HYBRID ENERGY CAPACITY OF TURKEY FOR SMALL AND MICRO SCALE ENERGY PRODUCTION

A Thesis Submitted to
The Graduate School of Engineering and Sciences of
Izmir Institute of Technology
In Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Energy Engineering

by
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March, 2017
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ACKNOWLEDGEMENTS

I first would like to thank my supervisor Assistant Professor Ferhat Bingöl for his help and supervision in shaping my thesis and for his valuable support, trust, understanding and time throughout the course of my studies. Also, I would very much like to thank my co-supervisor, Professor Gülden Gökçen Akkurt for her contribution in my thesis. This work would have never been complete without the valuable and constructive comments from my thesis committee raised during the viva. The comments raised both from Assistant Professor Ünver Özkol and Assistant Professor Utku Şentürk constitutes an important part of this thesis.

I would also like to thank Taylan Kabaş of the Enda Enerji for providing me the measured wind data used in this thesis.

My profound thanks to my colleagues from DNV GL, who have supported me throughout the course of this work, especially to Dr. Sena Serhadlıoğlu for her valuable support. I would also like to thank my friends for their encouragement throughout this thesis.

Finally, my special appreciation must go to my family who have always supported and motivated me, and who are always proud of me without doubting on my success.

ABSTRACT

HYBRID ENERGY CAPACITY OF TURKEY FOR SMALL AND MICRO SCALEENERGY PRODUCTION

Turkish state has opened a new possibility on investing small or micro scale energy production without license in 2014. This is a new step in Turkish energy market and two renewable energy sources are considered to be the main interest; wind and solar. Although there are studies covering both technology separately, currently there is no hybrid system assessment methodology and results for the country. This thesis aims to create a quantified hybrid energy capacity of Turkey. The study will include total energy capacity of a given location based on small scale wind and solar and furthermore would be able to suggest an optimum balance between these two sources to get the maximum production capacity out. The study does not cover areas that such investment cannot be done; environmental protected areas, historical places, city centers etc.

ÖZET

KÜÇÜK VE MİKRO ÖLÇEKLİ ENERJİ ÜRETİMİ İÇİN TÜRKİYE HİBRİT ENERJİ KAPASİTESİ

Türkiye 2014 yılında küçük ve mikro ölçekli lisanssız enerji üretimi için yasal düzenleme yapmıştır ve iki yenilenebilir enerji kaynağı esas ilgi alanı olarak dikkate alınmaktadır; rüzgar ve güneş enerjisi. Her iki teknoloji için de ayrı çalışmalar yapılmış olmasına rağmen henüz hibrit sistem değerlendirme metodolojisi ve sonuçları ülke çapında yapılmamıştır. Bu tez Türkiye'nin sayısal hibrit enerji kapasitesini yaratmayı hedeflemektedir. Çalışma, verilen alanın küçük ölçekli rüzgar ve güneş esaslı toplam enerji kapasitesini içerecek ve ayrıca bu iki kaynaktan üretilen maksimum kapasitesini elde etmek için optimum dengeyi önerecektir. Çalışma yatırım yapılamayan alanları örneğin çevresel korunan alanlar, tarihi alanlar, şehir merkezleri vb. kapsamayacaktır.

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CHAPTER 1

INTRODUCTION

1.1. History and Types of Renewable Energy

Energy is the main required element for survival and continuation of life for all living creatures. Recently, the global energy need is increased due to the increased human activities. however the world's energy resources are not infinite. For this reason, people and the state agencies have started to develop new technologies to generate more and reliable energy. By nature, all conventional energy resources are limited except for the renewable energy resources. As a consequence new technological developments have been focusing on renewable energy resources. This section summarizes the developments that considers the use of energy resources and methods that limited energy consumption.

Initially, the heat released after burning the wood was used to accommodate people like heating households, melting materials and cooking. Importance of the wood declined with mining the coal. In 1712, Thomas Newcomen invented the first steam engine to pump water. This invention stands as the stepping-stone for the industrial revolution in the world. [1]. According to studies, various protocols have been prepared globally and are being signed for a cleaner world since February 27, 2003[1]. Coal rich counties have been producing their energy by coal with ratios of; Mongolia 95%, South Africa 93%, Poland 83% and China81 [2]. In 2016, the energy generated via coal is 22.1% of the total energy production in Turkey. It is estimated that the coal reserves will be sufficient for another 142 years in the world[3].

Petroleum is in use for 4000 years, the first use of which was to produce asphalt to construct the walls and towers of Babylon. The modern history of petroleum began in 1846 with the discovery of the process of refining kerosene from coal by Abraham Gesner [4]. The Middle East has 47,9% of the global reserve in the world, which is also the biggest portion of the overall reserve. According to amount of reserves America, Europe and Africa have the biggest reserves respectively [5]. It is predicted that the lifetime of petroleum reserves is approximately 54 years. Reserve of Turkey assumed to be exhausted in 18 years[3]. One must remember that generating energy is only a small part of the petroleum usage and therefore the air pollution. In 2016, Energy production from petroleum in Turkey is about 2,0% in proportion to total energy production [3].

The first known natural gas well was drilled by the Chinese in 211 B.C. In later centuries, the Chinese adapted bamboo pipelines to transport natural gas to provide fuel for boiling water, heating and lighting. [4]. Natural gas was first extracted for industrial use in Fredonia, New York, USA in 1825. Generation of electricity by natural gas started near the end of the 19th century [6]. Middle East has the biggest reserve of natural gas with the ratio 43.2%. Respectively Europe, Asia, America and Africa have the largest reserves. Predicted life time of natural gas is nearly 61 years in the world[3]. It is assumed that the Turkish reserves of natural gas will be exhausted within 10 years. Energy production ratio from natural gas in Turkey is 47.2% in proportion to total energy production [3].

Figure 1.1. Test Turbines of Poul La Cour [8]

Wind has been considered as a power source since the ancient times. First sails have taken the advantage of wind. Windmills have been built in Persia with resistant materials at 7th century. The first wind mill which generated electricity for public use was invented by Poul La Cour, a Danish scientist, in 1891 [7]. The first wind farm was constructed in Hampshire, United Kingdom in December 1980 [9].The largest investors in wind energy are China (29.3%), USA (18.4%) and Germany (10.8%) [10]. Turkey produces approximately4,7% of its energy via wind in 2016 [3].

Waterwheels based mills are operated for various purposes, such as pumping water, grinding grain, tanning leather, cutting wood, and some other various early industrial operations since BC. 200[11].

Architecture Hydraulique, which described hydraulic machines having axis vertically and horizontally, was published by Bernard Forest de Belidor in the 18th century. Hydraulics and generator working by electricity have been combined in late of 19thcentury through the development on generators. This enterprise of the development of the first power stations were completed by putting an electricity generator and a turbine together. The world's first hydroelectric power plant is located in Appleton, Wisconsin, United States[12].Electricity generation by hydroelectric power plantsis largest in Asia. China has been producing 17% of its total energy production by hydroelectric [13]. Hydropower is 33,7% of the domestic energy production in Turkey [3].

The sun is the first energy resource in the world. In 212 BC., Archimedes used mirrors and set fire to Roman ships. "Archimedes death ray", which was then used to focus sunlight to enemy ships. In 1839, French scientist Edmond Becquerel discovered the first photovoltaic cell [14]. This was the first step to generate electricity using the Sun as a direct resource in the world [15]. Total installed Solar PV capacity of China is 43,5 GW (19,2% of total installed PV system in the world).Following countries are Germany and Japan with 39,7 GW and 34,4 GW installed solar PV system capacity respectively [16]. In 2016, energy production by solar systems is 0.8% of total energy production in Turkey. It is aimed to increase solar electricity generation from 660.2 MW to 3000 MW in 10 years by the Turkish State Agency [3].

Geothermal energy has been used since ancient times as a heating source for cooking, bathing and keeping warm. The first use of geothermal energy for electricity generation occurred in Italy in 1904-1905 [17]. Total installed and operating capacity of Geothermal energy is 13,3 GW in the world. Total installed geothermal energy capacity of U.S. is 3567 MW (about 27% of total installed capacity of geothermal energy). The ratios for the other countries are 14,5%in Philippines, 10,3%in Indonesia and 8%in Mexico of the global installed geothermal energy capacity in 2016 [18]. Total installed capacity of geothermal energy in Turkey is 725.2 MW which is 0.9% of total installed power plants in Turkey [3].

Bio-fuel is the largest alternative to petroleum use in engines. Bio-fuel firstly was used in 1898 by Rudolph Diesel in an engine that worked by peanut oil in America [19]. The US has been producing electricity via bio-fuels which comes to 62 TWh that is equivalent to 18% of the world's total biofuel electricity generation. The other leader countries on bio-fuel electricity generation are Germany 37 TWh (10.7%) and Brazil 36 TWh (10.5%), [20]. In Turkey, bio-fuels are being used as fuel for heating houses, operating cars and machines. European Commission decided to increase the usage ratio of bio-fuels by 5.75% until 2020 for all members and candidate countries[21].

Nuclear is a new source of energy in the world when compared to the other renewable sources. The first controlled nuclear chain has been invented in 1942 by

Enrico Fermi, an Italian physicist, and his team in the University of Chicago under the project named as ‘Manhattan Project’. Experimental Breeder Reactor-I (EBR-I) was the first fast-neutron reactor designed in 1951 [22]. Today, nuclear energy is one of the most preferred energy resources. United States has been producing 19.5% of the total nuclear energy produced in its own production. The other countries generating electricity via nuclear reactors are France 76.3%, Russian Federation 18.6%, South Korea 31.7% and Germany 14.1% [3]. If the nuclear power is used in the right way and with the safety precautions, nuclear stands as a clear way to generate electricity. With this approach, Turkey has started to develop projects with Russian Federation and Japan to construct the two nuclear reactors in Turkey [3]. In 2010, the agreement between Russian Federation and Turkey has been signed for Akkuyu Nuclear Power Plant. In addition to that, second nuclear power plant which will be located on Sinop will be constructed together with Japan according to agreement signed in 2013 [3].

Except these resources, hydrogen and wave can be used in order to generate electricity. However, these resources do not have a foundation in Turkey yet. For this reason, these resources will not be discussed throughout this thesis.

Since the fossil fuel resources will be exhausted entirely in the future, renewable energy systems will replace this conventional resource in the future. Due to the sustainability of wind and solar, the number and capacity of wind farms are increasing in the world continuously. Solar and wind energy systems are more popular than the other renewable energy resources for the state agencies because of their reliability. Hydro power is the most efficient resource within the portfolio of renewable energy resources, and only hydropower plants can generate electricity nearly as much as the fossil fuel resources.

Figure 1.2. shows that the fossils and nuclear sources have been producing 76,3% of the world’s total energy. In the other 23,7% left, hydraulic generates 16,6% and wind generates3.7%. Bio -power 2%, Solar PV 1,2% and other resources totally produce 0.4% of the world’s energy in

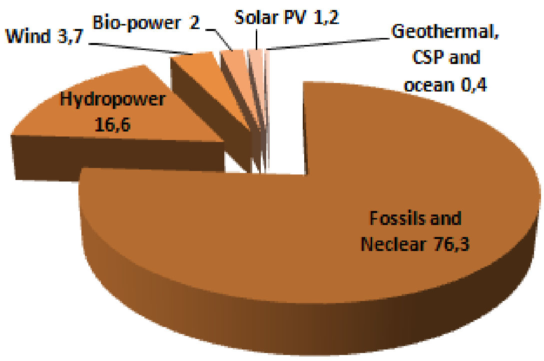


Figure 1.2. World energy production by source, 2015

the end of 2015 [24]. Based on these ratios, the renewable sources have been providing energy as half as the fossil fuels. It is assumed that the state agencies' investments will increase the production and usage of renewable systems in the world.

Renewable energy resources fulfill the requirement of energy demand in Europe with the ratio 42.5% in 2016 [25]. This ratio is different than the world statistics. Especially, wind hydro and solar are very effective to produce energy in Europe. This means clean, sustainable and energy-safe world.

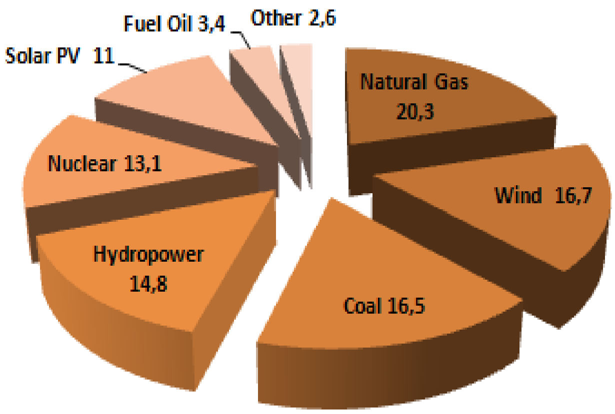


Figure 1.3 Europe energy production by source, 2016

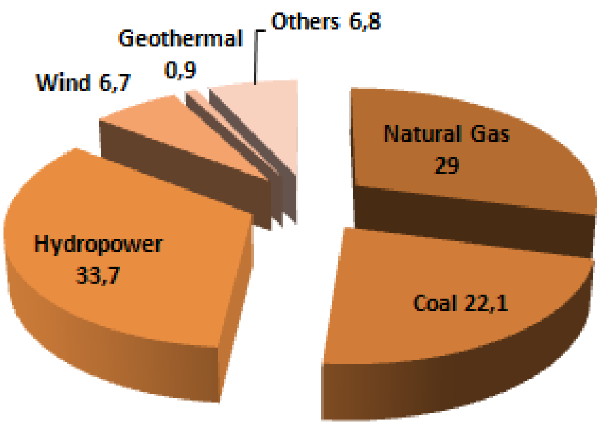


Figure 1.4 Turkey energy production by source, 2016

Proportion of using energy resources in Turkey to produce electricity resembles the world's energy generation. The investments on the renewable systems decreased the use of fossil fuel resources. Based on the data shared by the Turkish Ministry of Energy, October 2016, Turkey have been producing energy by fossil fuels with a percentage of 57.1% of its total energy production. All renewable energy generation is 42.1% of the total[3]. Hydraulic supplies the most energy with the ratio 17.7% among the renewable energy systems. Investments have been done to wind mostly after hydraulic with the ratio 6.7%. Especially until 2023it is expected that there will be improvements on renewable systems. The Turkish State Agency aims to increase total energy production by renewable systems by 30% in accordance with the target of 2023 [3].

1.2. Wind Energy

After the invention of the power generation from wind energy, wind has become a popular renewable energy resource in the world. Wind energy has been investigated more to generate energy. In years, wind energy has become a main energy resource with the developments in all associated areas like measurement technologies, materials of turbines and blades, wind farm site areas and all other important stages.

Wind has been used as a power resource since the ancient times. Propelling sailboats and sailing ships have used wind as natural ventilation for 5500 years. Windmills have been discovered in the 7th century and used in order to pump water and grind grain in Afghanistan, Iran and Pakistan [7]. From as early as the 13th century, horizontal axis windmills became very important for the agricultural activities, but then cheap fossil fuel based engines have taken a large part on the agricultural use [26].

James Blyth, a Scottish scientist, has worked on wind power and invented the first wind turbine. He applied and received the patent for wind energy production in the UK in July 1887[7]. Charles F. Brush has succeeded to generate electricity with a machine, which worked by wind in the US in the winter of 1887-1888. He has achieved to light his house and laboratory until 1900 [7]. Capacity of this windmill was 12 kW [26]. Poul la Cour a Danish scientist, has invented the first wind turbine to generate energy for public use. His experiments on wind energy have shaped wind turbine to its modern form [7].

There were a number of wind turbines installed in Denmark, totaling up to 100 kW, between 1900 and World War II [4].Balaclava wind turbine has been constructed in the USSR in 1931. This turbine has 100 kW capacity with 30 m diameter blades [26].The most impressive of all early wind turbines (Smith -Putnam Wind Turbine) has been constructed in 1941, on a mountain in Vermont, USA. 1250 kW capacity of the turbine has been supplied by a 53,4 m steel rotor at 33,5 m hub height [4]. Full-span pitch control and flapping blades were reducing the loads. This turbine has been used for 40 years, although one of its blades was broken in 1945 [26].

In the beginnings of 1950s, Andrea Enfield has designed a pneumatic wind turbine, which had capacity of 100 kW with 24 m blade diameter. Blades were hollow in this turbine[4]. Electricité de France tested a 1,1 MW 35 m diameter turbine in 1963

[26].The interest of electricity generation from wind energy has continued until the price of oil skyrocketed in 1973 in the world[26].

Mass production of the contemporary wind turbines has been initiated by the Danish wind turbine producers; Bonus, Nordtank, Vestas and Kuriant [7].U.S. Windpower has installed the world's first wind farm in December 1980. 20 wind turbines, which was totally 600 kW, have been located in the vicinity of Crotched Mountain in the south part of New Hampshire. However the developer overestimated the wind resource, and the turbines frequently broke down [9].

The first offshore wind farm was built at Vindeby in Denmark in 1991. Distance from the coast is 2.5 km and there are 11 Bonus turbines. Each of them could generate 450 kW energy and total energy capacity is 4.95 MW [27].

Investments and developments have been continuing since the first use of wind as an energy resource. Squirrel-cage generator (SCIG) and doubly-fed induction generator (DFIG) are two kinds of induction generators are two examples that were developed in the industry. More generators were developed such as the Synchronous generators (SG), electrically excited synchronous generators (EESG), permanent magnet synchronous generators (PMSG) and high temperature superconducting synchronous generators (HTS SG). SCIGs were more popular in 1990s until DFIGs became more popular in 2003. The Induction Generators were still leading the market. HTS generators in direct drive wind turbines began to be utilised in the market as a consequence of investments on the offshore wind farms, which are offered as the best way to produce vast amounts of energy while not occupying space on the ground [28].

Modern wind turbines have high rated power compared to their ancestors. As a result of the developments on increasing the capacity of the wind turbines, turbines with rated power of 2.5 – 3.0 MW took place in wind farms with the ratio of 70%[28].

Total installed wind power capacity is 456.5 GW globally with 21.7 GW new installations[10]. The total installed wind power capacity is expected to be 500 GW for the end of 2016. In 2016, China has become the leading country in wind power with an installed capacity of 158,000MW (34.6% of the world). The total installed capacity of wind energy in the USA is74,696MW (16.7% of the world) and in Germany is 47,420 MW (10.4% of the world. These three countries share the61,7% of the total wind capacity in the world [10].

Wind energy ratio in total energy production in Europe is 16.7% and this ratio is higher than the other renewable resources. Germany is the leader in Europe in wind energy industry with 47420 MW installed wind power capacity. Following countries are Spain (22987 MW), UK (13940 MW), Canada (11298 MW) and France(10861 MW) [10].

Offshore wind is still premature when compared to the global onshore installed capacity, but it is growing rapidly. More than 93% of the total offshore wind capacity is located in Europe. The UK has more than 53% of the world's offshore capacity. Germany (595 MW), China (430 MW), Denmark (350 MW), and Belgium (192 MW) are the following countries [20].

Turkey was introduced to the wind power in 1985 with Vestas 55 kW turbine at Dolphin Hotel in Çeşme, İzmir. The development of the modern Turkish wind power engineering began from November 21, 1988, when the first Enercon E-40 wind turbines each of which has a capacity of 500 kW, began to operate at Alaçatı - Çeşme in İzmir. [30]. In July 2016, 152 wind farms have been located in Turkey with 6.106 MW capacity. There are 35 other wind farms that are under construction which sums up to861,6 MW in capacity [31].

In 2016, The total installed wind capacity is 6.7 % of the overall installed energy capacity of Turkey, which corresponds to 4.5% of the overall energy production of the country. The state agency has planned to increase these numbers to 20,000 MW until 2020 [3].

1.3. Solar Energy

The sun is the source for living. People use solar power to heat water, to produce steam and to generate electricity. New methods were found to profit from the sun since the ancient times. The first utilisation area of the solar power was for drying body, clothes, salt water and heating spaces, food, and water [4]. Houses were built in order to collect sun beams for heating in the ancient Greek times. This construction behavior started in BC 400s[32]. The most attractive implementation of solar power was Archimedes's death ray which burned Roman fleet in the bay of Syracuse in 212 BC. Many scientists experimented and realised that it was reliable and applicable [32].

In 1839, the first photovoltaic effect was discovered by Edmund Becquerel, a French physicist, while he was working on two metal electrodes. He has used this system in order to create electrolytic cell. It has been discovered that these materials would generate electricity while subjected to light [15].

Research on solar energy paved the way to use the low-pressure steam to operate engines. August Mouchot was a precursor of the solar steam engines. He found solar-powered steam engines and one of them was presented at the 1878 International Exhibition in Paris [32]. This engine had parabolic dish collectors, which generated energy by solar systems.. Another example of this technology was set up in Algeria in 1875, which was designed by Mouchot. Its diameter was 5.4 m and collecting area was 18.6 m^2. Total weight was 1400 kg with metal plates [32].

Early 1890s, A solar power plant which was totally 930 square meters has been designed by Frank Shuman. After the construction, this solar energy system was able to generate 18.5 kW energy that was sufficient to pump 11,300 liters of water up-to 10 meters high. Frank Shuman and C.V. Boys built the largest pumping plant of the world in Meadi, Egypt in 1912. They used parabolic cylinders to focus sunlight into a long absorbing tube. Each cylinder was 62 m long and the total area was 1200 m^2. This engine generated37-45 kW continuously for a 5 hour period. Although this solar power plant was successful; it was shut down in 1915 due to the World War I and asthe fuel prices were cheaper [32]. However, studies in heating and pumping systems have continued throughout the years.

After the invention of the first photovoltaic effect back in 1839 by Becquerel, Adams and Day, photovoltaic effect in solid selenium was observed in 1876. The first PV cells which were produced by selenium wafers was invented by American scientist Charles Fritts. The single-crystal silicon was then improved by Czochralski who was a Polish inventor [33]. Russell Ohl, a scientist at the Bell Laboratory, invented a material which super-purified germanium. The first silicon solar cell was discovered by using super-purifying germanium. All rights of "Light sensitive device" has been protected by a patent in the US in 1946. Hoffman Electronics achieved efficiency value 8% in 1957 through Chapin, Pearson and Fuller, 9% in 1958 through the US Signal Corp, 10% in 1959 with 9600 cells and 14% in 1960 [33].

Oil crisis in 1970s caused to find new solutions and alternatives to the fossil fuels. David Clarson and Christopher Wronski, RCA Laboratories, fabricated the first amorphous photovoltaic cells in 1976. In 1980, in the University of Delaware, first thin-film solar cell that had more than 10% efficiency was developed with sulfide/cadmium sulfide. The Icare, the most nubile airplane which has been powered by solar systems performed a flight across Germany. Superficies of tail and wings of this airplane were enveloped by 3,000 super-efficient solar cells with totally 21 square meter area in 1996. The National Renewable Energy Laboratories reached the efficient of thin-film photovoltaic cells as 18.8% in 1999 [34].

Continued researched in solar energy has played an important part in reducing the costs. After 2000, the state legislatures and the national state agencies began implementing incentives which promoted the growth in solar power, which paved the way to drop costs [35].

One of the most preferred type is the Crystalline Silicon Cell. Most of the crystalline silicon cells are Single Crystal Silicon Cells. This type is the most efficient one, however, it is also the most expensive with a complex manufacturing process. Efficiency is high compared to the other types as 15-20%, and the lifetime of this system is in range of 20-30 years. Polycrystalline Silicon Cells are one of the other type of crystalline silicon cells. This type is stronger than single crystalline silicon cells due to using the edge-defined film-fed growth. Polycrystalline Silicon Cells are cheaper but, efficiency is lower about 10 to 14%. The other main type of photovoltaic cells is the Thin Film Systems. This type has an inexpensive layer such as metal, glass and in some cases plastics, generally has amorphous silicon as thin film module for decreasing the cost. Efficiency is lower than the other systems. According to the laboratory tests, the maximum efficiency value is 12%. This value decreases in years to 4%. Multi-junction photovoltaic cells is expected to have more than 35% efficiency under concentrated sunlight. Silicon spheres are assumed to have low cost and more than 10% efficiency. Organic photovoltaic cells are in the developing process which has 3% efficiency, but the aim is to lower the cost and increase the efficiency to 10% [36].

In 2015, 50 GW solar PV system was added and total capacity reached to 227 GW in the end of the year of 2015 in the world. China (15.2 GW), Japan (11 GW), and United States (7.3 GW) were the countries which added the most capacity in the world. China is the leader of PV capacity in the world and totally have43.5 GW capacity. With the new installations Germany has reached the total capacity of 39.7 GW. Japan has reached 34.4 GW capacity of PV systems and Italy added 0.3 GW and achieved 18.9 GW total capacity. The US added 7.3 GW and reached totally 25.6 GW [24].

Although Turkey has a big potential of solar energy, totally660.2 MW capacity PV system has been installed in order to generate electricity until July 2016. According to the State Agency’s aim, until 2023, total capacity will be 3000 MW [3].

CHAPTER 2

HYBRID ENERGY

Energy generation systems which include two or more different sources to generate energy are named as Hybrid Energy Systems. Wind, solar, biomass, geothermal and hydro are the main renewable energy resource systems. Combining different energy systems to design hybrid energy systems is tough, however, hybrid systems are of importance to provide sustainability in energy generation. Every resource can lose its efficiency for a period in a daily basis. During this period, energy generation should be continued without any shortage. For this reason, each energy resource has to supply energy independently from each other.

Wind and solar energy resources have been used together in this study. Wind and solar can be used almost all over the world as independent energy resources without any additional implementations. Other resources depend on geological and environmental requirements. Biomass needs process in order to produce usable material and using effectively. Geothermal energy is not available in everywhere, which is underground and has a limited amount of resources that are feasible to generate. If there is usable geothermal resource on the project area, this is very effective way to add geothermal to the hybrid system. Hydro has similar barriers in application to hybrid systems. Project area should be formed by suitable geological shapes. Due to its high efficiency values, hydro is an important power resource, hence there is a chance to use this resource in such systems. However, designing hybrid systems including hydro power, is not easy due to the geological effects on the other resources.

Wind turbines can have high capacities in megawatts with only one wind turbine. Solar energy systems as photovoltaic panels can have high capacities when numbers of them come together. So that, generally, PVs generate energy in kilowatts. In a system sometimes, it is possible not to meet the demand by only one wind turbine. In addition to that, two or more turbines can produce energy more than the demanded value. Unmet energy need can be completed by photovoltaic system. Alternatively, there can be less wind resources than solar, and using wind turbine can be more expensive than solar systems. We have to use more solar power when the solar resource is more effective. So that, hybrid system is shaped according to the resource capacity on project location.

Economy is another and significant issue for an energy system design. Investment and maintenance costs can be variable from region to region. By using hybrid energy systems considering project location, economically the most beneficial systems can be designed.

2.1. Hybrid Energy Methods

Two or more energy resources must be used in a hybrid energy system. One of the resources can be fossil resource, however using of one or more renewable energy resources provides sustainability to the system. Developers have been studying on many types of hybrid energy systems. Coal, Natural Gas, Petroleum, Wind, Solar, Hydro, Biomass, and Geothermal energy resources can be combined to design a hybrid energy system. One fossil resource and one or more renewable resources have been used in general implementation of hybrid systems. Fossil resource gives guarantee to the system to provide energy. But if there are measured and reliable renewable resources which are continuous, such as wind, solar, hydro, geothermal, biomass, renewable energy resources can be preferred to produce energy. Usage of only renewable resources is more beneficial for environment. There is no carbon emission and no air pollution in the renewable systems.

The most used renewable energy resource is the solar systems in hybrid energy systems. Sunlight reaches everywhere on the ground. This effect changes from region to region because of shape and rotating of the world. However, everywhere in the world can get sunlight in different measures, whereas the other resources, like fossils or renewables, require conditions like geological or chemical structure of the site. For this reason, solar is the main energy resource for hybrid energy systems. Solar energy resource can be used together with all other energy resources. For example, we can add solar power units to an energy system using only coal to make more powerful power plant. There can be only natural gas or petroleum to generate energy in system. Solar can be used together with these resources too. This supports decreasing the carbon emissions and supplies long life time to fossil resources.

Using the renewable resources within a system is very beneficial and efficient way to generate energy. Some conditions can be appropriate to create the system. A hydro energy system needs a geological shape which is required to design hydroelectric power plant. A geothermal energy system must be installed on the above of the resource area. Energy cannot be generated via geothermal resources which is far away from the project location. A power generation system can be designed without any requirement of resource's location as in the biomass energy system. Biomass must be carried to the energy system area after application of some chemical methods. Biomass is not like the other renewable resources. Transportation of the resource is a barrier to make common biomass energy systems. If there is power generation systems which has been working, solar power system can be installed to the most efficient location on the area of working power generation system. Hydro-solar, geothermal-solar, biomass-solar power generation systems can be designed with the appropriate conditions.

Wind energy systems are designed according to measurement of wind speed and direction at different heights. Wind is related to the site terrain and different sites can have different wind potentials. Wind turbines, especially small wind turbines, can be installed easily anywhere on the ground, however, energy capacity of a location, should be investigated in order to learn feasibility of investment. Same with wind energy investments, solar PV panels can be installed easily on ground or roofs of houses. In this regard, wind-solar hybrid system is the most preferred hybrid system.

