biogas production contains approximately 55-75% CH_4 gas, 25-45% CO_2 gas, 1-10% hydrogen gas (H_2), 0 - 0.3% nitrogen (N_2) gas and 0-3% hydrogen sulfide gas (H_2S) (Şenol et al., 2017).

Biomass accounts for about 10% of the world's primary energy use. In addition to its use in heating and transportation, biomass is also used for electricity generation. In electricity generation, biomass energy takes the second place after wind among renewable energy sources. Production based on solar energy takes the third place after biomass (Cordell et al., 2009).

According to ETKB data, the total economic energy equivalent of the wastes assessed to be collected in Türkiye is approximately 3,9 Mtoe/year. The installed capacity based on biomass and waste heat energy is 2.172 MW as of the end of June 2022, with a ratio of 2,14% in total installed capacity, and the change in installed capacity over the years is shown in Figure 32 (URL-18).

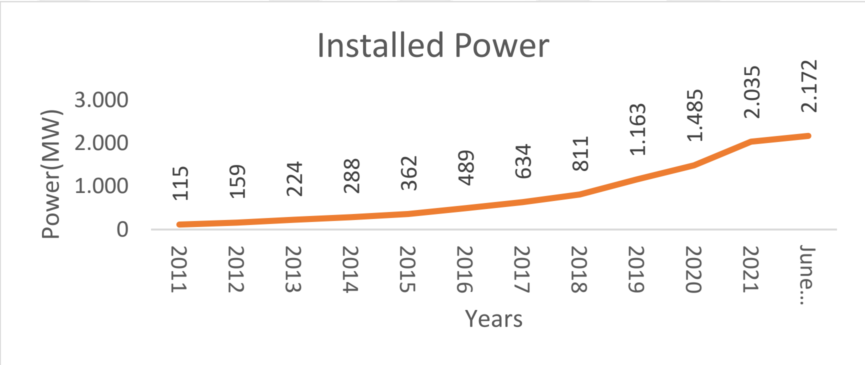


Figure 32. Yearly biomass and waste heat power development in Türkiye (URL-18)

1.2.6. Tidal and Wave Energy

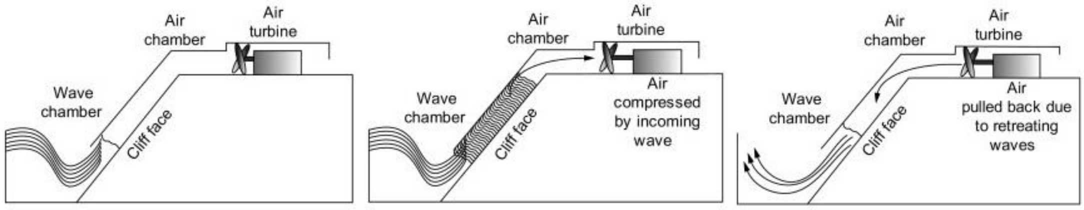
Wave energy is an energy source that utilizes the force of thrust created by waves in the seas. Tidal energy is defined as the rise and fall in sea level due to differences in gravitational attraction as a result of changes in the relative positions of the Moon and the Sun (URL-22).

Tidal and wave energy can also be classified under ocean energy. Ocean energy has five different energy forms: “tidal energy, wave energy, ocean current energy, thermal energy and osmotic energy”. Tidal, wave and current energies are mechanical energy sources. Research on harnessing ocean energy dates back only a few decades. Tidal energy is a potential energy related to the water level. This potential energy in the tidal current can be converted into kinetic energy with certain devices. The world tidal energy potential is around 1.200 TWh per year. Wave energy consists of kinetic and potential energy in water waves that have a wide distribution. Waves gain their kinetic energy from the wind that transmits water on the ocean surface. The global wave energy potential is estimated to be 29.500 TWh per year (Akgün et al., 2023).

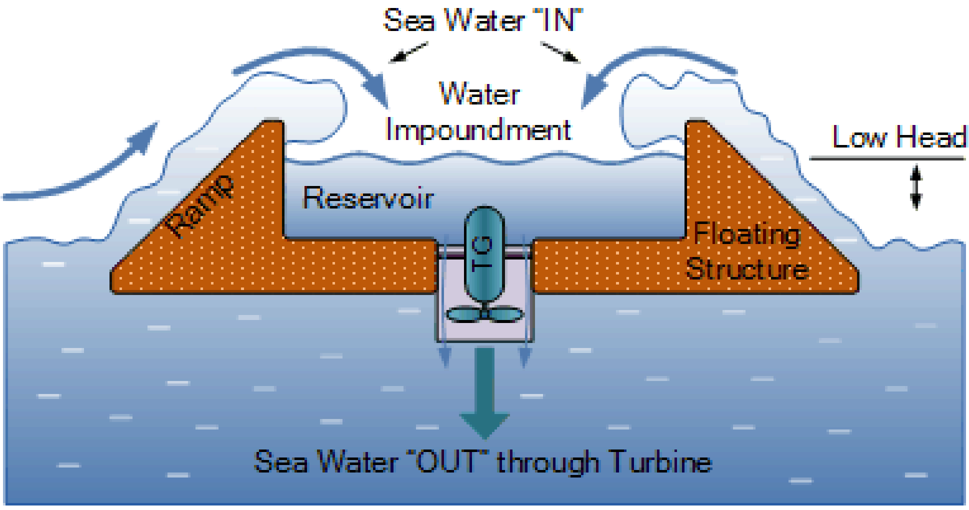
Sea waves are formed by the movements of the sea surface, whose equilibrium is disturbed as a result of external influences such as wind, moving vehicles in the seas, earthquakes under the seas or the gravitational force of the moon and the sun, during the restoration of the sea surface to its former equilibrium position. Sea waves generated by wind impact are more prominent in terms of energy production potential since they are permanent in comparison to sea waves generated by factors except wind (Örer et al., 2003).

It is possible to generate energy from wave energy or natural sea currents in the same way as wind energy. Since water is 1000 times denser than air, it generates extremely high forces even at low flow rates. In order to utilize these forces, special control and transmission systems designed for use on the sea are needed. The constant up and down motion of waves in wave energy production is the most obvious indication of the enormous power that exists in the sea. Wave energy converters must have an extremely wide range of applications. Thus, the potential of large waves generated by winter storms, hurricanes, typhoons and cyclones should be utilized as well as light waves in warm weather (Bostan, 2014).

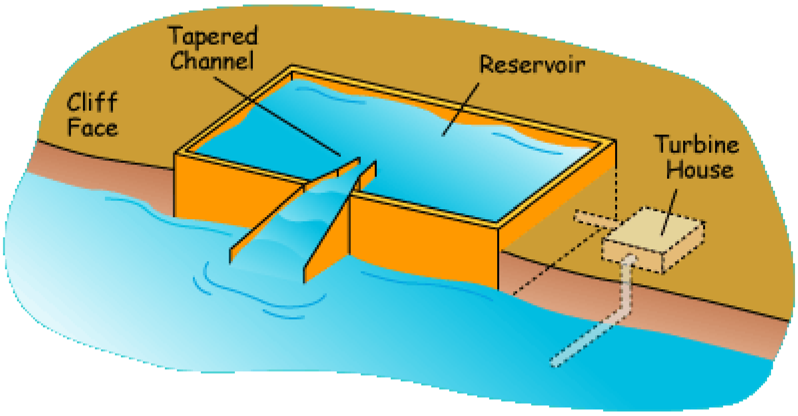
Technical systems such as oscillating water column system (OWC), wave capturing system, vertical channel system (Tapchan), wave dragon, pelamis system and wave cylinder are used to convert wave energy into electrical energy. The principle forms of five different forms of systems for obtaining mechanical energy from wave energy are given below (Figure 33).



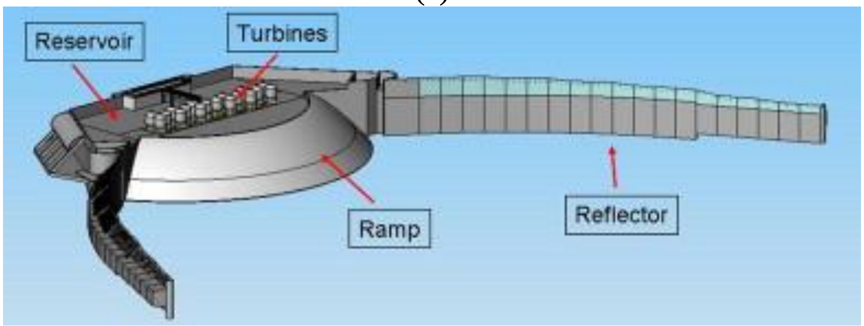
(a)


Sea Water "IN"
Water Impoundment
Low Head
Ramp
Reservoir
TG
Floating Structure
Sea Water "OUT" through Turbine

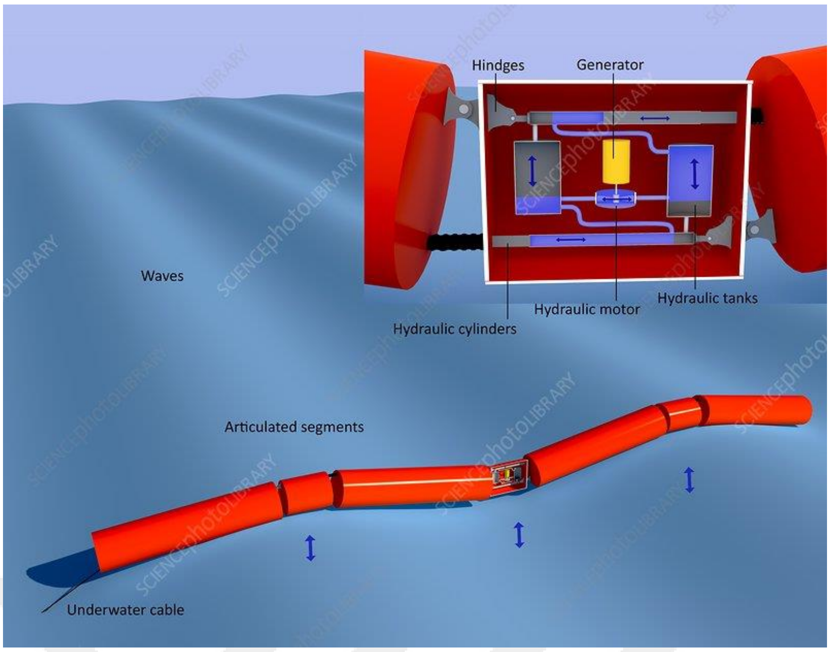
(b)


Tapered Channel
Reservoir
Cliff Face
Turbine House

(c)


Reservoir
Turbines
Ramp
Reflector

(d)



(e)

Figure 33. WEC systems principal schematics: (a). OWC (Folley, 2016), (b). Wave Capture System (URL-23), (c). Tapchan (URL-24), (d). Wave Dragon (Tedd et al., 2009), (e). Pelamis (URL-25)

Tides are the regular rise and fall of the ocean surface due to the effects of the sun, the moon and the earth, and the rotation of the earth and the moon against each other. Given that the moon is closer to the earth, the gravity on the moon is 2.2 times greater than on the sun. Tides occur in coastal areas with coastlines that allow water to flow through narrow channels. These currents are bi-directional; they are formed by flows along the coastline in the form of a tidal flood current and a tidal ebb current retreating from the coast. Tidal energy includes potential and kinetic energy. Therefore, facilities that harness tidal power can be categorized in two ways: tidal dams, which harness potential energy, and tidal stream turbines, which can harness kinetic energy (Sretenovic, 2016).

The turbines inside the tidal dam use the power of the tides in the same way that a river dam uses the power of a river. As the tide rises, the dam gates open. At high tide, the dam gates close to form a pool or tidal lagoon, and the water then passes through the dam's turbines to generate energy at a controllable ratio (Figure 34) (URL-26).

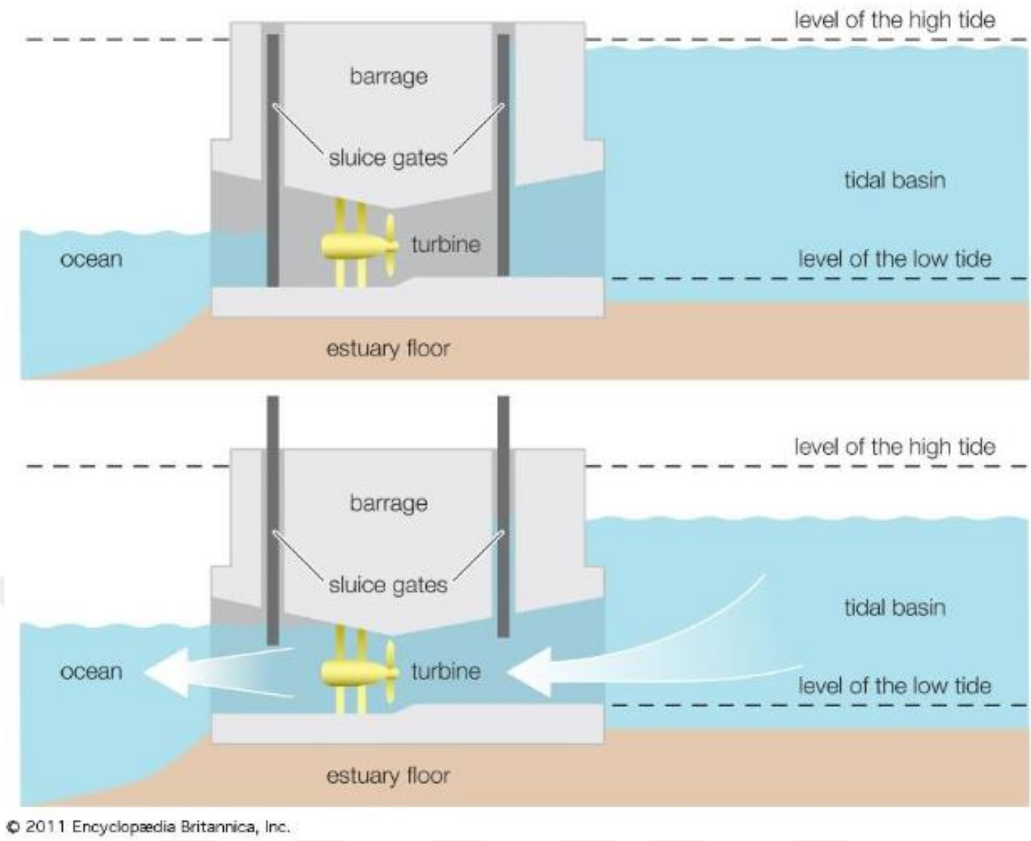


Figure 34. Tidal energy dam working principle (URL-26)

Tidal turbines are like wind turbines in having blades that rotate a rotor to power a generator. The turbines are installed on the sea or ocean floor in areas of strong tidal flow. Since water is approximately 1000 times denser than air, tidal turbines need to be significantly more robust and heavier than wind turbines (Figure 35) (URL-26).

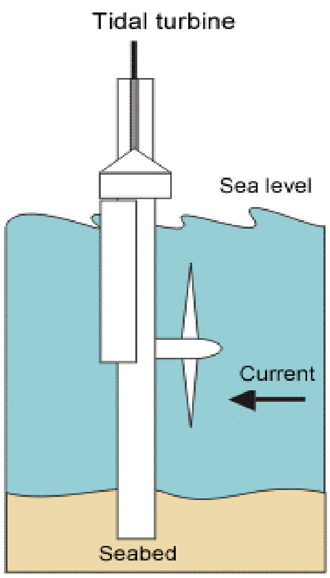


Figure 35. Tidal turbine working principle (URL-26)

The richest regions of the world in wave energy potential are those between 40º-60º latitudes in both the northern and southern hemispheres. However, the annual average potential of the southern hemisphere is higher (López et al., 2013). Table 5 shows the net wave power (excluding areas smaller than 5 kW/m and glaciers) of some regions rich in wave energy (Mork et al., 2010). The wave power of some countries; Ireland 21 GW, Portugal 10 GW, Denmark 3,4 GW, Sweden 1 GW, England 120 GW and Mediterranean countries France, Italy, Spain and Greece have a total wave power of 30 GW (Vicinanza et al., 2013).

Table 5. Net wave power of some regions rich in wave energy (Mork et al., 2010).

Region	**P_{net}(GW)**
Australia and New Zealand	574
Western South America	324
Northern and Western Europe	286
Southeast Asia and Melanesia	283
Western North America	207
East of South America	202

With a coastal length of 8.210 km, the wave potential in Türkiye is not suitable for installing small wave energy systems in every coastal area. Approximately one fifth of the total coastal length has the potential to generate 18,5 TWh/year (about 2,11GW) of wave energy (Hepbaşlı et al., 2001). The actual wave energy application in Türkiye is the prototype project named "Electricity Generation from Wave Energy" in Karasu district of Sakarya, which was initiated on February 15, 2008 in cooperation with the National Boron Research Institute (BOREN) and Türkiye Electromechanical Industry Inc. (TEMSAN) (Kapluhan, 2014b.) Wave energy application projects are also ongoing in Zonguldak on the Western Black Sea coast with foreign company partnerships. There is also a wave energy power plant planned in Ordu province.

There is no tidal energy application in Türkiye yet, whereas tidal power plants with applications in the world are given in Table 6.

Table 6. Tidal Power Plants in the World (URL-27)

Tidal Power Plant	**Country**	**Foundation Year**	**P_{net}(MW)**
Rance TDP	France	1966	240
Kislaya Guba TDP	Russia	1968	1,7
Jiangxia TDP	China	1980	3,2
Annapolis Royal TDP	Canada	1984	20
Strangford Lough TDP	England	2008	1,2
Uldolmok TDP	North Korea	2009	1,5
Sihwa Lake TDP	North Korea	2011	254
Meygen TDP	England	Planned	398
Bluemull Sound TDP	England	Planned	0,5

1.3. Literature Review

There are many examples of academic and scientific studies in the field of energy in the world and in Türkiye, especially on the use of alternative and renewable energy. As it is known, most of the world's energy supply is met from fossil fuels. This leads to an increase in global temperature and climate change after the increase in carbon emission rates, the effects of which are felt today. For this reason, governments are pursuing policies to maximize the use of renewable energy potentials. Attempts are being made to use energy efficiently in all areas where energy is used. In devices that use electrical energy, products are developed to ensure that their energy classes are at the best level. Energy commission units are established in industry, private sectors and all public institutions for the most efficient and economical use of energy. In order to reduce carbon emission levels, new generation engines are being developed and used in the automotive sector, and even the production of completely zero emission electric vehicles is increasing. Particulate filters are made mandatory for vehicles with large powerful engines and construction equipment, and additional emission-reducing systems such as adblue are installed. In the century of industry and technology, energy has become a global issue and a subject of research and development in all countries of the world. In this section, academic studies on energy, especially in the field of renewable energy, will be presented. Examples of studies on the use of renewable energy in public institutions in Türkiye will be discussed in order from general to specific.

Renewable energy was the only natural source for energy production in ancient times. Wind, hydroelectricity and especially biomass energy (heat energy by burning wood and waste) and solar energy, the main source of all these sources, were widely used sources before the discovery of fossil fuels, which today meet 80% of energy needs. Renewable energy has become the agenda of all nations due to its sustainability and its ability to be easily obtained from nature. Renewable energy is an indispensable and very useful energy source with many applications in science and technology, from automobiles to industry and thermal power plants. According to a study conducted by the International Renewable Energy Agency (IRENA) in 2019, the number of electric vehicles, which is approximately 2 million, is estimated to reach 200 million in 2030. The increase in population growth and energy demand will require the development of different energy sources. However, the urgent need to protect the atmosphere and prevent catastrophic climate change will favor clean sources. The 21st century's best alternative and efficient energy source is clean and renewable energy due to its easy availability in nature and wide range of applications (Deshmukh et al., 2023).

Many countries around the world are prioritizing the installation of renewable energy generation plants to meet their electrical energy needs. The growing importance of these renewable and alternative energy sources is due to the problems of climate change caused by the excessive use of fossil fuels. There are three main reasons that encourage the development and growth of renewable energy technologies. These are energy security, economic impacts and reduction of carbon dioxide emissions. Considering the transportation sector as the main emission generating source, the studies carried out in this sector allow for significant fuel savings and CO_2 emission reduction. As a result, concerns about climate change have made renewable energy sources an important component of world energy consumption (Abuzreda et al., 2023). Today, the international energy situation is undergoing new changes and adjustments. In the global energy market, it is aimed to realize the transition from the fossil energy system to a low-carbon energy system and, as a result, to enter the era of sustainable energy based on renewable energy. For this reason, many researches and studies have been conducted to analyze the development of renewable energy. As a result of some studies on the state of global energy in the last decade: global energy consumption has increased, fossil energy use is still dominant, total coal consumption continues to decline, the proportion of oil consumption in primary energy consumption has remained stable with a slight decrease, natural gas consumption has increased, nuclear energy consumption growth has been slow, renewable energy consumption has increased rapidly, and the overall energy structure varies according to the sources of countries. All countries have become increasingly concerned about achieving energy security, protecting the ecological environment and addressing climate change. The development and acceleration of the use of renewable energy has become a common action and main goal of countries (Li et al., 2022).

Creating a consumption model that is conscious and sensitive to the environment we live in through the economical and efficient use of energy is supported by countries all over the world. A simple improvement in energy use can reduce costs by 5% to 15%. Investments in energy-efficient technologies can also pay for themselves after a few years. In the case study, the significance of energy savings in the construction of public utility buildings through deep thermo-modernization using renewable energy sources such as compressor heat pumps and photovoltaics was calculated. It was found that 80% energy savings can be achieved when a comprehensive thermo-modernization of a school building built according to Polish regulations is carried out and implemented with appropriate investment costs. As a result of the implemented improvements, thermal energy savings of 72.30% can be achieved, and CO_2 emissions will also be reduced by reducing the energy demand used in the building by about 74% (Barwińska-Małajowicz et al., 2023).

A study evaluated the efficiency and economics of grid-connected and off-grid hybrid renewable energy systems for Al-Karak Governorate, Jordan. Using the "Hybrid Optimization of Multiple Energy Resources" (HOMER) software, the analysis showed that the use of a wind turbine, biogas plant, photovoltaic (PV) panels, flywheel, and batteries would reduce the cost of energy by minimizing the net current cost and reduce CO_2 emissions. The results indicate that the grid-connected PV/Wind system with storage is the optimal configuration for sustainable electrification of Al-Qarak governorate, providing environmental benefits and ensuring reliable and continuous energy access at the minimum net current cost (Al Afif et al., 2023).

In the study on the dynamic effects of economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity and forest areas in Türkiye to ensure environmental sustainability by reducing carbon dioxide emissions, data from 1990 to 2020 were analyzed. It is revealed that a 1% increase in economic growth, urbanization, industrialization and tourism will increase carbon dioxide emissions by 0,39%, 1,22%, 0,24% and 0,02%, respectively. A 1% increase in renewable energy use, agricultural productivity and forest area would reduce carbon dioxide emissions by 0,43%, 0,12% and 3,17%, respectively (Raihan and Tuspekova, 2022).

Environmental management programs are implemented in developed and developing countries. In international meetings and summits, the concept of "green entrepreneurship", an initiative to minimize environmental pollution, is at the forefront. The construction of green buildings, which emerged as a sub-branch of green entrepreneurship, is not practiced because it is individually costly. However, it is clear that green office practices in workplaces and public buildings will have significant benefits in terms of recycling and savings. This practice has not yet been fully adopted in Türkiye. In a study, the implementation levels of the green office program in the offices of operating renewable energy companies were determined. For the research, renewable energy companies registered in the database of EPDK (Energy Market Supervisory Authority), which are in operation and engaged in licensed energy production, were taken into consideration. As a result of the research, it was understood that necessary trainings (seminars, symposiums, etc.) should be provided and the knowledge and awareness of the employees should be increased in order to fully embed the green office awareness in the companies. It has been determined that companies do not implement some recycling and saving activities because they do not have much financial return. However, if all companies implement these measures, a significant amount of savings will be achieved in Türkiye as a whole. Therefore, this situation should be supported and encouraged by the government (Uslu and Erkan, 2016).

It is known that the demand for energy increases with each passing year in the world and that this demand is met by fossil fuels at a large rate. Due to the rapid depletion of fossil fuels and environmental damages, it has become imperative to turn to alternative energy sources. Renewable energy sources have been at the forefront in this regard. Especially in developed countries, the number of thermal power plants has decreased and renewable energy based power plants have increased. In Türkiye, there has been rapid progress in the installation of renewable energy plants and private and publicly supported projects are ongoing. In order for the investments to be made in renewable resources to be efficient, pre-feasibility and survey work must be done very well. All data should be collected and analyzed correctly to determine which methods are more suitable for which region. Renewable energy resources in Nevşehir province were investigated and a study was conducted on which method is advantageous and applicable. It was concluded that solar power plants are the most suitable method in terms of energy potential, cost and environmental impacts (Kaya, 2021).

Among the studies on the use of renewable energy in public buildings: In order to meet the energy needs of Çanakkale 112 Emergency Call Center from wind and solar energy, Solar Energy and Wind Energy facilities installation cost analyzes were made. A depreciation period of 3 years for solar energy and 5 years for wind energy was calculated. It is aimed that other public buildings can also use the energy produced and that it will be a suitable and exemplary project as grid-connected systems (Baydar, 2021).

Another study in 2021 analyzed the relationship between energy use and space utilization in higher education buildings, taking Balıkesir University Campus as an example. The impact of different classroom scenarios on energy consumption in an existing educational building, taking into account energy conservation and solar effects, was investigated. For the developed classroom scenarios, heating and cooling energy consumptions are calculated according to current and future climate scenarios with the building energy simulation tool. As a result of the simulations, it was found that an average of 15% in heating consumption and 12% in cooling consumption could be saved in the current year with different classroom scenarios. Future calculations for 2050 and 2080 were also made and it was concluded that the savings rate would increase (Özlük, 2021).

In the master's thesis study to determine the technical, economic and environmental impact assessment of a stand-alone and on-grid hybrid energy system to provide electricity to Eskişehir Technical University Electrical and Electronics Engineering Department, the hybrid optimization model of the multiple energy resources (HOMER) pro software was used to provide the optimum configuration of the stand-alone and on-grid hybrid system. The most economical case is compared with each other according to the current net cost and energy cost. It was found that the most suitable configuration of the two systems is the hybrid system consisting of 198 kW solar panel and grid structure. The study addresses the issues related to reliability, cost and environmental concerns of conventional energy sources by using hybrid renewable energy system. An awareness has been created for the growth and utilization of the hybrid renewable system (Adan, 2020).

In 2019, in a similar study conducted for Yalova University, the annual energy consumption of the Central Campus was examined and solutions were investigated by examining systems that can use electricity and natural gas more efficiently. In order to reduce the use of natural gas, ground source heat pump system calculations were made, and wind and solar energy systems were calculated for the electricity needs of the heat pump and the electricity needs of the campus. Since the wind energy production values were very low, calculations were made on solar energy and solar panels were considered on all buildings and suitable places on the campus. 1.908.886,13kWh/year solar panel production capacity was calculated and it was determined that 93,72% of the newly calculated energy value could be met with a payback period of 8,43 years. The total annual value of natural gas and electricity energy savings with heat pump and solar energy systems was calculated as 6.145.340,56 kWh/year (Kara, 2019).

The concept of public service is the services provided by the state/public in many areas from justice to health, education to security depending on social developments. Public services are the provision of needs based on the common good of the public by the state. The administrative authority of the state is responsible for carrying out these services. Uninterrupted energy is vital in the health sector, which is one of the most important service branches of the administration. In the 2019 study, Kütahya Dumlupınar University Evliya Çelebi Training and Research Hospital was taken as an example. It was emphasized that efficiency in public service delivery in Türkiye can be increased by creating public buildings that produce their own electrical energy needs, which is one of the biggest expenses of the administration in public service delivery (Ur, 2019).

A hybrid energy system consisting of wind and solar energy systems was considered in a study to meet the energy needs of Artvin Çoruh University Seyitler campus from renewable energy sources. In the study, current wind speeds and sunshine duration data of the State Meteorology General Directorate Artvin Central Meteorological Station were used. Weibull, Rayleigh, Lognormal and Gamma statistical approaches are used to determine the wind energy potential. A pre-feasibility study was conducted for a hybrid system consisting of a wind turbine and a solar panel, and Renewable Energy Technology Screen (RETScreen) renewable energy software was used to install this hybrid system under optimum conditions (Aydın, 2019).

The use of photovoltaic energy on university campuses has become widespread in recent years. In Osmanbey Campus, the new campus of Harran University, a study has been initiated in this context. In addition to reducing the energy consumption of the campus with the renewable energy technologies currently used, there are also efforts to create new production technologies, new application areas and new hybrid systems. In the use of technologies, attention is paid to the needs of the region and their availability in the region. In this study, the photovoltaic system and units installed in the new campus of Harran University are discussed. In the first phase of the integrated project, photovoltaic power applications were prioritized due to the high regional solar energy potential and the photovoltaic assisted units used in the campus were introduced in the study (Aktacir and Yeşilata, 2009).

In the literature review up to this chapter, renewable energy in the world, renewable energy in Türkiye and renewable energy applications for the regions/locations sampled in Türkiye and examples of the studies conducted are given. In addition to wind energy and solar energy applications found in many studies, biogas energy that can be obtained by incineration/anaerobic digestion from pruning, leaf, plant, etc. wastes of Artvin Çoruh University ANG Botanical Garden is also discussed in this thesis. Examples of ongoing academic studies are studies on obtaining biogas energy from solid wastes by incineration/anaerobic digestion method.

Biogas production by anaerobic digestion aims at sustainable energy management through the use of alternative biomass resources. In this study, the use of the abundant wastes in more sustainable heat and electricity generation as well as the use of the substrate released after anaerobic digestion as fertilizer was investigated. Prior to the study, grass samples were collected from uncultivated land, river banks and highway verges. In addition, corn silage collected from a biogas plant and cattle slurry collected from a small farm were also used. The location where the samples were collected and the study was conducted was Zagreb, the capital of Croatia. The collected samples were analyzed in the laboratory. The results showed that all grass samples had satisfactory digestion parameters, with carbon nitrogen ratio values (C/N) between 16,6-22,8. The low amount of impurities in the samples concluded that they are suitable for biogas production (Bedoić et al., 2019).

In Ekaterinburg, Russia, a study was carried out on the utilization of plant waste generated after cutting and pruning trees for landscaping green spaces in streets, parks, squares, forest parks. Currently, all this waste ends up in landfill. Coarse wood wastes are utilized for household heating needs, but no quantitative calorific value of the composition of these wastes is considered. For energy utilization from wood waste, various conversions have been recommended, such as heat and electricity generation, liquid and solid biofuel production, which are used in different countries. The heat and electricity that can be generated from the energy potential of the city's wood waste has been estimated to exceed 340.000 GJ, based on an approach that incorporates modern engineering developments. It was concluded that this value can be converted into 71.894 GCal of heat energy and 23.798 MWh of electricity (Khudyakova et al., 2017).

The European Union supports the use of biomass, an alternative energy source among renewable energy sources, in energy production in order to reduce greenhouse gas emissions and ensure energy supply security. This study aims to analyse the possible energy production from the residues of pruning in vineyards and olive groves in four municipalities in the Umbria Region of Italy, considering its economic and environmental sustainability. Geospatial, economic and environmental analyses were carried out during the study. An integrated approach model was used to estimate the total amount of biomass produced in the region and to determine its transportation conditions. In the analysis, a sample power plant was considered and estimated CO_2

emission values were calculated. Comparing the total energy consumption of the production stages with the power generated by the incineration plant, 293 kWh of energy will be produced by burning one ton of dry biomass from vine and olive pruning residues (estimated 146 kWh of energy consumed). The amount of CO_2 emitted by the breakdown of the 2.671 tons of biomass considered in the study was only 0,043 tons, while the CO_2 generated by the fuel consumption of an equivalent operating machine was 25,52 tons (Torquati et al., 2016).

Waste-to-energy processes use wastes as inputs to generate alternative energies such as heat, electricity and biogas from their energy content. In the 2022 study, two different waste management techniques for efficient energy recovery from municipal solid waste in Istanbul were evaluated from technical and economic perspectives. The first technique is the direct incineration of waste to obtain thermal energy and generate electrical energy in steam turbines. In the second technique, anaerobic digestion is proposed by separating non-organic materials and incineration is proposed for the remaining combustible fractions. It was concluded that 500 GWh of electrical energy could be generated annually with the first method, and with the second method, a total of 544.2 GWh of electrical energy could be generated, 156.3 GWh from anaerobic digestion and 388 GWh from the other incineration process (Demirel, 2022).

While waste disposal and management is a general problem, it becomes a particular problem in tourism cities, especially during tourism seasons. Fethiye district of Muğla is a tourism region preferred by local and foreign visitors for vacation in the summer months. In the thesis study conducted in 2022 on how organic solid waste can be utilized in this region, especially during tourism periods, a population and organic solid waste projection covering the next 30 years was created by utilizing the current population and solid waste information. In line with these projections, it was emphasized how organic solid wastes will be utilized, taking into account the country's targets. Within the scope of the organic solid waste reduction target, it has been determined that some of the organic solid wastes can be used as compost and some of them can be used for energy generation as a result of biogas production by anaerobic digestion. According to the results obtained, 2.326 tons of organic waste can be processed and 1.861 tons of dry biogas can be produced in a year, and this biogas will be converted into electricity through a cogeneration system that can generate 1,14 MW of power per hour. It is calculated that around 15 tons of compost can be obtained daily from the waste generated as a result of biogas production and other collected wastes (Engin, 2022).

The study around this thesis, wind, solar and biomass energy potentials are discussed in which the energy need of Artvin Çoruh University ANG Botanical Garden is investigated to be met from renewable energy sources.

2. MATERIAL AND METHODS

2.1. Description of the Study Area (ANG Botanical Garden)

Artvin Çoruh University Ali Nihat Gökyiğit Botanical Garden Application and Research Center was established with the regulation published in the Official Gazette dated 19.12.2018 and numbered 30630. The foundations of the ANG Botanical Garden started to be laid on 23.08.2019 with the allocation of the construction site area, which was used by the ERG construction company, which undertook the construction of the Deriner Dam, which has the largest installed power on the Çoruh River, for about 15 years as of 1995, to Artvin Çoruh University. Located within the borders (Figure 36) of Salkımlı Village, which is 10 km away from Artvin city center, it was designed as an activity area of 143 decares, which was decided to be built in the area that was previously a construction site (Figure 37). The existing buildings and prefabricated buildings remaining from the construction site were donated to Artvin Çoruh University by ERG company to be used in the Botanical Garden. The establishment of new units and activities continue today in the area, financed by the Ali Nihat GÖKYİĞİT (ANG) Foundation, a businessman from Artvin who has made significant contributions to Artvin Çoruh University.

Figure 36. AÇU ANG Botanical Garden on the google.map

Figure 37. AÇU ANG Botanical Garden Application and Research Center

Structural Landscape Implementation Project, Automatic Irrigation System Project, Environmental Lighting and Electricity Project, Infrastructure Stormwater and Green Area Drainage Projects were completed with the support of the ANG Foundation. The Botanical Garden includes entrance control units, guest house, meeting hall, management units, Medicinal-Aromatic Plants Product Laboratories and classrooms, offices, café with panoramic view, R&D and Exhibition Greenhouse, Production Greenhouse, Medicinal-Aromatic Plants, In addition to collection areas such as Endemic Plants, Honey Plants, Fodder Plants, Rose Garden, Fruiting Species Gene Garden, areas such as Organic Pond, Theme Area, Intercourse Walking Areas and Plant Tunnels, Labyrinth Garden, Local Houses and Plants Street have been created. Nearly 30.000 plants belonging to a total of 2.000 different species, 400 of which are rare, 200 of which are medicinal aromatic, and around 1.400 of which are decorative, are grown in the area. The Botanical Garden, which has attracted great interest from visitors since its establishment, was visited by the TBMM Medicinal and Aromatic Plant Research Commission in 2019 and opened with a ceremony in 2022.

The main objectives of the center are to contribute to the conservation and promotion of plant gene resources in Türkiye, especially the plants growing naturally in Artvin and its surroundings; to conduct scientific research in various fields related to world plants and vegetation; to collect plant taxa used and cultivated for medical, industrial, agricultural, ornamental plants and similar purposes within thematic gardens.

2.1.1. Technical Information and Energy Requirement

Within the ANG Botanical Garden, there are 1.164,32m^2 Administrative and Research Building, 390,41m^2 Café, 241,5m^2 Conference Hall, 1.064,38m^2 Guest House, 452m^2 R&D greenhouse and 200m^2 production greenhouse sections.

Laboratories and departments in the research building: Medicinal-Aromatic Plant Product Laboratory, Plant Genetics Laboratory, Herbarium (Dried Plant Museum), Seed Room and Plant Drying Room. In addition, as collection areas, there are Medicinal-Aromatic Plants Collection Area, Plants Under Dam Collection Area and Fruiting Species Gene Collection Areas.

The 452 m^2 R&D (Figure 38) and Exhibition Greenhouse, built with the support of the ANG Foundation, is a steel-constructed polycarbonate greenhouse with three sections, three different climates (black sea, tropical and desert), five different irrigation and fertilization automation systems, and a pool in which aquatic plants can be grown. There are more than 5000 potted plants of 1400 different plant species in the greenhouse. Next to this greenhouse is a 200 m^2 production greenhouse built within the scope of the specialization project. In the production greenhouse, it is aimed to carry out studies on the cultivation of Medicinal-Aromatic Plants and to organize courses and trainings for the people of the region.

Figure 38. A view from the R&D Greenhouse

ANG Botanical Garden has an installed electricity capacity of 250 kW and a contract power of 150 kW. Although the Botanical Garden is located within the borders of Salkımlı village, it is far from the collective village settlement area due to its location. For this reason, it is far from the LV (Low Voltage) network with its current operation. Since the electricity network plan made in the region is only intended to meet the village settlement, electrical energy may be insufficient with full capacity utilization for additional units to be built in the botanical garden in the future. In this context, it is important to consider and plan alternative energy sources. Generating clean and renewable energy in the botanical garden, using it and offering it to the grid can become an exemplary practice in line with the main activities of the center. It is a desired and expected situation to produce and use energy from renewable and clean energy sources without using fossil fuels, which are the main actors in the sources of electrical energy worldwide.

Currently, the ANG Botanical Garden can meet the electrical energy needs with 150kW contract power. However, this power may be insufficient in the coming years and additional grid investments may be required. Therefore, projects that can meet the energy need without the need for the existing grid are also being considered by the university administration.

In this master's study, three different sources were evaluated in order to meet the electrical energy needs of the botanical garden from renewable energy sources and to be applied in the future: wind energy, solar energy and biomass energy from potential plant wastes.

2.2. Material

In order to meet the energy needs of Artvin Çoruh University Botanical Garden from renewable sources, an area for solar panels has been identified in the campus project. In this context, solar energy system plans are made primarily because the area has a facade suitable for solar energy systems. Within the scope of the thesis, calculations will be made and the results will be analyzed for three different sources with the addition of wind energy turbines due to the fact that solar energy is only suitable for daytime use and the system cost is high with storage, and the idea that biomass energy can be obtained from plant wastes in the field.

2.2.1. Wind Energy Materials

In 2006, the Ministry of Energy and Natural Resources prepared the Türkiye Potential Wind Energy Map (PWEM) with a horizontal resolution of 200 m using a medium-scale numerical weather forecast model and a micro-scale wind flow model. Wind power plants with a capacity of 5 MW per square kilometer can be established in usable areas with a height of 50 meters above ground level and annual average wind speeds above 7,5 m/s. According to the PWEM data, the total capacity of wind power plants that can be built in Türkiye is 47.849,44 MW (URL-28). Figure 39 shows the Türkiye Wind Energy Potential Map and Figure 40 shows the wind power density map.

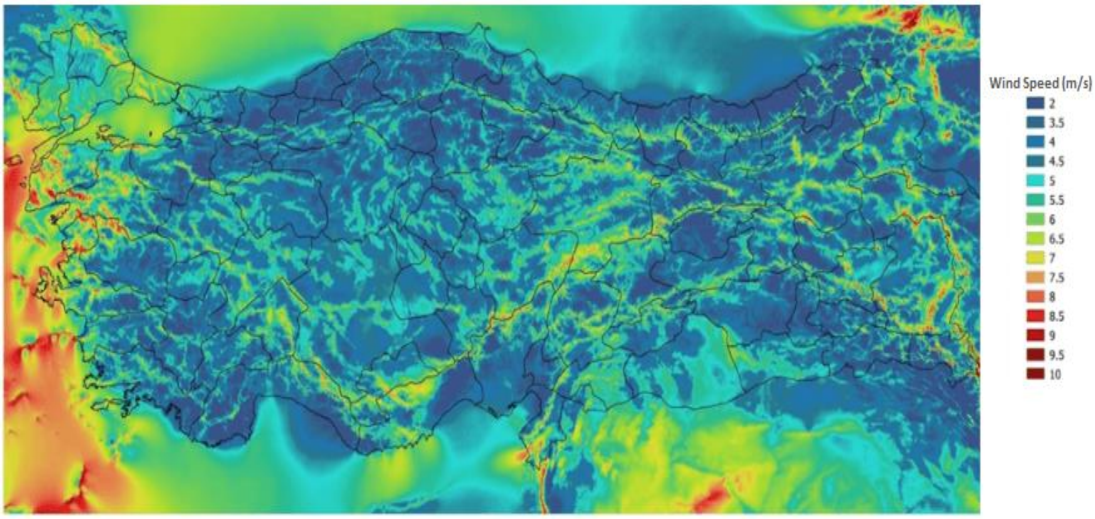


Figure 39. Türkiye Potential Wind Energy Map (PWEM) (URL-29)

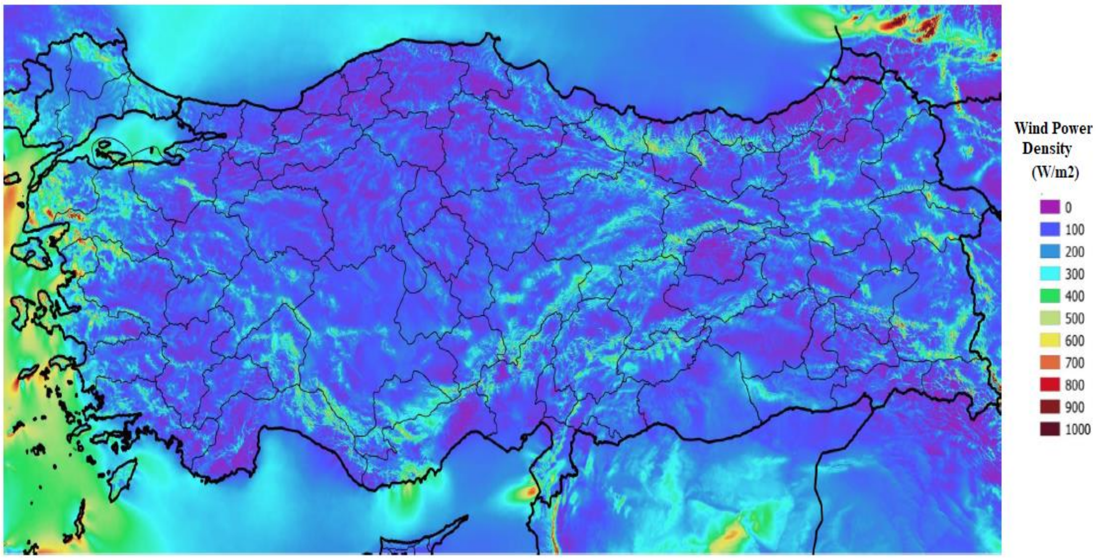


Figure 40. Annual Average Wind Power Density Distribution -100 Meters (URL-29)

According to PWEM data, the wind speed in Artvin region is 2 m/s. Although there are occasional yellow and green colored lines with wind speeds of 6-7 m/s, hourly - weekly - monthly - yearly wind speed data are needed for the optimum location where wind turbines will be installed. In order to obtain the average wind speed with the most accurate approach, an anemometer should be installed at the tower height of the turbine planned to be installed at the point where the turbine will be installed. This anemometer should measure and record hourly wind speeds for one year. Since anemometer measurement with this feature and under these conditions cannot be provided technically and economically within the thesis period, the study was carried out with the general wind speeds of the Artvin provincial center of the past years.

The wind rose of Artvin Province produced in Lakes Environmental software program is given in Figure 41. In the wind rose, it is observed how the wind direction and speeds are distributed. In this wind rose, the highest wind intensity comes from the west and west-northwest directions. This is the dominant wind direction in the region. Wind speeds are divided into different ranges. The majority of the wind blows in the speed ranges 0,50 – 2,10 m/s and 2,10 – 3,60 m/s, i.e. low speeds. Speeds above 11,10 m/s are very rarely observed. The graph shows that 12,09% of the data are calm winds, meaning that the wind speed is very low (below 0.50 m/s). This weather vane covers data from January 1, 2019 to December 31, 2019 and has a total of 8759 hours of measurements. The average wind speed in the region was determined as 1,87 m/s. Accordingly, the region is generally dominated by low wind speeds.