It is suggested to use more than two resources in a hybrid system. A hydroelectric energy system can be designed considering the wind and solar resources on the project location. Hydro-wind-solar hybrid energy system can be designed by this approach. This method can be applied as geothermal-solar-wind and biomass-solar-wind too. Existing energy systems which has been using fossil resources can be converted to the hybrid energy systems through the addition of wind, solar or both of them.

2.2. Turkish Laws on Micro Scale Energy Production

The Turkish State Agency has published a regulation about unlicensed electricity production on 2nd of October, 2013 [37]. This regulation includes the details related to the micro scale energy production. According to the regulation, anyone may install unlicensed energy power plants. The main requirement is that energy consumption must be in the vicinity of the area selected to install the energy power plant. This is the first rule to generate energy without license. If there is not already any power consumption in the area, then the investor must install a facility prior to the power plant's installation. Power consumption plant and power generation plant must be close to each other, because generated energy can be achievable directly from the consumption plant.

A micro scale energy power plant can be installed in combination with all energy resources. There is not any restriction about these energy resource. Fossil energy resources and renewable energy resources can be preferred in the systems. The main restriction is the capacity of the power plant. The maximum capacity of the unlicensed energy production power plant may not exceed one megawatt in total. It is not important which energy resource(s) has/have been combined in the system, as long as the total capacity is one megawatt. One resource may be used alone or together more than one resources can be combined in order to generate that amount of energy. For instance, only wind turbine(s) can be installed as one megawatt or solar PVs can be installed as one megawatt. Or they can be used together totaling up to one megawatt. In our project, wind and solar renewable resources have been used in order to design a hybrid energy system. According to the regional conditions and potentials of the resources, usage ratios can be changed. If the system will be a cogeneration system, this capacity can be maximum of100-kilowatts. Energy that is more than the requirement of the consumption can be sold to the energy supplier. However, energy must be supplied to the consuming power plant without any interruptions. This provides to use all the energy which have been produced at the power plant.

There must be some permissions from the state agency if there is any usage of the state area. If power production plant would be inside of the boundaries of the area which includes power consumption plant, there is no need for any permission about using the area which belongs to state agency. Only wind turbines may need permission regarding hub heights of the proposed wind turbines. Hub height of the selected wind turbine is allowed to be less than 60 meter. But if, the hub height of the wind turbine would be more than 60 meters, the state agency departments may ask for additional permissions, due to the possible interference with radar systems, or with wild life concerns. Large energy production systems need measurement for the potential of wind and solar at the location which is planned as the project area. This rule changes for the unlicensed energy production systems. There is not any condition to measure potential of wind and solar on the area.

The state agency supports using domestic materials on the power plant systems, and buys energy for ten years as guaranteed. Cost of the electricity is constant but new regulations provide cost changing on different periods within a day. Electricity distributor companies divided a day into three different time periods as daytime (06.00-17.00), peak time (17.00-22.00) and night time (22.00-06.00). On the daytime period the electricity costs decreases 6% compared to the constant costs. On the peak period the electricity costs increases 49% compared to the constant costs. And on the night period the electricity cost decreases 45% compared to the constant costs. Once energy production is higher than demanded energy amount, this surplus energy can be sold to grid, however when produced energy amount is lower than energy demand, missing energy amount is supplied by grid. In order to count sold and bought energy amount, two-way counter is located on the energy system. After calculation, consumer (producer at the same time) would pay, if the consumption is more than the production. Or consumer would get money from state agency, if the production is more than consumption. Cost of electricity can change from company to company. But the standard cost of lightening is 41.51 Kr/kWh on Enerji Piyasası Düzenleme Kurulu. This cost can be changed from company to company. But the periods are constant. State agency pays to the producer 13.3 $ Cent for each extra kilowatt when the producer generated more energy than the consumption. If there is more consumption than production, consumer pays to the state agency or seller company according to the using electricity.

These rules are taken from the related law which is 'Elektrik Piyasasında Lisanssız Elektrik Üretimine İlişkin Yönetmelik". This regulation is published on 2nd October, 2013 by the Enerji Piyasası Düzenleme Kurulu. This regulation has been revised and published in 2016 by EPDK [38].

2.3. Goals of the Thesis and Report Outline

The main goal of this study is to develop a tool which can calculate a number of wind turbines and solar PV panels in order to meet the identified electricity load. Based on electricity demand and project specific inputs like wind speed, solar irradiation, temperature, some loss factors, calculation and design of a wind-solar hybrid energy system that can be done by using the developed tool. Results will be compared to a commercial hybrid energy system calculation software, Homer Pro, in order to show the accuracy of the developed tool, also being in line with the predictions and being consistent with the Homer Pro Software results in order to verify results calculated by the developed tool. It is not expected to have the exact results with the aforementioned software hence hourly data use of the Homer software, instead of the monthly data use of the developed tool. This tool has been developed for users who would like to have an idea before a detailed energy production assessment. It can be used by the project developers, investors and stakeholders in order to decide for next stage of a project.

The specific objectives of this study are;

- To develop a tool in order to design a wind-solar hybrid energy system according to energy demand.
- To receive results that are in line and are consistent with a commercial software named as Homer Energy.
- To design the most economical hybrid energy system via the use of the developed tool.

Considering the main goal of the study, report outline has been shaped as;

- History of all energy resources have been mentioned in order to show development stages of all technologies and how renewable energy resources have been used to generate energy.
- Explanation of the hybrid energy system types.
- Importance of database use and measurement techniques of wind and solar resources, including the energy calculation formulas.
- Previous studies regarding the hybrid systems and explanation of their similarities and differences with this current study.
- Details of the developed tool and the use of Homer Energy Software.
- Results of the current study which are based on two locations which have been considered for energy calculations and different configuration have been found and shown.
- Discussions on the current study.
- Finally, achievements and missing points are provided in the conclusion of this study.

CHAPTER 3

DATABASE

It is important to evaluate energy resources and site locations to decide where would be preferred in order to design an energy power plant. Therefore, energy potential of the area should be known firstly. It is inevitable to lose energy and time, if potential of energy resource(s) at the site has not been investigated. There is therefore a need for a database including some parameters to calculate the potential of power generation, investment and operation costs, as well as the power distribution ratio for the wind and solar energy systems in a hybrid energy system. Especially for this study, database is the most critical point in order to optimize hybrid energy systems. Data of energy resources are depended on metrological differences for all locations.

Database of energy resources has been created throughout the continuous measurements in years. Measurement techniques are mainly two types, numerical and observed techniques. Numerical measurement techniques have been modeled based on terrain. Observed measurement techniques are based on sensors or special devices located on the ground. Instead of observed measurement methods, modeled virtual data based on satellites and modeling methods are on consideration in the world.

Data collection through measurement provides to create database for every energy system and the area that is desired. After calculation of energy potential of a site, a suitable energy system via the distribution ratios within the potential system will be chosen. For instance, once the solar direction on the ground is known, it would be easy to locate solar PV panels and design the system. With the same idea, calculation of costs of investment, operation and maintenance can be made, and that would provide to learn feasibility of the project. All these calculations depend on true and reliable datasets. All steps have been considered in this study with the knowledge of the importance of data of energy resources. After the best data collection, optimization of wind - solar hybrid energy system with the best economical and efficient solution would be possible.

3.1. Wind Data

There are different ways to collect wind data. Meteorological mast (will be called as 'Met Mast') with anemometers and wind vanes, satellites, created wind atlases are the most using methods. Their accuracy and sensitivity is important to calculate wind energy output from wind turbine.

Currently used wind measurement technique is mostly via cup anemometers located on met mast. Limit of missing data is 20% of the total measured period. If the missing period is more than 20% of the overall data, measurements should be continued or to be completed by nearest meteorological station data. Wind power plant projects and designs have been done according to this dataset from the met mast. Current standard to erect a met mast is WMO/CIMO No.8 [39]. World Meteorological Organisation (WMO) proposes to coordinate activities of its members in the generation of data and information on weather, climate and water, according to internationally agreed standards. Commission for the Instruments and Methods of Observation (CIMO) has periodically reviews contents, and recommends required details to the standard of WMO/CIMO. According to the WMO/CIMO, there should be some sensors and devices which measures various data. There should be at least 2 anemometers, that measures wind speed, at two different heights. Based on the information provided in WMO/CIMO standard, met mast should be at least 60 m high. There should be at least two anemometers which are located at the centre and top of the mast, with a lowest anemometer height of 30 m. It is possible to add one additional anemometer to 60 m height met mast, to 1.5 m below from the top anemometer. Additional anemometers can be located on mast in case the mast is taller than 60 m. There should be two wind vanes located on the met mast. One of them should be located on 30 m and another one should be located at least 1.5 - 2.5 m below from the top anemometer. It should be considered that booms are directed in accordance with prevailing wind direction. By this way, measurement would not be effected by the mast or other sensors. At least, one humidity and one temperature sensor should be located on met mast as well. According to WMO/CIMO, it should be considered to install same type of devices in the same direction, and also a number of devices should be in accordance with WMO/CIMO Standard. These would provide to collect data with minimum missing data and to synthesise data from one to another in order to fill any possible missing data periods

[40]. Below Figure 3.1 shows the details of the required meteorological mast configuration [39].

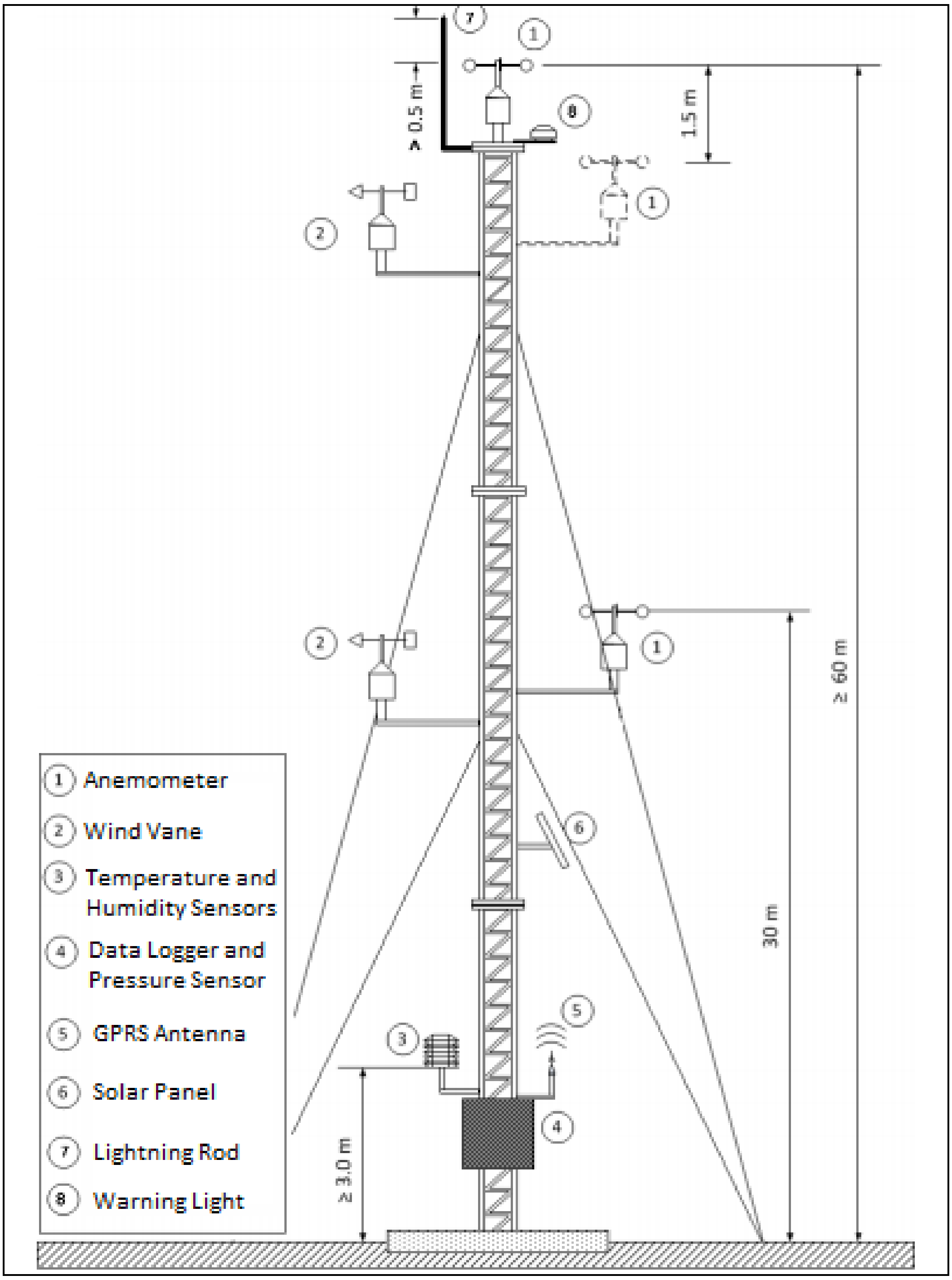


Figure 3.1. Measurement mast with required devices [39]

Measurements should continue at least one year in order to collect and assess features of the wind regime at the mast location [39]. By using the measured data, statistical data are created and behavior of the wind is observed.

Another measurement technique to obtain data is by satellites. This method has been developed to get data for offshore wind farms. There is not any met masts or any other technology in order to measure wind at the sea. This method provides wind data together with all the other meteorological conditions. By this method, pre-analysis could be done, or by comparison with measured data on site, and the reliability of measured data could be assessed. This method is useful to identify correlations of the on-site measurements and especially to generate wind atlas.

Wind atlases provide information on the wind regime at the desired location in the world. The first wind atlas has been made by Ib Troen and Erik L. Petersen in 1989. European Commission has provided a fund to Troen and Petersen, in order them to work on European Wind Atlas project. Considering 220 meteorological stations located across Europe, European Wind Atlas was first published in 1989 for the Commission of the European Communities by the Risø National Laboratory. Atlas includes the theory and the methods and the final product of the Observed Wind Climate and Regional Wind Climate dataset from each station [41]. After this evolution, countries have started to create their own wind atlases. Turkey has made its own wind atlas in 2002 [42].

In order to calculate the wind speed, some parameters should be calculated first. Measurement height and hub height of the wind turbine could be different; therefore, wind speed on hub height should be calculated based on wind speed at the measurement height by using a Log Law or Power Law or other special calculation methods which are preferred in commercial software. Power Law method will be used in this study in order to calculate wind speed at any height since it works better for small wind turbine. It should be noted that log law would give better results for larger wind turbines. Equation given below is the Power Law:

$$\frac{v}{v_0} = (\frac{z}{z_0})^{\propto} \tag{3.1.1}$$

Where (v) is the wind speed at the desired height (z), (v_o) is wind speed at the reference height (z_o), (α) is the ground surface friction coefficient. According to many authors, the typical value of α(1/7=0,143), corresponding to low roughness surfaces and well exposed sites, is used by many authors[43].

$$f(v) = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} . exp\left(-\left(\frac{v}{A}\right)^{k}\right) \quad (3.1.2)$$

Weibull distribution will give wind speed probability density where k (shape factor), A (scale factor) and v (wind speed).

k (shape factor): This parameter shows the frequency of the wind. If there is not much change in the wind speed at a site, with almost constant speed, k parameter would be a large value. Possible range for the k parameter is 1,5-3.

A (scale factor): This parameter shows frequency of the relative cumulative wind speed. It changes according to average wind speed. If average wind speed is much, A parameter would be of a large value [44].

Kidmo et al. [45] has done a study for different Weibull methods. The most known six methods have been explained in the study. Empirical Method has been used in this study due to absence of time series data. Below functions should be solved by using wind speed data at the site in order to calculate the Weibull k and A parameters [45]:

$$\sigma = A\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^{2}(1+\frac{1}{k})\right]^{\frac{1}{2}} \quad (3.1.3)$$

$$k = (\frac{\sigma}{U})^{-1,089} \quad (3.1.4)$$

$$A = \frac{v_m}{\Gamma(1+\frac{1}{k})} \quad (3.1.5)$$

Weibull distribution is applied for all measurements on a monthly basis. Then, all sectors and all months have their own specific Weibull parameters, and wind speed distribution is created. These parameters provide us to calculate wind speed at the site for all sectors. Based on the A and k parameters of the Weibull distribution, wind speed can be calculated for all months by using a Gamma Function. Below function shows the equation in order to calculate the wind speed by using Gamma Function:

Wind speed; $$U = A.\Gamma(1+\frac{1}{k}) \quad (3.1.6)$$

Wind speed calculated by the above equation is used in order to calculate the wind energy.

Air density is a significant parameter in order to calculate wind energy production with high accuracy, because an increase in the air density value causes to generate more energy from winds. Kinetic energy that passes through wind turbine is proportional to air density. Output power of wind turbine increases with increasing air density. On normal atmospheric pressure at the sea level with the temperature of 15ºC, the air density value is 1.225 kg/m^3. Air density depends on the temperature, altitude and humidity. Depending on these variables, it is expected that air density is lower at higher temperatures and higher values of altitude. Therefore, there is not any certain approach about air density level of cool or warm air. However, it has been known that at the high altitude (at mountains) air density decreases due to the decreasing air pressure [46]. The WAsP Air Density Calculator calculates air density [kg/m^3] as a function of altitude (elevation) Z [m a.s.l.] and the mean air temperature at the same height. A lapse rate of 6.5 K/km and a sea level pressure of 1013.25 hPa are assumed [47]. Below table presents, average air density values at variable altitude and temperatures. According to this table, air density value can be higher at lower altitude than higher altitude, for lower temperature value. For instance, at 0ºC and 1000 m altitude, air density is 1,142kg/m^3 , however air density at 40ºC and sea level is 1,127 kg/m^3. So that, air density should be calculated project specific instead of any assumption.

Table 3.1. Air Density Distribution according to Altitude (Z) and Temperature (T)

Z - T	**-20**	**-15**	**-10**	**-5**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
0				1,316	1,292	1,269	1,247	1,225	1,204	1,184	1,164	1,145	1,127
100				1,300	1,276	1,254	1,232	1,211	1,190	1,170	1,151	1,133	1,115
200				1,283	1,260	1,238	1,217	1,196	1,176	1,157	1,138	1,120	1,103
500			1,258	1,236	1,214	1,194	1,174	1,155	1,136	1,118	1,101	1,084	
1000		1,200	1,180	1,161	1,142	1,124	1,106	1,089	1,073	1,057	1,042		
1500	1,143	1,125	1,108	1,091	1,075	1,059	1,043	1,028	1,014	1,000			
2000	1,072	1,056	1,041	1,026	1,012	0,998	0,985	0,971	0,959				

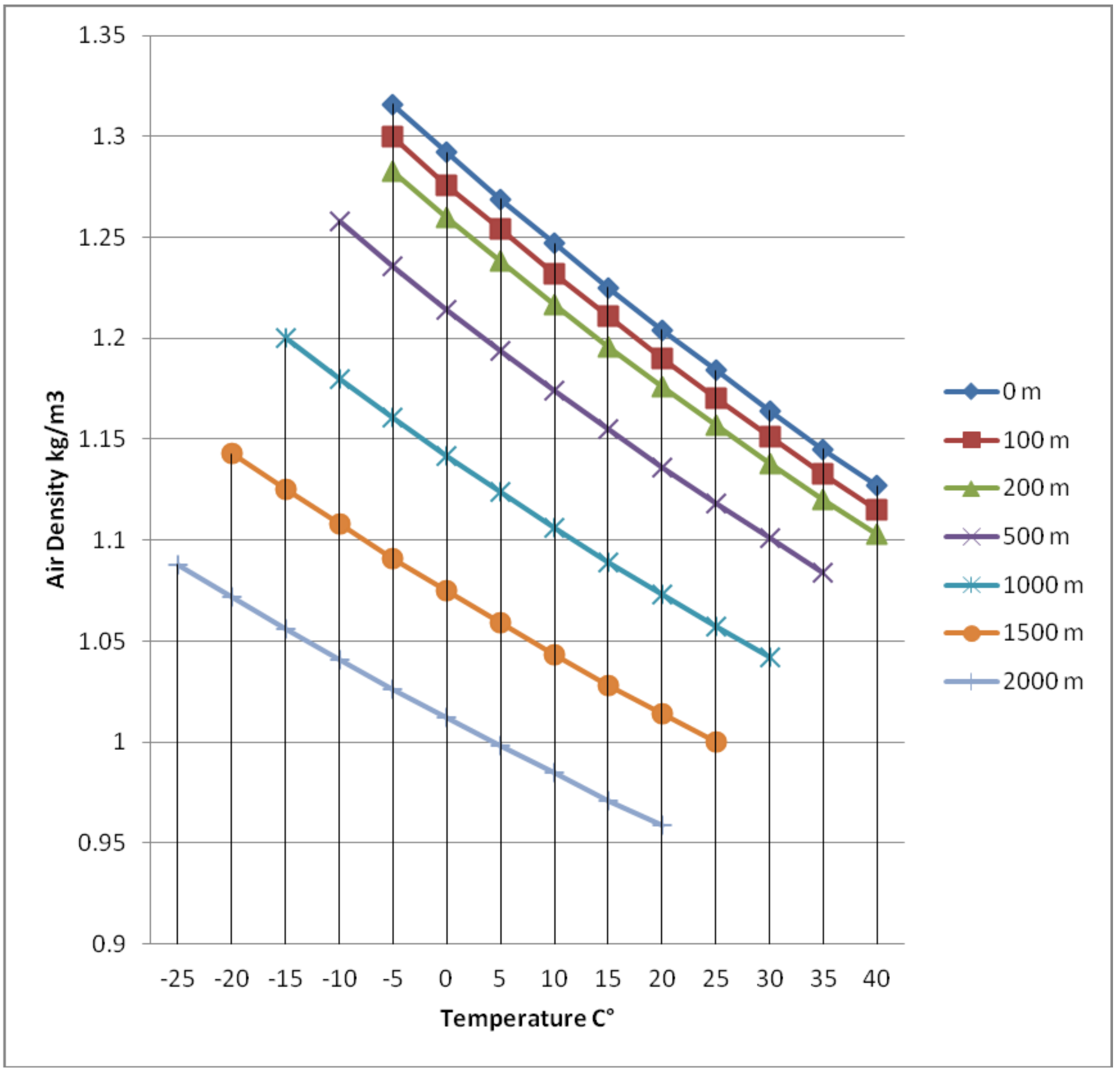


Figure 3.2 Air Density Distribution with respect to the Altitude (Z) and Temperature (T)

Based on the above functions and calculations, nominal power production by a wind turbine is calculated with below equation;

$$P = \frac{1}{2} x \rho x U^3 x A_s x C_p \qquad (3.1.7)$$

ρ: Air density [kg/m3]

U: Wind speed [m/s]

A_s: Swept area of turbine blade [m^2]

C_p: Capacity factor of wind turbine

However there is another method in order to calculate wind turbine energy production. That is through the design power curve of the wind turbine. Power curves are created based on measurements done by turbine manufacturers. According to nominal power production calculation, wind turbine is designed. After some computer based tests, a prototype is produced and tested on test site. Power output of the prototype is measured and according to recorded results power curve of wind turbine is clarified. If required, with design revisions, wind turbine model is published with its power curve. Therefore, reliable results are obtained by this method which is called the *effective* power production calculation. Below, difference between the two methods is shown[Figure 3.3]

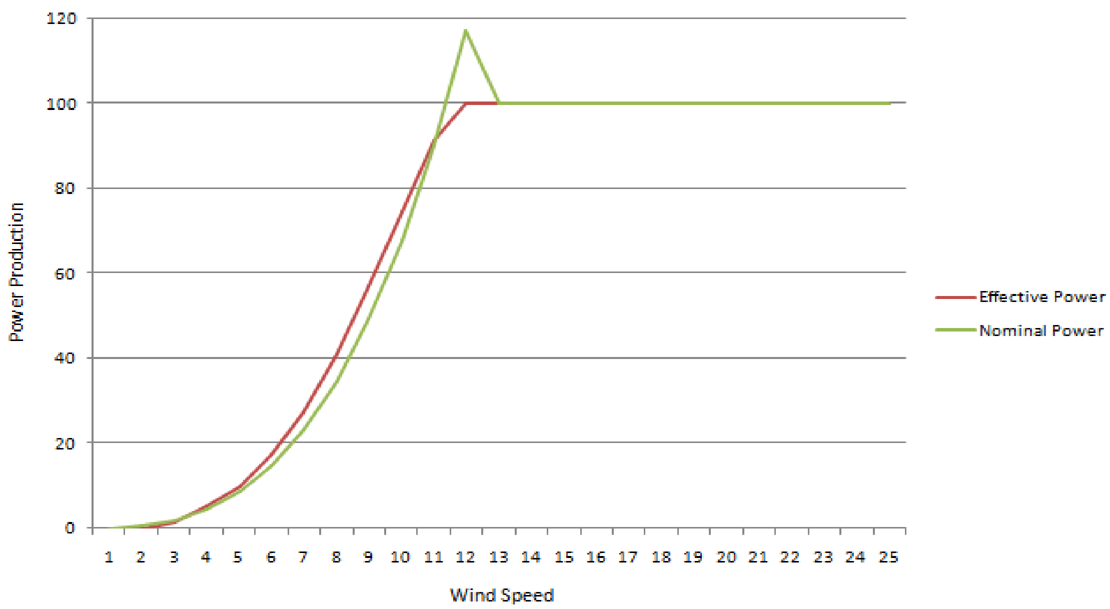


Figure 3.3. Power production difference between the Effective and Nominal power production

Polaris P25-100,100 kW wind turbine model has been used for this study. Cut-in wind speed, is 3 m/s for this wind turbine model, therefore the wind turbine started to generate power at this wind speed. When the formula 3.1.6 has been applied for all wind speeds, power production has extended to the maximum power generation value of the wind turbine after a wind speed (11 m/s is the limit for this sample). This issue has been avoided by changing power production values to 100 kW after 11 m/s. It has been seen that the results are similar to each other for each wind speed, however, there is a difference on every wind speed. And the most important point is the extension of the power production more than turbine capacity by using the equation 3.1.6 on *Nominal Power Production*. Measurements done by producer, Effective Power Production is clearly given in power curve [48]. It should be noted that power curve values are more reliable in order to assess energy production of the wind turbine according to manufacturer's tests and realistic values. Therefore, Effective Power Production values have been considered in this study by using power curve documents of the related wind turbines.

3.2. Solar Data

There will be solar data in our project to calculate the solar power of the hybrid energy system. Therefore, solar energy potential of the area which is planned for the wind-solar hybrid energy systems location should be known.

Solar measurement station is compulsory in Turkey in order to design a solar power plant. Rules listed in WMO/CIMO should be followed in order to install solar measurement stations [39]. This station needs some devices to measure the solar data. Pyranometer, sunshine duration sensor, anemometer, wind vane, thermometer and humidity sensors are the required devices on the station. Pyranometer provides the solar radiation measurements. It should be located parallel to the ground, directed to north-south direction and placed 2-5 meter above the ground. Total solar radiation on one square meter area is measured by Pyranometer for every minute. Sunshine duration sensor follows the period of the sun effect on the area. According to WMO/CIMO, this sensor should be directed to the north, and be parallel to the ground with ±5º. The sensor measures and collects data for every minute and converts them to hourly data. Anemometer and wind vane are related to measuring the wind at the site and explained in Section 3.1 in detail. It is important to know wind speed and direction on solar energy sites too. Temperature is very important for photovoltaic panels, because any increment in temperature of the cells decreases their efficiency. Therefore, thermometer is required for all solar measurement stations. Humidity is another important parameter on the efficiency of cells, thus, humidity sensor is other required device on the station. Thermometer and humidity sensors must not be under the effect of the sun directly. These devices must be kept safe in a box that ensures air circulation [40]. If there is any obstacles that is close to the solar measurement station like trees or buildings, the distance between the station and the obstacle should be at least ten times of the height of the obstacle. If there is another solar measurement station in the area, the distance between the stations can be minimum five times of the height of the stations. These conditions provide the sunlight to reach to the pyranometer and sunshine duration sensor without any interruption. This is so important in order to measure accurate values, because, there can be some interruption reasons like clouds, rainy weather etc. If there would be any possibility an obstacle interrupting the measurement, which will cause wrong measurements and wrong solar data results. This will affect all calculations, all solar energy system design, and all energy generation by solar potential [39]. Below Figure 3.4 shows the explained required details of a solar measurement station [39].