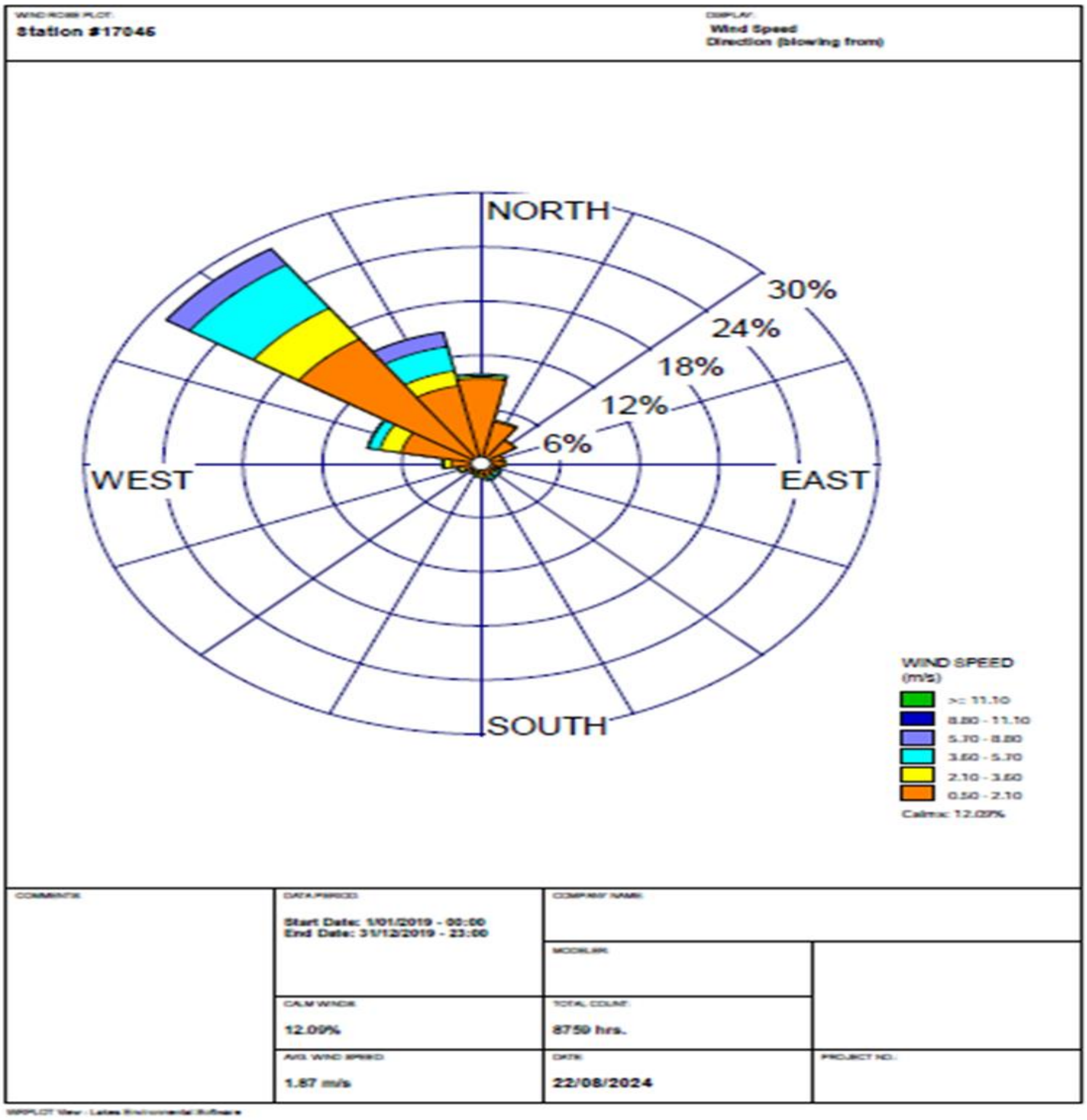


Figure 41. Artvin province wind rose plot.

Enes Halit AYDIN, a lecturer at Artvin Çoruh University, worked on “Optimization of the Use of Renewable Energy Resources on Artvin Çoruh University Campus” in his 2019 Master's Thesis at Selçuk University. In the wind energy section of the thesis, he used wind data from Artvin Meteorological Station Directorate for the years 2017 and 2018. In this thesis, 12-month wind speeds were obtained from the given thesis with the knowledge and permission of the author. According to the studies in the literature, the probability of wind speed was calculated with the Weibull Distribution Function, which is the most widely used and most suitable distribution function for determining wind speed. Since Artvin province has low wind potential and wind speeds (Figure 42), a 5 kW wind turbine model was used to convert wind energy into electricity. Graphs showing the 12-month and daily average speeds of the wind data used are given in Figure 42.

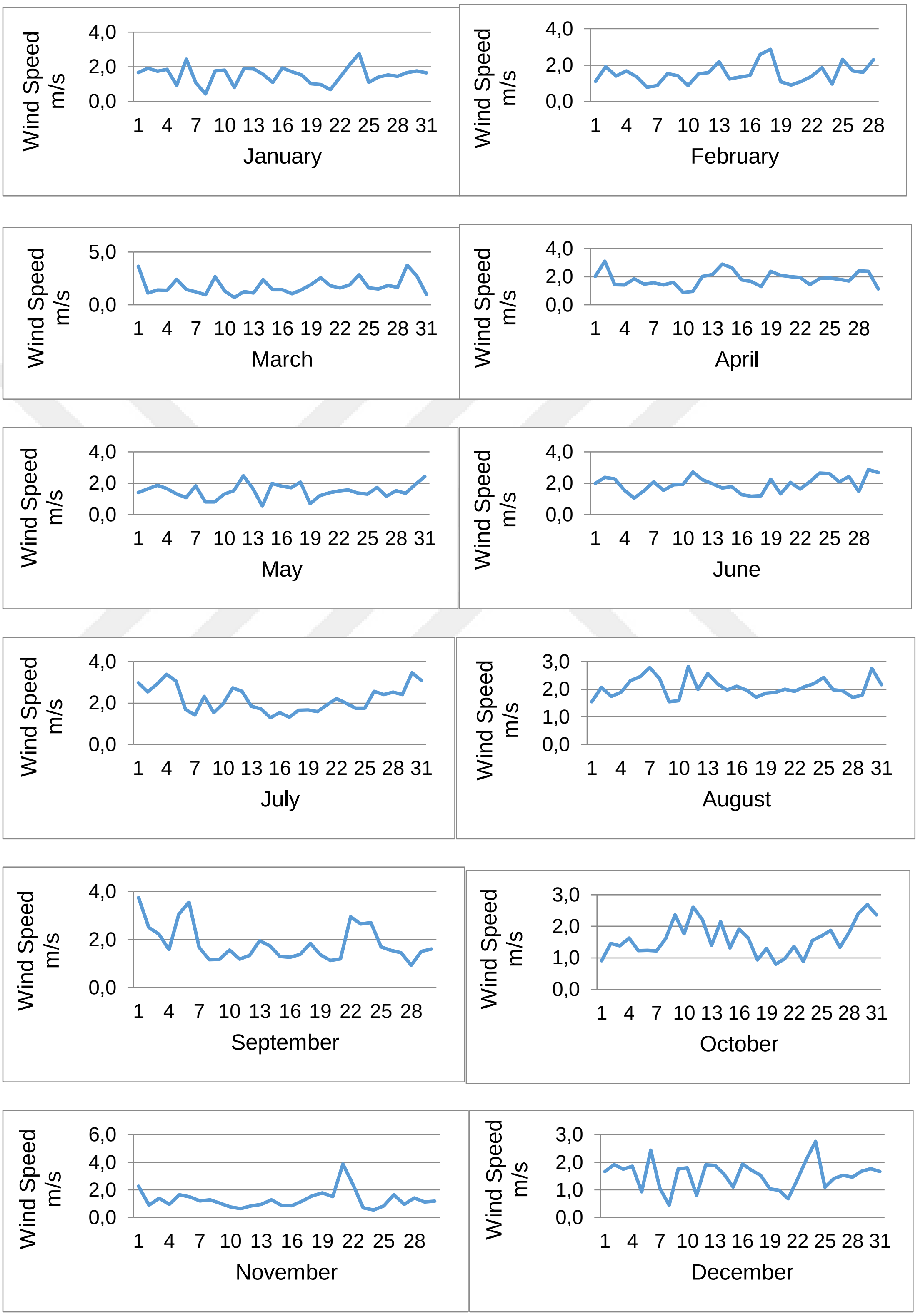


Figure 42. Artvin province 12 months’ daily average wind speeds

For annual hourly data, there should be 8760 (365x24) measurements in total. As seen in Table 7, the monthly and total distribution of the data obtained and used in the calculation is 8256 measurement values. This difference is due to the hours that cannot be measured in the measurement values. In addition, values with a measurement value of “0” were not included in the calculation. The measurement values were entered into the MATLAB program and the shape and scale parameters were calculated in the Weibull distribution function.

Table 7. Monthly measurement numbers used in the calculation

Months	**Number of hourly data**
January	688
February	649
March	728
April	696
May	730
June	695
July	744
August	726
September	602
October	704
November	646
December	648
Total	**8256**

The conversion of wind energy into electrical energy is realized through wind turbines. In wind turbines, the flow energy of the wind hits the turbine blades and creates a rotary motion. The mechanical rotary motion is converted into electrical energy in a generator connected to the turbine shaft. The power of the generators connected to the wind turbines is determined according to the wind characteristics of the installed location. For individual use, turbines with the required power are selected. Wind intensity varies hourly, monthly and seasonally. For this reason, the generator output power connected to the turbines and the electrical energy produced are not constant. As it is known, the electrical energy consumed has a constant voltage and a constant frequency. Devices operating with electrical energy can operate with this constant voltage and frequency. In order to regulate this variability in the output of wind turbines, there is a regulator or converter - inverter sections after the generators. In grid-connected systems, the connection takes place when synchronization is provided to match the grid values to which it is connected. In individual use, three-phase 380V, 50 hz or one-phase 220V 50 hz network values are supplied by providing three-phase 380V, 50 hz or one-phase 220V 50 hz network values in Türkiye standards.

Wind turbine manufacturers generate output power values by creating artificial winds at different speeds in their production facilities. Power values corresponding to different constant wind speeds are presented in the manufacturer catalogs by creating graphical curves. Looking at the PWEM data and wind measurement values obtained for Artvin province, it is seen that the average wind speed values are very low. For this reason, a small 5 kW turbine was found appropriate for the wind power generation analysis in this thesis. For the turbine selection, the SoyutWind 5 kW model of the Türkiye Soyut Wind company was selected and catalog values were obtained. Figure and tables excerpts containing the catalog values of the SoyutWind 5 kW model wind turbine for the production analysis are presented below (Figure 43, Table 8 - 9) (URL-30).

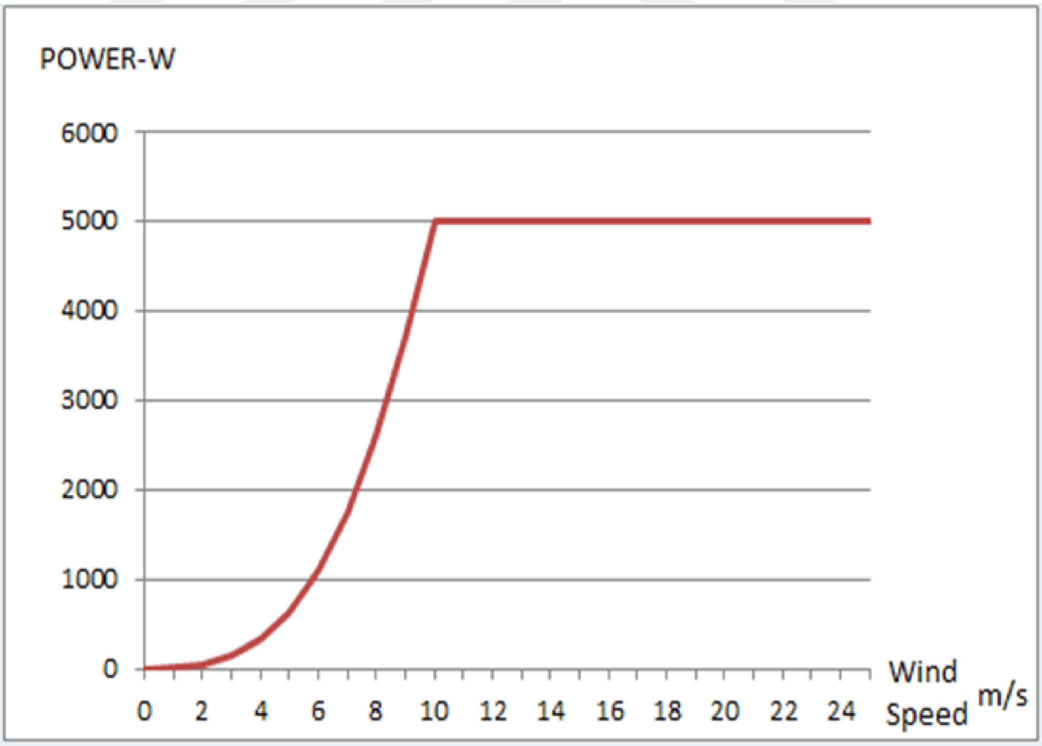


Figure 43. Power curve of the wind turbine

Table 8. SoyutWind 5 kW model turbine's wind speed and power values

Wind Speed (m/s)	**Power (kW)**
1	0,005
2	0,041
3	0,137
4	0,325
5	0,635
6	1,098
7	1,743
8	2,602
9	3,704
10	5,000
11	5,000
12	5,000
13	5,000
14	5,000
15	5,000

Table 9: Technical specifications of the wind turbine

Rated Wind Speed	10 m/s
Cut-in Wind speed	3 m/s
Cut-out Wind speed	25 m/s
Rotor Diameter	6,5 m
Swept Area	33,18 m^2
Tower Height	6,5 m
Operating Temperature	-30ºC - +50ºC
Blade Type	Fiberglass Composite
Tower Type	Steel Lattice
Yaw System (Facing – Avoiding)	Furling
Gear Box	No
Control System	PLC
Brake	Electromagnetic
Alternator	3 Phase Permanent Magnet (PMG)
Voltage	220/400 VAC – 50/60 Hz
Wind Speed Sensor	Yes
Temperature Sensor	Yes
Remote Control and Monitoring	Yes
Ligtning Protection	Yes
Battery Voltage	12V – 24V – 48V

2.2.2. Solar Energy Materials

Türkiye has a significant solar energy potential because of its geographical location. Total annual average sunshine duration is 2.741 hours according to the Solar Energy

Potential Map (GEPH) prepared by the Ministry of Energy and Natural Resources. The annual average total radiation value is 1,527.46 kWh/m2. The general potential outlook and annual average global irradiance distribution in PSEM are given in Figure 44 (URL-8).

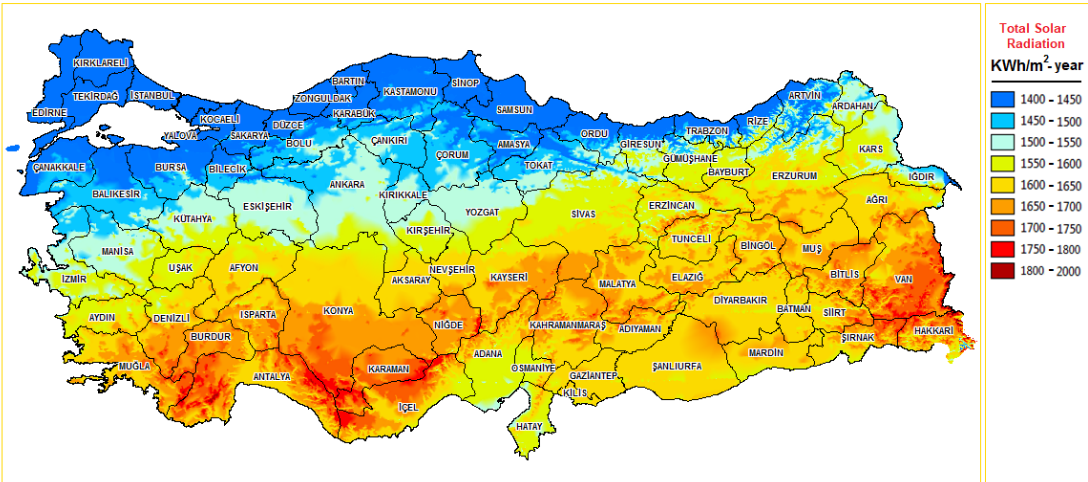


Figure 44. Türkiye Potential Solar Energy Map (PSEM)

Artvin solar energy potential map and Türkiye-wide comparative graphs were obtained by using PSEM data and graphs. Artvin province-wide and Artvin Center, where the project is planned, are lower than Türkiye average. However, ANG Botanical Garden Campus is located in a south-facing region in Artvin Center. For this reason, more efficient results will be obtained by using precisely located climate data through the simulation program to be used. Figure 45, Figure 46 and Figure 47 respectively show the solar energy potential map of Artvin, Artvin comparative monthly insolation values and monthly insolation durations and efficiency comparisons of panel types suitable for Türkiye and Artvin insolation conditions.

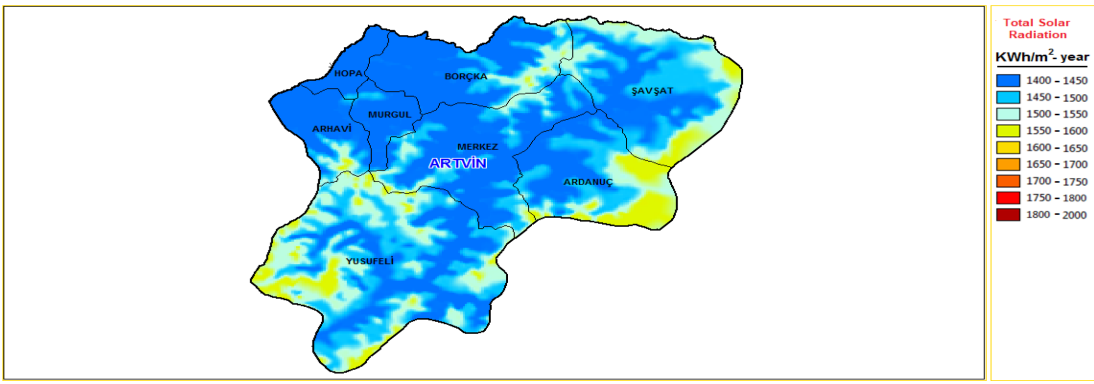
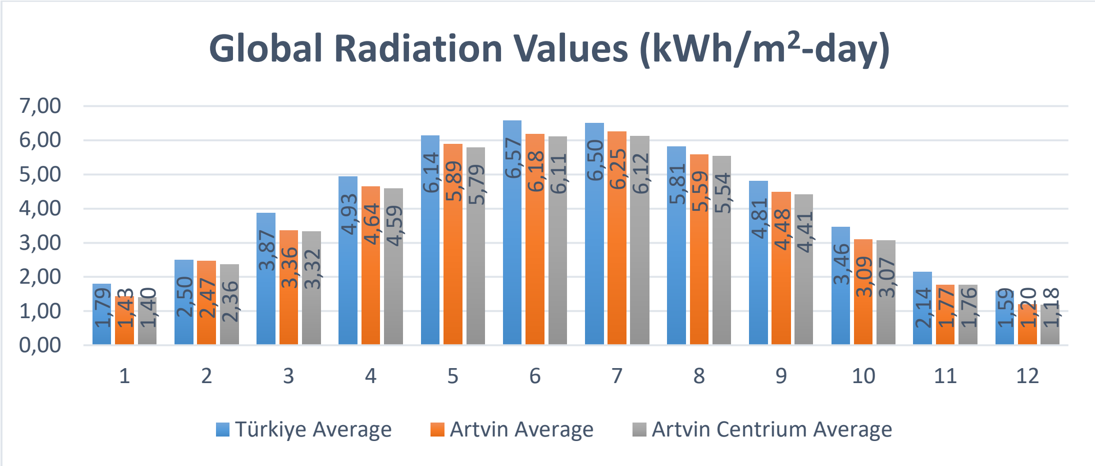
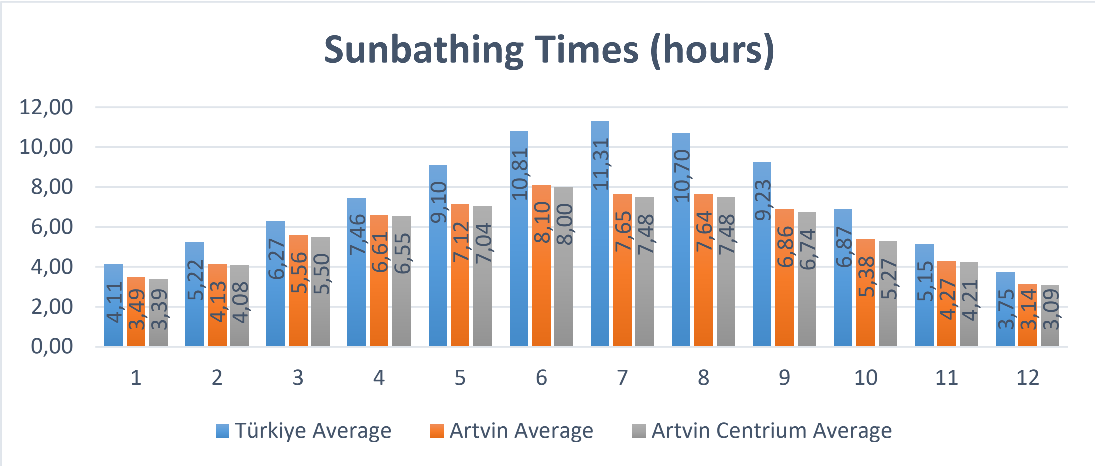


Figure 45. Artvin Potential Solar Energy Map



(a)



(b)

Figure 46. (a) Global solar radiation values, (b) Sunbathing times

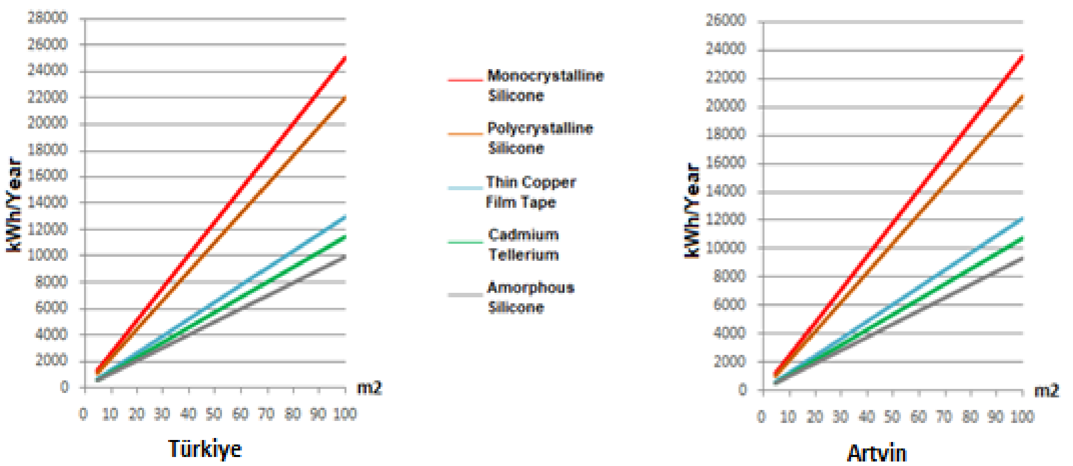


Figure 47. Appropriate PV panels around the Türkiye and Artvin Climate Conditions

Artvin Çoruh University ANG Botanical Garden is located at the fifth kilometer of the Artvin-Ardahan Highway, at the beginning of the Deriner Dam downstream area, on the borders of Salkımlı Village of Artvin Center, in a south-facing location. In relation to the field of activity and purpose of the botanical garden, in order to meet the energy needs of the campus from renewable sources, the relevant units of Artvin Çoruh University have determined the location for the installation of solar panels in the project of the campus. The location planned for solar energy and included in the project is the area between 1300-1400 m^2 in Figure 48. In addition to this area, the 1200-1250 m^2 parking lot area (Figure 49) adjacent to the existing area is a potential location where solar panels can be installed when the parking lot is covered or the parking lot is moved to the entrance of the campus. Within the scope of the thesis, both areas were evaluated and solar energy project design was made in PVSOL simulation program.

Figure 48. The region where solar energy installation is planned within the scope of the Project (URL-31)

Figure 49. The second area, which is called a parking lot in the project and where solar energy panels can be installed (URL-31)

PVSOL is a simulation program developed to design and install solar energy systems. PVSOL Premium 2021 (R8) version of the program was used. The database of the program contains the sunshine and climate values of all regions of the world to be used in solar energy installation. It can also work synchronously with Google Map and provide direct climate data in the location where the system will be installed. The program also includes current solar panels and inverters available on the market in its database. The program, which is suitable for three-dimensional design, presents all technical and economic calculations step by step in a way that the user can easily access and apply. General information about the PVSOL program and other simulaton programmes are given comparatively in Table 3. The start screen of the German PVSOL Premium 2021(R8) program developed by Valentin Software Company is shown in Figure 50.

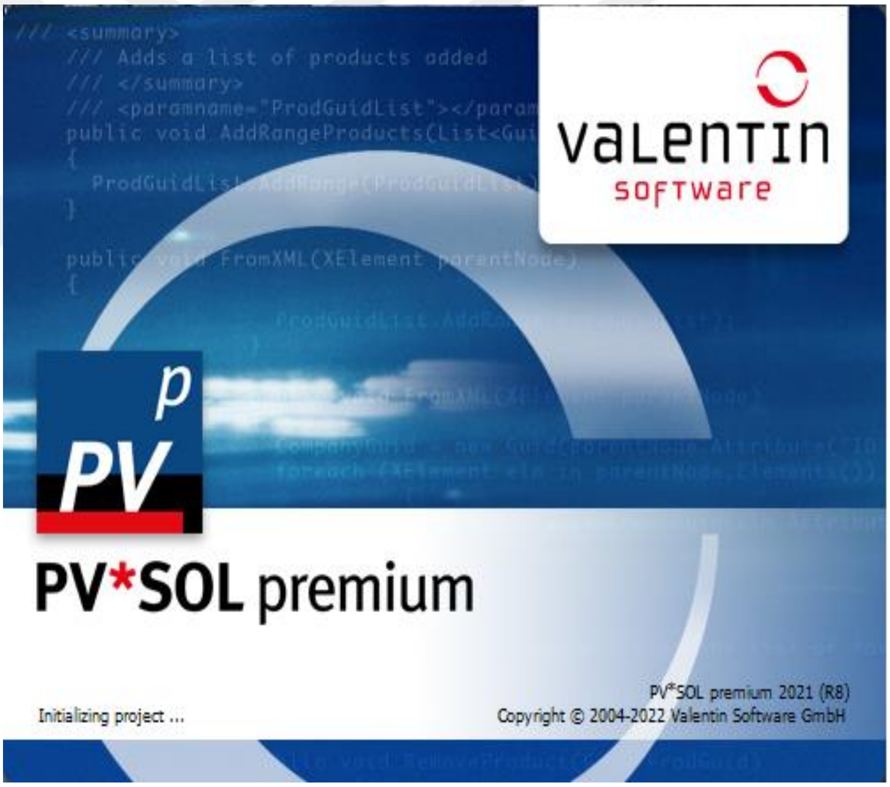


Figure 50. Start screen of the simulation program used in the thesis

2.2.3. Waste to Energy Materials

Technical and administrative units serving in the public or private sector recently in the world and in Türkiye operate in areas in the form of campuses according to their size. Campuses consist of service buildings and landscape areas. Universities in

Türkiye consist of one or more campuses depending on their location in the provinces where they are located, and there are small campuses of faculties and vocational schools in the districts. Universities also have additional campuses for application, research and development centers in line with their various activities and fields of study. Maintenance of the landscape areas of the campuses is carried out on a weekly, monthly and seasonal basis. After the maintenance works, grass mowing wastes, pruning wastes of ornamental plants and fruitless and fruit trees are generated. These wastes are important sources of biomass.

Artvin Çoruh University, a public educational institution, has ANG Botanical Garden campus, which operates as an application and research center, in addition to the campuses with educational activities. In the ANG Botanical Garden, applications and research are carried out on various plants and plant breeding, which is the main service subject. Here, samples were taken and analyzed to obtain biomass energy from plant wastes (Figure 51) generated after landscape maintenance in the area, especially plant wastes generated during plant cultivation, which is the subject of study and research. According to the results of the analysis, there was examined the energy yield of both incineration of solid plant wastes and the biogas energy yield that can be produced by anaerobic digestion by mixing the organic food wastes of the cafeterias in all campuses of the university.

Figure 51. Image of pruning waste deposits in ANG Botanical Garden

ANG The ANG Botanical Garden has many kinds of trees and saplings, both fruiting and non-fruiting. New species of trees were planted in the area before the botanical garden was established, as well as after the botanical garden was established. There are also greenhouses for plant cultivation for application and research purposes. According to the information received from the ANG Botanical Garden administrators and staff, the trees in the area are pruned before winter for maintenance and rejuvenation. A mixed sample of different species was taken with the primary objective of considering these wastes as a biomass potential. Branches and leaves from different tree species were taken for sample preparation. A sample of fig, apple, pomegranate, peach, walnut, black berry, rose, willow, acacia, thuja and firethorn shoots was taken prior to general pruning in fall 2023, filling a bag of approximately 0,5 m^3 (Figure 52 (a)). Support and an appointment was made with the Faculty of Forestry Laboratory to grind the samples prior to elemental analysis. Prior to grinding, the waste was chopped with the help of pruning shears and saws to a size of approximately 10 cm and re-bagged (Figure 52 (b)). In this state, the total amount of waste was measured to be approximately 0,25 m^3 and the total weight of waste was 4,8 kg. The volume-reduced analysis material was laid out in a warm closed room for natural drying and rough drying before drying in an oven (Figure 52 (c)).

0,25 m^3 of semi-compressed and naturally dried pruning waste has a mass of 4,8 kg. According to the interviews, 6-7 truckloads (AÇU official service vehicle) are used to transport this waste to landfills annually. On average, 25 m^3 of pruning waste can be loaded into the truck bed. In this case, the total amount of waste is calculated to be around **3500 kg.**

(a)

(b)

(c)

Figure 52. (a): Samples taken from pruning waste, (b): 10 cm chopped volume of the samples, (c): Laying and drying of the chopped pruning waste

Considering the Botanical Garden activity area, solid wastes generated by pruning wastes are generally generated during the cultivation and maintenance of herbaceous and woody plants. Such solid wastes have the potential to provide energy by incineration in waste utilization. As an alternative way of utilization, biogas production by anaerobic digestion method can be considered by obtaining a mixture with the daily food and food waste of the cafeterias and canteens in all campuses of Artvin Çoruh University. In all campuses of the university, cafeterias provide a daily four-course meal service for students and staff. The leftovers after this meal consist of organic wastes, which are disposed of in the garbage. According to the data obtained from

Artvin Çoruh University Department of Health, Culture and Sports, the total number of lunches eaten by campus is as follows (Table 10).

Table 10. Number of lunches eaten at ACU in one academic semester by campus

AÇU Campus	**Number of Meals**
Borçka-Hopa-Arhavi	28.207
Merkez - Seyitler	111.849
Ardanuç	1.347
Şavşat	1.975
Total	**143.378**

The number of meals eaten in the fall semester of the 2023-2024 Academic Year is shown in Table 10. The date range covers the 16-week period between beginning of the fall semester (02.10.2023) and the end of the fall semester (19.01.2024). The lunch menu is common to all campuses and the weekly menu is generally the same for the following weeks. When calculating the amount of waste generated by meals, the example of Borçka campus was taken. Table 11 shows the number of meals eaten in Borçka campus and the amount of food waste after meals by days within a week.

Table 11. Weekly lunch menu and waste amounts after lunch

Days	**Lunch Menu**	**Number of meals eaten**	**Approximate food waste volume** (Liters)	**Approximate food waste mass** (kg)
Monday	Lentil Soup Dry beans Rice pilaf Yogurt - Pickle	56	10	5
Tuesday	Yayla soup Potato with minced meat Bulgur pilaf Yogurt	88	15	7,5
Wednesday	Lentil soup Chicken drumstick Macaroni Yogurt - Salad	111	40	20
Thursday	Tomato soup İzmir meatball Bulgur pilaf Apple	120	10	5

Friday	Ezogelin soup Stew with peas Rice pilaf Kadayif - yogurt	55	6	3
Total Amount		**430**	**81**	**40,5**

In the Lunch menu column of Table 11, the weekly lunch menu applied in all cafeterias during the academic year at Artvin Çoruh University is given. For the quantity information of the meals eaten, Borçka Acarlar Vocational School cafeteria was taken as an example. In line with this information, a total of 81 liters and 40,5 kg of food waste is generated after 430 lunches eaten for a week. According to Table 10, a total of 143.378 lunches were eaten in all cafeterias of Artvin Çoruh University in one semester. If the number 286.756, which is twice this number for an academic year consisting of two semesters, is accepted, 666,87 times the number of meals eaten and subsequent waste will be generated. In this case, the total volume of food waste in an academic year with active students and staff will be 54.016,47 liters and 27.008,235 kg. This waste has organic content and has the potential to be utilized in anaerobic digestion.

2.3. Methodology

Energy resources are classified as primary energy sources and secondary energy sources according to their convertibility. Undoubtedly, the most important source of secondary energy sources is electrical energy. Electrical energy is a resource that is very easy to use and consume and very difficult to produce. Electrical energy can be obtained after one or more processes of primary energy sources.

The potential for energy production from renewable energy sources is almost infinite. However, today, the technical and economic conditions necessary for the conversion of the energy potential of all renewable energy sources into electrical energy have not yet reached the desired level. Energy generation from hydroelectric power plants can only be done by conventional methods where rivers are available. Similarly, the production of electricity from geothermal energy is carried out in places where geothermal resources are located by several known methods according to the temperature of the resources. Other renewable energy resources are ubiquitous and have the potential to be utilized.

The conversion methods studied and proposed in the thesis for wind, solar and biomass energies that can meet the electrical energy needs of Artvin Çoruh University ANG Botanical Garden are respectively discussed below.

2.3.1. Wind Energy Methods

Some methods are used to calculate the wind energy potential from wind energy according to the average speed of the wind. These methods consist of several methods formulated as probabilistic distribution functions. The most commonly used functions are Weibull, Rayleigh, Gamma and Lognormal. When the studies in the literature are examined, it is seen that the most appropriate probability distribution function for energy production calculations of wind speeds is the Weibull Distribution Function. Using the wind speeds given in the wind energy materials section of the thesis, the parameters of the Weibull distribution function were obtained in MATLAB program and the electrical energy equivalent of wind energy was calculated with the following equations.

In order to generate electrical energy from wind energy, theoretically a wind energy and a wind turbine that converts wind energy into electrical energy are needed. Wind turbine power is a function of wind speed. Let us denote this function by *P(v)*. In the calculations to be made with the Weibull distribution function used to determine the wind speed potential, when the Weibull distribution function is taken as *f(v)*, the wind turbine power is found by the integral calculation in equation (24) (Oral et al., 2015).

$$P = \int_0^\infty P(v).f(v)dv \qquad (24)$$

Energy production in a wind turbine starts with the initial speed V_i. In other words, this speed is referred to as the wind cut-in speed (V_{Cin}). Power and energy production increases until the wind speed reaches the nominal speed. The nominal speed is denoted by V_n. At a nominal speed V_n, a nominal power P_n is generated. When the turbine starts to generate nominal power, the power generation slows down in a controlled manner and remains constant. The turbine shuts itself down at wind speeds above the wind cut-out speed (V_{Cout}) and continues to generate at its rated power. This speed is denoted as V_o (Oral et al., 2015). Since the wind speed is not constant, the expression of the power output according to the wind speed ranges in the turbine model to be used is as follows. Since the power output is an average power to be produced with the average wind speed to be found by the Weibull distribution of the wind, it is denoted by P_{mean} and equation (25) is obtained according to the following wind speed ranges (Doğanşahin et al., 2019).

$$P_{mean} \rightarrow \begin{cases} v < V_{Cin} \rightarrow P_{mean} = 0 \\ V_{Cin} \leq v < V_n \rightarrow P_{mean} = P(v) \\ V_n \leq v < V_{Cout} \rightarrow P_{mean} = P_n \\ V_{Cout} \leq v \rightarrow P_{mean} = 0 \end{cases} \tag{25}$$

The ratio of the energy that can be produced with the wind potential and technical infrastructure at the location where the wind turbine will be installed in a certain time interval to the energy to be produced with continuous nominal power generation within this time period gives the capacity factor. The capacity factor is calculated by equation (26)-(29) given below (Doğanşahin et al., 2019).

$$CF = \frac{P_{mean}}{P_n} \tag{26}$$

$$CF = \frac{1}{P_n} \int_0^{\infty} P(v) f(v).dv \tag{27}$$

$$P_{mean} = \int_{V_{cin}}^{V_n} P(v) f(v).dv + P_n \cdot \int_{V_n}^{V_{cout}} f(v).dv \tag{28}$$

$$CF = \frac{1}{P_n} \int_{V_{cin}}^{V_n} P(v) f(v).dv + \int_{V_n}^{V_{cout}} f(v).dv \tag{29}$$

Wind turbine manufacturers produce turbines in different power ranges. The generators used in the turbines are produced as direct current or alternating current generators according to the conditions in the installation location and the customer's demand. Similarly, turbine generator types can vary according to the demand for grid-connected or off-grid and storage status. Wind is a variable resource. For this reason, wind turbines with alternating current asynchronous generators are preferred in wind power plants and other applications to use this resource with the best efficiency. In the test and trial stages of wind turbine production, artificial different wind speeds are obtained and turbine power curves are created. Wind speeds and turbine output powers tested and recorded by the manufacturer in the laboratory environment are transferred to wind turbine catalogs in the form of tables and speed-power (Figure 43, Table 8 - 9). Since the speeds specified in the catalog cannot be obtained in the real environment, a curve equation that depends on the wind speed *(v)* is needed. This curve equation was obtained with the curve fitting menu in MATLAB program. For this purpose, in the Table 8 the speed values given are entered as x and the power values as y on the MATLAB command screen (Figure 53).

```
>> x=[1 2 3 4 5 6 7 8 9 10 11 12 13 14 15]

x =

  Columns 1 through 13

     1     2     3     4     5     6     7     8     9    10    11    12    13

  Columns 14 through 15

    14    15

>> y=[0.005 0.041 0.137 0.325 0.635 1.098 1.743 2.602 3.704 5 5 5 5 5 5]

y =

  Columns 1 through 7

    0.0050    0.0410    0.1370    0.3250    0.6350    1.0980    1.7430

  Columns 8 through 14

    2.6020    3.7040    5.0000    5.0000    5.0000    5.0000    5.0000

  Column 15

    5.0000
```

Figure 53. Matlab command screen for the curve equation

After entering the values in the MATLAB command screen excerpt given in Figure 53, the curve fitting window in Figure 54 opens. Necessary settings are made here. The application also shows the degree of accuracy of the curve to be obtained. The degree of the equation also affects the degree of accuracy.

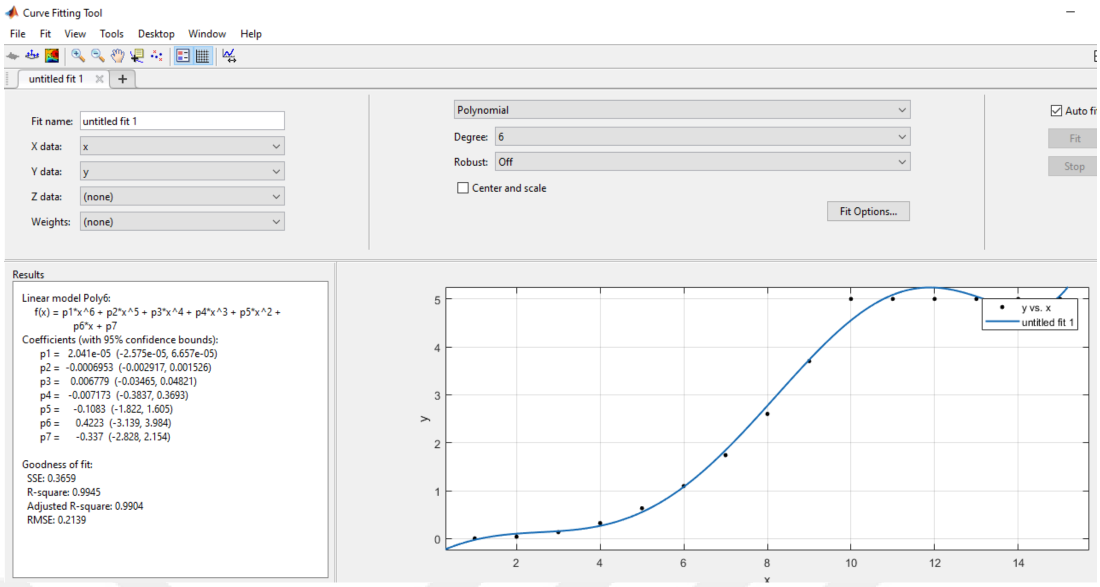


Figure 54. Matlab program curve fitting application window

With the Matlab curve fitting method, a 6th degree equation was obtained with 99.96% accuracy. Accordingly, the turbine polynomial curve equation (30) is as follows:

$$P(v) = 2{,}041.10^{-5}.v^{6} - 0{,}0006953.v^{5} + 0{,}006779.v^{4} - 0{,}007173.v^{3} - 0{,}1083.v^{2} + 0{,}4223.v - 0{,}337 \quad (30)$$

After obtaining the curve equation *P(v)* depending on the speed parameter *"v"* of the SoyutWind 5 kW model turbine, the two-parameter (k: shape parameter, c: scale parameter) Weibull distribution function *f(v)* used in the calculation was obtained from the MATLAB program. The two-parameter Weibull distribution function was calculated in MATLAB program considering a period of 12 months. A total of 7777 wind speed measurements were used to obtain the k and c parameters in the Weibull distribution function in equation (16). Hourly wind speeds for months and days, including January and December, were transferred to the MATLAB command screen with the number of measurements specified in Table 7.

In the MATLAB command screen, entered on a single line (Figure 55), the expression a=a(a~=0.0) was used to exclude the values that could not be measured and were 0,0 m/s from the wind speeds. Accordingly, 7777 of the 8256 wind speeds entered into the MATLAB program (Figure 56) were included in the calculation. The k and c parameters of the Weibull distribution function were found with the "wblfit" command, which calculates the parameters of the two-parameter Weibull distribution function.

```
a=[0.2 0.1  0.3 0.1 0.0 0.9 2.2 2.8 3.2 2.9 3.3 3.2 2.6 2.9 2.7 2.8 2.8 2.4 2.2 2.9 3.1 2.

a=a(a~=0.0);
%M ortalama hiz vm     c=param1    k=param2
param=wblfit(a);
```

Figure 55. A section from the matlab command screen

Figure 56 is the MATLAB result screen with the Weibull distribution function results for one year of hours. According to the result screen, k = 1,3006 and c = 2,0067.

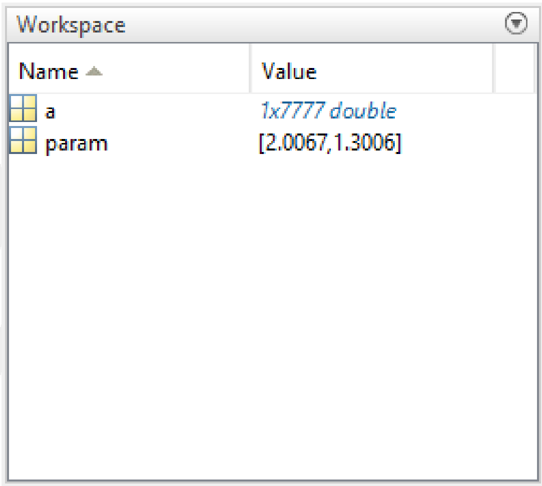


Figure 56. Weibull distribution results around the 7777 hourly speeds

When the shape (k) and scale (c) parameters of the Weibull distribution function obtained with the hourly wind measurements used are substituted in equation (16), the new *f(v)* Weibull distribution function depending on the speed variable v in equation (31) is obtained.

$$f(v) = 0{,}6481\left(\frac{v}{2{,}0067}\right)^{0{,}3006}.e^{-\left(\frac{v}{2{,}0067}\right)^{1{,}3006}} \quad (31)$$

The nominal power P_n of the sample turbine model used in the application and given in the material is 5 kW (Table 8). According to the speed-power table of the SoyutWind 5 kW model turbine, V_{Cin} = 3 m/s, V_{Cout} = 25 m/s. At all speeds greater than 10 m/s, the turbine remains constant with 5 kW power. Once all the variables are obtained, the new formula for the P_{mean} value in equation (28) takes the form of equation (32).

$$P_{mean} = \int_{3}^{10}(2{,}041.10^{-5}.v^6 - 0{,}0006953.v^5 + 0{,}006779.v^4 - 0{,}007173.v^3 - 0{,}1083.v^2 + 0{,}4223.v - 0{,}337).\left(0{,}6481\ \left(\frac{v}{2{,}0067}\right)^{0{,}3006}.e^{-\left(\frac{v}{2{,}0067}\right)^{1{,}3006}}\right)dv + 5.\int_{10}^{24}\left(0{,}6481\ \left(\frac{v}{2{,}0067}\right)^{0{,}3006}.e^{-\left(\frac{v}{2{,}0067}\right)^{1{,}3006}}\right)dv \quad (32)$$

Equation (32) is calculated as two separate integral operations in MATLAB program. The first operation is the integral calculation in the interval 3 - 10 and the second operation is the integral operation in the interval 10 - 24 multiplied by 5. The result of the first operation is **8,2992.10^{-2}** (APPENDIX-1, 1st step integral calculation) and the result of the second operation is **1,5546.10^{-3}** (APPENDIX-1, 2nd step integral calculation).