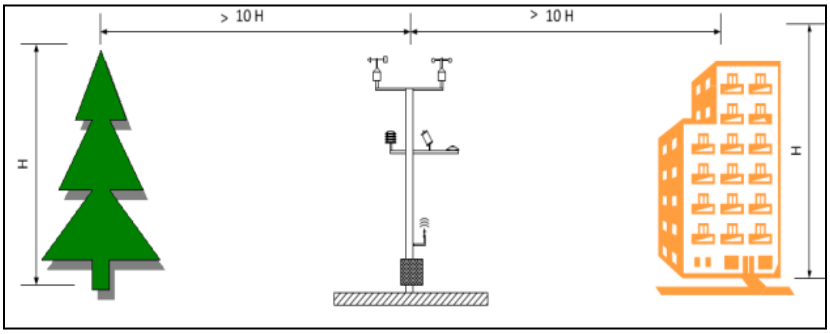


Figure 3.4. Distance between obstacles and solar measurement station [39]

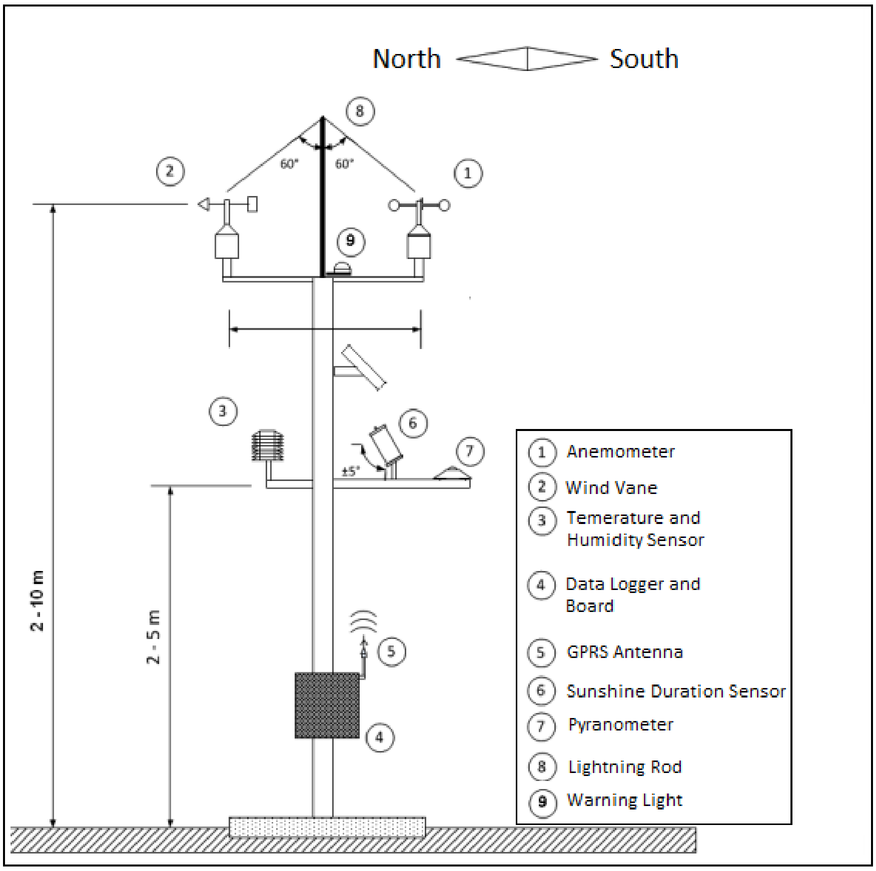


Figure 3.5. Solar measurement station with required devices [39]

The station should be installed on the proposed project area and must collect data for at least half of a year. It is allowed that there could be missing data up to 20% of the measurement period. Missing data should be completed by statistical data via the completing methods or from meteorology stations [39]. The measurement of the solar data is the most important step in the solar investments.

Modeling of the ground and the sun effect is an easy and reliable method to get solar data. Modeling process searches the shape of the land firstly. And after that, solar data is collected as most up-to-date data set from satellite, meteorological service centers, or another source. These data sets are long-term data and hence can be used for many years. Collecting data and building a model is a good way to learn solar energy potential of any point at the ground. However, this method is not allowed based on the Turkish regulations. But a modeling system in this project has been used, since availability of long-term data is easier to reach than to installing a solar measurement station. NASA solar data have been obtained and considered in this project. Homer Energy Software takes solar data from NASA too. So that, this harmony is useful for our project.

Data sets used in the renewable energy industry have been developed with a project named as Prediction of Worldwide Energy Resource (POWER) by NASA. Earth Science Enterprise has been used for this study. By using satellite monitoring technique and parameters recorded in time by meteorological departments, a solar data set has been produced and named as the Surface meteorology and Solar Energy (SSE) data set. This data set consists of totally 22 years of data between July 1983- June 2005. It was developed with only one grid (one degree of latitude-longitude). Missing data on the ground has been completed by using SSE data set. Coverage of this data set is suitable to use across the world. Climate has been affected by natural and man-made settlements. In case of measurements conducted on the ground that are close to these settlements, erroneous data sets would be recorded. Measured data sets which is influenced and recorded incorrectly, skeptical or missing periods can be extended by using SSE data set. Some parameters have been used for solar activities. Wind resource information, air density, temperature, cloudiness (clearness effect) and humidity are the main parameters in order to size and to define the location of the solar panels and other solar thermal activities. For the renewable energy systems, especially solar projects, the SSE data set has been used, and this data set enables to assess feasibility of the projects as pre-study.

Data sets are accessible in the web site of SSE [49]. It is important for the renewable energy projects globally to obtain data from a web site as a reliable dataset on one by one degree resolution. User-friendly interface of this web site provides to access data with specific latitude-longitude information. List of the parameters related to solar energy including 200 parameters is able to be arranged by the user. It is possible to get data map for any location occurred by minimum six degrees of latitude and longitude. The maps can be colored according to resource availability and parameters. More resources are included on the web site [48].

In developed tool for this study, there will be different solar data parameters. The most known method to measure solar energy potential of the area is to erect a solar measurement station. The most useful method is modeling the ground and taking data from last measurements to make it general.3

Solar radiation is the base of solar energy that comes directly and via diffusion from the sun. Below figures and equations explains the solar radiation [50].

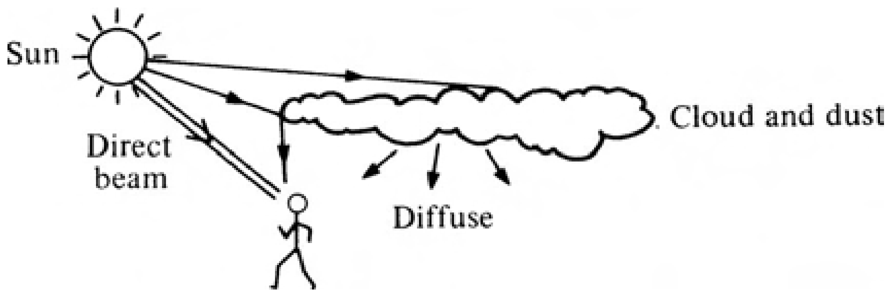


Figure 3.6. Origin of direct bean and diffuse radiation[50]

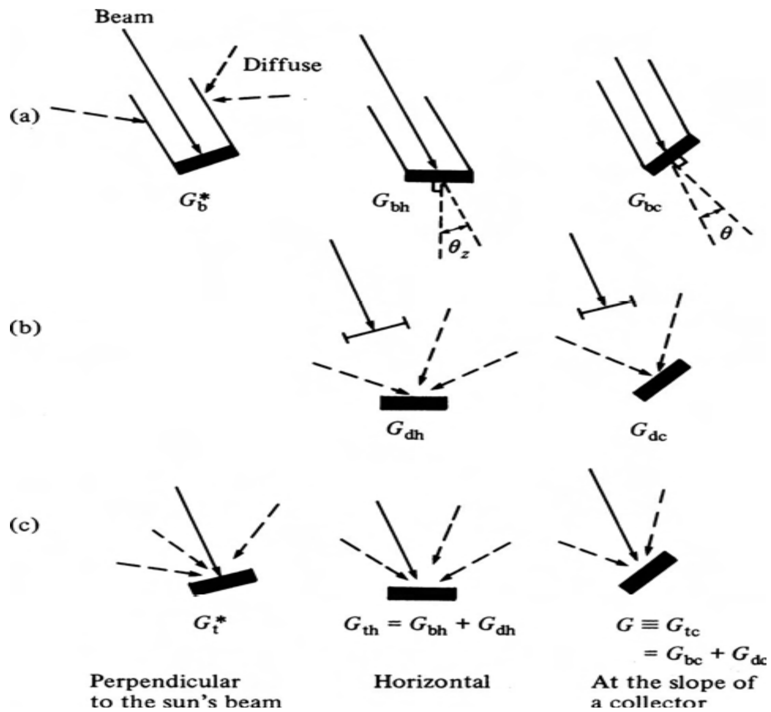


Figure 3.7. Techniques to measure various components of solar radiation. [50]

The detector is assumed to be a black surface of unit area with filter to exclude long wave radiation (a) Diffuse blocked. (b) Beam blocked. (c) Total. [50]

Where *b* for beam, *d* for diffuse, *t* for total, *h* for horizontal plane and *c* for the plane of a collector. Asterisk * denotes the plane perpendicular to the beam. Subscripts *c* and *t* are assumed if no subscripts are given.

$$G_{bc} = G_b^* Cos\theta \tag{3.2.1}$$

G_{bc} is beam solar radiation

θ is the angle between beam and the normal to the collector

$$G_{bh} = G_b^* Cos\theta_z \tag{3.2.2}$$

G_{bc} is horizontal solar radiation

θ_z is the zenith angle between the beam and the vertical

Total irradiance on any plane is the sum of the beam and diffuses components;

$$G_t = G_b + G_d \tag{3.2.3}$$

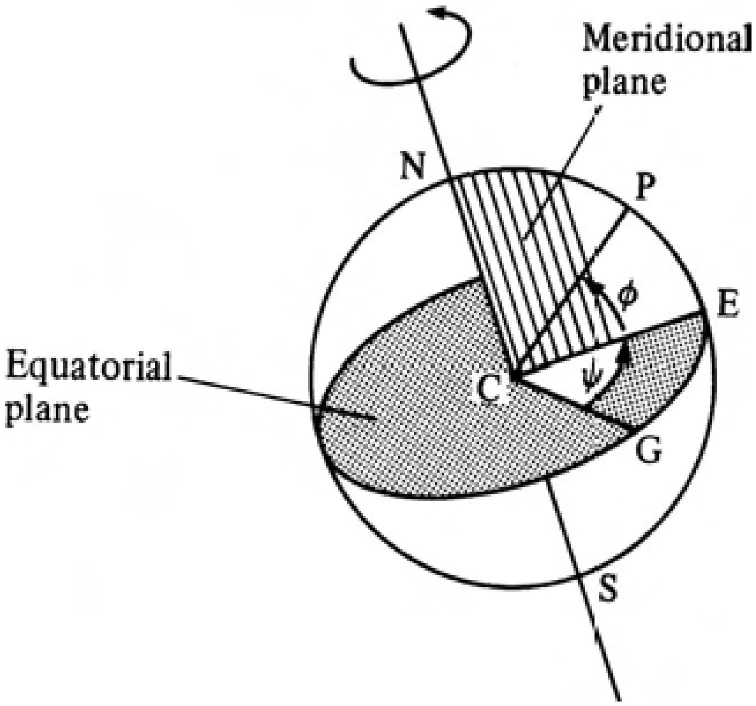


Figure 3.8. Definition sketch for latitude and longitude[50]

In this figure given symbols are;

N:North pole

S: South pole

C: Center of the Earth

P: Point on the Earth's surface

Φ: Latitude

Ψ: Longitude

E and *G* in Figure 3-8 are points on the equator having the same longitude as P and Greenwich respectively.

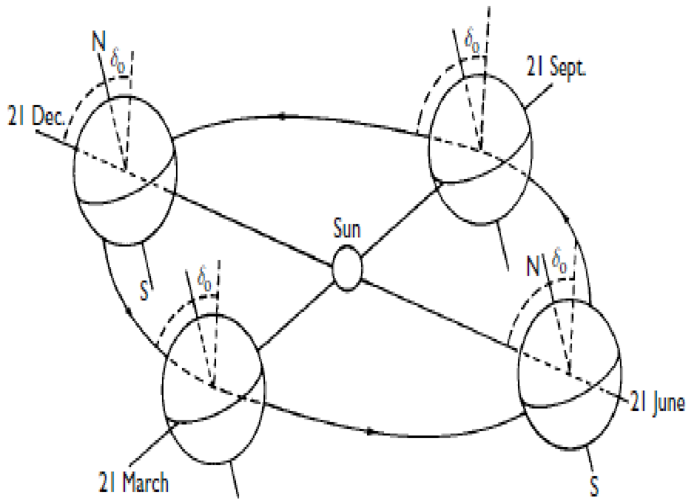


Figure 3.9. Seasonal revolving of the Earth around the Sun without scale.[50]

The hour angle ω at P is the angle through which the earth has rotated since the solar noon.

Since the Earth rotates at $360^{o}/24h=15^{o}h^{-1}$

$$\omega=(15^{o}h^{-1})(t_{solar}-12h)$$

$$\omega=(15^{o}h^{-1})(t_{zone}-12h)+\omega_{eq}+(\psi-\psi_{zone}) \quad (3.2.4)$$

where t_{solar} and t_{zone} are respectively the local solar and civil times (measured in hours),$_{zone}$ is the longitude where the Sun is overhead when t_{zone} is noon (i.e. where solar time and civil time coincide). ω is positive in the evening and negative in the morning. The small correction term $\omega_{eq}$is called the equation of time; it never exceeds 15 min and can be neglected for most purposes. It occurs because the ellipticity of the Earth's orbit around the Sun means that there are not exactly 24 h between successive solar noons, although the average intervals are 24 h [50].

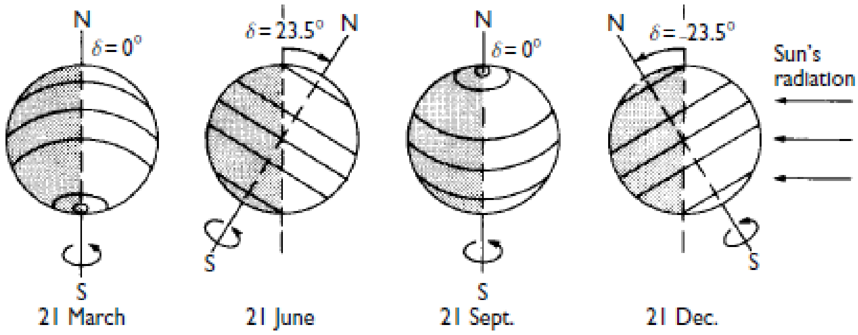


Figure 3.10 The earth as seen from a point further along its orbit. Circles of latitude 0°, ±23.5°, ±66.5° are shown[50]

$$\delta = \delta_0 \left[\frac{360^0(284+n)}{365}\right]$$

Where n is the day in the year (n=1 on 1 January) (3.2.5)

$N=(2/15)\cos^{-1}(-\tan\varphi\tan\delta)$ φ is the latitude of your location (3.2.6)

Insolation is the energy source at the location of solar power plant. This affects the photovoltaic system output power directly. Insolation depends on shape of location, longitude-latitude values, seasonal differences etc. The main reason of the difference in insolation is the position of the sun. Position of the sun changes from time to time in a day as well as in a season, and in a year. But, this change can be recordable in years. Records cannot be different from year to year in large ratios. General aspect of the historical long term records is that almost same insolation values have recorded in years. Today, the main methods to get insolation data are via direct measurement of the solar radiation pattern at the area which is planned as a solar power plant throughout a year or more data measurement or purchasing the data from the meteorological department. Both of them are efficient but expensive methods. Both of them gave solar radiation value that depends on insolation data. Solar radiation is related to the data that has solar power value at one square meter area during a day. All photovoltaic systems have been installed according to this data basically. Knowledge of monthly or daily solar radiation value ensures designing solar power plants at the first step. After this data we need to know other inputs. The most important inputs except solar radiation data are clearness and average temperature of location [50]. Clouds, dust and other natural and environmental effects avoid solar radiation to reach the ground, therefore a factor is considered as *Clearness*.

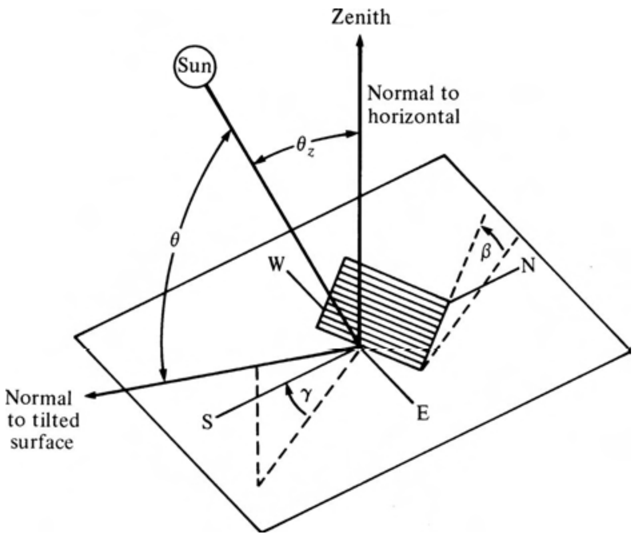


Figure 3.11. Zenith angle θz , angle of incidence θ, slope β and azimuth angle γ for a tilted surface[50]

$$\text{Cos}\,\theta = (A-B)\sin\delta + [C\sin\omega + (D+E)\cos\omega]\cos\delta \quad (3.2.7)$$

$A=\sin\varphi\cos\beta$

$B=\cos\varphi\sin\beta\cos\gamma$

$C=\sin\beta\sin\gamma$

$D=\cos\varphi\cos\beta$

$E=\sin\varphi\sin\beta\cos\gamma$

$$\cos\theta = \cos\theta_z\cos\beta + \sin\theta_z\sin\beta\cos(\gamma_s - \gamma) \quad (3.2.8)$$

This is of importance to find the optimum angle of photovoltaic solar panel between the ground and the panels, as efficiency of the panels would be affected directly by this angle. Since the maximum energy production would be expected at the solar energy system, it should be found for this study which is located in Izmir Institute of Technology Campus.

Based on the functions above, optimum angle of PV panels has been calculated as 38.5° for IZTECH campus area. This value will be considered in this study as a parameter in order to take advantage of sun light ideally.

$$H_c = \int (G_b cos\theta + G_d)dt \tag{3.2.9}$$

H_c is the total Insolation from the beam and the diffuse components.

$$G_h \approx G_h^{max} sin\left(\frac{\pi t'}{N}\right) \tag{3.2.10}$$

Where t' is the time after sunrise and N is the duration of daylight for the particular clear day.

$$H_h \approx (2N/\pi)G_h^{max} \tag{3.2.11}$$

So, at latitude $\pm 50°$ in midsummer, if $G_h^{max} \approx 900\, Wm^{-2}$ and N $\approx 16h$, $H_h \approx 33MJm^{-2}day^{-1}$. If $G_h^{max} \approx 200\, Wm^{-2}$ and N $\approx 8h$, $H_h \approx 3.7MJm^{-2}day^{-1}$. If $G_h^{max} \approx 950\, Wm^{-2}$ and N $\approx 12h$, $H_h \approx 26MJm^{-2}day^{-1}$. These calculations show that the Insolation depends on different variables and mostly depends on duration of sunlight. Clearness is the most important parameter at this point. Clearness effect causes to drop of energy production by 50-70% when compared to the clear sky energy production [50]

Insulation of panels is necessary in case of cloudless sky is common condition at the project area. Direct beam radiation effect can be avoided by the isolation. There are some ways to predict direct radiation with the knowledge of availability and current period of the required data. Based on the prediction of direct radiation, assessment of energy production of solar panels would be more reliable. If amount of clearness index in the period that we measured or computed by modeling is known, this would provide to calculate and design the most efficient solar power plant. Other important parameter is average temperature of the area. Increments in temperature is not beneficial for solar cells. Cell efficiency decreases with the increasing air temperature [51].

Thus, solar radiation, clearness and average temperature of the proposed area for the solar power plant, have been used as the parameters to calculate solar power. Data have been obtained from NASA for solar radiation and clearness index, meteorological department of ministry for average temperature. Solar beam strikes the ground by passing through the atmosphere. Dimensionless value of the clearness index is between

0 and 1, also this value is site specific. The following equation defines the monthly average clearness index:

$$K_T = \frac{H_{ave}}{H_{0,ave}} \tag{3.2.12}$$

H_{ave} :is monthly average radiation on the horizontal surface of the earth [kWh/m^2/day]

$H_{o,ave}$:is the extra-terrestrial horizontal radiation, meaning the radiation on a horizontal surface at the top of the earth's atmosphere [kWh/m^2/day] [52]

Clearness index has been included in solar irradiation data obtained from NASA.

In order to calculate energy produced by photovoltaic panels, basic formulation below has been used in this thesis.

$$P_{PV} = An_{PV}H_h n_d \rho_g \tag{3.2.13}$$

In the formula, A is area of photovoltaic panel, n_{PV} is photovoltaic module efficiency and ρ_g is the ground reflectance. Below equation identifies peak power that can be generated by a PV panel;

$$P_{pk} = An_{pv} \tag{3.2.14}$$

In this case, it is suitable to write this equation Power Output of Solar Photovoltaic Panels;

$$P_{PV} = P_{pk}H_h n_d \rho_g \tag{3.2.15}$$

Solar energy generation by PV modules is calculated by this formula finally. n_d is the de-rating factor of the PV modules. It should be considered as an efficiency coefficient in the calculation. Inverter and transformer losses, wiring losses, system availability and dust losses are included to n_d de-rating factor. It should be evaluated detailed and calculated project specific, however, in this thesis, energy results will be presented as a pre-assessment of the hybrid system. Suitable range of de-rating factor can vary between 0.65 - 0.90 according to the project. This effect has been considered as 0.80 for this thesis. In addition to that ρ_g, ground reflectance factor, has been considered in this study. This fraction should be included in the calculation of solar power output as a loss of 0.20 for grass-covered areas. It is possible to assume this value 0.70 for snow-covered areas [50].

Panasonic HIT N330 model PV panel is considered in this study. One panel capacity is 330W and maximum module efficiency is 19,7% which is significantly good for energy production. It is expected that power output of PV panels will decrease as ratio of 5-10% due to aging on cells. This loss has been included in loss factor assumptions. Relevant information provided in technical document [54] of this PV panel have been used in the study.

CHAPTER 4

METHOD AND THEORY

In accordance with the development on energy generation systems, several studies have been made in years regarding the hybrid energy technology in the world [55, 56, 57, 58, 59]. Some of them focused on using different energy resources together, whereas the rest looked into finding the best and useful ratio of each energy supplying system for the proposed hybrid energy systems. Thus, the first step is the choice of the energy resources that are desired to be used together, and the second step is the optimization of the system. Some conditions should be considered during the design process of the system. The most important condition is the economy; the energy saving system's material, data on resources, size of each part or module of the energy providing system should be considered in order to optimize a hybrid energy system. At the beginning of the calculations, all design parameters should be clear with respect to these conditions that should be considered in our own optimization model.

Wind and solar energy resources are used in order to make a hybrid system in this study, because these resources are available almost in everywhere around the world. In addition to that, there is no need to carry these resource from the source area to energy production system, as it is the case for fossil fuels.

Our method is based on the economy of the hybrid energy system. And also the methodology will consider the design of the hybrid energy system with minimum investment on the wind and solar energy systems. There will be different results according to the location that is considered for installation of energy generator systems. For instance, result of the study as "40% of the system is wind energy, 60% of the system is solar energy" is the best result for a point or it could be as "100% of the system is wind energy" is the best result for a location. These results are dependent to the energy resource of the point of interest for implementing the wind and solar power energy facilities. Wind and solar data are obtained for different locations. After using data of the energy resources of each location, calculation of the best combination of wind and solar energy hybrid system, considering the investment on the wind turbines and solar photovoltaic panels will be completed. Some parameters will be required in order to calculate hybrid energy system for any location as specified at the Section 3.1 and Section 3.2. The selection parameters are the Weibull A, Weibull k and the air density calculation for the wind energy, and for solar radiation calculations, clearness index and average temperature are the used parameters. A special table for any location where we would like to assess the potential for the hybrid energy is used. This table data will provide us the calculation requirements. Electricity demand of the consumer who would like to use hybrid energy system should be known for the model. This will provide us to optimize hybrid energy system that we would like to calculate according to the demand. In addition to the main data, loss factors for both components, ground reflectance and derating factor for solar system would be considered in this study. Wind and solar energy distribution of the system for all electricity requirements of the consumer will be optimized.

This calculation will be based on the unlicensed energy production rules. The proposed energy generating system will consider the limit of 1 MW installed capacity as requested by the regulations for the proposed unlicensed energy power plant. This capacity limit can be increased to 2MW, 3MW or 5 MW by founding a cooperative which contains partners between 100-500, 500-1000 and more than 1000 respectively. According to the regulation published by Energy Market Regulatory Authority, EMRA, distance between power production system and energy consumer should be closer than 5-6 km for the projects which are under 0.5 MW capacity, and this distance should be closer than 10-12 km for the projects which are between 0.5-1.0 MW capacity [37, 38].

100 kW wind turbines have been considered in this study, however due to high energy demand, numbers of wind turbines can be increased to meet the need for larger capacity wind turbines, therefore 250 kW, 750 kW and 1000 kW wind turbines can be considered in order to estimate investment cost of the project.

4.1. Assessment of Wind and Solar Energy

There are various studies which are conducted regarding the hybrid energy systems prior to this thesis. Considering these studies, it is observed that many different areas and results on hybrid energy technologies are made by researchers.

Esmail, Mokheimer and Abdullah et al. [44] have developed a sizing optimization method for off-grid hybrid wind-solar energy systems. Battery has been added to the system in order to supply energy in case of no energy production occurs. MATLAB has been used in order to run the mathematical model. Row data in Dhahran, Saudi Arabia have been used for this study and results have been compared with the predictions of the Homer software. Results found in this study are consistent with Homer results.

Borowy and Salameh et al. [54] have improved a methodology in order to calculate battery size and power of PV system for a stand-alone wind-solar hybrid system in 1996. 30 years hourly wind and solar data have been assessed for calculation of hourly energy production, and the calculations were extended to daily and monthly production. Electrical load of a house has been considered on the study and the system has been designed according to minimizing the costs of the hybrid system.

A linear programming technique has been developed to optimize the hybrid wind-solar energy systems that is related to minimise the electricity production costs by Chedid and Rahman in 1997 [56]. Different variables used in the study are the cost of the system, the cost of energy production, battery losses and unmet energy requirements.

There are researches about the effects of variables in performance and economy of the system [57, 58, 59]. Eke, Kara, and Ulgen et al. [58] have conducted a similar study to this current thesis project. Their research has been based on energy demand of the Solar Energy Institute of the Ege University. 8 years of data have been used in this project and a model has been developed considering the hourly data. Hourly, daily, and monthly basis correlations have been conducted. Based on the results found in the study, for wind-solar resources economic and efficient utilisation is possible.

Habib et al. [59] has studied an optimization technique for wind-solar hybrid energy system in order to meet the demand of fixed 5 kW energy. He found that the cost of the hybrid energy system depends on the wind and solar energy systems usage ratio. The capital cost decreased 30% according the optimal usage ratio. He completed the study in 1999.

Zolot et al. [60] has found a methodology to evaluate and segregate load demand and characteristics for sizing hybrid energy system to know load types which are best suited and published in the study back in 2003. In the same year, Celik et al. handled stand-alone wind-solar hybrid system based on the techno-economic principle and developed a methodology. This method tried to optimize system costs based on the worst month, however their method was not effective to save costs of the proposed system, therefore he decided to use a third energy resource in order to make the system more efficient with respect to the energy and economical costs [61].

Vick et al. [62] has studied a combination of wind generator (500 W) and solar PV panels (100 W) in order to pump water. This hybrid system pumped water for 4000 people in 2003. A plain calculation methodology has been studied by Zhou, Yang and Fang2008 in order to calculate the lead-acid battery acting in a similar way to the stand-alone wind-solar hybrid energy systems. Main focus in this study was thelead-acid battery system investigation. Monthly and hourly variations of Battery state of charge (SOC) have been investigated and it has been seen that PV system has effected battery system more than wind turbines and [63].

Hocaoglu et al. [64] developed a new technique in 2099 to optimize battery capacity, together with the optimum number of PV modules and wind generators. This technique has been developed according to the production and consumption balance. In order to verify this technique, based on the date recorded on Campus of Anadolu University, the technique has been worked and results have been compared with SOC method results in order to validated. A sizing method based on the performance of the wind-solar hybrid system considering one year data has been studied by Engin and Engin2012, also the total cost of the system and the best size for hybrid energy system has been considered in this study [65].

Xiang et al. [66] and Engin et al. [67] have both developed models for sizing the hybrid system, using wind generator, photovoltaic cells and batteries, however, Xiang's model was completely stand-alone hybrid micro grid system, whereas Engin has studied annual performance of the variables in PV-wind systems. They have done these studies in 2012 and 2013 respectively. Studies have been conducted based on the required battery capacity, and then wind turbine and photovoltaic panel numbers have been calculated. Also, Xiang has preferred to use the Weibull distribution in order to calculate wind speed in their study. Xiang has tested developed model for an office located in Zhoushan and according to different configurations, the optimum cost efficient system designed. Also, Engin has applied his model to a security lighting system and found cost of energy as well as loss of load probability.