2.3.2. Solar Energy Methods

The PVSOL Premium program enables photovoltaic system designs to be designed and simulated to industrial standards. The program offers a wide range of tools for design and simulation, from small rooftop systems with a few modules to large commercial projects. 3D design is the most important feature of PVSOL premium. In this way, realistic shading factors can be calculated in the project designed in the program and more accurate results can be obtained. Economic efficiency can be calculated thanks to the existing tariff information in the program's database. When information such as unit prices, inflation rates and tax rates regarding system installation costs are entered, a detailed and meaningful 20-year economic analysis report is automatically prepared by the program (URL-32).

PVSOL Premium 2021(R8) version was used for the design of solar energy systems in the designated areas of the ANG Botanical Garden. In order to create the project, firstly the identification information of the project was entered. Then, Salkımlı Village, where the ANG Botanical Garden is located, was selected on the map and the 1991-2010 climate data stored in the database of the program were selected (Figure 57). With the help of the maps.google link in the program, the places where solar panels will be installed were marked by encircling them. Panel installation areas were delimited by selecting polygon open surface. Since the areas where the panels will be installed are in the form of two separate locations, the polygon selection was automatically named as Polygon 01 and Polygon 02 in the program (Figure 58).

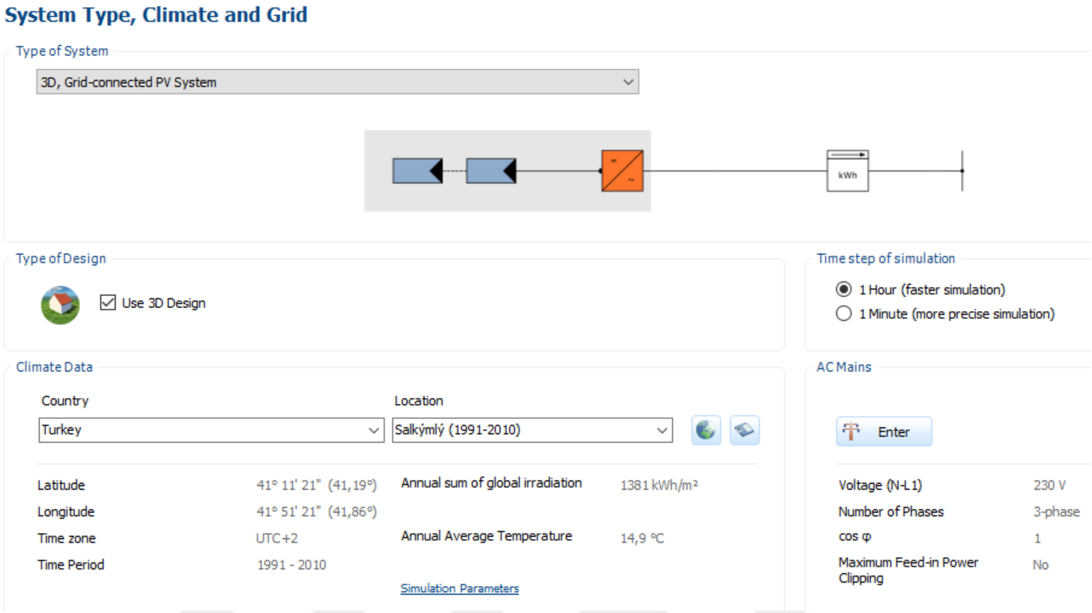
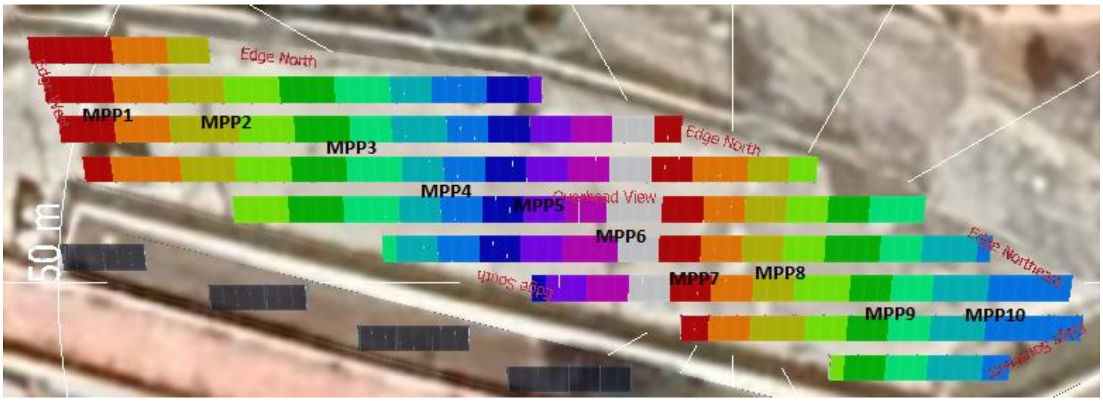


Figure 57. Entering the climate data for the location Salkımlı/Artvin/Türkiye

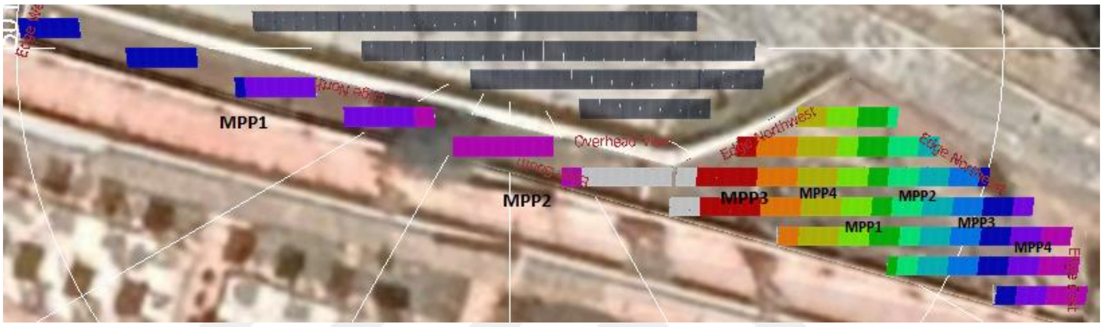
Figure 58. Polygon areas where the pv panels are installed

During the design phase of the system in the determined polygon areas, solar panel placement and inverter connection stages were carried out respectively. CWT400-72PM modeled 400 watt panels belonging to CW Energy company, which are registered in the system database, were preferred and the placement settings of the panels were started. In the program, angle settings and shading factors were made automatically according to the dimensions of the panel. Since the inclination of the place to be installed is a flat area, the surface angle was selected as 0^o degrees. The facade of the panels was adjusted to be south-facing 180^o degrees flat and 15^o degrees inclination with minimum shading. Afterwards, panel placement was made automatically in the selected areas respectively. Panels were placed in the selected areas with a total of 527 pv modules (210,8kW), 322 pv modules (128,8kW) in Polygon 01 and 205 pv modules (82 kW) in Polygon 02. The panels were positioned in 3D in arrays and rows in Polygon 01 and Polygon 02 areas as shown in Figure 58.

After panel installation, inverter selection was started. Inverters belonging to Huawei Technologies were selected from the inverters registered in the program database. Large power inverters were preferred to avoid high power loss due to inverters. Since the Polygon 01 area is a more uniform area, only one inverter could be connected. Panels were automatically connected to this inverter with 10 MPPT devices. In Polygon 02 area, two inverters and 4 MPPT devices were connected to each inverter and the panels were connected by the program. MPPT and module, array connections of the inverters are given in detail in Figure 59 and Table 12.



(a)



(b)

Figure 59. (a): MPPT connection configuration of the first inverter in the Polygon 01 (b): MPPT connection configuration of the second and third inverters in the Polygon 02

Table 12. (a): Polygonal open area 01 inverter 1 configuration, (b): Polygonal open area 02 inverter 1 configuration, (c): Polygonal open area 02 inverter 2 configuration

(a)

Polygon 01 Inverter 1		
MPPT Number	**Number of strings**	**Modules in series in the string**
MPP 1	2	17
MPP 2	2	16
MPP 3	2	16
MPP 4	2	16
MPP 5	2	16
MPP 6	2	16
MPP 7	2	16
MPP 8	2	16
MPP 9	2	16
MPP 10	2	16

(b)

Polygon 02 Inverter 1		
MPPT Number	**Number of strings**	**Modules in series in the string**
MPP 1	2	14
MPP 2	2	14
MPP 3	2	14
MPP 4	1	19

(c)

Polygon 02 Inverter 2		
MPPT Number	**Number of strings**	**Modules in series in the string**
MPP 1	2	14
MPP 2	2	14
MPP 3	2	12
MPP 4	2	11

The cabling, circuit breaker, disconnector and fuse connections of the panel, array, MPPT and inverters were made automatically by the program. In the internet-based training videos used during the project preparation phase with the PVSOL program, it was found that some manual changes were made in the wiring section. These are changes such as the use of a higher cross-section in the cables at the panel outputs, the use of a higher value fuse and the addition of additional disconnectors/cutters. Although these changes increase the cost, they reduce losses in the system and increase the operational safety of the system. In this direction, some manual changes were made in the cabling section.

The most important part of the sequential menus while preparing a project in the PVSOL program is the section where the financial analysis is made. In this section, the most accurate and up-to-date information must be entered in order to calculate the cost and recycling of the prepared project in the most accurate way and present it in the project report. Data entries were made step by step on the pages opened by logging into the relevant menu in the program. Turkish Lira (TL) is set as the currency.

A period of 25 years was selected as the project investment period. 25 years is an optimum time interval for solar energy investments where the return can be clearly seen. The annual average return on capital employed is taken as 33%. This rate is a rate that should be entered in the project report in order for the cash flow graph to be stable according to the average profitability of the company that will make the investment. Since the university is an educational institution, a stable slope was obtained in the cash flow graph with an average profitability rate of 33%.

The unit price of electrical energy was entered as 219,8349 kr/kWh (2,1983TL/kWh) based on the tariffs set by (EPDK) EMRA (URL-33) as of 03.07.2023 when the project was finalized, which is defined as “Public and Private Services Sector and Other” (“Kamu ve Özel Hizmetler Sektrörü ile Diğer”) in the relevant table. The tariff period range is taken as the previously determined period range starting on 02.11.2022 and ending on 01.11.2047. 700 USD/kW value is used as the average cost for obtaining electricity from solar energy with photovoltaic panels. The TL equivalent of 1 USD on 03.07.2023 is 26,03 TL according to the central bank prices. Accordingly, 1 kW solar energy installation cost is 700*26,03=18.221TL/kW. 18.221 Turkish lira value was entered and registered in the relevant section of the program. The total installed power of the solar power plant created with photovoltaic panels in the prepared project is 210,8 kW. The total investment cost of the system was calculated by the program (210,8*18.221) and reflected on the financial analysis screen as 3.840.986,8 TL (Figure 60).

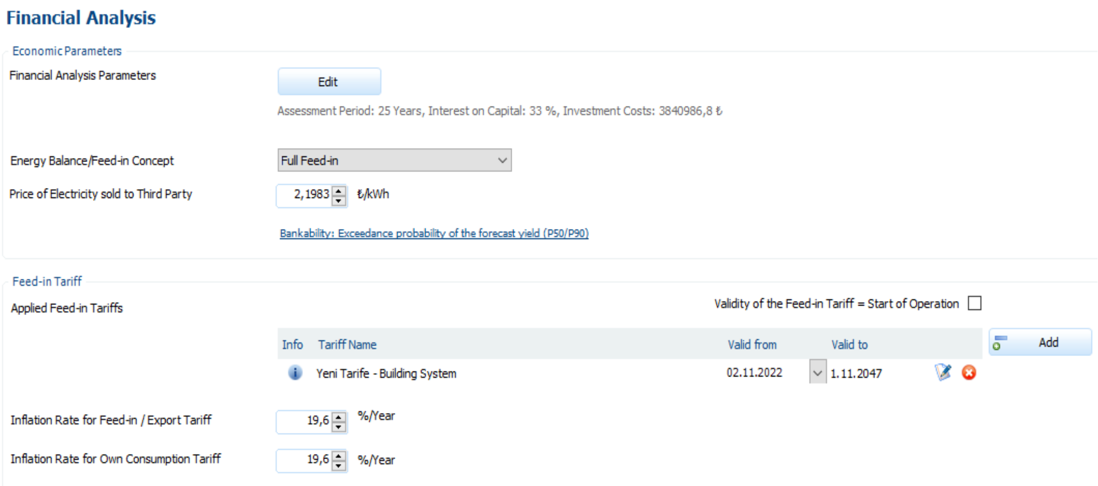


Figure 60. PVSOL programme financial analysis screen

Finally, in the financial analysis section of the PVSOL program, the inflation rate was calculated and entered as a % value in the relevant section. TUIK data was used to calculate the inflation rate (URL-34). The inflation rate of the electricity market was calculated from the PPI (Üretici Fiyat Endeksi) values in the section 35.1 (DV column)

(Electricity, transmission and distribution services) of the “Domestic producer price index” table taken from the official website of TUIK. The Covid 19 pandemic effect that emerged in early 2020 worldwide, the effect of the 2022 Russia-Ukraine war, and the effect of the Kahramanmaraş-based earthquake, which is described as the disaster of the century, which occurred on February 6, 2023 in Türkiye, caused sudden fluctuations in the markets, resulting in unstable increases in inflation rates. For this reason, in order to calculate the inflation value in the electricity market in the most accurate way, 10-year values between June 2013 and June 2023 were taken into consideration. According to the calculated result, an average annual incremental inflation rate of 19.63% was found and entered into the program (Figure 60).

For the preparation of the ANG Botanical Garden Solar Power Plant project, after the 3D design of the system was made and all variables were entered, the project file was prepared in the “Results” section. In the last section, a report file containing all the details of the project was output to the external environment with the “Presentation” menu, where the prepared project can be presented in different formats.

2.3.3. Waste to Energy Methods

At ANG Botanical Garden, the samples taken from the pruning wastes were firstly chopped to approximately 10 cm in size, mixed and laid out in a natural drying environment as stated in the material section. For elemental analysis, 1 mm sized wastes need to be ground. In order to grind the samples, drying process was carried out in the laboratory of the Faculty of Forestry in the JSR brand JSOF-400T modeled oven device. The drying process was carried out at a temperature of 70^{o}C and over a period of 48 hours (Figure 61).

Figure 61. Sample dried at 70^{o}C for 48 hours in an oven

A secondary drying process was carried out to determine the moisture content of the used pruning waste. Here, mixed samples were taken separately from tree branches and leaves. Before drying, the samples were weighed with RADWAG brand PS4500.R2 model sensitive counter scale. 55,47 g of branch sample and 7,8 g of leaf sample were subjected to drying. These samples were dried in an oven at 105^{o}C for about one day.

To calculate the moisture ratio, the difference between the weight before drying (m_{first}) and the weight after drying (m_{last}) was divided by the weight after drying and multiplied by 100 for the percentage value. Accordingly, the moisture content (M%) formula was obtained as in equation (33) below (Yıldız and Topkoç, 2023).

$$M(\%) = \frac{m_{first} - m_{last}}{m_{last}} x100 \quad (33)$$

For elemental analysis, the samples were dried for 48 hours and ground using a LAVION brand HC-1500Y model grinding device in the laboratory of the Faculty of Forestry. The ground material was sieved with a 1 mm mesh sieve and made ready for elemental analysis, these processes were repeated 3 times and the average values were used in the calculation (Figure 62).


(a) (b)

(c)


(d) (e)

Figure 62. Grinding of waste samples for elemental analysis

After chopping, drying, grinding and sieving of the mixed samples taken from pruning wastes, the prepared sample was brought to suitable conditions for elemental analysis. Elemental analysis of the prepared sample was carried out in Van Yüzüncü Yıl University Science Application and Research Center Elemental Analysis Laboratory. The sample (sawdust) was read 3 times in the device. Thermo Scientific Flash 2000 CHNS/O Analyzers device was used during the analysis. Approximately 2,250 mg of sawdust sample was weighed for each repetition and analyzed in the elemental analysis device.

For the calculation of the higher heating value (HHV) of the biomass used in the thesis study, seven mathematical models given in Table 13 below using the results of elemental analysis of biomass or any fuel were used (Callejón-Ferre et al., 2011; Yin, 2011; García et al., 2014; Özyuğuran et al., 2018).

Table 13. Higher heating value estimates based on elemental analysis results (MJ/kg)

Model No	Equality
1	HHV = 0,3259C + 3,4597
2	HHV = -3,147 + 0,468C
3	HHV = 5,736 + 0,006C^2
4	HHV = -2,907 + 0,491C – 0,261H
5	HHV = -5,290 + 0,493C + 5,052H^{-1}
6	HHV = -3,440 + 0,517(C+N) – 0,433(H+N)
7	HHV = -3,393 + 0,507C – 0,341H + 0,067N

3. RESULTS AND DISCUSSIONS

ANG Botanical Garden's electrical energy needs are provided by ÇEDAŞ, which is a public enterprise in the region. There is an electricity subscription with 250 kW installed power and 150 kW demand factor. However, since the campus is far from the existing residential area, additional investments in the existing grid may be required in the future power increase, and even the provision by the supplier may pose a problem. For this reason, considering alternative situations, this study and analysis on wind, solar and biomass energy generation from plants/trees has been carried out in this study in order to set an example and applicability. In addition, comparisons were made with similar studies in the literature and recommendations were presented.

At Artvin Çoruh University, the energy subscription/consumption/monitoring works of the campuses are carried out by the Department of Construction and Technical Affairs. According to the data obtained from the relevant unit, the monthly and annual total energy consumption values of the ANG Botanical Garden for the last three years are organized in Table 14 below.

Table 14. ANG Botanical Garden electricity consumption values in the period of the years 2021-2022-2023

Electricity Consumption Values (kWh)			
	2021	**2022**	**2023**
January	6.276	6.494	6.624
February	6.257	5.957	6.166
March	7.908	6.514	7.343
April	3.804	4.293	6.378
May	5.397	4.278	6.756
June	2.906	3.734	6.568
July	2.634	3.510	6.944
August	2.731	5.566	6.324
September	3.056	6.071	5.294
October	4.379	5.937	5.622
November	6.702	5.618	8.103
December	8.810	6.127	8.787
Total	**60.860**	**64.099**	**80.909**

According to Table 14, the annual electrical energy use of the ANG Botanical Garden is gradually increasing. This increase is due to the establishment of new units in the campus and their energy needs. There are also new units planned to be established in the campus in the coming years. With the findings obtained within the scope of the thesis, it is aimed to meet this electrical energy need on-site and from renewable energy sources.

3.1. Wind Energy Potential

For electricity generation from wind energy to be efficient, it can be said that the average wind speed should be at least 5m/s considering the turbine characteristics of the companies producing wind turbines. For the production capacity of a wind turbine planned to be installed in a place, the hourly wind speeds for a year in that place should be known. Because wind speeds vary hourly, daily, monthly and seasonally. In the location where the wind turbine will be installed, wind speeds may vary according to landforms, altitude and temperature.

Using the 12-month period hourly wind speeds, shape(k) and scale(c) parameters were obtained for the Weibull distribution function. Accordingly, the curve equation of the wind turbine generating at variable wind speeds and the power calculation equation depending on the variable "v" Equation (32) were obtained. By calculating equation (32) in MATLAB program, the average power expression in Equation (34) was found.

$$P_{mean} = 8{,}2992x10^{-2} + 1{,}5546x10^{-3} = 0{,}0845 \text{ kW} \tag{34}$$

The instantaneous value of the average power that can be obtained from the turbine with a nominal power of 5 kW according to the wind speeds in the region was found to be 0,0845 kW. The reasons for this low value are that the turbine used should generate power at a minimum wind speed of 3 m/s and the hourly wind speeds in the region are generally less than 3 m/s.

Capacity factor calculation of the wind selected wind turbine:

In order to obtain the planned electrical energy from wind energy in any region, the average turbine power is calculated with the probability density function, using the hourly data of the wind speeds in that region, according to the selected wind turbine speed/power output values. The capacity factor is the ratio of the average power that the turbine can produce to the nominal power of the turbine, depending on the wind speeds in the area where the wind turbine will be installed equation (26). Accordingly, the capacity factor value is showed in the equation (35):

$$CF = \frac{P_{mean}}{P_n} = \frac{0{,}0845}{5} = 0{,}0169 \quad \Rightarrow \quad \%CF = 1{,}69\% \tag{35}$$

The nominal power labelled value of the wind turbine used in the study is 5 kW. The power value of 0,0845 kW is calculated according to the average wind speed calculated with the Weibull distribution function of the wind speeds measured at the location where the wind turbine is installed. In this case, the capacity factor is found as 0,0169 from the ratio of the two values. According to the percentage calculation, 1,69% is a very low value, even below 10%.

The calculated capacity factor value for wind energy for the sample wind turbine is a very small value. In this case, generating electricity from wind energy in the region will not be an appropriate method considering the investment costs. To calculate the energy that can be obtained in one year from the calculated turbine power, the founded power value is multiplied by the value of 8760 hours (24hoursx365). Since the annual generated energy value is founded in a value of 740,22 kWh. If we consider the hourly average power of a small house as 1 kW (for example, only refrigerator operation), the energy it needs in a year is 8760 kWh. The calculated energy is at a level that cannot meet even 10% of this value. The ratio of the energy that can be produced with a wind turbine to the energy required for the annual energy need of a small house with an installed power of 1 kW is only 8,45%. Therefore, the wind potential of the region is not a suitable solution for energy production.

In 2019, in a similar study conducted for Artvin Çoruh University Seyitler campus (Aydın, 2019), it was concluded that Artvin province is not at a sufficient level in terms of wind energy potential. In this study, wind speed data were obtained from the meteorology directorate. The real and net energy equivalent of wind energy will only be possible if wind speed measurements are measured hourly for at least one year in the planned area and calculations are made accordingly.

In a master's thesis titled "Renewable Energy Use in Public Buildings: The Case of Çanakkale 112 Emergency Call Center" in 2021 (Baydar, 2021), a study was conducted on meeting the energy needs of Çanakkale 112 Emergency Call Center from renewable energy sources. In this study, solar energy and wind energy potential calculations were made. Wind energy was not deemed suitable for this region. In the case of inappropriateness here, the factor of decreasing wind power and speed due to the fact that the building is located in residential areas comes to the fore. This is due to the decreased wind power caused by the blockage of the buildings in the neighborhood and the disturbance of the people living in this area by the sound of the turbines as they rotate. Another situation is that the installation of high wind turbine towers is not suitable due to the location of the campus near the airport. Since the ANG botanical garden is far from the settlement, there is no environmental factor in the installation of wind turbines as in the example. On the contrary, with the necessary measurements, several wind turbines to be installed in various parts of the campus will add a different visual beauty in the campus landscape.

Wind energy utilization and applications have been on an increasing trend since the 2000s. The installed capacity of wind energy in the world is 10-15%. In Türkiye, 11% levels have been reached by 2023. There are many small-scale sample applications in public and private buildings. However, even the installation cost of a small 10 kW turbine with other equipment can exceed 15.000 dollars. Therefore, it would be more appropriate to plan and project wind energy as a hybrid system.

3.2. Solar Energy Potential

Photovoltaic systems have been considered to generate electrical energy from solar energy in the ANG Botanical Garden. In photovoltaic systems, DC electrical energy is obtained from solar panels. A project analysis was made in this direction due to its ease of installation and operation, being more economical and conventional compared to other solar energy systems.

During the installation-project phase of the ANG Botanical Garden, there is an area designated to meet the energy needs of the campus by obtaining solar energy from photovoltaic systems. This area is approximately 1400 m^2 (Figure 48). The area adjacent to this area (approximately 1200 m^2), which is considered as a parking lot (Figure 49) in the project, was added to this study and system designs were made for both areas. The system was designed in 3D in PVSOL simulation program. The design project obtained from the simulation program was calculated in the results section of the program and a report output was obtained. The 3D view of the project in the result report is shown in Figure 63. Technical information of the project is presented in Table 15.

Figure 63. PV system project 3D overview

Table 15. 3D grid connected PV system technical information

Climate Data	Salkımlı, TUR (1991-2010)	
PV Generator Output	210,8	kWp
PV Generator Surface	1.052,9	m²
Number of PV Modules	527	
Number of Inverters	3	

In the PVSOL program, the system design project was obtained by adjusting the conditions of the place where the PV system will be installed in the most realistic conditions possible. With the installation of the selected PV panels in the determined areas, a total surface area of 1.052,9 m^2 PV panels were installed. The installed power was found to be 210,8 kW. 527 PV panels were used and 3 inverters were connected to the grid. The efficiency and financial analysis values of the system are given in Table 16 and Table 17 taken from the results page of the program.

Table 16. 3D grid connected PV system's yield table.

PV Generator Energy (AC grid)	256.900	kWh
Grid Feed-in	256.900	kWh
Down-regulation at Feed-in Point	0	kWh
Own Power Consumption	0,0	%
Solar Fraction	0,0	%
Spec. Annual Yield	1.218,34	kWh/kWp
Performance Ratio (PR)	81,5	%
Yield Reduction due to Shading	6,6	%/Year
CO_2 Emissions avoided	123.534	kg / year

Table 17. 3D grid connected PV system gain status and financial analysis

Total investment costs	3.840.986,80	₺
Return on Assets	41,80	%
Amortization Period	8,8	Years
Electricity Production Costs	5,24	₺/kWh
Energy Balance/Feed-in Concept	Full Feed-in	

According to the results in Table 16, the amount of energy loss in the PV system is calculated as 256.900 kWh per year. The annual energy production of the PV system under the specified and adjusted conditions is 1.218.340 kWh and the system performance is 81,5%. The annual efficiency reduction due to shading is 6,6% and the annual CO_2 emission value reduced and avoided is 123,5 tons.

The total cost of the project was calculated by the program according to the unit prices entered and found to be 3.840.986,80 TL (700USD/kW) (Table 17). The system's rate of return on assets is 41,8% and the amortization period is 8,8 years. 1 kWh energy production cost is 5,24 TL. A detailed analysis showing the investment and profit status of the system after energy production according to the selected 25-year investment period is given in Table 18, Accordingly, at the end of the first year, the production cost was deducted according to the investment cost of the system and a profit was started to be made as of the ninth year from the initial value of -3.348.633,23

TL. As of the 25th and 26th years, the increase in production and profitability by deducting only operating expenses can be seen from the cash flow graph in Figure 64.

Table 18. Cash flow table of the PV system project in the 25 years period in details

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Investments	-₺3.840.986,80	₺0,00	₺0,00	₺0,00	₺0,00
Operating costs	-₺57.759,20	-₺43.427,97	-₺32.652,61	-₺24.550,83	-₺18.459,27
Feed-in / Export Tariff	₺550.112,77	₺630.483,15	₺562.211,61	₺503.209,65	₺451.851,55
Annual Cash Flow	**-₺3.348.633,23**	**₺587.055,18**	**₺529.559,00**	**₺478.658,82**	**₺433.392,28**
Accrued Cash Flow (Cash Balance)	-₺3.348.633,23	-₺2.761.578,05	-₺2.232.019,05	-₺1.753.360,23	-₺1.319.967,96
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Investments	₺0,00	₺0,00	₺0,00	₺0,00	₺0,00
Operating costs	-₺13.879,15	-₺10.435,45	-₺7.846,21	-₺5.899,40	-₺4.435,64
Feed-in / Export Tariff	₺406.853,97	₺367.196,95	₺332.063,82	₺300.795,42	₺272.855,21
Annual Cash Flow	**₺392.974,81**	**₺356.761,49**	**₺324.217,61**	**₺294.896,02**	**₺268.419,57**
Accrued Cash Flow (Cash Balance)	-₺926.993,14	-₺570.231,65	-₺246.014,04	₺48.881,98	₺317.301,56
	Year 11	**Year 12**	**Year 13**	**Year 14**	**Year 15**

Investments	₺0,00	₺0,00	₺0,00	₺0,00	₺0,00
Operating costs	-₺3.335,07	-₺2.507,57	-₺1.885,39	-₺1.417,59	-₺1.065,86
Feed-in / Export Tariff	₺247.802,59	₺225.272,48	₺204.959,60	₺186.606,43	₺169.993,80
Annual Cash Flow	**₺244.467,53**	**₺222.764,91**	**₺203.074,21**	**₺185.188,84**	**₺168.927,95**
Accrued Cash Flow (Cash Balance)	₺561.769,08	₺784.533,99	₺987.608,20	₺1.172.797,04	₺1.341.724,98
	Year 16	**Year 17**	**Year 18**	**Year 19**	**Year 20**
Investments	₺0,00	₺0,00	₺0,00	₺0,00	₺0,00
Operating costs	-₺801,39	-₺602,55	-₺453,05	-₺340,64	-₺256,12
Feed-in / Export Tariff	₺154.933,69	₺141.263,49	₺128.841,60	₺117.543,93	₺107.261,02
Annual Cash Flow	**₺154.132,29**	**₺140.660,93**	**₺128.388,56**	**₺117.203,29**	**₺107.004,91**
Accrued Cash Flow (Cash Balance)	₺1.495.857,28	₺1.636.518,21	₺1.764.906,77	₺1.882.110,05	₺1.989.114,96
	Year 21	**Year 22**	**Year 23**	**Year 24**	**Year 25**
Investments	₺0,00	₺0,00	₺0,00	₺0,00	₺0,00
Operating costs	-₺192,57	-₺144,79	-₺108,86	-₺81,85	-₺61,54
Feed-in / Export Tariff	₺97.895,92	₺89.362,29	₺81.582,95	₺74.488,72	₺68.017,32
Annual Cash Flow	**₺97.703,35**	**₺89.217,50**	**₺81.474,09**	**₺74.406,86**	**₺67.955,78**
Accrued Cash Flow (Cash Balance)	₺2.086.818,32	₺2.176.035,81	₺2.257.509,91	₺2.331.916,77	₺2.399.872,55
	Year 26				

Investments	₺0,00
Operating costs	-₺46,27
Feed-in / Export Tariff	₺29.725,79
Annual Cash Flow	**₺29.679,52**
Accrued Cash Flow (Cash Balance)	₺2.429.552,07

Degradation and inflation rates are applied on a monthly basis over the entire observation period. This is done in the first year.

The economic and numerical data of the PV project results prepared in PVSOL simulation program for ANG Botanical Garden are given in this section. Other technical information not given here in the presentation file provided by the program is given in APPENDIX-2.

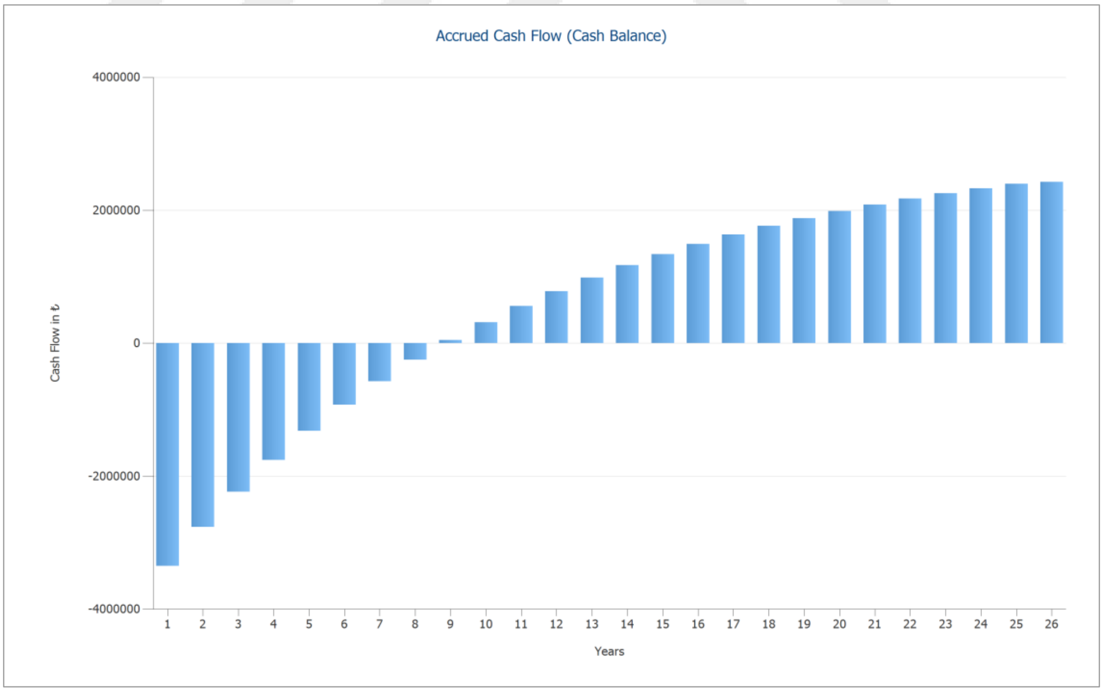


Figure 64. Cash flow curve graphic of the system

ANG Botanical Garden meets its electrical energy needs with 250 kW installed power and 150 kW contract power. In the current situation, all of this contract power is not yet fully utilized. This is because the campus project is still ongoing and there are areas/units that are not operational. New comprehensive units are planned to be established in the future. Therefore, the energy need and utilization rate will also increase.

The installed power of the solar energy project prepared for the ANG Botanical Garden within the scope of this thesis is 210,8 kW and the annual net energy production amount is 1.218.340 kWh. In the current situation, this installed power and production amount is capable of meeting the energy needs of the campus. Since the system is a grid-connected storage-free system, excess energy will be given to the grid during production and energy will be purchased from the grid when there is no production (no daylight). When the subscription is made in the form of mutual offsetting, it is a system that gives/sells energy to the grid according to the total production amount of the system.

Table 14 shows that the ANG Botanical Garden consumed 60.680 kWh of electricity in 2021, 64.099 kWh in 2022 and 80.909 kWh in 2023. It is seen that there is an increasing energy demand. The designed solar energy system has the capacity to meet this need with an annual production capacity of 1.218.340 kWh.

The installed capacity of solar energy in the world has reached 1.000.000 MW today. This development accelerated as of 2010. In Türkiye, the installed capacity of 12.000 MW has been reached by the end of 2023 by showing development as of 2010. Türkiye ranks 15th among the world countries in solar energy installed capacity.

Until the 2010s, solar energy was widely used in applications other than electricity generation. Today, there are examples of all uses of solar energy worldwide. Researches and studies in the literature emphasize the importance of the use of solar energy. In Türkiye, there are many studies and applications on solar energy and renewable energy in the relevant departments of universities. In public buildings, systems that will pay for themselves between 5-10 years on average are designed with campus-based or building-based projects. With the widespread use of solar energy, solar energy systems are also becoming widespread and system unit costs are becoming accessible and applicable.

3.3. Biomass Energy Potential

To utilise renewable energy in the ANG Botanical Garden, the biomass energy potential of pruning wastes of fruiting/non-fruiting trees and shrubs in the botanical garden was also determined. In the botanical garden, pruning wastes of plant origin are generated annually around 3.500 kg on average and up to 5.000 kg depending on the annual situation. These wastes will increase in the following years in direct proportion to the growth and volume increase of the plants. The analysis of the sample prepared for elemental analysis from the biomass to be used within the scope of the study was carried out in the Thermo Scientific Flash 2000 CHNS/O Analyser device with 3 repetitions. Samples weighing 2,335 g, 2,227 g and 2,184 g were analyzed respectively. As a result of the analysis, the C, H, N, O and S ratios of each sample are detailed in Table 19 below. The amount of oxygen was found by subtracting the sum of the other elements from 100. Each analysis was repeated at least three times and the results were averaged.

Table 19. Results of elemental analysis of ANG Botanical garden pruning waste

	Analysis 1	**Analysis 2**	**Analysis 3**	**Average**
Sample weight (g)	2,34	2,23	2,18	2,25
C (%)	45,85	45,46	45,59	45,63
H (%)	5,88	5,83	5,79	5,83
N (%)	2,25	2,14	2,01	2,13
S (%)	0,00	0,00	0,00	0,00
O (%)	46,01	46,58	46,61	46,40
C/N	20,35	21,28	22,64	21,42

Carbon (C), hydrogen (H) and oxygen (O) are the elements of biomass that make up the components of the organic part of the fuel. Carbon is the most important contributor to combustion. In general, among the wastes that make up biomass wastes, woody biomass has a carbon content of 47% and mixed biomass has a carbon content of 46-47%. Agricultural biomass has a lower carbon content of 45% (Harun and Afzal, 2016). As can be seen from Table 19, the carbon content of the mixture of various woody pruning wastes used in this study is close to 46%. Accordingly, it can be said that it would be more convenient to use the mixture in incineration.

In order to determine the moisture content of the waste, 55,47 g of branch sample and 7,8 g of leaf sample were dried in an oven at 105^{o}C for about one day. After drying, 42,26 g for the branch sample and 6,8 g for the leaf sample were weighed. Using these values according to Equation (33), the moisture content of the waste was found from the following equations (Equations 36-37).

$$M(\%) = \frac{55,47-42,26}{42,26} x100 = 31,25\% \quad \text{(Moisture content of tree branches)} \qquad (36)$$

$$M(\%) = \frac{7,8-6,8}{6,8} x100 = 14,7\% \quad \text{(Moisture content of tree leaves)} \qquad (37)$$

The moisture value of the tree branches obtained in equation (36) was higher than expected. This is due to the fact that the pruned trees are alive and the old branches are cut for rejuvenation. In incineration, the moisture content of the waste should generally be below 30%. Ideally, the moisture content should be between 15-25%, as this range provides a favorable balance for the incineration process and improves energy efficiency. With longer periods of natural drying, the moisture content will decrease.

The models and equations to be used for HHV of biomass are given in Table 13. The equations in Table 13 give the HHV values in units of MJ/kg by multiplying the percentages of the elemental contents of the elemental analyzed waste or biomass by some coefficients. In Table 13, 7 different calculation equations are given. Elemental analysis of the sample used in the study was performed 3 times. Table 20 was obtained by substituting the element ratios in Table 19 into the equations in Table 13.

Table 20. Higher heating values of the samples

Samples	**HHV Mathematics Models (MJ/kg)**						
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Analysis 1	18,4024	18,3111	18,3497	18,0702	18,1732	17,9074	17,9986
Analysis 2	18,2744	18,1272	18,1344	17,8909	17,9883	17,7182	17,8106
Analysis 3	18,3175	18,1891	18,2067	17,9669	18,0584	17,7918	17,8814
Average	18,3314	18,2092	18,2301	17,976	18,0721	17,8052	17,8961

ANG Botanical garden generates around 3.500-5.000 kg of biomass waste (tree pruning waste) annually. According to the samples taken, elemental analysis and the results of the HHV mathematical model used in the calculation, it can be said that the average HHV value is 18 MJ/kg. Considering that 5.000 kg of waste is generated annually, the energy equivalent of the incineration of this waste is 90.000 MJ (18*5.000). The electrical energy (1 kWh = 3,6 MJ) equivalent of the calculated energy value corresponds to 25.000 kWh. This value is a value that can meet one year's energy in a section that requires heat energy in the botanical garden. Another alternative is to burn this waste to generate electricity with a small thermal steam turbine generator. Electrical efficiency in thermal power plants is around 40%. Accordingly, 10.000 kWh of electrical energy can be obtained annually from 25.000 kWh of energy. Waste heat energy can also be utilized as heat energy in the campus.

The value of landfill gas potential generated in landfills for the population within the municipal boundaries in Türkiye is 0,97 billion m^3/year. The lower heating value of this gas is 19-23 MJ/m^3 (5,27–6,38 kWh/m^3). Based on the calculation of 17,20 MJ/m^3 (4,77 kWh/m^3), the energy equivalent is accepted as approximately 5 kWh/m^3 (Özcan et al., 2011; Veneziani, 2011).

The number of lunches eaten in all cafeterias of Artvin Çoruh University was taken as an example for the spring semester of the 2023-2024 academic year. A total of 143.378 lunches were eaten in one semester. Taking Borçka Acarlar Vocational School as an example, the amount of food waste for a week was obtained. According to the calculations, it was determined that 54.016,47 liters and 27.008,235 kg of food waste is generated annually. When food waste is stored and utilized without mixing with other municipal wastes, the energy equivalent will be higher due to its high organic matter content. Accordingly, the energy equivalent of food waste can be accepted as 5-10 kWh/m^3. Since 1 m^3 = 1000 liters, approximately 55 m^3 of food waste is generated from Artvin Çoruh University dining halls in a year. In this case, the annual energy equivalent of cafeteria waste will be in the range of 275-550 kWh.

Biomass resources can be categorized under four main headings: Agricultural biomass resources, Biomass resources obtained from forest and forest products, Animal biomass resources, Biomass resources obtained from urban and industrial wastes

(URL-18). Today, the installed capacity of biomass energy in Türkiye is close to 2.500 MW. This corresponds to a ratio of 2,5%. The majority of the registered biomass power plants are established by the waste management practices of metropolitan municipalities. Others are located in provinces with agricultural and industrial production.

Biomass is everywhere where there is life and consumption. However, the processing and conversion of biomass into energy has not yet reached an accessible and feasible level in the world and in Türkiye. Countries with good economies in the world and similarly in Türkiye, metropolitan municipalities and provinces with large industries are implementing energy production from biomass. Small-scale waste management systems for recyclable waste are found in all regions. After the recyclable wastes are separated, the other wastes are stored in landfills. These wastes are incinerated for disposal without energy generation. In small-scale agricultural and animal husbandry enterprises, animal waste is directly used as fertilizer on agricultural land.

There are many studies in the literature on the utilization of agricultural, industrial, forest-based and urban wastes and obtaining energy from waste. In these studies, waste quantities and energy equivalents for the sampled waste source are calculated on an annual basis. Generally, it is seen that wastes are separated according to their types and evaluated separately. The heating values calculated according to the results of elemental analysis in solid wastes are directly proportional to the amount of carbon. It is recommended to generate energy by incineration for solid wastes. The heat energy equivalent calculated according to the amount of solid wastes is found and alternatives are offered either to be used directly in the need for heat energy or to produce electrical energy from this heat energy with 40-50% efficiency. Landfill gas can also be obtained from landfill wastes stored in landfill collection areas. Biogas production by anaerobic digestion is proposed for liquid wastes of animal, urban and industrial origin. This biogas is converted into electricity and heat energy with a total efficiency of 65-75% in gas engine cogeneration systems.

In the world and in Türkiye, there are enterprises, public buildings, housing estates and factories that directly use natural gas for electricity and heat energy. Here, natural gas is used directly as fuel in gas engine (cogeneration) systems. Enterprises with wastes required for biogas production use the same system by producing biogas. The waste remaining after biogas production can be used as fertilizer in agricultural areas.

Within the scope of the thesis, the pruning wastes of mixed fruiting and non-fruiting trees in the ANG Botanical Garden were analyzed and energy values were extracted. According to the findings obtained, it was deemed appropriate that heat energy can be obtained by incineration. In addition, the annual amount of food waste generated after lunch in all cafeterias of Artvin Çoruh University was calculated and approximate energy values were obtained according to the literature.

4. CONCLUSION AND SUGGESTIONS

The aim of this thesis is to investigate the possibility of meeting the electrical energy needs of Artvin Çoruh University ANG Botanical Garden with local facilities. In this context, renewable energy sources such as wind energy, solar energy and biomass energy where garden pruning residues will be utilized are discussed. The energy data that can be obtained from each source is presented and the usability of these data in the campus is discussed in line with the energy needs of the campus. In this chapter, the applicability of the renewable resources studied within the scope of the thesis in the ANG Botanical Garden and recommendations are presented.