Clearness has important effect for solar radiation on the ground and on the atmosphere that have been shown by Hollands and Huget in 1983. They have added a daily clearness index (K_t) to the literature that provided to calculate difference of solar radiation between the ground and atmosphere [68].

Tina, Gaglianoand, and Raiti et al. [69] developed a probabilistic approach for wind-solar hybrid energy systems in 2006. This study was based on the convolution method to evaluate the long term performance of the hybrid systems. Power generation could be controlled in any period by analytical expressions. The evaluation of the hybrid energy generation and economical situation according to load models could be possible in a range of only one hour of a day to whole year period.

In 2007, an optimization methodology in order to size the hybrid wind-solar energy system has been studied by Diaf et al. [70]. Their mathematical model includes PV modules, wind generators and batteries to optimize the system. Based on the loss of power supply probability method, different configurations have been found. Considering lowest levelised cost, economical one has been selected. It has been found that configuration with more PV panels decreased energy cost. However configuration containing one wind turbine and battery is optimal configuration from technical and economical point.

Hongxing, Wei and Chengzhi et al. [71] have developed a model for optimal design of the hybrid PV-wind system in 2009. The model used battery banks to calculate optimum choice leads to minimum annualized cost of the system with required loss of power supply probability.

Nfah, Ngundam and Tschinda et al. [72, 73] have studied a method to generate electricity from hybrid energy system which includes solar-diesel systems to provide energy to schools and households in remote areas of the far north province of Cameroon. They researched the same area electricity supply with wind-diesel hybrid energy system in 2007. No comparison has been conducted between two studies. Based on the model with solar PV panels, when number of PV panels are increased, system has worked more efficiently and cost of energy has decreased. For the area, hybrid system with wind turbine has studied and found that the suitable wind turbine models for the area according to wind speed frequency, and capacity factor of wind turbines.

An optimization method for wind-solar hybrid energy system has been developed by Yang, Lu, and Zhou in 2007. Their model has aimed to optimize the system with various components considering a battery bank. They have developed this methodology based on the technique of LPSP for the system reliability [74]. Nema, Nema, and Rangnekar et al. [75] has introduced an article about stand-alone and grid connected wind-solar hybrid energy systems which includes design, operation and control mechanisms in 2009. This study has focused on control systems in order to use produced energy efficient. For rural areas or ships, this control units are important due to absence of grid connection. And advantage of grid connection possibility has been explained in this study.

Dihrab and Sopian et al. [76] presented a hybrid energy system that works with renewable resources to supply electricity to the industrial and domestic demand of three cities in Iraq. Their study has been published in 2010. In 2012, Rehman and Sahin at al. have showed an idea of wind-solar hybrid energy system that was based completely on renewable resources. They tested their system for pumping water from underground on some regions in Saudi Arabia. Their study has almost achieved the goal for water pumping requirement of five areas by optimization of the wind-solar hybrid energy system to decide which source should be distributed within the system specifically [77].

Askarzadeh et al. [78] has aimed to find the optimum size of a wind-photovoltaic hybrid energy system in 2013. The developed method has provided to learn the necessary number of wind turbines, solar panels and batteries using harmony search technique and discrete harmony search technique.

Bayod-Rajula, Haro-Larrode, and Martinez-Garcia et al. [79] have presented an analysis of the interaction of the wind-solar hybrid system which uses batteries together with grid connection in 2013. Battery and renewable energy system sizing is combined and optimized. The main idea was to analyze the combination of the resources with the sizing factor and the size of the batteries effect on the amount of energy absorbed or injected to the grid.

Nogueira, Camargo, et al. [80] have developed a methodology for sizing hybrid wind-solar-battery energy system in 2014. Their method was based on the hourly load data, solar radiation, wind speed, and parameters related with photovoltaic panels, wind generators and batteries to optimize system leading to minimise the cost and reliability.

Belmili, Hocine, et al. [81] have studied LPSP algorithm with techno-economic algorithm for sizing standalone Wind-PV system in 2014. This method considered the cost, lifetime, load profile and meteorological characteristics of each installation site using different compounds.

The most studied hybrid energy system model has been wind solar hybrid model. In addition to the main components, battery has been inserted to systems in some studies; stand-alone or grid connected hybrid models have also been studied in order to find the most beneficial, efficient, and economical solutions. There are many similarities between previous studies with this study, such as using the Weibull distribution in order to calculate the wind speed, the use of satellite solar data in order to calculate the solar energy, grid connection in order to supply energy in case of weather conditions are not suitable to meet energy demand in peak periods. One of the important differences of our study is that we use the power curve directly to calculate energy production of the wind turbine, and include the clearness effect in computing the solar power production. Grid connection is considered in this study because the number of wind turbines and solar panels are calculated based on the monthly energy consumption due to considerable difference between most and least energy demands monthly. Most of the listed studies [54, 56, 63, 65, 67, 71, 79] have used batteries in the beginning of their calculations by identifying battery size according to energy demand. And the other components have been calculated after battery sizing. Weibull distribution is preferred in some of the studies mentioned above [67, 80, 81], which was also preferred in our study. Clearness effect has been explained in detail in [68], with this information, we have decided to use this parameter in our study too. Power law was used in order to calculate the wind speed at different heights in some studies [44, 74]. All studies have been conducted to find the most economical solution for any wind-solar hybrid system. Some of them preferred to decrease investment cost, and some of them aimed to decrease the energy production costs. Solar energy calculation is constantly same for all projects by using related energy formula which includes the cell efficiency, PV array, solar radiation and ground reflectance.

With the light of the previous studies, wind energy has been calculated by using the Weibull distribution, power law, power curve supplied by manufacturer. As for the solar energy computations, solar radiation published by NASA, clearness effect, efficiency and PV array are used in this current study. The most distinct part of our study is that the presented results are compared with a commercial software named HOMER developed by the National Renewable Energy Laboratory in the USA. There is only one study [44] which covers almost the same parameters as ours except for the grid connection and the clearness effect. In addition to that battery has been considered in that previous study[44]. Therefore, the present project stands as a novel study which has contained different variables and parameters, and which has been compared with an approved commercial software.

4.2. Hybrid Assessment Method and Comparison

As mentioned in previous sections, in this study wind-solar hybrid energy systems have been assessed in order to calculate the change in the use ratio of wind and solar resources from one location to another. One of the main reasons for this study is to provide a simple and quick calculation method for pre-feasibility stages of such hybrid energy projects. Pre-feasibility study on the earlier stages of a project is very important due to the high investment costs. It has been aimed that via the development of such a method that works with simple inputs to provide realistic results quickly. In order to identify a project whether it is feasible or not, conducting a preliminary study would be beneficial prior to getting the permissions for the project and to conduct a final energy production assessment. These stages of a project are also early stages; however their costs are not negligible when compared to the construction process too. Energy production assessment of a hybrid energy system through this method at the beginning of a project would provide a chance to decide the next processes regarding the investment in the project to decide whether it is feasible or not after final loss and uncertainty calculations. For this reason, it has been decided that this thesis' main target should be to provide a simple, quick and user friendly calculation method.

In this study, comparisons between the developed method and a hybrid optimization software which was developed by NREL named Homer Pro, are conducted and results are evaluated. It is not an aim to be a competitor to Homer in this study; however it has been aimed to obtain similar results to Homer predictions. It has been expected to receive similar results with the commercial software' predictions by using our model. At the end of the study, results are compared based on number of wind turbines, number of PV modules, and their ratio to total capacity.

This model has been designed for wind-solar hybrid energy systems; however it is possible to exclude one of the resources from the system in order to check and study before investment. It allows designing an energy system with only one resource. The most used renewable resources in the world are the sun and the wind, therefore this study has been shaped based on the most demanded renewable energy resources.

The calculation model has been developed with the approach explained above and has been explained in next section. The developed model has been named as Hybrid Optimisation Tool, and this name has been contracted with the capitals as HOT.

4.2.1. Developed Tool - Hybrid Optimisation Tool (HOT)

Our method is based on the economical analysis of the system. With the light of the past studies about hybrid system optimizations, a tool has been developed as a calculation model with using of different data inputs that can be received online or by conducted measurements of wind or solar energy. There will be parameters for wind energy calculations which are Weibull A parameter, Weibull k parameter and air density parameter. The used parameters for the predictions on the solar energy are Solar radiation, Clearness and Temperature. This data set will be enough for the optimization of our hybrid energy system.

Various places around the world have different values for such data inputs, because of sunlight angle, altitude above the sea, shape of the ground, and many other effects from the nature and the places. So, there will be different optimised results according to the point that we would like to calculate wind solar hybrid energy system. Data collection and assessment of data sets are so important to calculate the best hybrid energy system with renewable energy resources as the wind and solar. In our project, data collection was supplied from different sources like the state agency state archieves, NASA data sets, WAsP software. There is another important subject, which is to evaluate the data set without any mistakes. This provides us to make calculations more accurately.

It has been supposed to use the data set in a specific layout. It is suitable to use a table including all data for the point of interest for the project site. This table can be prepared for anywhere in the world. There is a table which includes wind and solar energy data set of Izmir Institute of Technology. Using this data set, it has been desired to meet energy demand of IZTECH, Mechanical Engineering Building.

IZTECH energy consumption has been recorded and reported monthly by the Directorate Construction and Technical Works[1] (DCTW) of IZTECH [82]. Based on the information provided by DCTW the below table has been created. This energy consumption values have been used in this study.

[1]İzmir Yüksek Teknoloji Enstitüsü, Yapı İşleri ve Teknik Daire Başkanlığı

Table 4.1. Monthly Electricity consumption of Mechanical Engineering Building of IZTECH (kWh)

	2011	2012	2013	2014	2015	2016
January	37.239	37.173	35.776	29.123	~36.430	~ 30.700
February	36.732	35.283	31.316	41.681	~36.008	~ 29.000
March	37.761	35.592	32.605	43.167	~35.430	~ 30.000
April	25.945	22.626	25.803	35.173	~25.330	~ 20.000
May	18.673	16.793	21.736	30.172	~20.420	~ 17.000
June	28.584	35.882	40.789	45.124	~22.910	~ 51.500
July	35.361	51.471	49.309	59.216	~44.400	~ 41.000
August	36.111	48.355	44.197	63.129	~51.480	~ 53.500
September	22.141	22.394	33.839	51.632	~34.975	~ 30.000
October	18.319	16.580	14.675	13.657	~21.500	~ 15.000
November	29.556	18.390	23.404	22.764	~22.000	~ 29.000
December	35.457	35.232	40.309	34.289	~41.007	~ 34.500
Total	361.879	375.771	393.758	469.127	391.890	~ 381.200

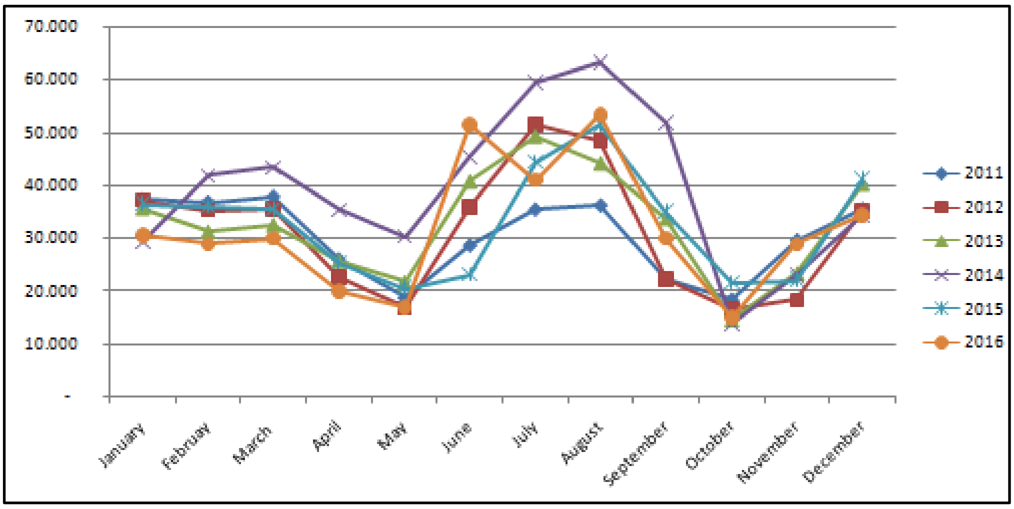


Figure 4.1. Monthly Electricity consumption of Mechanical Engineering Building of IZTECH (kWh)

Past years electricity consumption of the Mechanical Engineering Building of IZTECH is shown in Table 3.1. In addition to this table, Figure 4.1shows the energy consumption as a graphic of monthly data provided by DCTW.

Table 4.2. Wind Solar Hybrid Energy data table

Project Name:				Location:			Date
				Easting:			
Site Name:				Northing:			
	WIND DATA			SOLAR DATA			DEMAND
Data / Months	Weibull A	Weibull k	Density (kg/m^3)	Clearness	Solar Radiation ($kWh/m^2/day$)	Average Temperature (°C)	Energy Demand (kW)
January							
February							
March							
April							
May							
June							
July							
August							
September							
October							
November							
December							
Average							
Total							

Functions below related to the energy production of the hybrid system that is used in this study;

Wind energy; $$U = A.\Gamma(1 + \frac{1}{k})^n \tag{3.1.6}$$

$$P = \frac{1}{2} x \rho x U^3 x A_s x C_p \tag{3.1.7}$$

A and *k* values which have been calculated by using WAsP software are located in our table. *n* is constant for our system, which is set to 1. *U* value will be used in order to find energy production of the wind turbine according to its power curve. In addition to that, there will be losses on the wind turbine during its operation by turbine availability, grid connections, wake losses (from obstacles or other wind turbines if there is any) and temperature conditions. These losses will be included to our calculation as an assumption of 15%. Therefore energy output of wind turbine will be multiplied with 0,85. It should be noted that, for the detailed analysis, losses on the wind turbine should be calculated on a project specific basis in order to find the most realistic results. This will provide us to know how many wind turbines are needs to be used in hybrid system.

Γ (Gamma Function) allows to calculate wind speed by using the Weibull distribution. One of the best wind speed prediction method is to use the Gamma Function considering the Weibull parameters [83]. With this approach, it has been decided to use this calculation method for wind speed.

Solar energy; $$P_{PV} = P_{pk} n_d H_h \rho_g \tag{3.2.15}$$

And finally; $$N_{wt} P_W + N_{pv} P_s \geq Demand_{mont\,h} \tag{4.2.1}$$

For solar energy production of the hybrid energy system, the final equation (3.2.15) will be used in this study. The optimum angle between the ground and photovoltaic panel should be known before installation. Using equation (3.2.12), produced energy will be found. n_{PV} is efficiency of the solar photovoltaic panel that is generally between 8.8-37.9% [84]. H_h is solar radiation value taken from the Homer Pro Software which is written at the table. K_T taken from Homer Pro Software is clearness effect in the sky. Optimum area of photovoltaic panels for our hybrid energy system will be found with this calculation. According to the results of the required area calculation, number of photovoltaic panels will be calculated.

Monthly production of wind and solar energy will be calculated by the formulas 3.2.12 and 3.2.13. After that, they will be summed and yearly production will be found. Every month production will supply monthly demand and yearly production will supply yearly demand. Thus, the system will be taken under guarantee of energy supply during all the time that the consumer needs. In addition to that, the system will be connected to the grid. This will provide us to get energy if the system will have any problem or will not meet the energy demand. Or, this will provide us to sell surplus energy to the grid. We will not use a battery in our system, due to the associated high costs. This cost makes the system expensive when compared to the energy production costs.

In this study, monthly data have been used, since it is more achievable for Turkey and we cannot reach detailed data measured per second or per minute. It would be better solution with the minimum range or time series, however monthly data is the most available data in Turkey. It is expected that this study will be developed by next researchers using more sensitive data sets.

Steps of our calculation method of hybrid energy system with the items which is listed below;

Table 4.3. Steps of the developed hybrid energy calculation method

1	Data table and location details are filled as in the part 4.2.1.
2	Wind velocity is calculated by using Weibull A and k parameters from the formula 4.2.1
3	Power curve of the wind turbine defines the energy production with respect to the site wind velocity. So, in this step, power production of the wind turbine is calculated from the curve at the point of associated wind velocity.
4	Air density value is calculated from the table 3.1 according to the altitude and temperature. Air density is added to the calculation of wind turbine energy production via dividing site air density to 1.225 kg/m^3. Ratio is multiplied power curve value.
5	Multiplied power value by air density is hourly power production of wind turbine. This value is multiplied with number of days of the month.
6	Optimum angle between ground and photovoltaic panel surface is calculated as shown in the Section 3.2.
7	Solar radiation value is calculated according to the optimum angle of the PV.
8	One panel capacity, de-rating factor, radiation value and reflectance factor are multiplied in order to calculate one module's daily energy production
9	Daily energy production from the solar system is multiplied by the number of days in a month. By this way, monthly energy production of one solar PV panel is calculated.
10	The formula 4.2.2 is used to find optimum results of the wind solar hybrid energy system.

Calculation steps of developed tool are listed below with their exemplary views from the tool. Required data are entered in red colored tabs, and blue colored tabs give results. Considering all data input located in red colored tabs, all results will be calculated automatically in blue colored tabs.

According to information given in data table, *Data Input* tab of the tool is filled.

Inputs			Expected Project Lifetime		20	Years					
Wind Data						Solar Data					
Measurement H	70	m	Wind Turbine Loss Factor				One PV Panel Capacity		PV Panel Derating Factor		Ground Reflectance
Hub Hieght	30	m	0,85				0,33	kW	0,8		0,8
	Weibull A	Weibull k	Air Density			Clearness	Solar Radiation	Average Temperature	Angle of the PV	ration of the Sunli	uration of the Month
January	7,93608	1,11124	1,25064		January	0,479	2,17	7,74	38,5	4,86	31
February	10,4604	1,97041	1,24937		February	0,513	3,03	8,03	38,5	5,86	28
March	8,60214	1,47775	1,23724		March	0,566	4,43	10,8	38,5	6,96	31
April	9,32848	1,58534	1,2161		April	0,597	5,82	15,72	38,5	8,03	30
May	7,6827	1,82411	1,19252		May	0,658	7,28	21,4	38,5	9,77	31
June	9,18117	2,07954	1,17389		June	0,72	8,34	26,08	38,5	11,89	30
July	11,2684	2,56303	1,16365		July	0,729	8,23	28,78	38,5	12,2	31
August	12,4396	2,61801	1,16487		August	0,719	7,34	28,45	38,5	11,48	31
September	10,0618	2,13829	1,18016		September	0,692	5,86	24,49	38,5	9,67	30
October	9,63997	2,01459	1,20156		October	0,63	4,07	19,18	38,5	7,61	31
November	10,5636	1,90777	1,2265		November	0,531	2,56	13,29	38,5	5,55	30
December	10,1922	1,77049	1,23724		December	0,443	1,82	8,99	38,5	4,67	31
Wind Speed	at Measurement Height		at Hub Height			Monthly Energy Demand			Energy Cost		
January	7,63	m/s	6,76	m/s		January	29.123	kWh	Purchasing	0,12	USD
February	9,27	m/s	8,21	m/s		February	41.681	kWh	Selling	0,1	USD
March	7,78	m/s	6,89	m/s		March	43.167	kWh			
April	8,37	m/s	7,42	m/s		April	35.173	kWh			
May	6,83	m/s	6,05	m/s		May	30.172	kWh			
June	8,13	m/s	7,20	m/s		June	45.124	kWh			
July	10,00	m/s	8,86	m/s		July	59.216	kWh			
August	11,05	m/s	9,79	m/s		August	63.129	kWh			
September	8,91	m/s	7,89	m/s		September	51.632	kWh			
October	8,54	m/s	7,57	m/s		October	13.657	kWh			
November	9,37	m/s	8,30	m/s		November	22.764	kWh			
December	9,07	m/s	8,04	m/s		December	34.289	kWh			
			7,74928036			Annual	469.127	kWh			
Investment Cost of Wind Turbine			220000	$		Investment Cost of 100 kW PV			170000	$	
20 Years Maintenance Cost of Wind Turbine			220000	$		20 Years Maintenance Cost of 100 kW PV			85000	$	

Data Input | Power Curve | Hybrid - Optimisation | Hybrid - Options_1 | Economical Analysis | Config_1 | Config_2

Figure 4.2.Data Input of Hybrid Optimisation Tool

In this tab of the tool below data and information should be entered;

1- *Project lifetime,*
2- *Measurement height and hub height of wind turbine*
3- *Wind turbine loss factor as an assumption*
4- *Monthly Weibull parameters*
5- *Monthly air density values*
6- *One PV panel capacity, de-rating factor and ground reflectance factor*
7- *Solar radiation, average temperature, duration of month (if required angle of PV panel, duration of sunlight, Clearness) - clearness is included in solar radiation data used in the study, it is assumed that PV panels are directed to the sun with required angle.*
8- *Monthly energy demand*
9- *Energy purchasing cost from grid and energy selling cost to grid*

10- Investment, maintenance and operation costs for both of 100 kW wind turbine and 100 kW PV panels.

Based on the Weibull parameters, using Gamma Function (Formula 3.1.5), monthly wind speeds are calculated automatically at measurement height. And hub height wind speeds are calculated automatically using Power Law equation (Formula 3.1.1). In *Hybrid - Optimisation* tab power output of wind turbine will be calculated directly considering monthly hub height wind speeds, monthly air density and wind turbine loss factor.

Based on PV panel capacity, daily average of solar radiation values for each month, de-rating factor and ground reflectance, using power output formula of solar PV panels (Formula 3.2.15), daily and monthly power output of one PV panel will be calculated automatically in *Hybrid - Optimisation* tab.

Number of wind turbine and PV panel will be calculated automatically in *Hybrid - Optimisation* tab according to entered Energy Demand. Energy costs and investment costs will be used in *Economical Analysis* tab.

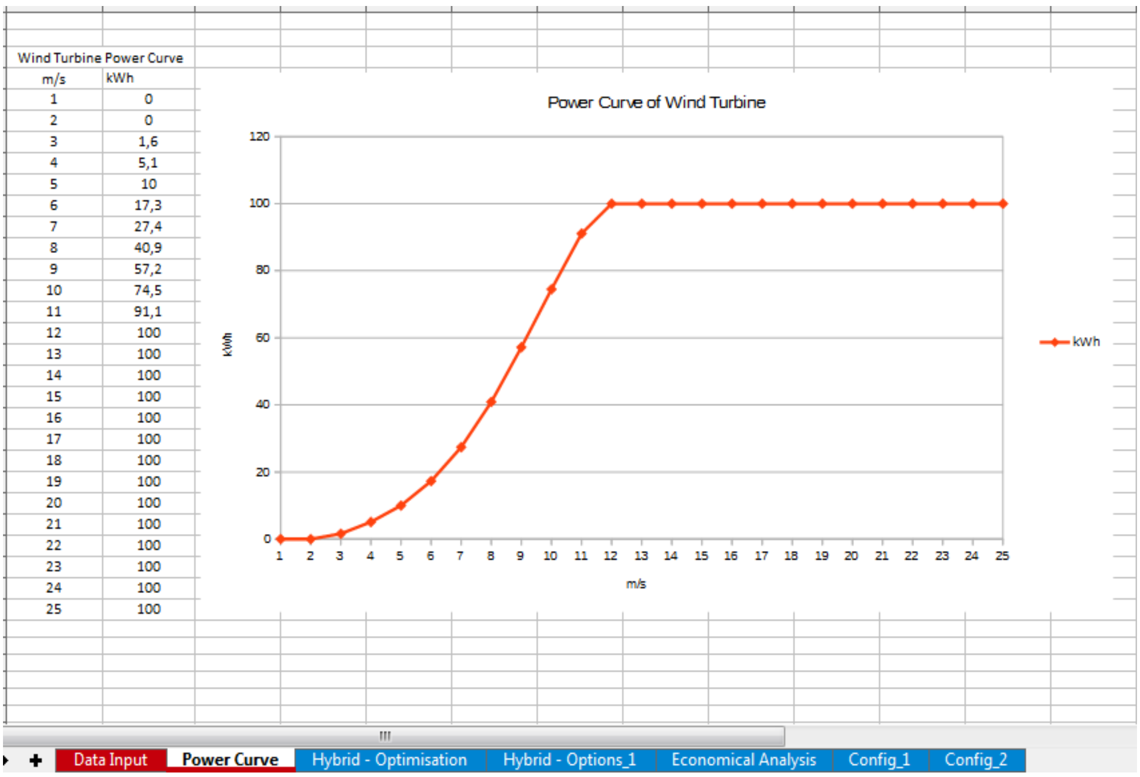


Figure 4.3. Power curve input of Hybrid Optimisation Tool

Power curve of wind turbine should be entered in Power Curve tab. According to monthly average wind speeds at hub height and power curve of wind turbine, hourly power output of wind turbine is calculated. The tool finds relevant range for each monthly wind speeds and interpolates in order to calculate power output for each month.

100 kW Wind Turbine Energy Generation			With 0.85 loss factor		Number of Wind Turbines		Generated by WTG				
	Hourly	Daily	Monthly								
January	21,69	520,48	16134,74		1		16134,74	Hybrid System generated mont		Demand	Difference
February	38,49	923,84	25867,61		1		25867,61	January	29134,54	29.123	11,54
March	22,59	542,12	16805,81		2		33611,63	February	41689,39	41.681	8,39
April	27,86	668,55	20056,55		1		20056,55	March	43182,98	43.167	15,98
May	14,72	353,35	10953,72		2		21907,43	April	35175,51	35.173	2,51
June	24,57	589,56	17686,94		2		35373,88	May	30200,90	30.172	28,90
July	44,38	1065,15	33019,67		1		33019,67	June	45149,70	45.124	25,70
August	57,28	1374,79	42618,63		1		42618,63	July	59260,91	59.216	44,91
September	32,32	775,72	23271,53		2		46543,07	August	63138,73	63.129	9,73
October	29,23	701,53	21747,41		0		0,00	September	51666,86	51.632	34,86
November	39,01	936,27	28088,14		0		0,00	October	13669,96	13.657	12,96
December	35,62	854,89	26501,54		1		26501,54	November	22773,10	22.764	9,10
		775,52			1	2		December	34294,54	34.289	5,54
								Total	469337,13	469.127	210,13
1 Solar PV Energy Generation					Number of Solar PV Panels						
	Daily	Monthly	100 kW PV					Average	23863,58	29.123	-5259,42
January	0,46	14,21	4305,28		915		12999,79	1WTG+544PV	35615,11	41.681	-6065,89
February	0,64	17,92	5429,76		883		15821,78		32584,04	43.167	-10582,96
March	0,94	29,00	8789,12		330		9571,35		40116,83	35.173	4943,83
April	1,23	36,88	11174,40		410		15118,96		36882,72	30.172	6710,72
May	1,54	47,66	14443,52		174		8293,47		46433,12	45.124	1309,12
June	1,76	52,84	16012,80		185		9775,81		62332,27	59.216	3116,27
July	1,74	53,88	16328,32		487		26241,24		68761,34	63.129	5632,34
August	1,55	48,06	14562,56		427		20520,10		43469,69	51.632	-8162,31
September	1,24	37,13	11251,20		138		5123,80		36243,44	13.657	22586,44
October	0,86	26,65	8074,88		513		13669,96		36911,91	22.764	14147,91
November	0,54	16,22	4915,20		1404		22773,10		32983,79	34.289	-1305,21
December	0,38	11,92	3610,88		654		7793,00		496197,84	469.127	27070,84
	1,07				544						
				Rounded	540						
				C2	140						

Data Input | Power Curve | Hybrid - Optimisation | Hybrid - Options_1 | Economical Analysis | Config_1 | Config_2

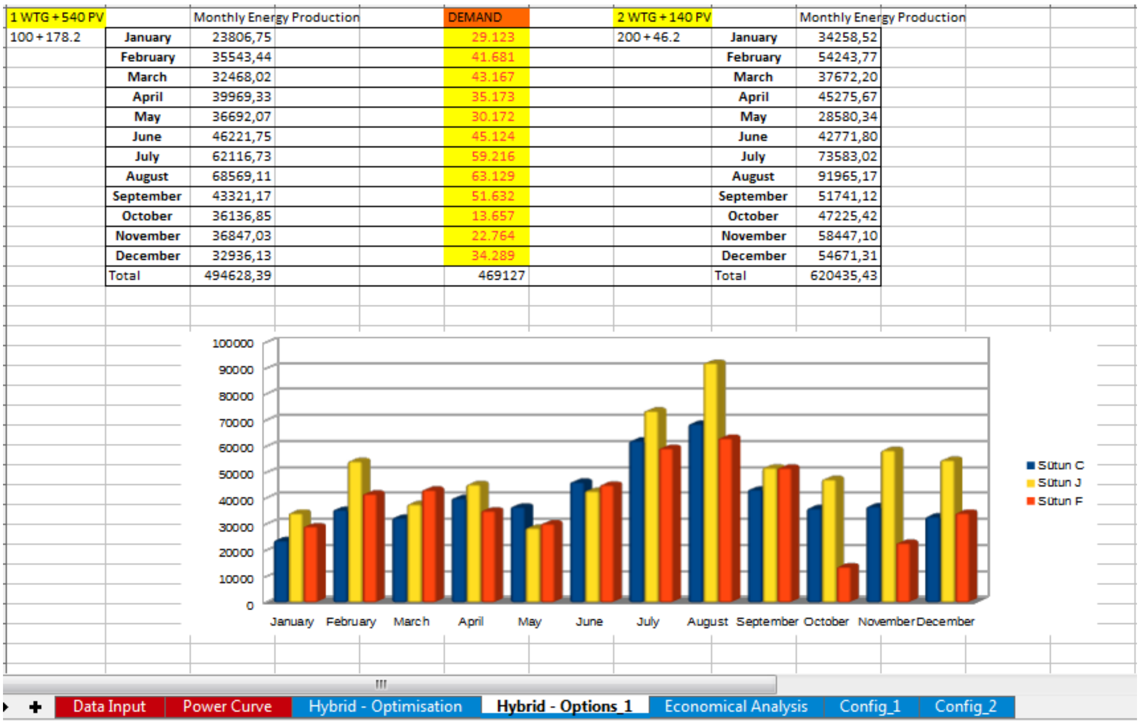
Figure 4.4. Hybrid configuration calculation of Hybrid Optimisation Tool

Interpolated power output according to hub height wind speeds is multiplied by loss factor of wind turbine and monthly air density values. Hourly, daily and monthly power output of one wind turbine is calculated for each month.

Daily and monthly power output of one solar PV panel is calculated for each month. Also, 100 kW PV panel power output is calculated for each month.

At this step, considering same capacity of wind turbine and solar PV panel, primary energy resource selection should be done as it has been explained in Section5.1 and Section 5.2. According to primary energy resource, calculations will go on. For this example, wind energy is the primary energy resource.

Monthly energy demand is divided by monthly energy production of wind turbine. Calculated numbers have decimals, however these numbers have been rounded to small integer number. By this way monthly required wind turbine numbers have been calculated. Uncompleted energy amount is divided by one PV panel monthly power output. Calculated numbers are rounded to one bigger integer and by this way, monthly configurations which can provide monthly energy demand have been found. In order to use constant numbers as a configuration, average of monthly calculated numbers of wind turbine and PV panels, is the optimised configuration. For this example, 1 wind turbine and 544 PV panels are calculated as a configuration. However it is suitable to use numbers that can be divided by 20 for PV panels, therefore, average number of PV panels is rounded to 540. So that, the tool calculated optimised configuration with 1 wind turbine and 540 PV panels (100 kW wind turbine + 178,2 kW PV panel).



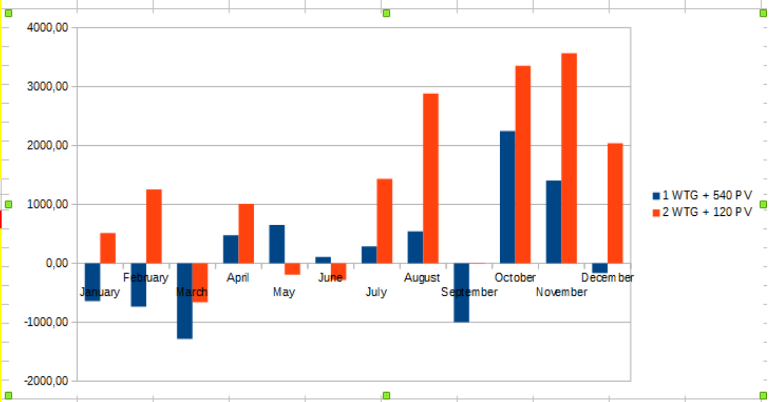
1 WTG + 540 PV		Monthly Energy Production	DEMAND	2 WTG + 140 PV		Monthly Energy Production
100 + 178.2	January	23806,75	29.123	200 + 46.2	January	34258,52
	February	35543,44	41.681		February	54243,77
	March	32468,02	43.167		March	37672,20
	April	39969,33	35.173		April	45275,67
	May	36692,07	30.172		May	28580,34
	June	46221,75	45.124		June	42771,80
	July	62116,73	59.216		July	73583,02
	August	68569,11	63.129		August	91965,17
	September	43321,17	51.632		September	51741,12
	October	36136,85	13.657		October	47225,42
	November	36847,03	22.764		November	58447,10
	December	32936,13	34.289		December	54671,31
	Total	494628,39	469127		Total	620435,43

Figure 4.5. Energy results of configurations found in Hybrid Optimisation Tool

According to optimised configuration and if required according to alternative configuration, monthly energy productions are calculated in *Hybrid - Optimisation_1* tab. Also, yearly energy production by each configuration has been calculated at the bottom of monthly production values.

	1 WTG + 540 PV	2 WTG + 140 PV	DEMAND
January	-5316,25	5135,52	29.123
February	-6137,56	12562,77	41.681
March	-10698,98	-5494,80	43.167
April	4796,33	10102,67	35.173
May	6520,07	-1591,66	30.172
June	1097,75	-2352,20	45.124
July	2900,73	14367,02	59.216
August	5440,11	28836,17	63.129
September	-8310,83	109,12	51.632
October	22479,85	33568,42	13.657
November	14083,03	35683,10	22.764
December	-1352,87	20382,31	34.289

	1 WTG + 540 PV	2 WTG + 120 PV	DEMAND
January	-637,95	513,55	29.123
February	-736,51	1256,28	41.681
March	-1283,88	-659,38	43.167
April	479,63	1010,27	35.173
May	652,01	-191,00	30.172
June	109,78	-282,26	45.124
July	290,07	1436,70	59.216
August	544,01	2883,62	63.129
September	-997,30	10,91	51.632
October	2247,99	3356,84	13.657
November	1408,30	3568,31	22.764
December	-162,34	2038,23	34.289
	1913,81	14942,07	



Data Input | Power Curve | Hybrid - Optimisation | Hybrid - Options_1 | Economical Analysis | Config_1 | Config_2

Figure 4.6. Difference between produced and demanded energy in kW and in USD

In *Economical Analysis* tab of Hybrid Optimisation Tool, first, montly difference between demanded and produced energy amounts are calculated on above table in Figure 4.6. Missing energy is calculated as negative amount and completed from grid, also surplus energy is calculated as positive amount and sold to grid. Therefore in below table in Figure 4.6, monthly income or expense for energy has been calculated considering energy cost entered in *Data Input* tab.Monthly missing or surplus energy amount has been multiplied with relevant energy cost automatically. Bottom of the table yearly income or expense is calculated.

Energy Cost For 1 year	56295,2	in USD	if there is no energy generation	
Energy Cost For 20 years	1125904,8	in USD	if there is no energy generation	
	1 WTG + 540 PV	2 WTG + 140 PV		
For 20 years	38276,18	298841,39	in USD	income/expense if there is energy production
			in USD	income/expense if there is energy production
Investment and Operational Cost for 20 years	894410	997810	in USD	
20 Years Expense	856133,82	698968,61	in USD	20 years total expense (investment and operational cost for 20 years)
Net Profit	269.770,98	426.936,19	in USD	profit (+)/loss(-) at the end of 20 years
Cost of Energy	0,091	0,074		
Profit Volume R	31,51%	61,08%		

Data Input | Power Curve | Hybrid - Optimisation | Hybrid - Options_1 | Economical Analysis | Config_1 | Config_2

Figure 4.7. Economical Analysis in Hybrid Optimisation Tool

Later on *Economical Analysis* tab, economical details are calculated regarding the configurations.

- As energy demand is already known, if no hybrid energy system is installed, energy amount and buying cost from grid are multiplied and yearly energy cost is calculated. This cost is multiplied with lifetime of the project (20 years) entered in *Data Input* tab to find 20 years energy cost.
- Yearly income or expense amount is multiplied with lifetime of the project to find project lifetime income or expense.
- Based on the investment cost entered in *Data Input* tab, investment, maintenance and operational cost for each configuration is calculated for lifetime of the project.
- Difference between investment cost and total income is calculated as net expense for lifetime of the project.
- Net profit is calculated as difference between 20 years energy cost in case of no energy generation and net expense for 20 years.
- Then, kWh energy cost calculated once net expense is divided by 20 years energy demand in kW.
- And in order to have idea about feasibility of the project, profit volume ratio is calculated dividing net profit by total investment cost of the project.

Hybrid optimisation tool can calculate all results automatically based on inputs required in *Data Input* and *Power Curve* tabs.

4.2.2. Homer Pro Software

Homer Pro Software has been developed by National Renewable Energy Laboratory - NREL - Golden, Colorado[85]. Homer has been named by the first characters of Hybrid Optimization Model for Electric Renewable as HOMER. In order to provide solution for the analysis and optimization of the renewable energy systems, HOMER has been developed by NREL in 1993. The first version of the software has been published in February 14, 2000. In years, development has continued in the direction of renewable energy industry' demands and total user number has passed 30,000 people worldwide. In 2009, Homer Pro has been published as a commercial company in order to distribute and enhance HOMER by NREL. This step has provided the software to be well known by the industry and the decision makers. The latest version of the software has been published in 8 September 2016 as Homer Pro 3.7.4, and this version of software has been used for this study.

The software can calculate different hybrid energy systems using wind turbines, solar photovoltaic panels, biomass, hydrogen tanks, hydraulic turbines, fuel cells, converters, boilers, generators and batteries. It is possible to add electrical load and thermal load to the system. Homer Pro Software can solve system according to the loads with the optimum results. It considers that Net Present Cost and environmental effects of the hybrid energy system and calculates all values with optimistic solutions.

The software includes its own library, but we can add our own components. This provides us to solve projects according to available turbines, PV and all other components. Different sensitivity in data and constraints that are required for the related project can be chosen in accordance with the system. The best results can be calculated through this sensitivity and constraints. In addition to that, the software provides user to calculate the system with the connection to grid. If electricity price is entered in the software, results can be found based on our production and consumption values. Electricity generation can be less than our demand and can be supplied from the grid. Or, surplus energy can be sold to the distributors or state agency with the connection to the grid. Systems that will provide us to earn money via an investment can be designed while we generate our own electricity.

Below, it is explained how to create a project in Homer Pro;

- Figure 4.8 shows the home screen of Homer. The first step is to choose location of a planned hybrid energy system by clicking to the map on this screen of inputs or by naming the location in the related area and search in order to find the project place. Related information cells can be filled in this stage. After that, Electrical load should be identifiedasexplainedinthe*Electric#1*tab.

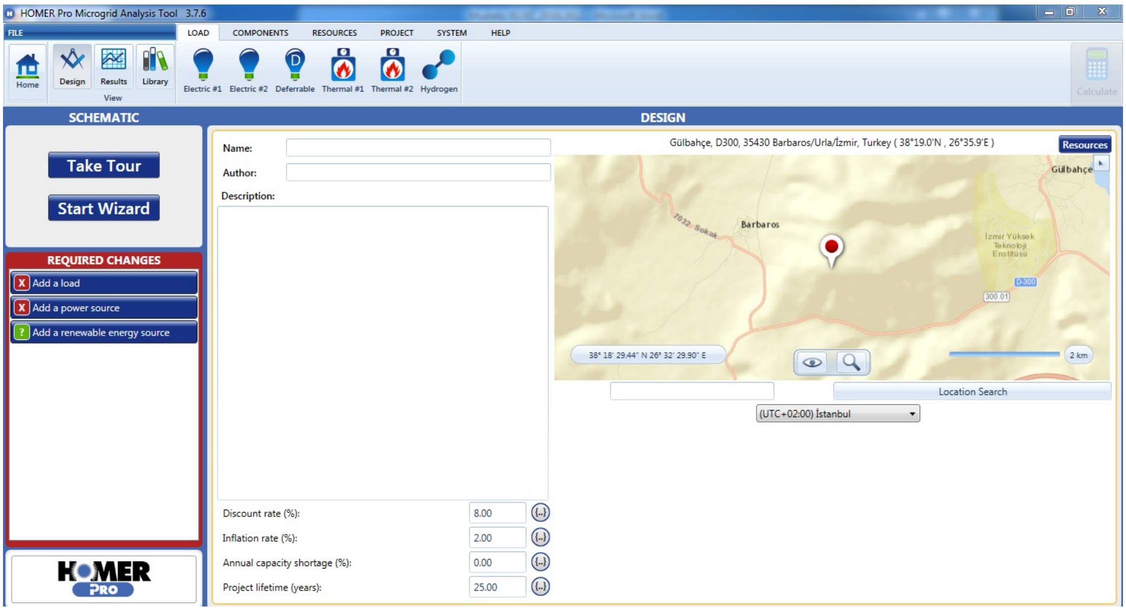


Figure 4.8. Interface - Home Screen of Homer Pro Software

- Electrical Load should be identified in Homer. Load Type can be chosen as AC or DC, monthly and daily data can be inputted manually or can be imported as time series data. Also, sensitivity values can be identified as shown in Figure 4.9. Next step should be the selection of the components by clicking to *COMPONENTS* tab.

Figure 4.9. Electrical Load Input to Homer Pro Software

- In components tab, the choice and input data for the required components are carried out. First PV components should be selected after clicking on the PV button. Opened screen allows the user to choose the PV types located in Homer database or it is possible to add a new PV module to the library as it shown in Figure 4.10.

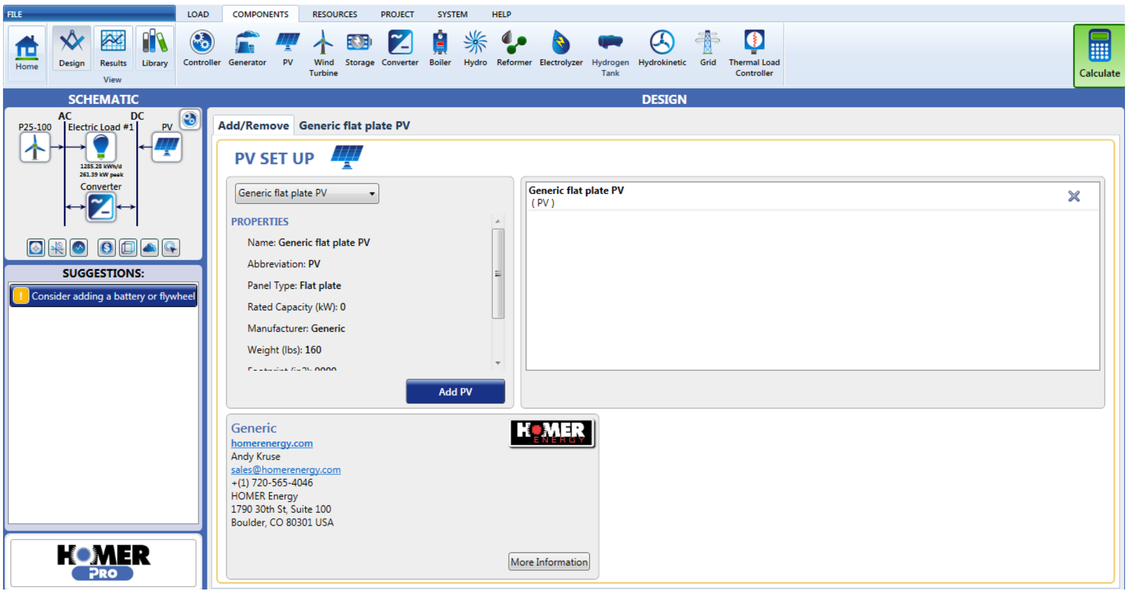


Figure 4.10. PV Input in Homer Pro Software

- After clicking the *Add PV* button, capital cost, replacement cost, maintenance cost should be entered in accordance with the size input, and other sensitivity values like output current, lifetime, derating factor. These factors can be entered accordingly from the PV icon which is added as it is shown in Figure 4.11. Sizes to consider column should be filled according to system range considered.

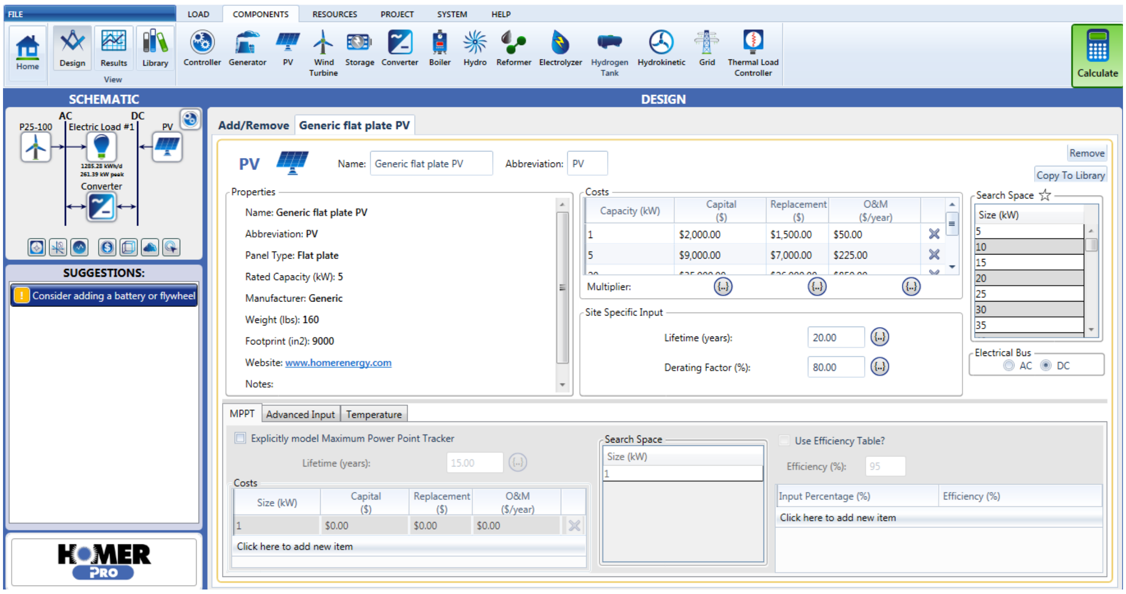


Figure 4.11. PV Cost Input in Homer Pro Software

- Wind Turbine component should be selected after clicking on the *Wind Turbine* button. Opened screen allows to choose the wind turbine types located in Homer database or it is possible to add a new wind turbine to the library of Homer as it shown in Figure 4.12. Capital cost, maintenance cost, quantity, and other sensitivity values can be entered accordingly and are shown in Figure 4.12.

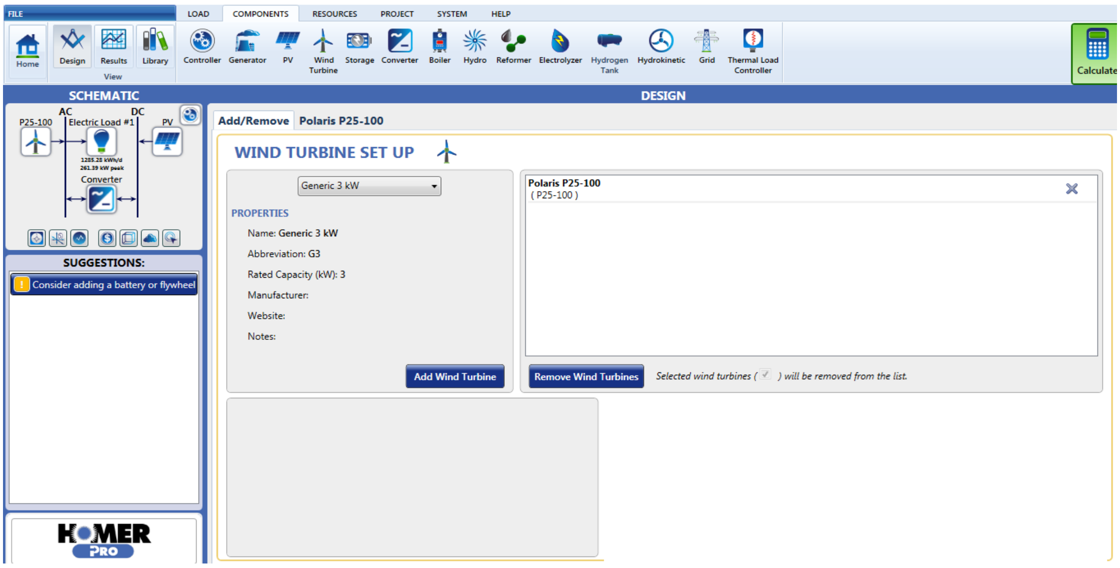


Figure 4.12. Wind Turbine Input in Homer Pro Software

- In order to input Capital cost, maintenance cost, quantity, and other sensitivity values of wind turbine, clicking to the wind turbine icon in schematic view of the system. This opens a screen allowing to adjust values regarding wind turbine as shown below.

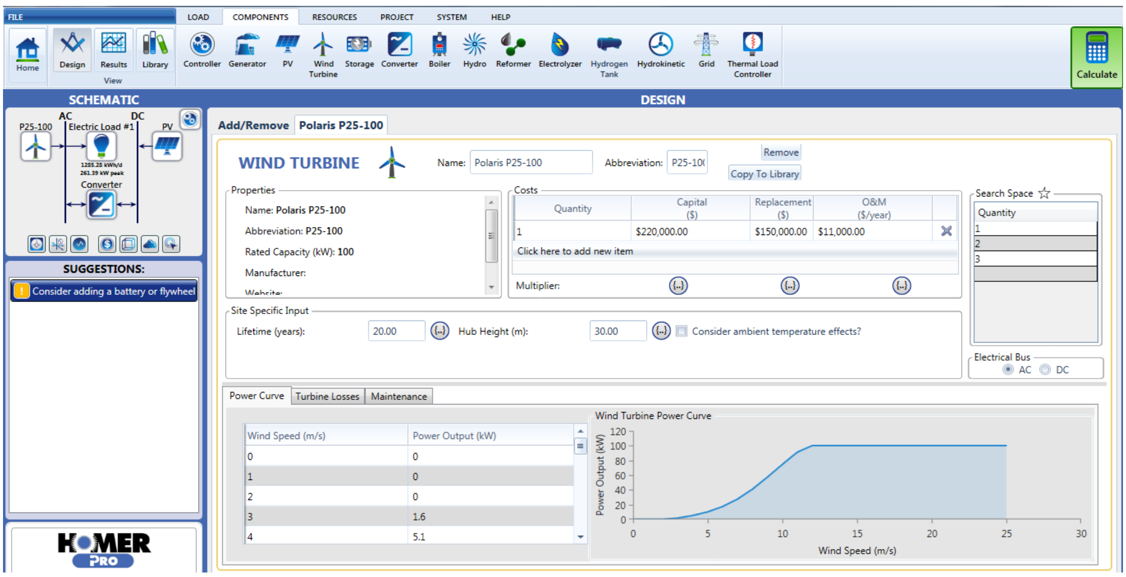


Figure 4.13. Wind Turbine Cost Input in Homer Pro Software

- In case of primary load and PV panel currents are different, Converter should be added to the system. By clicking to *Converter* button size, cost, lifetime and other relevant values can be filled in the cells shown in Figure 4.14. The software allows to input further types of converters to the library in order to select and use in the project.

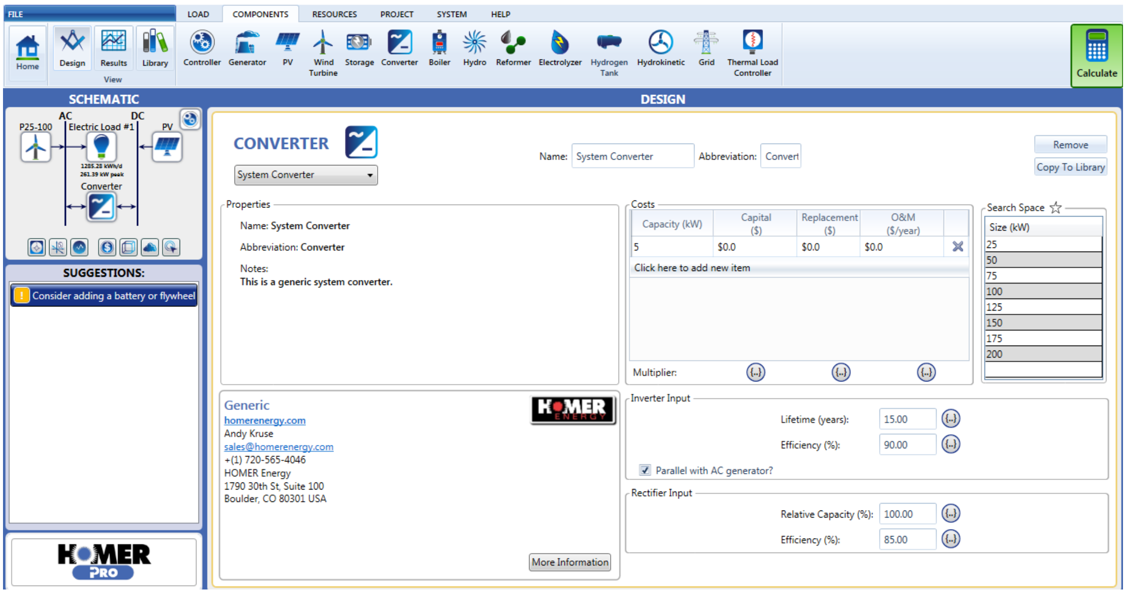


Figure 4.14. Converter Input in Homer Pro Software

- In order to insert data to project, *RESOURCES* tab should be clicked. For solar resource, after clicking to *Solar Resource GHI* button, opens a screen which allows to input data manually, either as a time series or online datasets. Location information is used in this part if it is desired to download data. NASA's Surface meteorology and Solar Energy database is used for the data access.

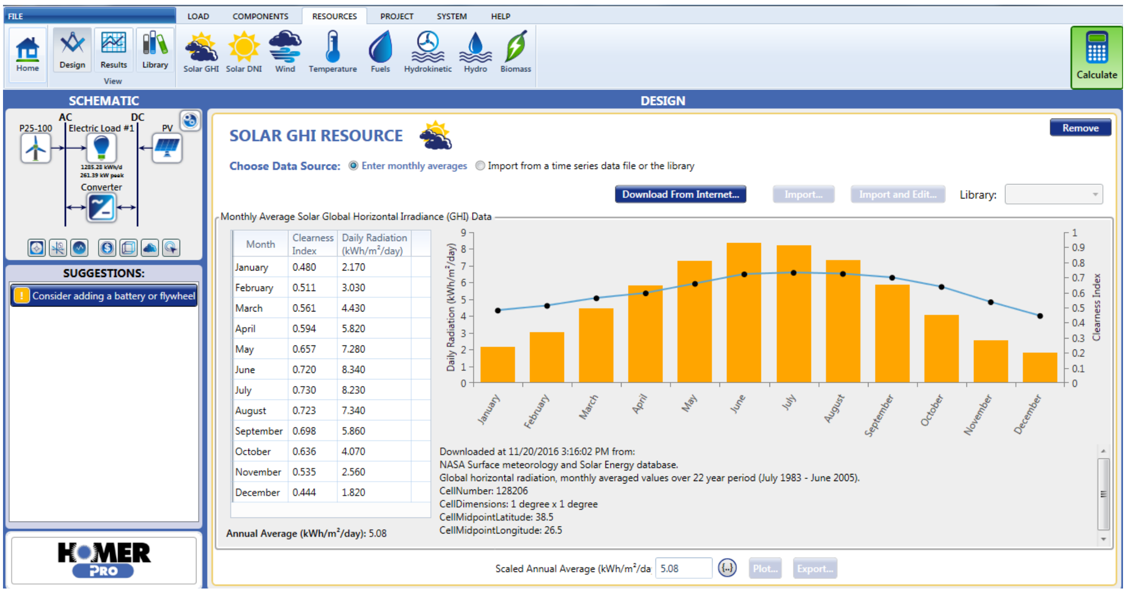


Figure 4.15. Solar Data Input in Homer Pro Software

- In order to input wind resource, *Wind* button should be clicked. In the opened screen, manual data input can be preferred, data set can be imported by a time series data file and also a new feature of the software data can be downloaded online as shown in Figure 4.16.