4.1. Wind Energy Potential

In order to calculate the energy production values of wind turbines correctly and to make the most appropriate turbine installation, at least one year and 8760 hours (365x24) measurements are usually made. 8760 wind speeds are entered into MATLAB program with developed mathematical functions and average wind speed is calculated with special commands. The value of the energy to be produced is calculated by replacing the wind speed found in the power and production equations depending on the wind speed. Under Türkiye's conditions, according to ETKB sources, wind speed should be at least 7.5 m/s in order to obtain MW power in large power wind power plants. For this purpose, a potential wind energy map (PWEM) has been created by ETKB according to regions, provinces and districts. In the catalogs of small power (0-500 kW) wind turbines, power output can be obtained from the turbines at wind speeds of 3 m/s and above.

In the thesis, a wind turbine with a power of 5 kW was selected for the study area and power and energy calculations were made according to the wind speeds provided (wind speeds measured at the Meteorological station in Artvin City Center). For real values, an anemometer that has been previously installed and measured for a year should be installed at the point where the turbine will be installed. Since this situation cannot be provided with the existing facilities, calculations were made with the available data and recommendations and estimates were made accordingly. Accordingly, the works, results and recommendations according to the selected wind turbine and wind speeds used are presented in items.

- A 5 kW SoyutWind 5 kW model wind turbine was used in the study, and the power curve equation was created according to the catalog values of this wind turbine. According to the catalog value, this wind turbine gives nominal power output at a speed of 3 m/s.
- When the wind speeds obtained and used are examined in general, almost all speed values are lower than 3 m/s. In fact, in 8760 hours of annual measurements, there are nearly 1000 hours of unmeasured values of 0 m/s. For this reason, speed values of 0 m/s and above are included in the calculation.
- For the calculation of the average wind speed, the Weibull distribution function, which is the most widely used and most accurate in the literature and studies, was used. The coefficients of the shape and scale parameters for the power equation depending on the average wind speed in the Weibull distribution function were obtained with MATLAB program. After finding the wind power equation, the hourly average power value of the wind turbine was calculated together with the power curve equation.
- The average power value of the wind turbine was found to be 0,0845 kW. For the 5 kW nominal power turbine, the capacity factor was 1,69% due to this low value.
- 0,0845 kW is a value that can meet the needs of a small electrical device with a value of only 84,5 watts (e.g. a simple lighting armature). Considering a small

security cabin that consumes an average of 1 kWh of electrical energy per hour, the calculated power value is not even equivalent to 10% of this consumption.

- According to ETKB PWEM map and Artvin province Meteorology station wind speed data, it is not technically and economically feasible to generate electricity by installing wind turbines in Artvin province. However, considering the location of the campus where the ANG botanical garden is located, it is thought that there is sufficient wind power. There are no factors that reduce wind speed due to the altitude of the settlement and the openness of the surrounding area. The geographical features facing the Çoruh River valley, facing south, with warm temperature values due to the dams are also conditions that have a positive effect on wind speed. For this reason, wind turbines can be considered to be installed in the area by making measurements in this regard in the future.
- In the literature, there are studies on the production of electricity from wind turbines and meeting the electricity energy for the places shown as an example. In these studies, since the region / settlement sampled for energy needs is not suitable for wind turbine installation, areas away from residential areas are determined and the energy produced here is given to the national transmission / distribution line and subscription projects are proposed according to production / consumption values.
- ANG Botanical garden is located away from the residential area. Due to its location, there are no factors that would prevent the installation of wind turbines. The geographical location is also favorable for sufficient wind speed. Since wind turbines can be installed within the campus, there will be no additional energy transportation line costs. Generation of renewable energy from wind and its use in the botanical garden will create a positive awareness for visitors by visually exhibiting it.
- ANG Botanical Garden's energy needs are currently supplied by the national distribution company. There is a 250 kW installed power and a corporate electricity subscription with a demand factor of 150 kW. The energy need of the campus is gradually increasing with the newly established units. Total energy consumption in 2023 is 80.909 kWh. It has increased by 25% compared

to the previous year. According to these values, the average hourly consumption in 2023 is 10 kWh. However, there are new units under construction in the campus and new projects planned for the coming years.

- The wind energy power proposed to be installed can be at a maximum of 5-10 kW according to the conditions of Artvin and the campus. The investment cost of this will be around 15.000 USD on average according to data from the internet. The installation of wind energy alone is not technically and economically feasible. However, it can be a suitable investment with the joint use of other equipment such as regulation, storage and installation with other renewable energy generation facilities.

4.2. Solar Energy Potential

Solar energy is the miraculous basic source that provides the formation and continuity of all the resources needed for the life of living things on earth. The natural use of solar energy in daily life can be said to be heat and light energy, and the ability to grow food products by creating moisture and mineral balance in the soil. The electrical energy that can be produced from the energy coming from the sun on the Earth is 60.000 times more than the entire world's electrical energy needs. It is not possible in today's conditions to convert all this potential energy of the sun into other energy sources and electrical energy.

The use of solar energy by converting it into electrical energy consists of small-scale uses that were not very common until 15-25 years ago. Other areas of use are still continuing from the past to the present. The common, traditional and conventional usage area consists of systems installed for hot water supply in houses and buildings. Electric energy generation from solar energy is done in two ways. The first is photovoltaic technology and the second is thermal solar technology. Photovoltaic technology is widely used today. In photovoltaic technology, the conversion of solar energy into electrical energy is achieved through special solar panels that receive sunlight. These panels are placed in selected areas in a way and at an angle to maximize the use of sunlight.

In the ANG Botanical Garden installation project, there is an area for the installation of solar panels. It was planned to install solar panels in this area to generate electricity and use it for the needs of the campus. However, it could not be put into operation. Within the scope of the thesis, a project design was carried out both for this area and for a second area adjacent to this area, which was considered as a parking lot. This project was prepared using simulation programs used in the design of PV projects today. Among the simulation programs used, the PVSOL program, which is closer to reality, where three-dimensional design is made, was preferred. The results, findings and recommendations of the solar energy project prepared in the PVSOL simulation program are listed below.

- The area designated for photovoltaic panels in the ANG Botanical garden project is approximately 1400 m^2. In the study, a system was designed for an area of 1200 m^2 adjacent to this area and considered as a parking lot. According to the designed system, a system with a power of 210,8 kW was created using a total of 527 PV panels.

- The annual energy production value of the PV system is (700 USD/kW) 1.218.340 kWh. The annual energy loss value of the system is 256,900 kWh. When this loss value is deducted, approximately 1.000.000 kWh of energy is produced. When compared to the consumption values of the ANG Botanical Garden in recent years, there is a consumption corresponding to only 10% of this production value.

- Solar energy gives energy output in the panels depending on the sunshine duration. During the dark hours of the night, there is no production. Due to this situation and the higher investment and operating costs of storage systems, PV systems are mostly planned as grid-connected systems. The project designed for ANG Botanical Garden is also a grid-connected storage-free system. The generated energy will be produced during daytime hours to meet the needs of the campus, and the excess will be given to the national distribution grid. At night, since there is no production in the PV panel, the energy need will be met from the grid.

- In grid-connected systems, production and consumption values are compared with the distribution company and income is obtained on the side where energy production is more by mutual offsetting. According to the results of the project, the system covers its investment cost in 8,8 years. From this period onwards, there will be a period of income generation for AÇU and ANG Botanical Garden. Another evaluation is to calculate the sum of the energy consumption values of all the campuses of AÇU and to invoice according to the consumption value in return for the energy produced with the protocol signed with the energy distribution company.

- When the general annual utilization is evaluated in the production of electrical energy with the PV system, the times when the production is high and the times when the need is high are opposite to each other. For example, while the need for electrical energy in the winter months is high due to the need for heating and lighting due to the short daylight hours, the production of electrical energy in the PV system is low since the sunlight shows itself for less time compared to this situation. For this reason, it is recommended that the designed system should be grid connected. According to the production data and consumption values obtained, the energy need of the campus can be met by the grid-connected PV system alone. However, considering that the grid capacity may be insufficient in the region, it would be beneficial to establish alternative backup systems.

- Other renewable energy sources planned within the scope of the thesis for the energy needs of ANG Botanical Garden are wind energy and the project of extracting the energy equivalent of plant/tree wastes. A study was also carried out for the food waste of all cafeterias of the university on energy production from waste. Since there is no real wind energy data for wind energy, the production capacity was calculated at very low values with the wind data of Artvin province. Accordingly, the installation of a wind turbine is not economically feasible. Considering the geographical conditions of the campus, it is seen that it has favorable conditions for wind energy. If real measurements are made, it is thought that the energy to be produced from the wind turbine will be efficient enough. The wind turbine can be installed together with the PV system and designed as a hybrid system supporting the PV system. The economic recycling of the system will be at acceptable levels if it is installed together with the PV system. Electric energy cannot be produced directly from the energy of wastes. Heat energy is produced by incineration, landfill gas in landfills and biogas by anaerobic digestion. The amount of waste included in the study is not sufficient to amortize the intermediate system investment costs for electricity generation.

4.3. Biomass Energy Potential

Biomass is defined as the layer formed after the use of resources that are offered to the service of humans and other living things for the continuity of life on earth. In nature, resources can be used directly by living beings and other resources useful for humanity are obtained from these resources through certain production methods. The parts of resources that cannot be used during production and after consumption are thrown into nature. The main biomass resources consist of agricultural and animal resources, forest and forest industry biomass resources, industrial biomass resources and municipal/urban waste resources. Recyclable wastes are included in municipal/urban waste sources and facilities/systems are established by local governments and municipalities for their recovery.

After separating recyclable wastes, waste-to-energy production methods have been developed for the other parts. For example, forest and forest industry wastes are either directly burned or pellets are produced from them and used as stove and heating fuel. Thus, they are converted into heat energy and benefit is provided. Biopellets with low thermal value can also be produced from agricultural wastes or biofuels can be obtained directly from some plants. Biogas can be produced from animal wastes and domestic/urban wastes. Landfill gas can also be produced in landfills.

Biomass is directly produced wherever there is human and life activity. More and diverse sources of biomass waste are generated in human settlements such as hospitals, business centers, large workplaces, schools, universities, and in large places such as factories where any production is carried out. Energy production from biomass or waste requires intermediate conversion or production systems. For this reason, it is generally not applied in institutions such as schools and universities due to technical and economic conditions. The studies in the literature are studies that measure the amount of biomass formed in a selected area, calculate the total energy values that can be produced from this biomass and present recommendations. The AÇU and ANG Botanical Garden, which were selected as the study area in the thesis, consist of settlements where potential biomass is formed, as in these examples. In line with the aim of the thesis, wind and solar energy systems were first considered for the electrical energy needs of the ANG Botanical Garden and projects were created for them. As a third study, the biomass generated by the pruning wastes of the fruiting/non-fruiting trees in the Botanical Garden was analyzed and findings were obtained for its use as an energy source. Again, the annual value of the amount of food waste generated in all cafeterias of AÇU was obtained and an approximate energy estimate was made for this according to the literature. According to the findings of the study, conclusions and recommendations are as follows.

- A mixed biomass of fig, apple, pomegranate, peach, walnut, black berry, rose, willow, acacia, thuja and firethorn shoots (from all fruiting and non-fruiting trees on the campus) was collected from the ANG Botanical Garden prior to the general pruning in the fall of 2023, filling a bag of approximately 0,5 m^3. This pruning is carried out every year and an estimated 3500 kg of waste was estimated based on approximate information on the average volume and mass of pruning waste generated in previous years. Since the trees will grow further and new trees will be grown over the years, energy analysis and calculations were made for an average of 5000 kg of pruning waste.

- For moisture content determination of biomass, branches and leaves were evaluated separately. The moisture content of the tree branches was found to be 31,25% and the moisture content of the leaves was found to be 14,7%. The moisture content of the branches was high. This is due to the fact that the pruned trees were alive and old branches were cut for rejuvenation. Longer periods of natural drying will reduce the moisture content.

- Elemental analysis was performed to find the energy values of the biomass sample. Elemental analysis was performed in three replicates. Looking at the carbon ratios of all repeated samples, an average carbon ratio close to 46% was obtained. According to the literature, carbon content is the most important element that determines the amount of energy after incineration. Compared to similar biomass studies, the carbon ratio of the sample is high. Accordingly, it is recommended to obtain energy by incinerating these biomass wastes.

- For biomass HHV calculation, seven mathematical models "*using elemental analysis results of biomass or any fuel*" were used in the literature. HHV calculation was made in seven different models according to the elemental ratios of all samples. According to this, it can be said that the HHV value of the biomass subject of the study is 18 MJ/kg. Considering a total of 5000 kg of biomass, this corresponds to 90.000 MJ of heat energy. 90.000 MJ equivalent corresponds to 25.000 kWh. When this heat energy is used in a thermal steam power plant, it can produce 10.000 kWh of electrical energy with 40% efficiency. 10.000 kWh corresponds to the current electricity consumption of the ANG botanical garden for only 1-2 months. It is not economical to use this resource to generate electrical energy as the system installation requires additional investments in steam boiler, steam turbine and generator. Accordingly, it is more appropriate to incinerate the biomass and use it where heat energy is required.
- The value of 5-10 kWh/m^3 in the literature is taken as a basis for the energy equivalent of food waste, which is calculated according to the number of meals eaten in the cafeterias of AÇU in a year. Approximately 55 m^3 of food waste is generated in a year. Accordingly, the annual energy equivalent of cafeteria waste is in the range of 275-550 kWh. This value is equivalent to the energy equivalent of a small faculty building with only around 1000 students at AÇU. Considering the collection and processing of waste and the installation of systems, there is no economic feasibility.

In this study on meeting the energy needs of the ANG Botanical Garden of AÇU from renewable energy sources, projects were developed and calculations were made for solar energy, wind energy and biomass energy. Energy production from solar energy is capable of producing enough energy both for the ANG Botanical Garden and for all units of the AÇU. Energy production from wind energy alone is not technically and economically feasible. When installed together with solar energy, wind energy installation will also be appropriate when solar energy systems are calculated together to support the system when solar energy is not available and the investment recovery is calculated together with solar energy systems. For biomass energy, the pruning waste of trees in the ANG Botanical garden is taken as an example. According to the energy value of this biomass, it would be appropriate to incinerate it and use it where heat energy is required. It may be suggested that food waste should be analyzed with more real values and used in biogas production by anaerobic digestion in a mixture with lawn mowing waste from all campuses. The biogas obtained can be used for electricity and heat energy production with the existing natural gas subscription by planning a cogeneration system in the ANG Botanical Garden.

APPENDICES

APPENDIX-1. Commands and results for integral calculation of wind energy in MATLAB

1st step integral calculation

$$\int_{3}^{10} (2{,}041.10^{-5}.v^{6} - 0{,}0006953.v^{5} + 0{,}006779.v^{4} - 0{,}007173.v^{3} - 0{,}1083.v^{2} + 0{,}4223.v - 0{,}337).\left(0{,}6481\left(\frac{v}{2{,}0067}\right)^{0{,}3006}.e^{-\left(\frac{v}{2{,}0067}\right)^{1{,}3006}}\right)dv$$

```
>> syms x

>> y=(((2.041*10^-5)*x^6)-(0.0006953*x^5)+(0.006779*x^4)-
(0.007173*x^3)-(0.1083*x^2)+(0.4223*x)-
0.337)*((0.6481*(x/2.0067)^0.3006)*exp(-(x/2.0067)^1.3006))

y =

-(6481*exp(-
((10000*x)/20067)^(6503/5000))*((10000*x)/20067)^(1503/5000)*(-
(3011984372355295*x^6)/147573952589676412928 +
(3206505288612563*x^5)/4611686018427387904 -
(976956859966227*x^4)/144115188075855872 +
(8269905952544913*x^3)/1152921504606846976 + (1083*x^2)/10000 -
(4223*x)/10000 + 337/1000))/10000

>> int(y,x,3,10)

…………………………………….

ans =

  8.2992e-02
```

2nd step integral calculation

$$+5.\int_{10}^{24}\left(0{,}6481\left(\frac{v}{2{,}0067}\right)^{0{,}3006}.e^{-\left(\frac{v}{2{,}0067}\right)^{1{,}3006}}\right)dv$$

```
>> syms x
>> y=5*((0.6481*(x/2.0067)^0.3006)*exp(-(x/2.0067)^1.3006))
y =
(6481*exp(-
((10000*x)/20067)^(6503/5000))*((10000*x)/20067)^(1503/5000))/2000
>> int(y,x,10,24)
…………………….

ans =

   1.5546e-03
```

APPENDIX-2. Solar energy project report prepared in PVSOL simulation program

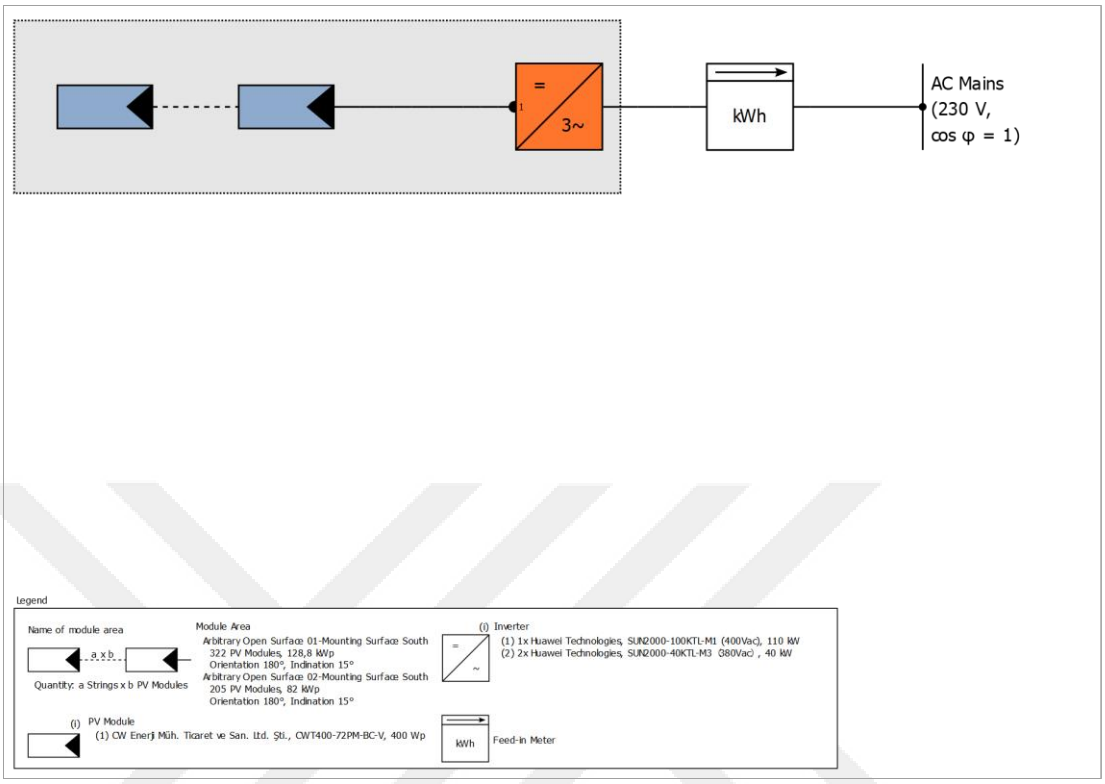


Figure I. Schematic diagram of the PV project

Table I. System Data

Type of System	3D, Grid-connected PV System
Start of Operation	20.06.2022

Table II. Climate Data

Location	Salkımlı, TUR (1991 - 2010)
Resolution of the data	1 h
Simulation models used:	
- Diffuse Irradiation onto Horizontal Plane	Hofmann
- Irradiance onto tilted surface	Hay & Davies

Table III. PV Generator, 1. Module Area – Arbitary Open Surface 01-Mounting Surface South

Name	Arbitrary Open Surface 01-Mounting Surface South	
PV Modules	322 x CWT400-72PM-BC-V (v1)	
Manufacturer	CW Enerji Müh. Ticaret ve San. Ltd. Şti.	
Inclination	15	°
Orientation	South 180	°
Installation Type	Mounted - Roof	
PV Generator Surface	643,3	m²

Figure II. Module Area – Arbitary Open Surface 01-Mounting Surface South.