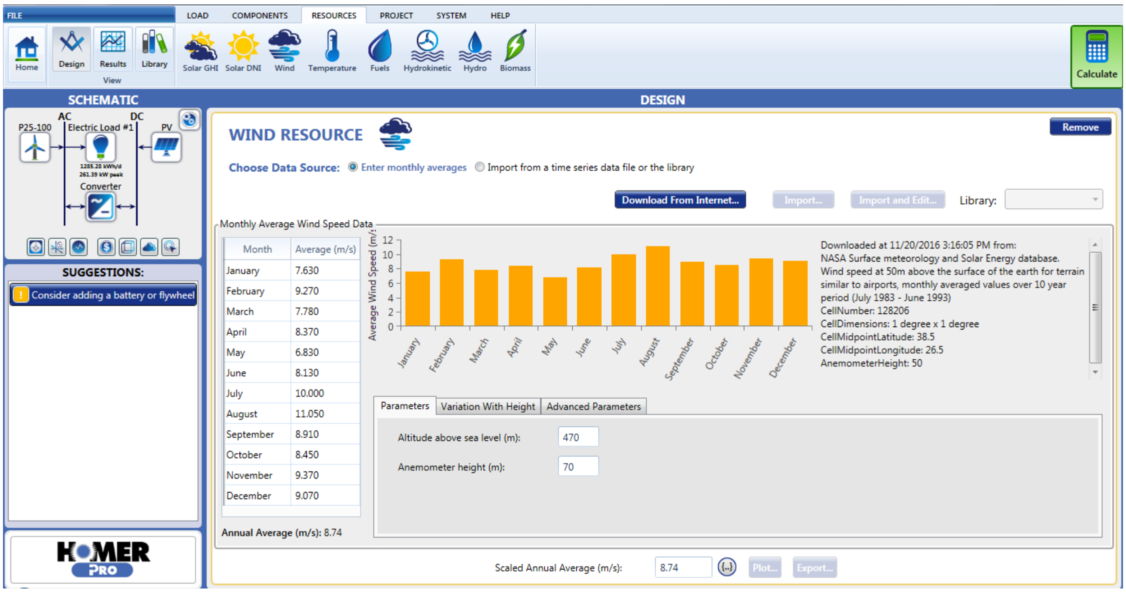


Figure 4.16. Wind Resource Input in Homer Pro Software

- In the *PROJECT* tab, settings regarding the Economics, Constraints, Emissions and Optimisation can be adjusted as shown in Figure 4.17, Figure 4.18, Figure 4.19, Figure 4.20 respectively.

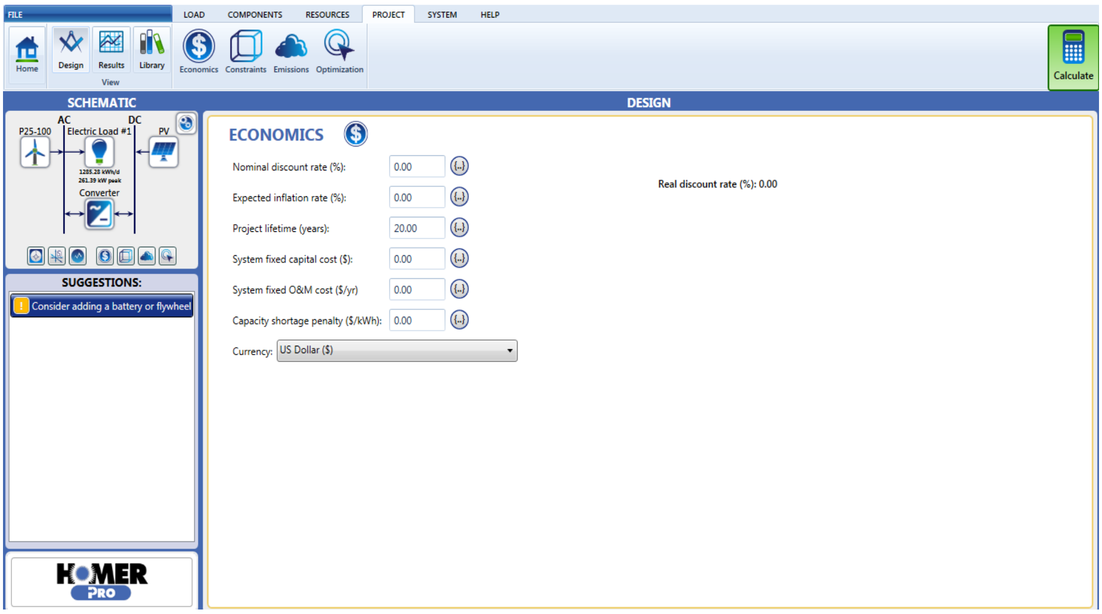


Figure 4.17. Economics Input in Homer Pro Software

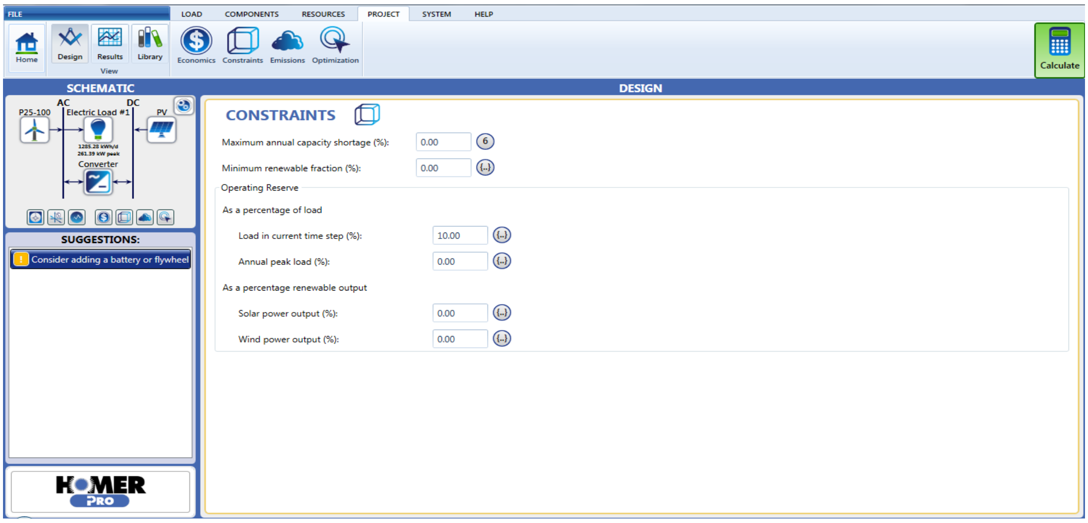


Figure 4.18. Constraints Input in Homer Pro Software

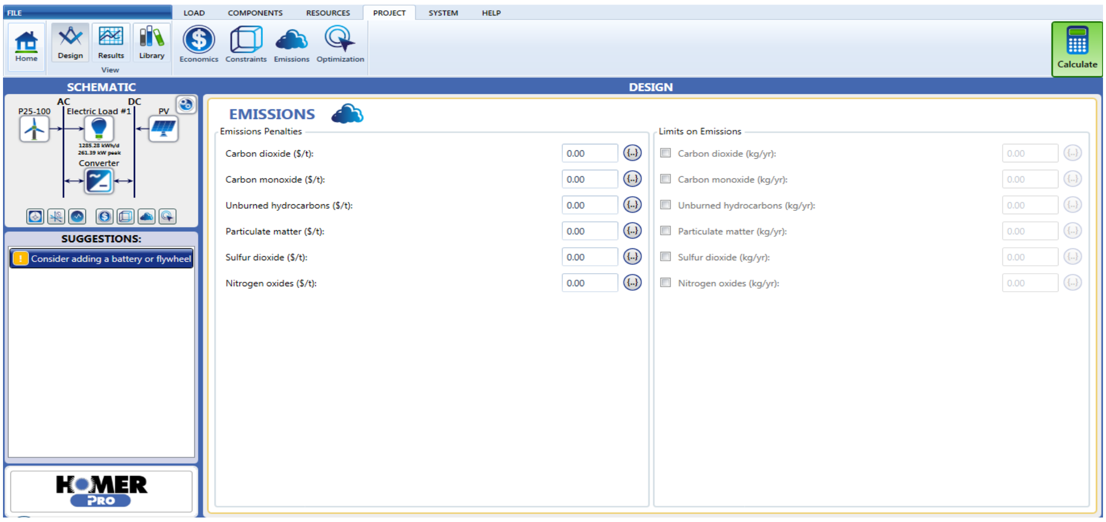


Figure 4.19. Emissions Input in Homer Pro Software

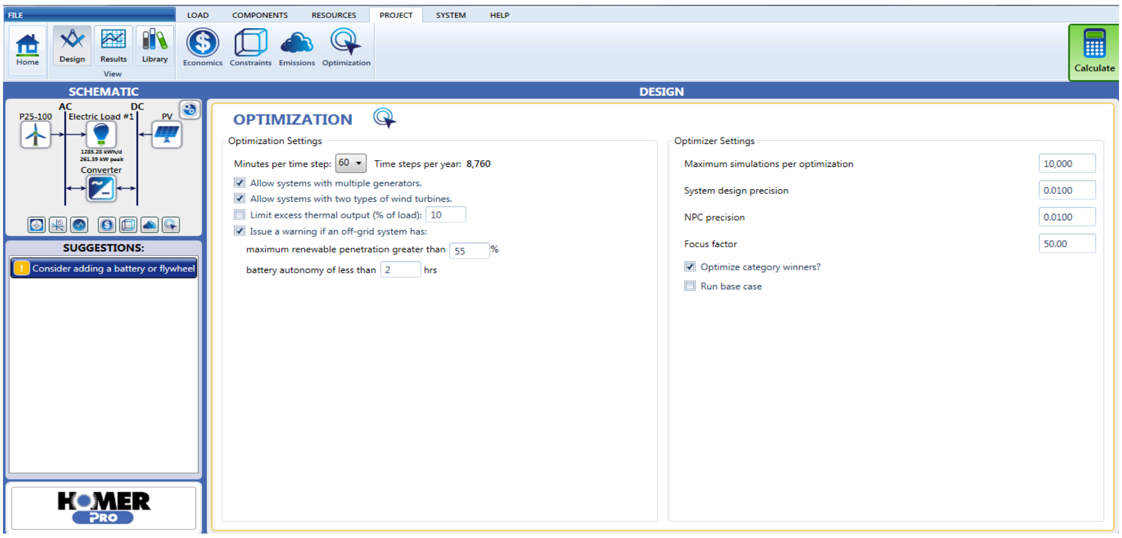


Figure 4.20. Optimization Input in Homer Pro Software

For the advanced use of the software, SYSTEM tab can be organized to include the sensitive parameters and detailed results can be obtained by Homer Pro.

Finally, the user should press *Calculate* button which is located on the upper right part of the screen in order to get result from the software.

To summarize the steps with an example; first, the user needs to input the amount and type of load. After that, components must be chosen, like wind turbine, photovoltaic panel, converters and select between connecting or not connecting to the grid. Software must know the resources' data like wind speed, radiation value of the sun. When user inputs these values, the software can calculate the system output. But if the user wants detailed results, and the optimised solution for the system, the user has to input sensitivity information to Homer. The user can indicate the software to calculate the system until five wind turbines increasing one by one, 10 kW PV increasing 1 kW by 1 kW, 20 kW converter increasing 5 kW by 5kW etc. The software can calculate the system output and conclude that "10 kW, 3 kW PV and 2 kW converter is the best result". This result would be calculated according to the demand, resources and constraints.

Homer Pro Software makes calculations according to hourly datasets for a year using 8760 hours. The software controls hourly production and energy demand, and calculates energy production by all the system components according to every hour in a year. Homer converts hourly data to monthly data and shows the monthly data, but it calculates the system with hourly data. The best result of the optimization is calculated with this method. When the user enters the sensitivity data, the software wants to know the cost of every single component, so the software decides the best optimization result according to energy production and economical costs of the system. The software presents different optimization results with different scenarios. One of the solutions may produce more energy but may be expensive. One of the other can produce the cheapest energy but can be inadequate for demand. But, one of them will be definitely the best solution according to net present cost and produced energy cost per kW [84].

There are different optimization programs that give similar results with one another, but Homer Pro Software has been preferred, due its common goals with our study. Also, Homer includes a module that supply wind data, solar data and temperature data of any coordinate in Turkey. Homer is the most valid solution for our study for these reasons.

4.2.3. Uncertainty

There should be a numerical indication which shows accuracy of calculated results in order to assess level of reliability of the results. Without numerical indications showing accuracy of the results, it is not possible to compare and comment on the results according to certificates or standards. For that purpose, there should be an additional easy, applicable, understandable calculation to show quality of processes which have been followed. This can be provided by calculation of uncertainty.

Errors on measurements and error analysis have been used for many years for evaluation of results. However, uncertainty is a relative concept. Although all suspected components are calculated and corrections are done, it is assumed that there is still uncertainty on calculated results. This uncertainty is suspicion about how calculated results represents measured quantity [86].It is important to express uncertainty in a global way hence uncertainty calculations have been being used for engineering, science, industrial and trade significantly. In order to compare results found for different locations, for different systems as well as for different configurations, uncertainty of results should be calculated and identified as it has been in this study.

In this study wind and solar energy resources have been used together in order to design hybrid energy system. For that reason, required uncertainty calculations have been done in order to find accuracy of results which have been found in this study. Based on uncertainty results, assessment of results can be done easily.

Information regarding each individual uncertainty component and calculation methods will be explained in this section. In order to combine each individual uncertainty component Root Mean Square (RMS) method [50] is used.

$$\varepsilon_{total} = (\varepsilon_{wind}^2 + \varepsilon_{solar}^2)^{\frac{1}{2}} \quad (4.2.2)$$

This method is applied to wind and solar uncertainty components to calculate uncertainty associated with each resource, and then total uncertainty is defined using Formula 4.2.2.

4.2.3.1. Uncertainty on Wind Energy

Uncertainty of measurement, vertical extrapolation, power curve, air density and annual variability of wind resource will be considered for wind energy in this study. It is recommended to consider horizontal extrapolation as well. However, it is preferred to locate wind turbine to measurement location, therefore, horizontal extrapolation uncertainty is not included in consideration. For this study below equation (4.2.3) has been considered.

$$\varepsilon_{Wind} = (\varepsilon_{Measurement}^2 + \varepsilon_{Vertical}^2 + \varepsilon_{AirDensity}^2 + \varepsilon_{Future}^2 + \varepsilon_{PowerCurve}^2)^{\frac{1}{2}}$$

- **Measurement Uncertainty**

Accuracy of wind data measurements should be under control during the measurement period, in order to provide high quality results. All important events also should be recorded. According to IEC Standard [87], calibration of anemometer, mounting effects and terrain effects are the main components for measurement uncertainty.

Based on the information provided in documents published by manufacturers of anemometer, accuracy of anemometer is ±1% [88, 89, 90]. In addition to that, mounting and terrain effects cause uncertainties. These are given in standards [87, 91].

According to IEC [87], given example is that "The standard uncertainty of the anemometer calibration is estimated to be 0,1 m/s. Uncertainty due to operational characteristics of the anemometer is derived from the classification which is estimated to be a class 1,2A. Assuming a rectangular uncertainty distribution, the class corresponds to a standard uncertainty of 0,034 m/s + 0,0034Vi. The standard uncertainty of the flow distortion due to mounting effects is estimated to be1 % of the wind speed. Considering a wind speed range of 30 m/s of the measurement channel and an uncertainty of the data acquisition system of 0,1 % of this range, the standard uncertainty from data acquisition is 0,03 m/s. In this example, it is assumed that site calibration is not undertaken, and the flow distortion due to the terrain is estimated to be 3%of the wind speed. The uncertainty of each wind speed bin is:" [87]

$$\varepsilon_{v,j} = \sqrt{\begin{gathered}(0{,}1m/s)^2 + (0{,}034m/s \ + 0{,}0034. V_i[m/s])^2 + \\ (0{,}01. V_i[m/s])^2 + (0{,}03. V_i[m/s])^2 + (0{,}001\ .30m/s)^2\end{gathered}}$$

According to this formula, it is possible to calculate measurement uncertainty.

According to Measnet - Measuring Network of Wind Energy Institutes - [91], if all stages of measurement campaign are followed by Measnet, uncertainty value of 0%; if none of the stages are followed by Measnet, uncertainty value of 5% can be considered. If anemometers are calibrated by a Measnet Facility and documents are provided and checked, uncertainty value of 1-2% can be considered.

In this study, measured data from Urla Wind Farm have been used. Any document associated with the mast located for wind data measurement on site has not been provided to us, however it has been known that without valid conditions like configuration requested by IEC, valid sensor types calibrated by a Measnet Facility and checks done by the same facilities, it is not possible to use data recorded on that mast. Therefore it is possible to assume measurement uncertainty value of 2,5% for measured wind data in our study. This value is used for calculations done in HOT and Homer Pro for MEB configurations.

In addition to that, NASA SSE Wind Data have been used in this study Sample house scenario. Based on the information provided by NASA [92], "Ten-year average SSE "airport" estimates were compared with 30-year average airport data sets over the globe furnished by the RETScreen project. In general, monthly bias values varied between +0.2 m/s and RMS (including bias) values are approximately 1.3 m/s. This represents a 20 to 25 percent level of uncertainty relative to mean monthly values". Due to its low resolution (1 degree by 1 degree Latitude/Longitude), and warning about increasing 20-25 percent uncertainty level, it is possible to increase uncertainty value to 3,5% for NASA wind data in this study for Homer Pro calculations for MEB configurations.

NASA wind data have been downloaded in Homer Pro as hourly data, however, the data has been used as monthly means in HOT. There is therefore an additional uncertainty for measurement uncertainty should be considered in HOT when NASA wind data is used. So that, a pragmatic adjustment has been applied and measurement uncertainty is increased to 4,0% for MEB configurations calculated in HOT.

- **Vertical Extrapolation Uncertainty**

Vertical extrapolation called as shear in wind speed calculation, has an uncertainty due to α component which is calculated considering different measurement heights wind speeds. Based on power law equation (3.1.1), using ratio between measurement heights and ration between wind speeds at these heights, α component is calculated. At least two measurement height wind speed should be used to calculate shear component α. Therefore, shear uncertainty depends on measurement and terrain effects with a standard assumption of 0,14 [26]. However, in this study monthly wind speed values recorded at only one measurement height have been used. So that, it is not possible to calculate shear component. It has been assumed as 0,143 (1/7). Based on the studies which have been done before [93, 94, 95, 96], in normal conditions shear α component is in a range of 0,14 - 0,20.

In this study, shear α component is assumed as 0,143 (1/7), and hub height wind speeds have been calculated. Measured data recorded at 70m and NASA data presented at 50m have been used.

Considering measured data recorded at 70m, shear α component is assumed as 0,143 (1/7), 0,167 (1/6) and 0,2 (1/5), and wind speeds and deviations have been calculated. Calculated standard deviations are 1,00, 0,98 and 0,96 respectively for measurement height 70m and hub height 30 m. Once the calculated wind speeds are compared, the difference between wind speeds is 2% with α as 0,143 and 0,167,. And this value is 4,7% if α =0,143 is compared with α= 0,2. According to this calculations, it is possible to assume a shear uncertainty for vertical extrapolation from 70m to 30min range of 0% - 4,7%for this study.

Considering NASA data recorded at 50m, shear (α) component is assumed as 0,143 (1/7), 0,167 (1/6) and 0,2 (1,5), and wind speeds and deviations have been calculated. Calculated standard deviations are 0,72, 0,71 and 0,70 respectively for measurement height 50m and hub height 30 m. Once the calculated wind speeds are compared, bias between wind speeds with α as 0,143 and as 0,167, there is 1,21% difference. And this value is 2,9% for 0,143 and 0,2. According to this calculations, it is possible to assume a shear uncertainty for vertical extrapolation from 50m to 30m in range of 0% - 2,9% for this study.

- **Air Density Uncertainty**

Air density depends on temperature and air pressure recorded on site. According to IEC [87], calibration and mounting effects of temperature and pressure sensors identify air density uncertainty. According to technical data sheets of temperature and pressure sensors provided by the manufacturers, in general, uncertainty values are 1% and 0,2%respectively [97, 98, 99]. These values are included in total uncertainty calculation as RMS.

$$\varepsilon_{AirDensity} = (\varepsilon_{Temperature}^2 + \varepsilon_{Pressure}^2)^{\frac{1}{2}}$$

$$\varepsilon_{AirDensity} = (0{,}01^2 + 0{,}002^2)^{\frac{1}{2}}$$

$$\varepsilon_{AirDensity} = 0{,}01019 \sim 1{,}02\%$$

- **Annual Variability of Wind Resource**

Observations show that wind resource may vary from year to year. It is known that measured wind speeds are at the lowest level in 2002 and 2014 in Turkey [100, 101]. Since wind resource can vary in years as it has been experimented in Turkey as well, uncertainty of future wind resource should be considered in wind energy calculations. Future wind resource uncertainty depends on two components which are called as normal and climate. The uncertainty for future wind resource for a plant life of 10 years is assumed 1,4%, and 2,2% for a plant life of 25 years. Lifetime is assumed as 20 years in this study, therefore the uncertainty of future wind resource is assumed as 2% [102].

- **Power Curve Uncertainty**

If measured power curve of related wind turbine is available, it is possible to calculate uncertainty of the power curve according to IEC Standard [87], however, if the measured power curve is not available and only calculated power curve is available as it is used in this study, then assumption have to be taken considering wind speed dependence of the power curve uncertainty [91]. Otherwise, all uncertainty values associated with wind energy explained above will be evaluated in RMS rule and total uncertainty will be found as power curve uncertainty as it has been done in IEC Standard [87].The uncertainty on this overall turbine performance loss estimate is modeled as a normal distribution with a typical standard deviation which depends on the project sensitivity value, typically of between 1,6% and 3,1%. The magnitude of this uncertainty which is in a range of 5,2% - 7,8% depends the suitability of the provided power curve for the site conditions [103].

4.2.3.2. Uncertainty on Solar Energy

In order to identify uncertainty of solar energy, solar radiation, cell efficiency, and annual variability of solar resource will be considered. In addition to that, snow is one other important uncertainty component, however, due to climatic conditions of Urla, Izmir, snow is not included in uncertainty calculations.

$$\varepsilon_{Solar} = (\varepsilon_{Radiation}^2 + \varepsilon_{Efficiency}^2 + \varepsilon_{Future}^2)^{\frac{1}{2}} \quad (4.2.4)$$

- **Solar Radiation Uncertainty**

Solar radiation value is measured by pyranometer, so that, measurement accuracy of pyranometer should be known in order to calculate solar radiation uncertainty. However, in this study, NASA data has been used, therefore any uncertainty value belonged any sensor has not been considered. NASA Science Mission Directorate's satellite has been recorded data and used re-analysis research programs in order to collect reliable, general and achievable data set. Obtained data have been derived according to energy market and suggestions by participants.

Data modeled and recorded by NASA, have been presented on SSE - Surface Meteorology and Solar Energy - release 6.0 [104, 105] for 22 years. Solar radiation values on SSE data set have been compared with data from Baseline Surface Radiation Network (BSRN). According to this comparison, uncertainty values have been found for this data set.

Table 4.4. NASA SSE release 6.0 solar radiation uncertainty

Parameter	Region	Bias (%)	RMS (%)
Direct Normal Radiation	Global	-4.06	22.73
	60° Poleward	-15.66	33.12
	60° Equatorward	2,40	20.93

Based on the data provided in above table, uncertainty value of 22,73% is the uncertainty value for solar radiation data used in this study.

NASA Solar data have been downloaded in Homer Pro as hourly data for Homer calculations. However, for HOT calculations, solar data are taken directly from NASA SSE as monthly means. So that, there is an additional uncertainty should be applied for HOT calculation with this data set. Given uncertainty value is pragmatically adjusted to 25% (increasing %10 of given uncertainty value).

- **Cell Efficiency Uncertainty**

Efficiency of solar PV panel - Panasonic N330 - used in this study is 19,7% as module efficiency [54]. Based on the information provided in warranty document [106], first year energy production warranty of PV module is 95% at least. In addition to that, maximum yearly loss of energy production is 0,6%, so that at the end of 25 years, 80,6% of installed capacity will be available. Also, a tolerance value is presented in technical data sheet of the PV module. According to the technical data sheet [54], +10% / -0%, values are given as tolerance and uncertainty of the modules. This values mean that the PV module can produce 10% more than its capacity, and it is expected that energy production would not be less than module capacity.

- **Annual Variability of Solar Resource**

Sun effects have been recorded for many years, there is therefore a valuable data collected by satellites as well as stations located ground. However solar resource is not constant for the same days in each year, there is differences and different measurements for each location. Considering this, it should be defined as an uncertainty for annual variability of solar resource. According to study done by Suri et. Al [107], yearly standard deviation of variability is in range of 4 - 6% for Mediterranean Islands, Europe and Turkey. Izmir is under consideration of this study, and relative difference of years with lowest and highest sum of global horizontal irradiation in relation to the long-term average is presented in this study for Izmir as - 6,7% / +4,7% [107].

CHAPTER 5

RESULTS

Two different electricity consumption data have been used in this study. Each data have been assessed monthly and hybrid energy systems have been designed based on these consumptions. Calculations have been conducted considering the equations which have been given in Section 3 and Section 4.

Firstly, economical energy resource has been identified in order to design the hybrid energy system. In order to find the economical resource, 20 years energy generation by 100 kW wind turbine and 100 kW PV panel has been calculated separately using the wind and solar energy datasets which are obtained for the site of interest. Then, 20 years cost of each 100 kW energy system has been calculated assuming operational costs are 100% and 50% of the initial investment costs for wind turbines and solar PV panels respectively. Based on the calculated total costs and generated energy amounts per component, energy cost has been calculated per kW energy. According to the result, energy supplying system has been selected considering to lower the energy price. This calculation has been done according to the wind and solar data recorded by two energy consumer. Energy cost calculation is significantly important due to the variability of the data recorded at a location. Solar data could be accepted regardless of the variability due to the large grid resource, however, wind data vary spatially. Solar data has low resolution of one-degree by one-degree resolution in latitude and longitude [109]. Two energy consumers were preferred in this study that are located in the same grid for the solar data. Therefore, the same solar data have been used for these two locations. Wind speed is affected as altitude changes rapidly, also ground cover and surrounding obstacles are causes of wind speed change. Measurement of the wind data, especially on site, is of importance due to this variety. For instance, wind speed is most likely high on a location which has high altitude above the sea level and is located on a smooth area without surrounding mountains, where solar data could be quite accurate as well. For this location it is more likely that wind can be the primary energy supplying system due to the high energy production and low energy production costs. However, once hybrid energy system is installed on a location which has lower altitude, forestry and complex area, the wind speeds are more affected by the terrain and hence probably lower. On the other hand as the solar data is not affected by these changes significantly. For this location, the solar PV system might be the primary energy supplying system. With this approach, if the primary energy supplier is chosen to be the wind energy, wind turbine number will be calculated as one unit less than the exceedance of the energy consumption, and remaining energy will be supplied by the solar PV panels. If primary energy supplier is taken as the solar PV panels, then the wind turbine number will be set to one in order to construct the hybrid energy system and the remaining energy will be supplied by the solar PV panels. Number of the PV panels have been rounded up to the closest multiples of 20. By this method, hybrid energy system will be reliable in energy generation with both of the resources.

Based on the information obtained from the energy market, 100 kW wind turbine investment costs considering all the required services is between 200.000 $ - 250.000 $. This cost has been assumed as 220.000 $ for this study in order to be conservative for economical analysis. All the required components and materials are included in this investment cost. Operational cost has been assumed as 100% of the investment cost for 20 years of operation. Operational cost includes project costs, allowance costs, maintenance costs, service costs, and other expenses like salary of employees on site. For PV panels, investment cost of 100 kW solar system is between 150.000 $ - 200.000 $ according to the Turkish energy market. Solar PV system cost has been assumed as 170.000 $ for this study in order to be conservative for the economical analysis as it has been in the wind turbine part. All the required components like cable, inverter, construction for panels, are included in this investment cost. Operational cost has been assumed as 50% of investment cost for 20 years of operation. Operational cost includes project costs, allowance costs, maintenance costs, service costs, and other expenses like salary of employees on site. Any purchasing or renting price for land has not been added to the investment costs assuming all energy systems will be located on private lands like IZTECH campus area for Mechanical Engineering Building. In addition to that, no interest rate has been applied to investment costs assuming all costs in USD. Currency differential on energy buying (in TL) and selling (in USD) will provide the hybrid system to compensate for the difference in years. Unit cost of electricity has been taken from the website of EMRA [110], when taxes and service costs are included to the specified unit cost, final cost of electricity has been calculated as 0.4117 TL. The USD/TL rate is assumed to be 3.4 and the final cost of electricity is 0.12 USD.

A calculation has been developed for the wind-solar hybrid energy system in this thesis. Considering the above explanations, energy calculations have been conducted by the developed tool and in Homer Pro, which predicted different configurations. System optimization has been conducted by the tool and the software. Additional alternative configurations have been selected for comparison. In addition to the energy calculations, economical feasibility analysis have been conducted for each configuration found by the developed tool and Homer Pro software. At the end of the study, results of the tool and the software have been compared in order to show the approximation of the developed tool to the Homer Pro software.

5.1. Power Plant of Mechanical Engineering Building

Table 4.1 shows the energy consumption at the Mechanical Engineering Building (MEB) of IZTECH, which has been measured and recorded each month. Although lower consumptions have been recorded in the previous years, the highest energy consumption has been recorded in the year of 2014. Thus, 2014 has been considered as a basis for this study in order to be in the conservative side. Data and information which are required to design and calculate the hybrid energy system for the MEB, is presented in Table 5.1.

Table 5.1. Data Table of Mechanical Engineering Building of IZTECH

Project Name: Wind-Solar Hybrid Energy System for Mechanical Engineering Building of IZTECH			**Location:** Gülbahçe - Urla			**Date**	
			Easting: 465440[1]				
Site Name:			**Northing:** 4241273[1]				
	WIND DATA			**SOLAR DATA**			**DEMAND**
Data / Months	Weibull A	Weibull k	Density (kg/m³)	Clearness	Solar Radiation (kWh/m²/day)	Average Temperature (ºC)	Energy Demand (kW)
January	7,94	1,11	1,251	0,48	2,17	7,7	29.123
February	10,46	1,97	1,249	0,51	3,03	8,0	41.681
March	8,60	1,48	1,237	0,57	4,43	10,8	43.167
April	9,33	1,59	1,216	0,60	5,82	15,7	35.173
May	7,68	1,82	1,193	0,66	7,28	21,4	30.172
June	9,18	2,08	1,174	0,72	8,34	26,1	45.124
July	11,27	2,56	1,164	0,73	8,23	28,8	59.216
August	12,44	2,62	1,165	0,72	7,34	28,5	63.129
September	10,06	2,14	1,180	0,69	5,86	24,5	51.632
October	9,64	2,01	1,202	0,63	4,07	19,2	13.657
November	10,56	1,91	1,227	0,53	2,56	13,3	22.764
December	10,19	1,77	1,237	0,44	1,82	9.0	34.289
Average	**9,78**	**1,92**	**1,210**	**0,61**	**5,08**	**17,8**	**39.094**
Total					**60,95**		**469.127**

1. Coordinate system is UTM ED50.

This data sheet is the base requirement of this study in order to compute the wind resource capacity, solar resource capacity and the energy demand of consumer. Wind data shown in Table 5.1, have been measured on the met mast which is located in the Urla RES, within the IZTECH Campus. Height of the recorded wind data is 70.0 m. According to these data, energy generations of 100 kW wind turbine and 100 kW PV panel have been compared in order to define primary resource.

Table 5.2. Primary Energy Resource Definition for Mechanical Engineering Building of IZTECH

Financial Analysis of Primary Energy Resource		
	100 kW Wind Turbine (kW)	**100 kW PV Panel (kW)**
January	16.134,7	4.305,3
February	25.867,6	5.429,8
March	16.805,8	8.789,1
April	20.056,5	11.174,4
May	11.413,2	14.443,5
June	17.686,9	16.012,8
July	33.019,7	16.328,3
August	42.618,6	14.562,6
September	23.271,5	11.251,2
October	21.747,4	8.074,9
November	28.088,1	4.915,2
December	26.501,5	3.610,9
Total	**283.211,7**	**118.897,9**
20 Years Total	**5.664.234,6**	**2.377.958,4**
Investment Cost	220.000 $	170.000 $
Operational Cost	220.000 $	85.000 $
20 Years Total Cost	440.000 $	255.000 $
Energy Cost	0,0777 $	0,1072 $

According to results above, wind turbine has been calculated as the primary energy resource. Further energy calculations and optimization have been conducted in regard to these results. Total energy production of each configuration and monthly difference between the produced and demanded energy amount are shown in the first tables at each result section. Then, energy production of each resource will be separately shown in the following table, and the economical analysis for each configuration will be provided in the final section.

5.1.1. Results of Mechanical Engineering Building with HOT

Based on the Table 5.1 and results in Table 5.2, the developed tool has optimized one configuration in addition to the one alternative configuration. One 100 kW wind turbine and 544 PV panels which totals up to 279.5 kW of a hybrid energy system configuration has been optimized by the HOT tool. However, the number of the PV panels have been rounded up to 540, and the optimized result has become to include one wind turbine and 540 PV panels which has totally 278.2 kW of capacity. Alternative configuration includes 2 wind turbines and 138 PV panels which means maximum calculated wind turbine number and minimum PV panel number rounded up to 140. This alternative hybrid energy system configuration has a total capacity of 246.2 kW.

5.1.1.1. Results of the Optimized Configuration for MEB with HOT

278.2 kW (100 kW WTG + 178.2 kW PV)

The optimized configuration in HOT for MEB includes one 100 kW wind turbine and 544 solar PV panels, which was rounded down to 540.

Table 5.3. IZTECH Monthly Energy Production of Optimized Configuration by HOT

	1 Wind Turbine (100kW) / 540 PV Panels (178.2kW) 278.2 kW	Energy Demand (kW)	Difference between Produced and Demanded Energy Amount
January	23.806,8	29.123,0	-5.316,2
February	35.543,4	41.681,0	-6.137,6
March	32.468,0	43.167,0	-10.699,0
April	39.969,3	35.173,0	4.796,3
May	36.692,1	30.172,0	6.520,1
June	46.221,8	45.124,0	1.097,8
July	62.116,7	59.216,0	2.900,7
August	68.569,1	63.129,0	5.440,1
September	43.321,2	51.632,0	-8.310,8
October	36.136,9	13.657,0	22.479,9
November	36.847,0	22.764,0	14.083,0
December	32.936,1	34.289,0	-1.352,9
Total	**494.628,4**	**469.127,0**	**25.501,4**

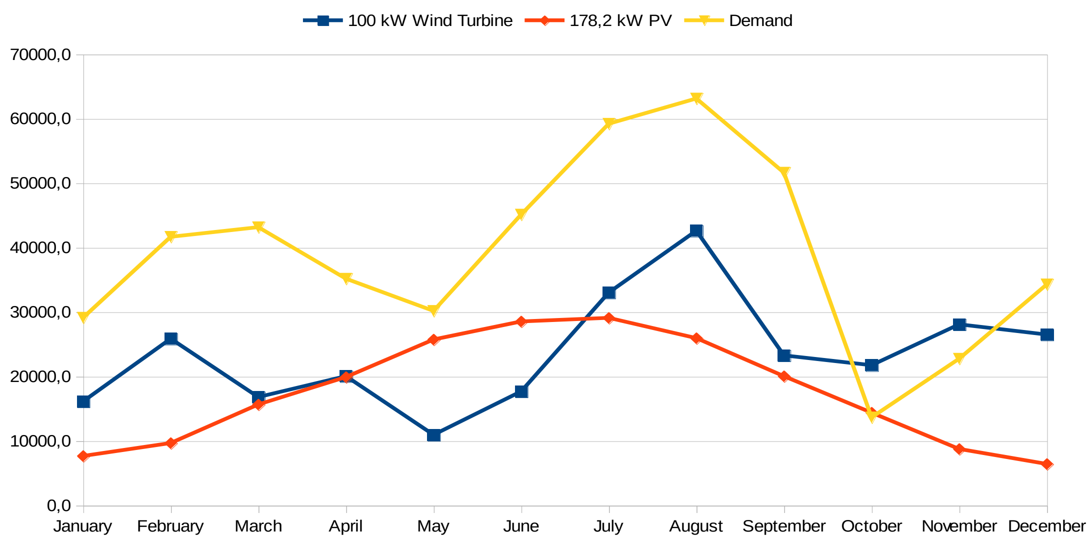


Figure 5.1.IZTECH Energy Consumption and Energy Generation by each Resource for Optimized Configuration by HOT

In case of no energy supplying system will be installed for Mechanical Engineering Depart of IZTECH, total energy cost is computed to be 56.295,2 USD annually, and 1.125.904,8 USD for 20 years.

Table 5.4. IZTECH - Produced and Demanded Energy Difference in kW and in USD for Configuration-1 by HOT

	Difference Produced-Demanded (kW)	**Difference Produced-Demanded (USD)**
January	-5.316,2	-637,9
February	-6.137,6	-736,5
March	-10.699,0	-1.283,9
April	4.796,3	479,6
May	6.520,1	652,0
June	1.097,8	109,8
July	2.900,7	290,1
August	5.440,1	544,0
September	-8.310,8	-997,3
October	22.479,9	2.248,0
November	14.083,0	1.408,3
December	-1.352,9	-162,3
Total	**25.501,4**	**1.913,8**
20 Years Total	**510.027,8**	**38.276,2**

Energy system investment should be assessed for 20 years. With this approach, 20 years operational costs should be added to installation cost of the proposed wind solar hybrid energy system. As it has been mentioned in Section 5, total investment cost is calculated for the proposed configuration below:

100 kW Wind Turbine installation cost	:	220.000 $
100 kW Wind Turbine operational cost	:	220.000 $
178.2 kW Solar PV Panel installation cost	:	302.940 $
178.2 kW Solar PV Panel operational cost	:	151.470 $
20 Years Total Investment Cost	:	894.410 $

Total expense is not only the investment costs of this configuration when concerned with the monthly energy selling or buying from the installed facility. This aspect should be included in the total expense calculations.

20 Years Total Energy Expense	:	- 38.276,2 $
20 Years Total Investment Cost	:	894.410,0 $
20 Years Total Expense for this configuration	:	856.133,8 $

Difference between the energy cost in case of no energy supplying system is installed and the total expense in case this investment takes place and taken into operation, which should be calculated as well to understand the system benefits or loss.

20 Years Total Energy Cost without hybrid system	:	1.125.904,8 $
20 Years Total Expense for this configuration	:	856.133,8 $
20 Years total benefit or loss	:	- 269.771,0 $

According to the final result, this configuration will bring in 38.276,2 $ in 20 years, however when we consider energy cost that will be paid for this consumption, the system will be lucrative as 269.771,0 $ for 20 years.

Final energy cost per kW at the end of 20 years can be calculated by dividing 20 Years Total Expense by 20 Years Energy Demand;

20 Years Energy Demand	:	9.382.540 kW
20 Years Total Expense for this configuration	:	856.133,8 $
Energy Cost for per kW for 20 Years Investment	:	0.091 $

Profit volume ratio can be also calculated by dividing 20 years total benefit or loss by 20 years total investment cost. This ratio becomes ;

20 Years total benefit or loss	:	- 269.771,0 $
20 Years Total Investment Cost	:	894.410,0 $
Profit volume ratio	:	30,16%

5.1.1.2. Results of Alternative Configuration for MEB with HOT

246,2 kW (200 kW WTG + 46,2 kW PV)

The alternative configuration in the developed tool for the Mechanical Engineering Building of IZTECH is designed to include two 100 kW wind turbines and 160 solar PV panels.

Table 5.5. IZTECH Monthly Energy Production of Alternative Configuration by HOT

	2 Wind Turbine (200kW)	140 PV Panels (46,2kW)	Energy Demand (kW)	Difference between Produced and Demanded Energy Amount
	246,2 kW			
January	34258,5		29.123,0	5.135,5
February	54243,8		41.681,0	12.562,8
March	37672,2		43.167,0	-5.494,8
April	45275,7		35.173,0	10.102,7
May	28580,3		30.172,0	-1.591,7
June	42771,8		45.124,0	-2.352,2
July	73583,0		59.216,0	14.367,0
August	91965,2		63.129,0	28.836,2
September	51741,1		51.632,0	109,1
October	47225,4		13.657,0	33.568,4
November	58447,1		22.764,0	35.683,1
December	54671,3		34.289,0	20.382,3
Total	**620435,4**		**469.127,0**	**151.308,4**

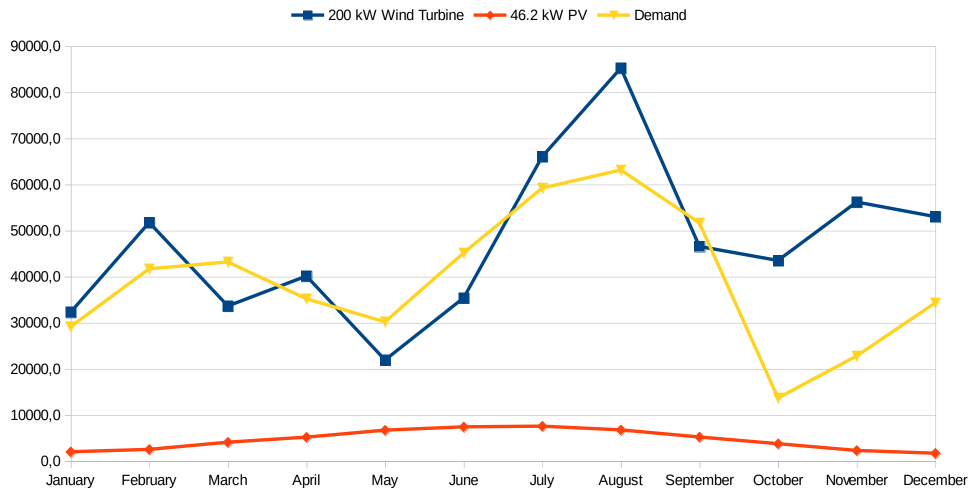


Figure 5.2. IZTECH Energy Consumption and Energy Generation by each Resource for Alternative Configuration by HOT

Table 5.6. IZTECH - Produced and Demanded Energy Difference in kW and in USD for Alternative Configuration by HOT

	Difference Produced-Demanded (kW)	**Difference Produced-Demanded (USD)**
January	5.135,5	513,6
February	12.562,8	1.256,3
March	-5.494,8	-659,4
April	10.102,7	1.010,3
May	-1.591,7	-191,0
June	-2.352,2	-282,3
July	14.367,0	1.436,7
August	28.836,2	2.883,6
September	109,1	10,9
October	33.568,4	3.356,8
November	35.683,1	3.568,3
December	20.382,3	2.038,2
Total	**151.308,4**	**14.942,1**
20 Years Total	**3.026.168,6**	**298.841,4**

As it has been provided in the previous Section 5.1.1.1, if there an energy supplier system will not be installed for the Mechanical Engineering Depart of IZTECH, total energy cost will be 56.295,2 USD yearly, and 1.125.904,8 USD for 20 years.

Energy system investment should be assessed for 20 years. With this approach, 20 years operational cost should be added to the installation cost of the proposed wind solar hybrid energy system. As it has been mentioned in Section 5, total investment cost is calculated for the proposed configuration below:

200 kW Wind Turbine installation cost	:	440.000 $
200 kW Wind Turbine operational cost	:	440.000 $
46,2 kW Solar PV Panel installation cost	:	78.540 $
46,2 kW Solar PV Panel operational cost	:	39.270 $
20 Years Total Investment Cost	:	997.810 $

Total expense is not only the investment costs of this configuration when concerned with the monthly energy selling or buying from the installed facility. This aspect should be included in the total expense calculations.

20 Years Total Energy Cost	:	- 298.841,4 $
20 Years Total Investment Cost	:	997.810,0 $
20 Years Total Expense for this configuration	:	698.968,6 $

Difference between the energy cost in case of no energy supplier system is installed and total expense in case of this investment is installed and operated should be calculated in order to understand the system benefit or loss.

20 Years Total Energy Cost without hybrid system	:	1.125.904,8 $
20 Years Total Expense for this configuration	:	698.968,6 $
20 Years total benefit or loss	:	- 426.936,2 $

According to the final result, this configuration will bring in 298.841,4 $ in 20 years, however when we consider energy cost that will be paid for this consumption, the system will be lucrative as 376.446,2 $ for 20 years.

Final energy cost per kW at the end of 20 years can be calculated dividing 20 Years Total Expense by 20 Years Energy Demand;

20 Years Energy Demand	:	9.382.540 kW
20 Years Total Expense for this configuration	:	698.968,6 $
Energy Cost for per kW for 20 Years Investment	:	0.074 $

Profit volume ratio can also be calculated by dividing 20 years of total benefit or loss by 20 years of total investment cost. This ratio becomes ;

20 Years total benefit or loss	:	- 426.936,2$
20 Years Total Investment Cost	:	997.810,0 $
Profit volume ratio	:	61,08%

5.1.2. Results of Mechanical Engineering Building with Homer

Same inputs have been entered to Homer Software and results have been calculated. Homer uses each quantity and size of the energy system defined by the user in Homer. For instance, if 1 and 2 wind turbines and 5, 10 and 15 kW PV panels would be considered for calculations, Homer does calculations for 1 wind turbine + 5 kW PV, 1 wind turbine + 10 kW PV, 1 wind turbine + 15 kW PV, 2 wind turbines + 5 kW PV, 2 wind turbines + 10 kW PV and 2 wind turbines + 15 kW PV. Each individual result can be found in Homer, however Homer gives the most appropriate results based on its assessment. Below figures show the results list of Homer.

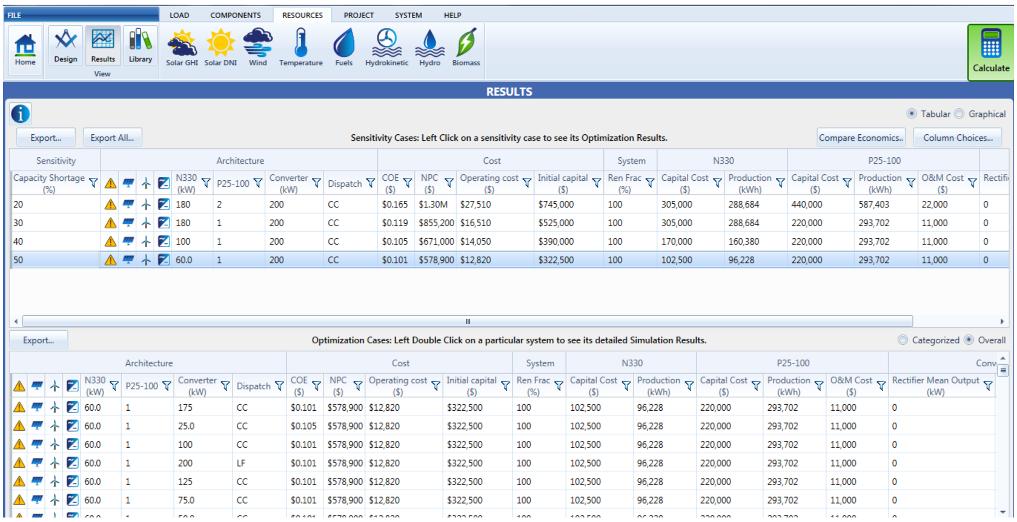


Figure 5.3. Mechanical Engineering Building Homer Results List

As seen in figure above, the most appropriate results are located in the upper list. All results can be seen in the lower list. In order to compare the results computed by Homer and HOT, the closest results have been evaluated for this study. Section 5.1.1 mentions that two results have been found by HOT as optimized configuration and one alternative configuration. Homer has calculated all configurations and presented four of them as the most appropriate configurations. One of them, which is 1 wind turbine + 180 kW PV, is compatible with the optimized configuration by HOT. The other configuration with 2 wind turbines + 40 kW PV has been selected from below list. Homer has a calculation methodology based on hourly data and takes into consideration of hourly excess and unmet energy amounts. With this approach, if there is more excess and/or unmet energy amount, Homer tends to present the cheapest configuration.

5.1.2.1. Results of Optimized Configuration for MEB with HOMER

280 kW (100 kW WTG + 180 kW PV)

The optimized configuration in HOMER for the Mechanical Engineering Building of IZTECH uses one 100 kW wind turbine and 180 kW solar PV panels.

Table 5.7. IZTECH Monthly Energy Production of Optimized Configuration by Homer

	1 Wind Turbine (200kW)	180 kW PV Panels	Energy Demand (kW)	Difference between Produced and Demanded Energy Amount
	280 kW			
January	37.570,0		29.123,0	8.447,0
February	43.650,5		41.681,0	1.969,5
March	46.040,6		43.167,0	2.873,6
April	48.912,5		35.173,0	13.739,5
May	45.025,3		30.172,0	14.853,3
June	50.469,8		45.124,0	5.345,8
July	59.304,4		59.216,0	88,4
August	62.552,2		63.129,0	-576,8
September	52.957,2		51.632,0	1.325,2
October	48.812,9		13.657,0	35.155,9
November	45.418,0		22.764,0	22.654,0
December	41.672,5		34.289,0	7.383,5
Total	**582.386,0**		**469.127,0**	**113.259,0**

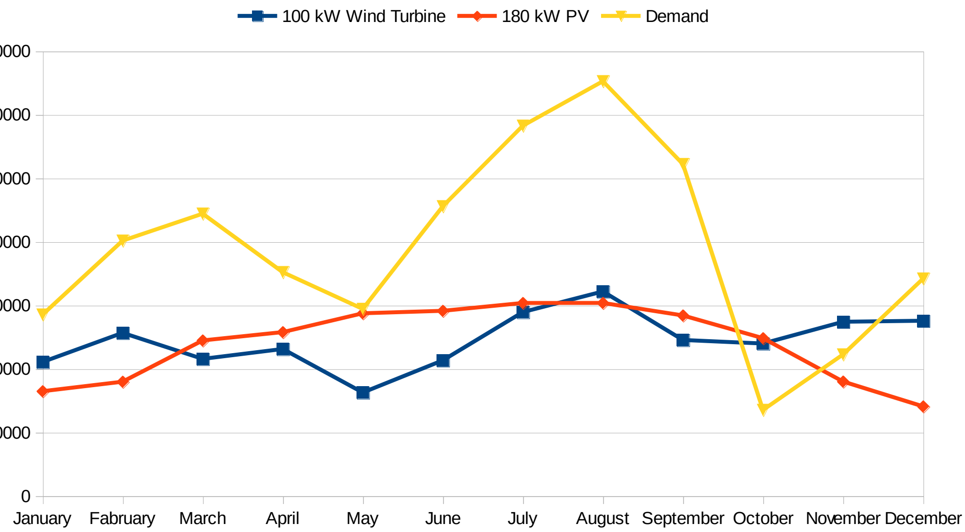


Figure 5.4. IZTECH Energy Consumption and Energy Generation by each Resource for Optimized Configuration by Homer

Table 5.8. IZTECH - Produced and Demanded Energy Difference in kW and in USD for Optimized Configuration by Homer

	Difference Produced-Demanded (kW)	**Difference Produced-Demanded (USD)**
January	8.447,0	844,7
February	1.969,5	196,9
March	2.873,6	287,4
April	13.739,5	1.373,9
May	14.853,3	1.485,3
June	5.345,8	534,6
July	88,4	8,8
August	-576,8	-69,2
September	1.325,2	132,5
October	35.155,9	3.515,6
November	22.654,0	2.265,4
December	7.383,5	738,3
Total	**113.259,0**	**11.314,4**
20 Years Total	**2.265.179,8**	**226.287,3**

As discussed in Section 5.1.1.1, if no energy supplying system will be installed for the Mechanical Engineering Department of IZTECH, the total energy costs will be 56.295,2 USD yearly, and 1.125.904,8 USD for 20 years.

Energy system investment should be assessed for 20 years. With this approach, 20 years operational cost should be added to installation cost of the proposed wind solar hybrid energy system. As it has been mentioned in Section 5, total investment cost is calculated for the proposed configuration below:

100 kW Wind Turbine installation cost	:	220.000 $
100 kW Wind Turbine operational cost	:	220.000 $
180 kW Solar PV Panel installation cost	:	306.000 $
180 kW Solar PV Panel operational cost	:	153.000 $
20 Years Total Investment Cost	:	899.000 $

Total expense is not only the investment costs of this configuration when concerned with the monthly energy selling or buying from the installed facility. This aspect should be included in the total expense calculations.

20 Years Total Energy Cost	:	- 226.287,3 $
20 Years Total Investment Cost	:	899.000,0 $
20 Years Total Expense for this configuration	:	672.712,7 $

Difference between the energy cost in case of no energy supplier system is installed and total expense in case of this investment is installed and operated, should be calculated in order to understand the system benefit or loss.

20 Years Total Energy Cost without hybrid system	:	1.125.904,8 $
20 Years Total Expense for this configuration	:	672.712,7 $
20 Years total benefit or loss	:	- 453.192,1 $

According to the final result, this configuration will bring in 226.287,3 $ in 20 years, however when we consider energy cost that will be paid for this consumption, the system will be lucrative as 453.192,1$ for 20 years.

Final energy cost per kW at the end of 20 years can be calculated dividing 20 Years Total Expense by 20 Years Energy Demand;

20 Years Energy Demand	:	9.382.540 kW
20 Years Total Expense for this configuration	:	672.712,7 $
Energy Cost for per kW for 20 Years Investment	:	0.072 $

Profit volume ratio can also be calculated by dividing 20 years total benefit or loss by 20 years total investment cost. This ratio becomes ;

20 Years total benefit or loss	:	- 453.192,1 $
20 Years Total Investment Cost	:	899.000,0 $
Profit volume ratio	:	50,41%

5.1.2.2. Results of Alternative Configuration for MEB with HOMER

240 kW (200 kW WTG + 40 kW PV)

The alternative configuration in HOMER for the Mechanical Engineering Building of IZTECH includes one 200 kW wind turbine and 40 kW solar PV panels.

Table 5.9. IZTECH Monthly Energy Production of Alternative Configuration by Homer

	2 Wind Turbine (200kW)	40 kW PV Panels	Energy Demand (kW)	Difference between Produced and Demanded Energy Amount
	240 kW			
January	45.829,5		29.123,0	16.706,5
February	55.331,8		41.681,0	13.650,8
March	48.573,0		43.167,0	5.406,0
April	51.990,9		35.173,0	16.817,9
May	38.942,6		30.172,0	8.770,6
June	49.146,4		45.124,0	4.022,4
July	64.619,8		59.216,0	5.403,8
August	71.109,2		63.129,0	7.980,2
September	55.411,1		51.632,0	3.779,1
October	53.487,5		13.657,0	39.830,5
November	58.828,9		22.764,0	36.064,9
December	58.284,8		34.289,0	23.995,8
Total	**651.555,4**		**469.127,0**	**182.428,4**

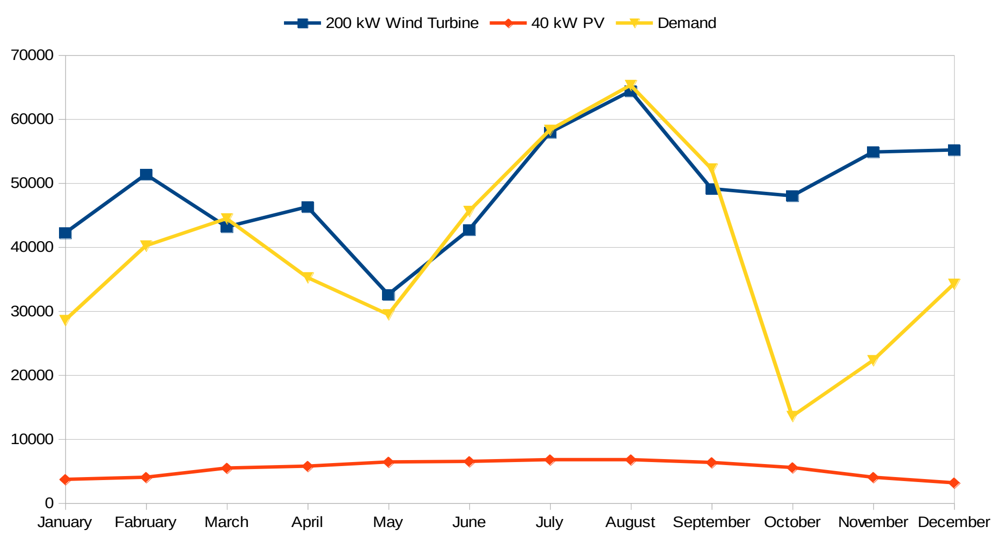


Figure 5.5. IZTECH Energy Consumption and Energy Generation by each Resource for Alternative Configuration by Homer

Table 5.10. IZTECH - Produced and Demanded Energy Difference in kW and in USD for Alternative Configuration by Homer

	Difference Produced-Demanded (kW)	**Difference Produced-Demanded (USD)**
January	16.706,5	1.670,6
February	13.650,8	1.365,1
March	5.406,0	540,6
April	16.817,9	1.681,8
May	8.770,6	877,1
June	4.022,4	402,2
July	5.403,8	540,4
August	7.980,2	798,0
September	3.779,1	377,9
October	39.830,5	3.983,0
November	36.064,9	3.606,5
December	23.995,8	2.399,6
Total	**182.428,4**	**18.242,8**
20 Years Total	**3.648.568,1**	**364.856,8**

As discussed in Section 5.1.1.1, in case of no energy supplier system will be installed for Mechanical Engineering Depart of IZTECH, total energy cost will be 56.295,2 USD yearly, and 1.125.904,8 USD for 20 years.

Energy system investment should be assessed for 20 years. With this approach, 20 years operational cost should be added to the installation cost for the proposed wind solar hybrid energy system. As mentioned in Section 5, total investment cost is calculated for the proposed configuration below:

200 kW Wind Turbine installation cost	:	440.000 $
200 kW Wind Turbine operational cost	:	440.000 $
40 kW Solar PV Panel installation cost	:	68.000 $
40 kW Solar PV Panel operational cost	:	34.000 $
20 Years Total Investment Cost	:	982.000 $

Total expense is not only the investment costs of this configuration when concerned with the monthly energy selling or buying from the installed facility. This aspect should be included in the total expense calculations.

20 Years Total Energy Cost	:	- 364.856,8 $
20 Years Total Investment Cost	:	982.000,0 $
20 Years Total Expense for this configuration	:	617.143,2 $

Difference between the energy cost in case of no energy supplier system is installed and total expense in case of this investment is installed and operated, should be calculated in order to understand the system benefit or loss.

20 Years Total Energy Cost without hybrid system	:	1.125.904,8 $
20 Years Total Expense for this configuration	:	617.143,2 $
20 Years total benefit or loss	:	- 508.761,6 $

According to the final result, this configuration will bring in 364.856,8 $ in 20 years, however when we consider energy cost that will be paid for this consumption, the system will be lucrative as 508.761,6 $ for 20 years.