Table IV. PV Generator, 2. Module Area - Arbitrary Open Surface 02-Mounting Surface South

Name	Arbitrary Open Surface 02-Mounting Surface South	
PV Modules	205 x CWT400-72PM-BC-V (v1)	
Manufacturer	CW Enerji Müh. Ticaret ve San. Ltd. Şti.	
Inclination	15	°
Orientation	South 180	°
Installation Type	Mounted - Roof	
PV Generator Surface	409,6	m²

Figure III. Module Area - Arbitrary Open Surface 02-Mounting Surface South

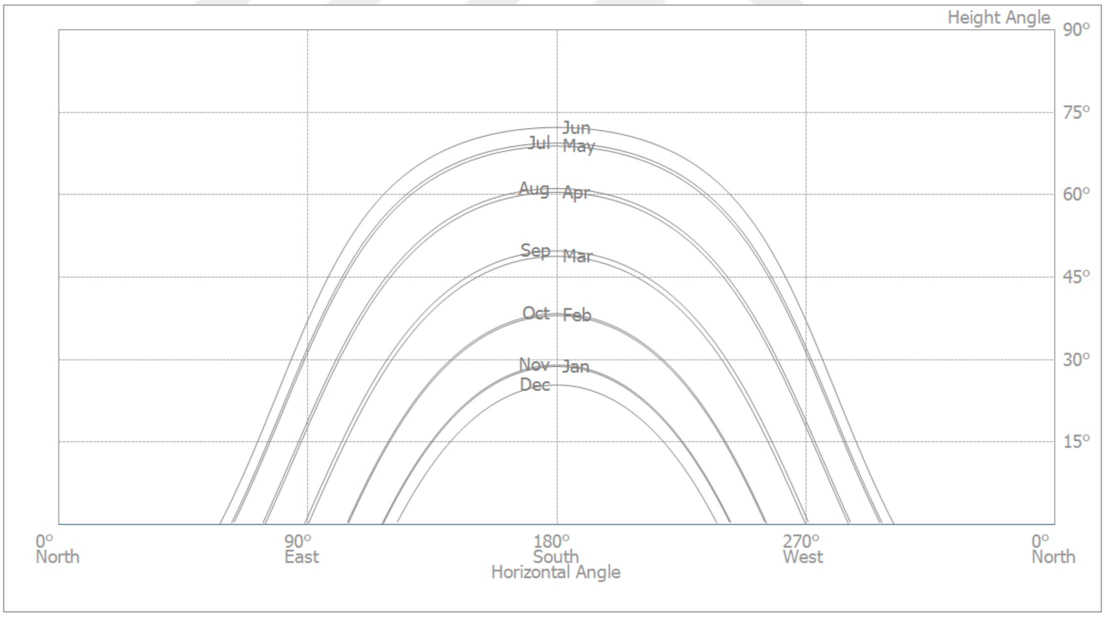


Figure IV. Horizon Line, 3D Design

Table V. Configuration of the inverter 1

Module Area	Arbitrary Open Surface 01-Mounting Surface South
Inverter 1	
Model	SUN2000-100KTL-M1 (400Vac) (v6)
Manufacturer	Huawei Technologies
Quantity	1
Sizing Factor	117,1 %
Configuration	MPP 1: 2 x 17
	MPP 2: 2 x 16
	MPP 3: 2 x 16
	MPP 4: 2 x 16
	MPP 5: 2 x 16
	MPP 6: 2 x 16
	MPP 7: 2 x 16
	MPP 8: 2 x 16
	MPP 9: 2 x 16
	MPP 10: 2 x 16

Table VI. Configuration of the inverter 2

Module Area	Arbitrary Open Surface 02-Mounting Surface South
Inverter 1	
Model	SUN2000-40KTL-M3（380Vac） (v1)
Manufacturer	Huawei Technologies
Quantity	1
Sizing Factor	103 %
Configuration	MPP 1: 2 x 14
	MPP 2: 2 x 14
	MPP 3: 2 x 14
	MPP 4: 1 x 19
Inverter 2	
Model	SUN2000-40KTL-M3（380Vac） (v1)
Manufacturer	Huawei Technologies
Quantity	1
Sizing Factor	102 %
Configuration	MPP 1: 2 x 14
	MPP 2: 2 x 14
	MPP 3: 2 x 12
	MPP 4: 2 x 11

Table VII. AC Mains information

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

Table VIII. Simulation Results Total System

PV Generator Output	210,8	kWp
Spec. Annual Yield	1.218,34	kWh/kWp
Performance Ratio (PR)	81,5	%
Yield Reduction due to Shading	6,6	%/Year
Grid Feed-in	256.900	kWh/Year
Grid Feed-in in the first year (incl. module degradation)	252.689	kWh/Year
Standby Consumption (Inverter)	73	kWh/Year
CO_2 Emissions avoided	123.534	kg / year

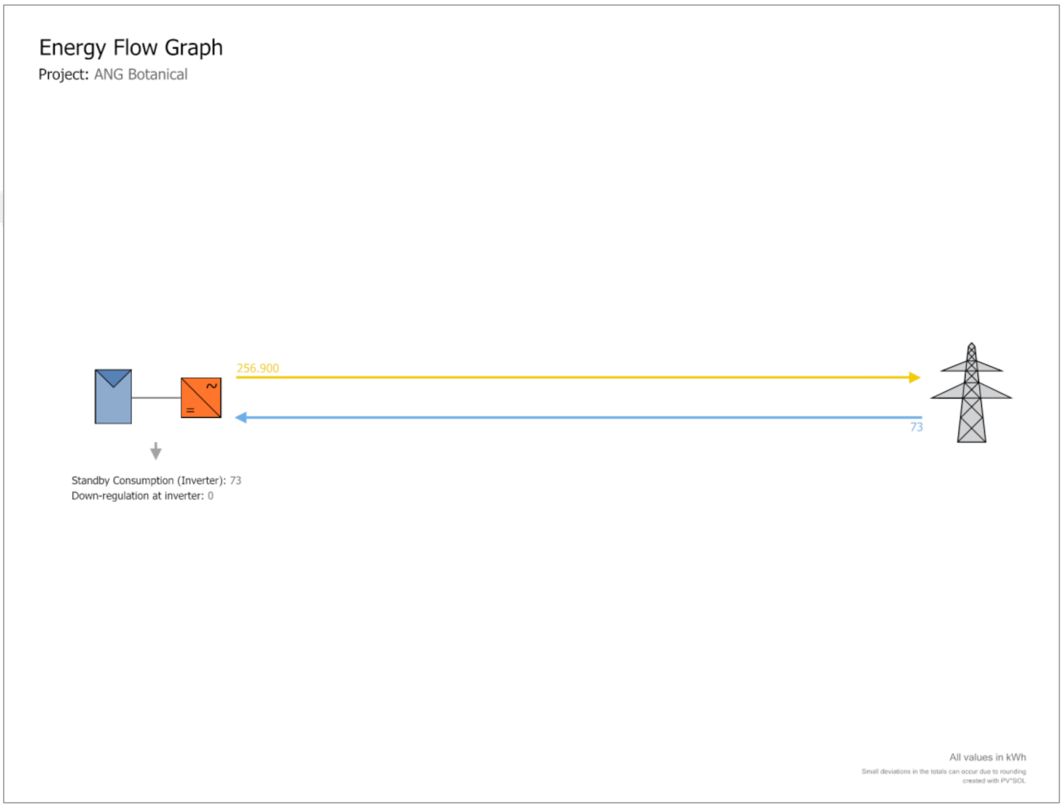


Figure V. Energy Flow Graph

Table IX. System Data

Grid Feed-in in the first year (incl. module degradation)	252.689	kWh/Year
PV Generator Output	210,8	kWp
Start of Operation of the System	20.06.2022	
Assessment Period	25	Years
Interest on Capital	33	%

Table X. Economic Parameters

Return on Assets	41,80	%
Accrued Cash Flow (Cash Balance)	2.429.552,07	₺
Amortization Period	8,8	Years
Electricity Production Costs	5,24	₺/kWh

Table XI. Payment Overview

Specific Investment Costs	18.221,00	₺/kWp
Investment Costs	3.840.986,80	₺
One-off Payments	0,00	₺
Incoming Subsidies	0,00	₺
Annual Costs	76.819,74	₺/Year
Other Revenue or Savings	0,00	₺/Year

Table XII. Remuneration and Savings

Total Payment from Utility in First Year	773.383,51	₺/Year
Yeni Tarife - Building System		
Validity	2.11.2022 - 1.11.2047	
Specific feed-in / export Remuneration	3,4259	₺/kWh
Feed-in / Export Tariff	1.025.813,83	₺/Year
Inflation Rate for Feed-in / Export Tariff	19,63	%/Year
Remuneration of Electricity sold to Third Party		
Price of Electricity sold to Third Party	2,20	₺/kWh
Remuneration of Electricity sold to Third Party	283.080,27	₺/Year

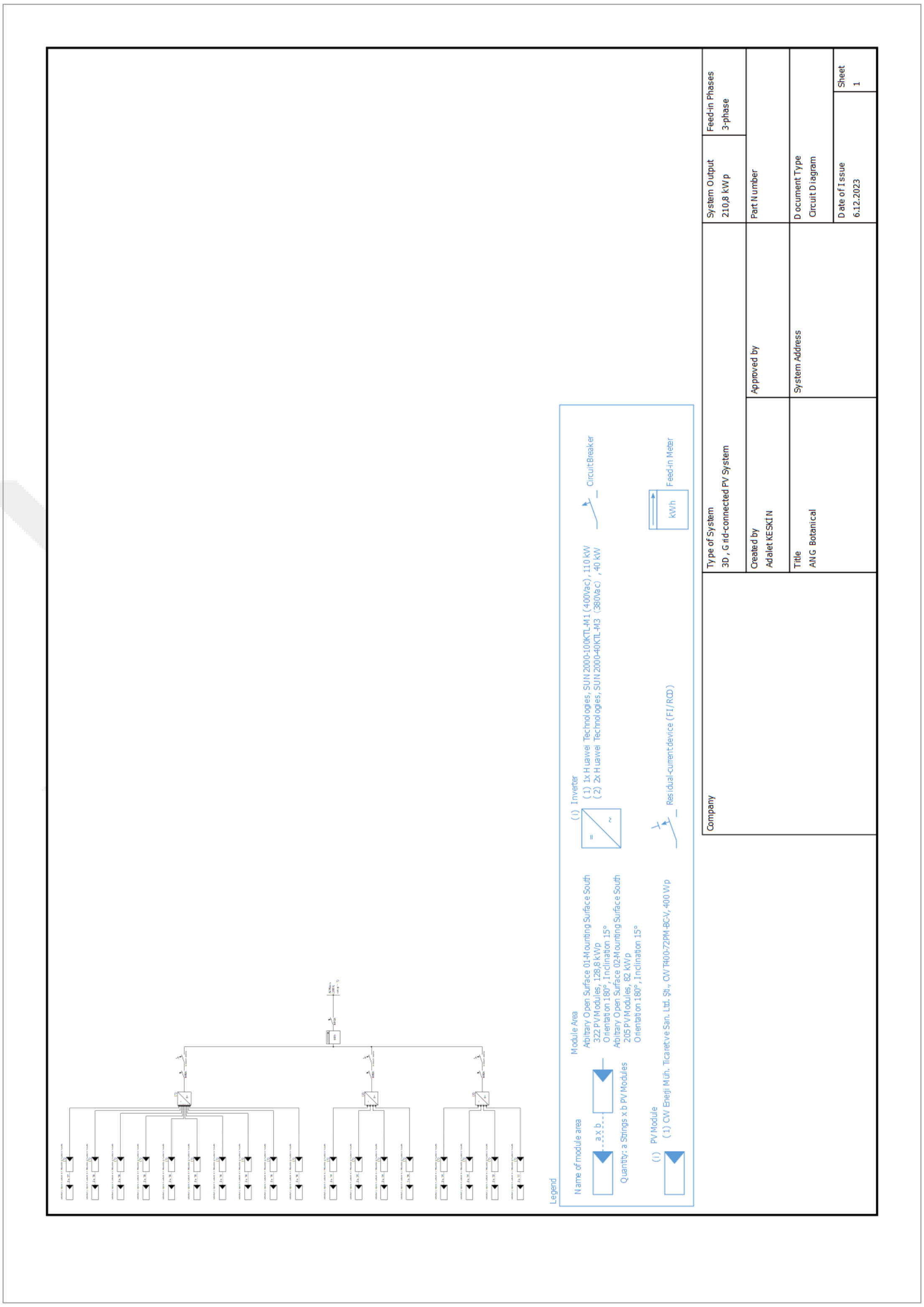


Figure VI. Circuit Diagram

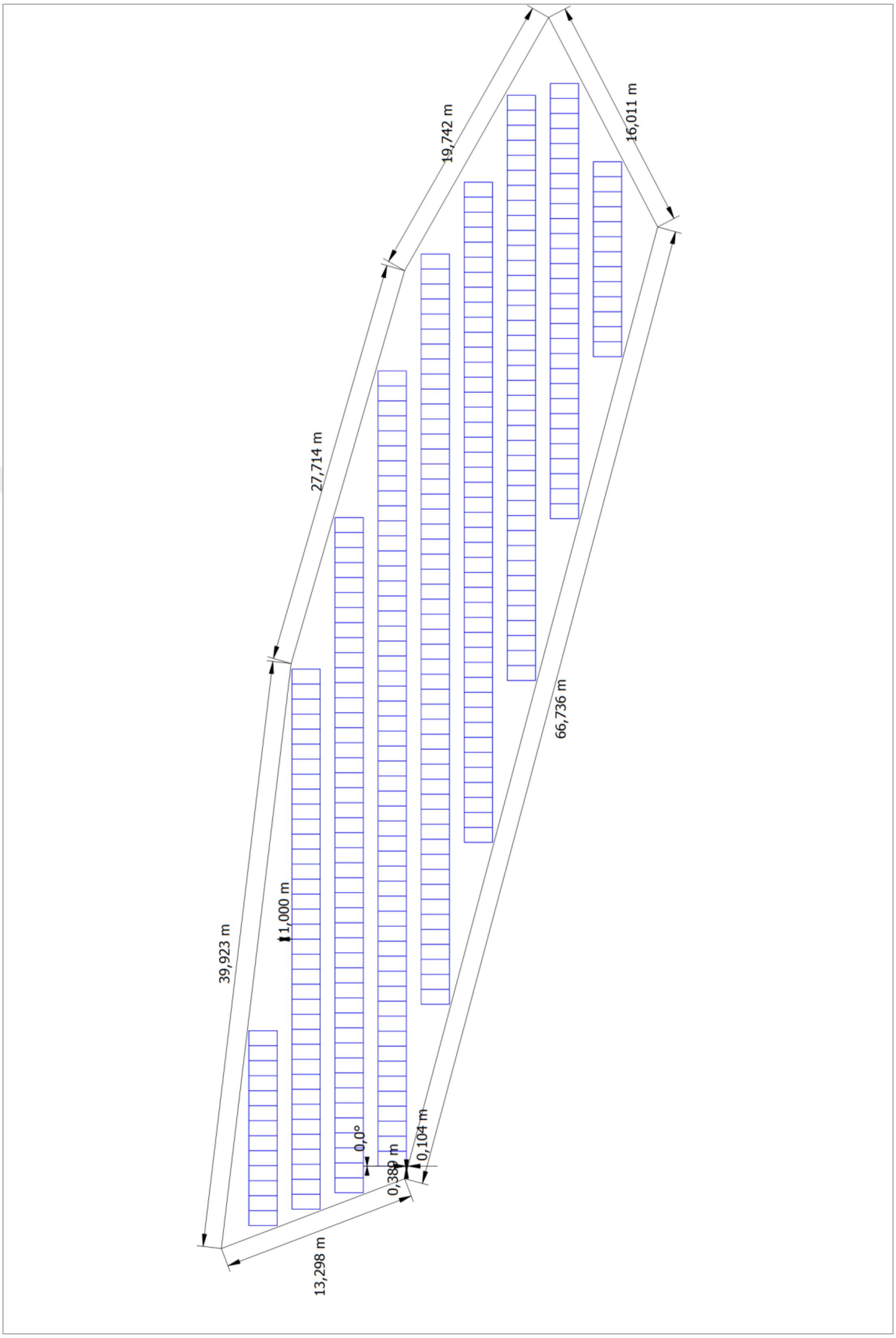


Figure VII. Dimensioning Plan (Surface 01)

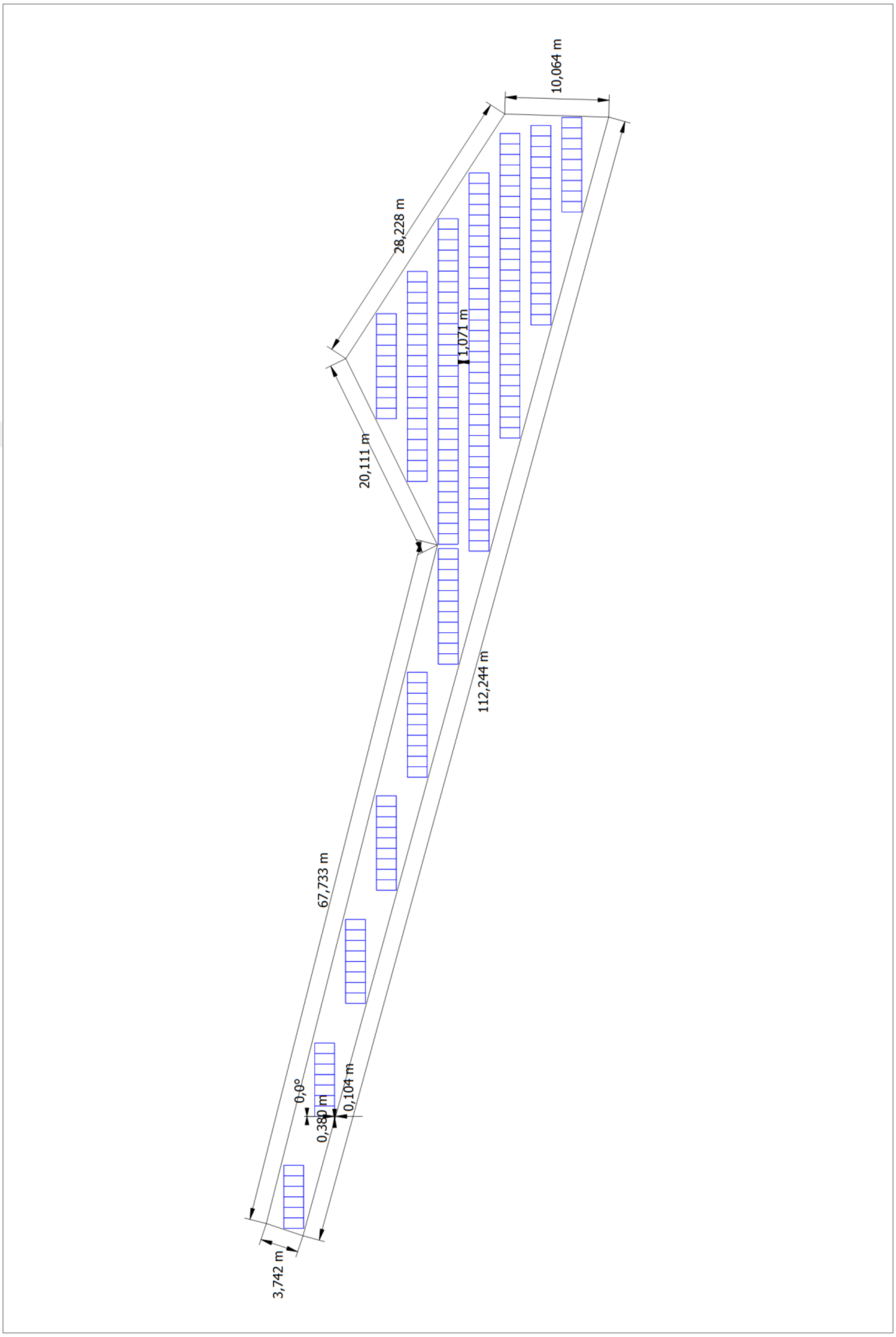


Figure VIII. Dimensioning Plan (Surface 02)

Figure IX. String Plan (Surface 01)

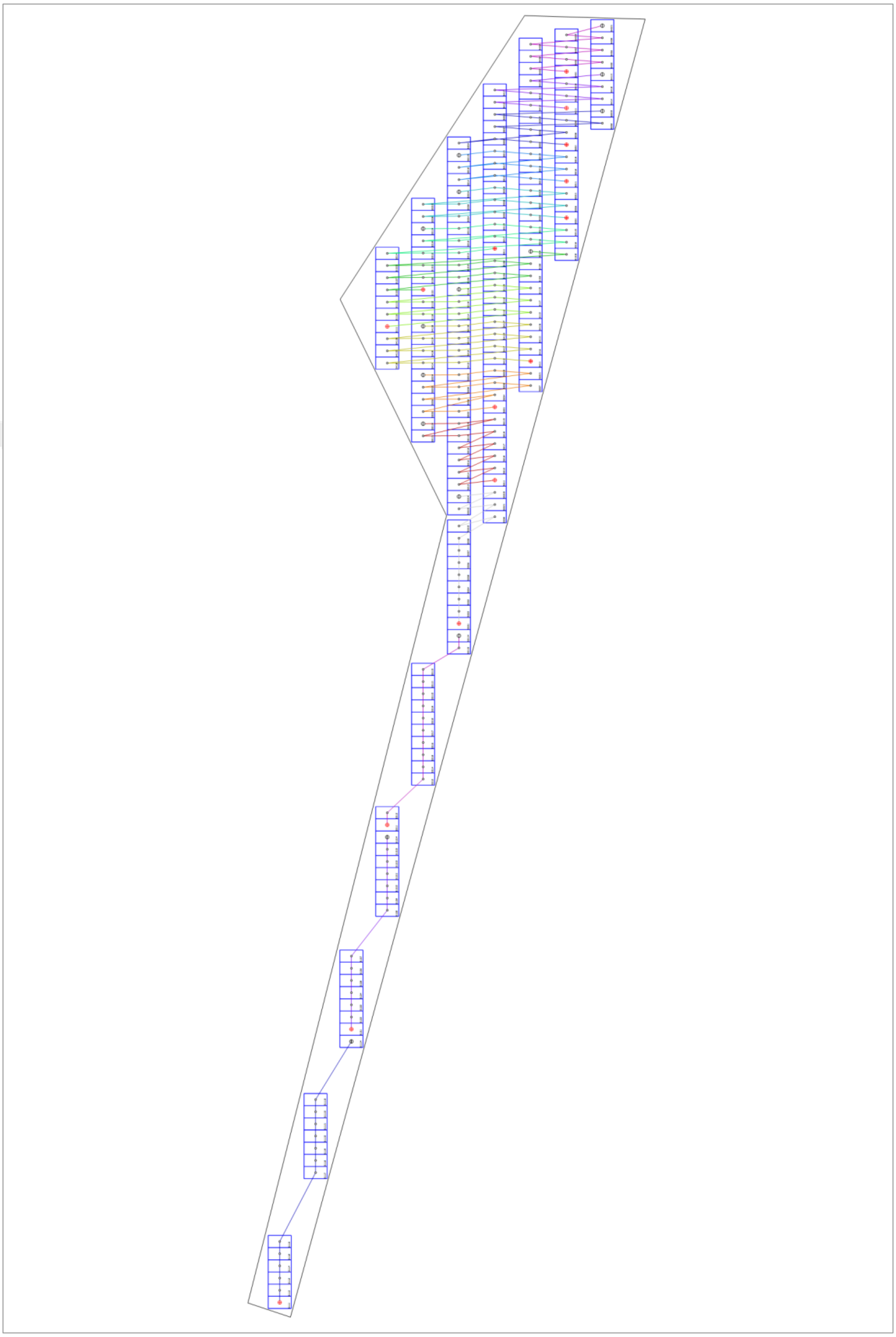


Figure X. String Plan (Surface 02)

Table XIII. Parts list

#	Type	Item number	Manufacturer	Name	Quantity	Unit
1	PV Module		CW Enerji Müh. Ticaret ve San. Ltd. Şti.	CWT400-72PM-BC-V	527	Piece
2	Inverter		Huawei Technologies	SUN2000-100KTL-M1 (400Vac)	1	Piece
3	Inverter		Huawei Technologies	SUN2000-40KTL-M3（380Vac）	2	Piece
4	Cable			AC cables 3-phase 10 mm² Copper	25	m
5	Cable			String Cable 10 mm² Copper	225	m
6	Cable			AC cables 3-phase 6 mm² Copper	50	m
7	Cable			String Cable 6 mm² Copper	270	m
8	Cable			String Cable 10 mm² Aluminium	30	m
9	Components			Feed-in Meter	1	Piece
10	Components			Circuit Breaker B 80A	4	Piece
11	Components			Residual-current device (FI/RCD) B 80A/100mA	3	Piece

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3. Lecturer, Artvin Çoruh University Borçka Acarlar VHS 2014 –

Publications

1. Books

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