Final energy cost per kW at the end of 20 years can be calculated by dividing 20 Years Total Expense by 20 Years Energy Demand;

20 Years Energy Demand	:	9.382.540 kW
20 Years Total Expense for this configuration	:	617.143,2 $
Energy Cost for per kW for 20 Years Investment	:	0.066 $

Profit volume ratio can be also calculated dividing 20 years total benefit or loss by 20 years total investment cost. This ratio becomes;

20 Years total benefit or loss	:	- 508.761,6 $
20 Years Total Investment Cost	:	982.000,0 $
Profit volume ratio	:	51,81%

5.2. Power Plant of Sample House

In this section, energy consumption of a sample house located in the urban area(SHUA) has been considered. In order to be consistent with the energy consumption of the Mechanical Engineering Building of IZTECH, monthly energy consumption amounts of the sample house have been multiplied with 100. Required data and information has been shown in Table 4.2. However, it is not possible to calculate the Weibull parameters without the measured wind data. For this reason, wind data have been supplied by the Homer Pro database like the solar data. In this regard, this part of the study shows that calculations can be done without the Weibull parameters too.

Table 5.11 includes all the required data in order to design and calculate the hybrid energy system for the sample house.

Table 5.11. Data Table of Mechanical Engineering Building of IZTECH

Project Name: Wind-Solar Hybrid Energy System for an House located in Urla Town	**Location:** Urla	**Date**
	Easting:	
Site Name:	**Northing:**	

Data / Months	**WIND DATA**		**SOLAR DATA**			**DEMAND**	
	Monthly Mean Wind Speed	Air Density (kg/m^3)	Clearness	Solar Radiation ($kWh/m^2/day$)	Average Temperature (ºC)	Energy Demand of one house (kW)	Energy Demand of 100 houses (kW)
January	6,21	1,251	0,48	2,17	7,7	718,0	71.800
February	7,22	1,249	0,51	3,03	8,0	673,0	67.300
March	6,43	1,237	0,57	4,43	10,8	533,0	53.300
April	5,57	1,216	0,60	5,82	15,7	481,0	48.100
May	4,74	1,193	0,66	7,28	21,4	254,0	25.400
June	4,65	1,174	0,72	8,34	26,1	298,5	29.850
July	5,35	1,164	0,73	8,23	28,8	200,0	20.000
August	5,15	1,165	0,72	7,34	28,5	262,0	26.200
September	5,02	1,180	0,69	5,86	24,5	282,0	28.200
October	6,31	1,202	0,63	4,07	19,2	493,0	49.300
November	5,88	1,227	0,53	2,56	13,3	434,0	43.400
December	6,14	1,237	0,44	1,82	9.0	533,0	53.300
Average	**5.72**	**1,210**	**0,61**	**5,08**	**17,8**	**430,1**	**43.010**
Total				**60,95**		**5.161,5**	**516.150**

This data sheet is the base requirement of this study in order to have information on the wind resource capacity, the solar resource capacity and the energy demand of the consumer. Wind data shown in Table 5.1, have been provided by the Homer Pro Software as 50 m height data instead of the measured data. According to these data, energy generations of 100 kW wind turbine and 100 kW PV panel have been compared in order to define primary resource.

Table 5.12. Primary Energy Resource Definition for Urban Area

Financial Analysis of Primary Energy Resource		
	100 kW Wind Turbine (kW)	**100 kW PV Panel (kW)**
January	10.097,5	4.305,3
February	14.264,1	5.429,8
March	10.942,8	8.789,1
April	6.863,3	11.174,4
May	4.364,8	14.443,5
June	3.917,6	16.012,8
July	5.928,2	16.328,3
August	5.386,6	14.562,6
September	4.932,1	11.251,2
October	10.122,1	8.074,9
November	8.211,0	4.915,2
December	9.685,9	3.610,9
Total	**94.716,0**	**118.897,9**
20 Years Total	**1.894.319,2**	**2.377.958,4**
Investment Cost	220.000,0 $	170.000,0 $
Operational Cost	220.000,0 $	85.000,0 $
20 Years Total Cost	440.000,0 $	255.000,0 $
Energy Cost	0,2323 $	0,1072 $

According to the results above, the solar PV panel has been assumed as the primary energy resource. In this study, while each wind turbine unit has 100 kW capacity, each solar PV panel has 0.33 kW capacity. It would be the most economical solution to design the system with only PV panels, however, the aim of this thesis is to design a wind-solar hybrid energy system and for this location, one 100 kW wind turbine will be held constant in order to provide the reliability for the energy generation. Further energy calculations and optimization have been done with regards to this assumption. Total energy production of each configuration and monthly difference between the produced and demanded energy amounts will be shown in the first tables in each result section. Then, the energy production of each resource will be separately shown in following tables, and economical analysis of each configuration will be provided in the final section.

5.2.1. Results of Sample House Located in Urban Area with HOT

Based on the Table 5.11 and results in Table 5.12, HOT has optimized one configuration in addition to two additional alternatives. 1621 PV panels which is 534,9 kW and one 100 kW wind turbine hybrid energy system configuration has been optimized by the HOT. However, the number of the PV panels have been rounded down to 1620, and hence the optimized configuration becomes to include 1 wind turbine + 1620 PV panels which has totally 634,6 kW of capacity. One of the alternative configurations includes 1 wind turbine and 2000 PV panels which has totally 660 kW capacity. The other alternative configuration includes 1 wind turbine and 1200 PV panels which has totally 396 kW capacity.

5.2.1.1. Results of Optimized Configuration for SHUA with HOT

634,6 kW (100 kW WTG + 534,6 kW PV)

The optimized configuration assumed by HOT for the SHUA includes one 100 kW wind turbine and 1621 solar PV panels, which is rounded down to 1620.

Table 5.13. Urban Area Monthly Energy Production of Optimized Configuration by HOT

	1 Wind Turbine (100kW)	1620 PV Panels (534,6kW)	Energy Demand (kW)	Difference between Produced and Demanded Energy Amount
	634,6 kW			
January	33.113,5		71.800,0	-38.686,5
February	43.291,6		67.300,0	-24.008,4
March	57.929,4		53.300,0	4.629,4
April	66.601,7		48.100,0	18.501,7
May	81.579,8		25.400,0	56.179,8
June	89.522,0		29.850,0	59.672,0
July	93.219,4		20.000,0	73.219,4
August	83.238,0		26.200,0	57.038,0
September	65.081,0		28.200,0	36.881,0
October	53.290,4		49.3000	3.990,4
November	34.487,7		43.400,0	-8.912,3
December	28.989,7		53.300,0	-24.310,3
Total	**730.344,2**		**516.150,0**	**214.194,2**

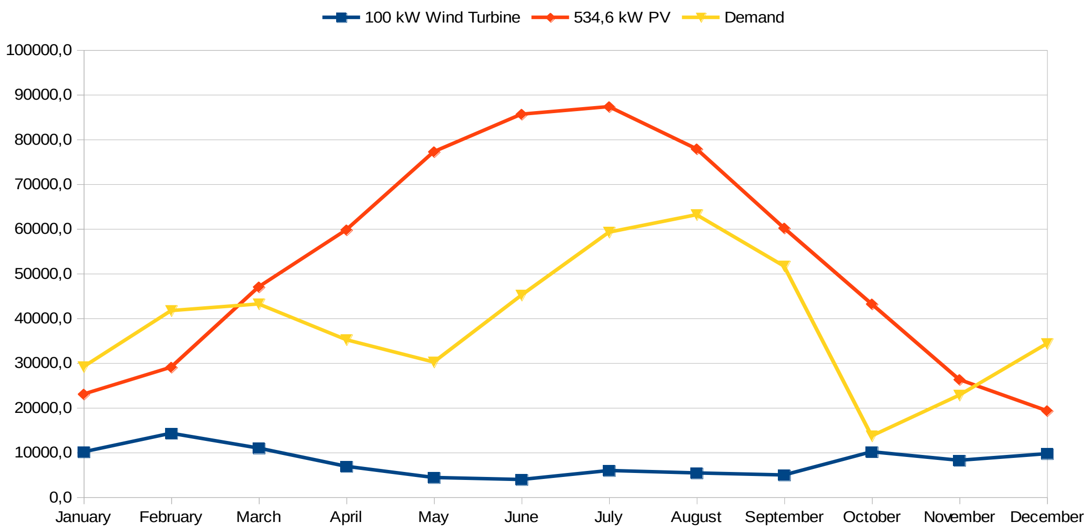


Figure 5.6. Urban Area Energy Consumption and Energy Generation by each Resource for Optimized Configuration by HOT

In case of no energy supplier system will be installed for this sample house, total energy cost will be 61.938,0USD yearly, and 1.238.760,0 USD for 20 years.

Table 5.14. IZTECH - Produced and Demanded Energy Difference in kW and in USD for HOT Configuration-1

	Difference Produced-Demanded (kW)	**Difference Produced-Demanded (USD)**
January	-38.686,5	-4.642,4
February	-24.008,4	-2.881,0
March	4.629,4	462,9
April	18.501,7	1.850,2
May	56.179,8	5.618,0
June	59.672,0	5.967,2
July	73.219,4	7.321,9
August	57.038,0	5.703,8
September	36.881,0	3.688,1
October	3.990,4	399,0
November	-8.912,3	-1.069,5
December	-24.310,3	-2.917,2
Total	**214.194,2**	**19.501,1**
20 Years Total	**4.283.884,8**	**390.021,5**

Energy system investment should be assessed for 20 years. With this approach, 20 years operational cost should be added to installation cost for the proposed wind solar hybrid energy system. As mentioned in Section 5, the total investment cost is calculated for the proposed configuration is as below:

100 kW Wind Turbine installation cost	:	220.000 $
100 kW Wind Turbine operational cost	:	220.000 $
534,6 kW Solar PV Panel installation cost	:	908.820 $
534,6 kW Solar PV Panel operational cost	:	454.410 $
20 Years Total Investment Cost	:	1.803.230 $

Total expense is not only the investment costs of this configuration when concerned with the monthly energy selling or buying from the installed facility. This aspect should be included in the total expense calculations.

20 Years Total Energy Expense	:	- 390.021,5 $
20 Years Total Investment Cost	:	1.803.230,0 $
20 Years Total Expense for this configuration	:	1.413.208,6 $

Difference between the energy cost in case of no energy supplier system is installed and total expense in case of this investment is installed and operated should be calculated in order to understand the system benefit or loss.

20 Years Total Energy Cost without hybrid system	:	1.238.760,0 $
20 Years Total Expense for this configuration	:	1.413.208,6 $
20 Years total benefit or loss	:	- 174.448,5 $

According to the final result, this configuration will bring in 390.021,5 $ in 20 years, however when we consider energy cost that will be paid for this consumption, the system will be unprofitable as 174.448,5 $ for 20 years.

Final energy cost per kW at the end of 20 years can be calculated dividing 20 Years Total Expense by 20 Years Energy Demand;

20 Years Energy Demand	:	10.323.000 kW
20 Years Total Expense for this configuration	:	1.413.208,6 $
Energy Cost for per kW for 20 Years Investment	:	0.137 $

Profit volume ratio can be also calculated dividing 20 years total benefit or loss by 20 years total investment cost. This ratio ;

20 Years total benefit or loss	:	- 174.448,5 $
20 Years Total Investment Cost	:	1.803.230,0 $
Profit volume ratio	:	- 9,67%

5.2.1.2. Results of Alternative Configuration-1 for SHUA with HOT

760 kW (100 kW WTG + 660 kW PV)

The first alternative configuration in the developed tool for the sample house located in the urban area is one 100 kW wind turbine and 2000 solar PV panels.

Table 5.15. Urban Area Monthly Energy Production of Alternative Configuration-1 by HOT

	1 Wind Turbine (100kW)	2000 PV Panels (660kW)	Energy Demand (kW)	Difference between Produced and Demanded Energy Amount
	760 kW			
January	38.512,3		71.800,0	-33.287,7
February	50.100,5		67.300,0	-17.199,5
March	68.951,0		53.300,0	15.651,0
April	80.614,4		48.100,0	32.514,4
May	99.692,0		25.400,0	74.292,0
June	109.602,0		29.850,0	79.752,0
July	113.695,1		20.000,0	93.695,1
August	101.499,5		26.200,0	75.299,5
September	79.190,0		28.200,0	50.990,0
October	63.416,3		49.3000	14.116,3
November	40.651,3		43.400,0	-2.748,7
December	33.517,7		53.300,0	-19.782,3
Total	**879.442,2**		**516.150,0**	**363.292,2**

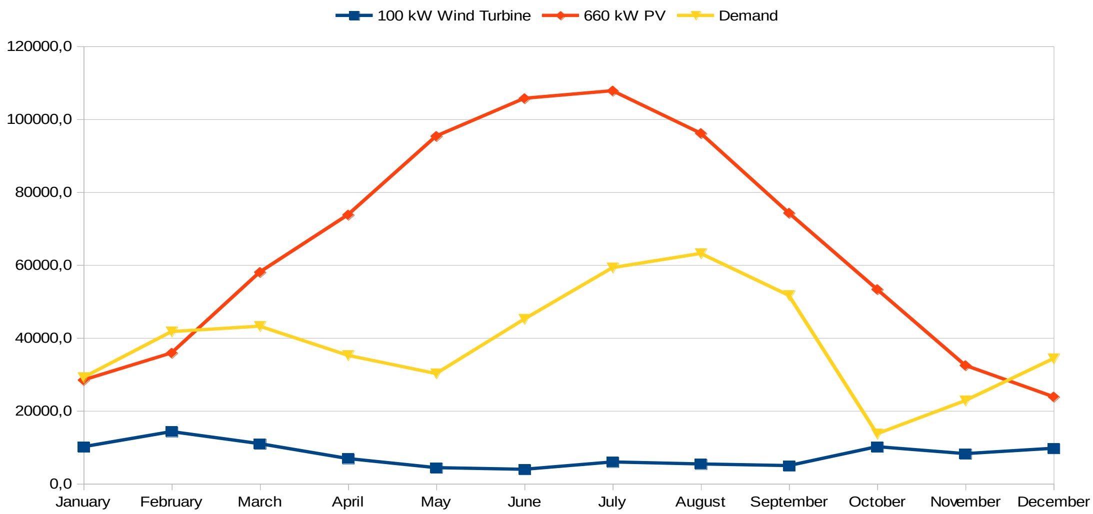


Figure 5.7. Urban Area Energy Consumption and Energy Generation by each Resource for Alternative Configuration-1 by HOT

In case of no energy supplier system will be installed for the sample house, the total energy cost will be 61.938,0USD yearly, and 1.238.760,0 USD for 20 years.

Table 5.16 Sample House - Produced and Demanded Energy Difference in kW and in USD for HOT Alternative Configuration-2

	Difference Produced-Demanded (kW)	**Difference Produced-Demanded (USD)**
January	-33.287,7	-3.994,5
February	-17.199,5	-2.063,9
March	15.651,0	1.565,1
April	32.514,4	3.251,4
May	74.292,0	7.429,2
June	79.752,0	7.975,2
July	93.695,1	9.369,5
August	75.299,5	7.529,9
September	50.990,0	5.099,0
October	14.116,3	1.411,6
November	-2.748,7	-329,8
December	-19.782,3	-2.373,9
Total	**363.292,2**	**34.868,9**
20 Years Total	**7.265.844,7**	**697.377,2**

Energy system investment should be assessed for 20 years. With this approach, 20 years operational cost should be added to installation cost of the proposed wind solar hybrid energy system. As mentioned in Section 5, the total investment cost is calculated for the proposed configuration as below:

100 kW Wind Turbine installation cost	:	220.000 $
100 kW Wind Turbine operational cost	:	220.000 $
660 kW Solar PV Panel installation cost	:	1.122.000 $
660 kW Solar PV Panel operational cost	:	561.000 $
20 Years Total Investment Cost	:	2.123.000 $

Total expense is not only the investment costs of this configuration when concerned with the monthly energy selling or buying from the installed facility. This aspect should be included in the total expense calculations.

20 Years Total Energy Expense	:	- 697.377,2 $
20 Years Total Investment Cost	:	2.123.000,0 $
20 Years Total Expense for this configuration	:	1.425.622,8 $

Difference between the energy cost in case of no energy supplier system is installed and total expense in case of this investment is installed and operated should be calculated in order to understand the system benefit or loss.

20 Years Total Energy Cost without hybrid system	:	1.238.760,0 $
20 Years Total Expense for this configuration	:	1.425.622,8 $
20 Years total benefit or loss	:	- 186.862,8 $

According to the final result, this configuration will bring in 697.377,2 $ in 20 years, however when we consider energy cost that will be paid for this consumption, the system will be unprofitable as 186.862,8 $ for 20 years.

Final energy cost per kW at the end of 20 years can be calculated dividing 20 Years Total Expense by 20 Years Energy Demand;

20 Years Energy Demand	:	10.323.000 kW
20 Years Total Expense for this configuration	:	1.425.622,8 $
Energy Cost for per kW for 20 Years Investment	:	0.138 $

Profit volume ratio can also be calculated by dividing 20 years total benefit or loss by 20 years total investment cost. This ratio becomes ;

20 Years total benefit or loss	:	- 186.862,8 $
20 Years Total Investment Cost	:	2.123.000,0 $
Profit volume ratio	:	- 8,80%

5.2.1.3. Results of Alternative Configuration-2 for SHUA with HOT

496 kW (100 kW WTG + 396 kW PV)

The second alternative configuration in the developed tool for the sample house includes one 100 kW wind turbine and 1200 solar PV panels.

Table 5.17. Urban Area Monthly Energy Production of Alternative Configuration-2 by HOT

	1 Wind Turbine (100kW)	1200 PV Panels (396kW)	Energy Demand (kW)	Difference between Produced and Demanded Energy Amount
	496 kW			
January	27.146,4		71.800,0	-44.653,6
February	35.766,0		67.300,0	-31.534,0
March	45.747,7		53.300,0	-7.552,3
April	51.114,0		48.100,0	3.014,0
May	61.561,1		25.400,0	36.161,1
June	67.328,2		29.850,0	37.478,2
July	70.588,3		20.000,0	50.588,3
August	63.054,3		26.200,0	36.854,3
September	49.486,9		28.200,0	21.286,9
October	42.098,7		49.300,0	-7.201,3
November	27.675,2		43.400,0	-15.724,8
December	23.985,0		53.300,0	-29.315,0
Total	**565.551,7**		**516.150,0**	**49.401,7**

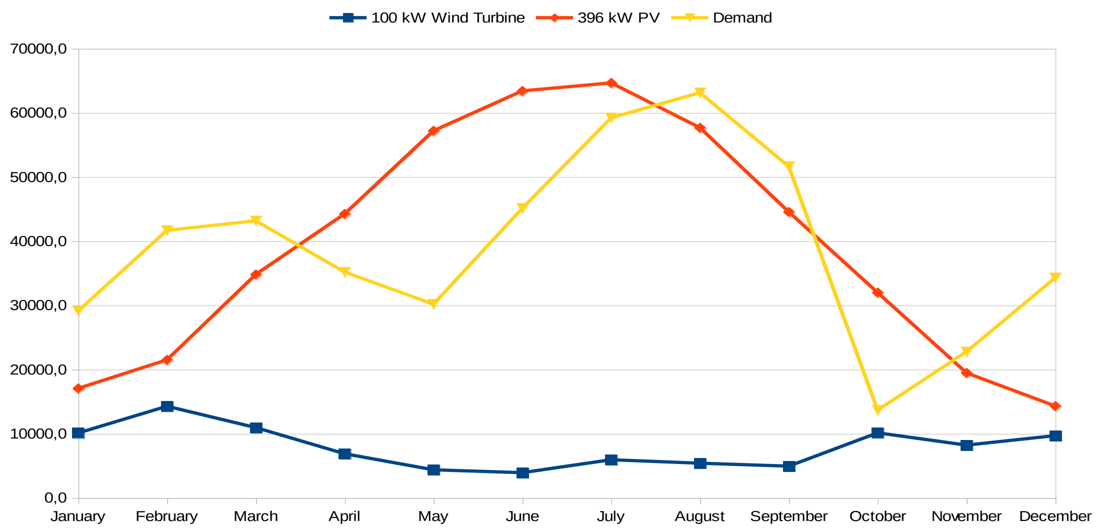


Figure 5.8. Urban Area Energy Consumption and Energy Generation by each Resource for Alternative Configuration-2 by HOT

In case of no energy supplier system will be installed for sample house, total energy cost will be 61.938,0USD yearly, and 1.238.760,0 USD for 20 years.

Table 5.18. Urban Area - Produced and Demanded Energy Difference in kW and in USD for HOT Alternative Configuration-2

	Difference Produced-Demanded (kW)	**Difference Produced-Demanded (USD)**
January	-44.653,6	-5.358,4
February	-31.534,0	-3.784,1
March	-7.552,3	-906,3
April	3.014,0	301,4
May	36.161,1	3.616,1
June	37.478,2	3.747,8
July	50.588,3	5.058,8
August	36.854,3	3.685,4
September	21.286,9	2.128,7
October	-7.201,3	-864,2
November	-15.724,8	-1.887,0
December	-29.315,0	-3.517,8
Total	**49.401,7**	**2.220,6**
20 Years Total	**988.034,5**	**44.411,0**

Energy system investment should be assessed for 20 years. With this approach, 20 years operational cost should be added to installation cost of the proposed wind solar hybrid energy system. As it has been mentioned in Section 5, total investment cost is calculated for the proposed configuration below:

100 kW Wind Turbine installation cost	:	220.000 $
100 kW Wind Turbine operational cost	:	220.000 $
396 kW Solar PV Panel installation cost	:	673.200 $
396 kW Solar PV Panel operational cost	:	336.600 $
20 Years Total Investment Cost	:	1.449.800 $

Total expense is not only the investment costs of this configuration when concerned with the monthly energy selling or buying from the installed facility. This aspect should be included in the total expense calculations.

20 Years Total Energy Expense	:	- 44.411,9 $
20 Years Total Investment Cost	:	1.449.800,0 $
20 Years Total Expense for this configuration	:	1.405.389,0 $

Difference between energy cost in case of no energy supplier system is installed and total expense in case of this investment is installed and operated should be calculated in order to understand the system benefit or loss.

20 Years Total Energy Cost without hybrid system	:	1.238.760,0 $
20 Years Total Expense for this configuration	:	1.405.389,0 $
20 Years total benefit or loss	:	- 166.629,0 $

According to the final result, this configuration will bring in 44.411,9 $ in 20 years, however when we consider energy cost that will be paid for this consumption, the system will be unprofitable as 166.629,0 $ for 20 years.

Final energy cost per kW at the end of 20 years can be calculated dividing 20 Years Total Expense by 20 Years Energy Demand;

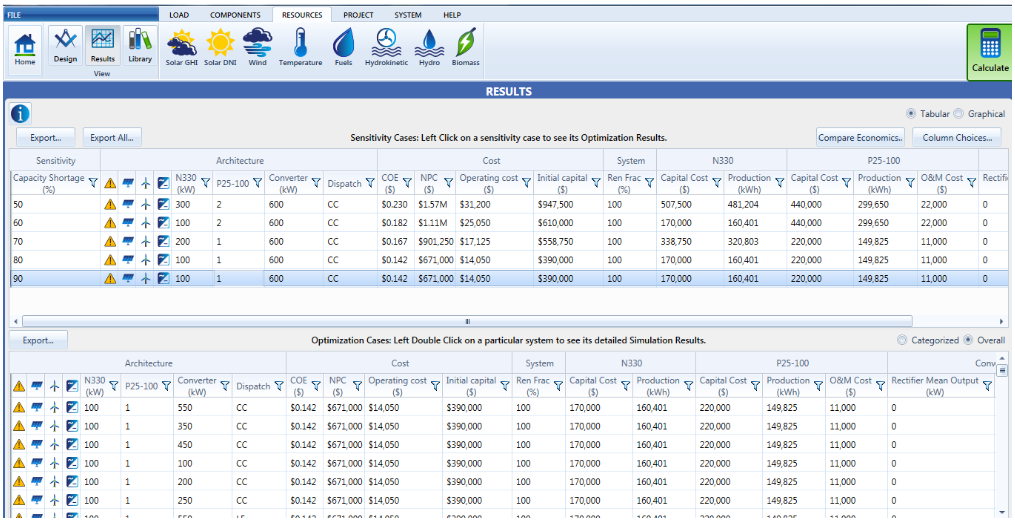
20 Years Energy Demand	:	10.323.000 kW
20 Years Total Expense for this configuration	:	1.405.389,0 $
Energy Cost for per kW for 20 Years Investment	:	0.136 $

Profit volume ratio can be also calculated dividing 20 years total benefit or loss by 20 years total investment cost. This ratio ;

20 Years total benefit or loss	:	- 166.629,0 $
20 Years Total Investment Cost	:	1.449.800,0 $
Profit volume ratio	:	-11,49%

5.2.2. Results of Sample House Located in Urban Area with Homer

The same method, which has been explained in Section 5.1.2, has been followed for this part of the analysis. Below figure shows the results of list of Homer for the sample house located in urban area.



Sensitivity: Capacity Shortage (%)	Architecture: N330 (kW)	P25-100	Converter (kW)	Dispatch	Cost: COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	System: Ren Frac (%)	N330: Capital Cost ($)	Production (kWh)	P25-100: Capital Cost ($)	Production (kWh)	O&M Cost ($)	Rectifi
50	300	2	600	CC	$0.230	$1.57M	$31,200	$947,500	100	507,500	481,204	440,000	299,650	22,000	0
60	100	2	600	CC	$0.182	$1.11M	$25,050	$610,000	100	170,000	160,401	440,000	299,650	22,000	0
70	200	1	600	CC	$0.167	$901,250	$17,125	$558,750	100	338,750	320,803	220,000	149,825	11,000	0
80	100	1	600	CC	$0.142	$671,000	$14,050	$390,000	100	170,000	160,401	220,000	149,825	11,000	0
90	100	1	600	CC	$0.142	$671,000	$14,050	$390,000	100	170,000	160,401	220,000	149,825	11,000	0

Architecture: N330 (kW)	P25-100	Converter (kW)	Dispatch	Cost: COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	System: Ren Frac (%)	N330: Capital Cost ($)	Production (kWh)	P25-100: Capital Cost ($)	Production (kWh)	O&M Cost ($)	Conv: Rectifier Mean Output (kW)
100	1	550	CC	$0.142	$671,000	$14,050	$390,000	100	170,000	160,401	220,000	149,825	11,000	0
100	1	350	CC	$0.142	$671,000	$14,050	$390,000	100	170,000	160,401	220,000	149,825	11,000	0
100	1	450	CC	$0.142	$671,000	$14,050	$390,000	100	170,000	160,401	220,000	149,825	11,000	0
100	1	100	CC	$0.142	$671,000	$14,050	$390,000	100	170,000	160,401	220,000	149,825	11,000	0
100	1	200	CC	$0.142	$671,000	$14,050	$390,000	100	170,000	160,401	220,000	149,825	11,000	0
100	1	250	CC	$0.142	$671,000	$14,050	$390,000	100	170,000	160,401	220,000	149,825	11,000	0

Figure 5.9. Urban Area Sample House Homer Results List

As seen in the above figure, the most appropriate results are located in the upper list. All results can be seen in the below list. In order to compare results computed by Homer and by HOT, the closest results have been evaluated. In Section 5.2.1, it has been mentioned that three results have been found by HOT as optimized configuration with 1 wind turbine + 525 kW PV, 1 wind turbine + 650 kW PV and 1 wind turbine + 400 kW PV. Homer has calculated all configurations and presented five of them as the most appropriate configurations. None of the presented results are compatible with results found by HOT. This is due to the fact that Homer has a calculation methodology that is based on hourly data, which takes into consideration of hourly excess and unmet energy amounts. With this approach, if there is more excess and unmet energy amount, Homer tends to present the cheapest configuration. For this reason, all configurations have been selected from below list shown in Figure 5.9.

5.2.2.1. Results of Configuration-1 for SHUA with HOMER

625 kW (100 kW WTG + 525 kW PV)

The first configuration calculated by Homer for the sample house includes one 100 kW wind turbine and 525 kW solar PV panels.

Table 5.19. Urban Area Monthly Energy Production of Configuration-1 by Homer

	1 Wind Turbine (100kW)	525 kW PV Panels	Energy Demand (kW)	Difference between Produced and Demanded Energy Amount
	625 kW			
January	63.876,3		71.800,0	-7.923,7
February	71.953,2		67.300,0	4.653,2
March	88.283,0		53.300,0	34.983,0
April	86.613,8		48.100,0	38.513,8
May	91.349,1		25.400,0	65.949,1
June	91.749,2		29.850,0	61.899,2
July	98.756,1		20.000,0	78.756,1
August	97.791,4		26.200,0	71.591,4
September	91.268,1		28.200,0	63.068,1
October	88.158,2		49.300,0	38.858,2
November	65.695,8		43.400,0	22.295,8
December	56.438,3		53.300,0	3.138,3
Total	**991.932,5**		**516.150,0**	**475.782,5**

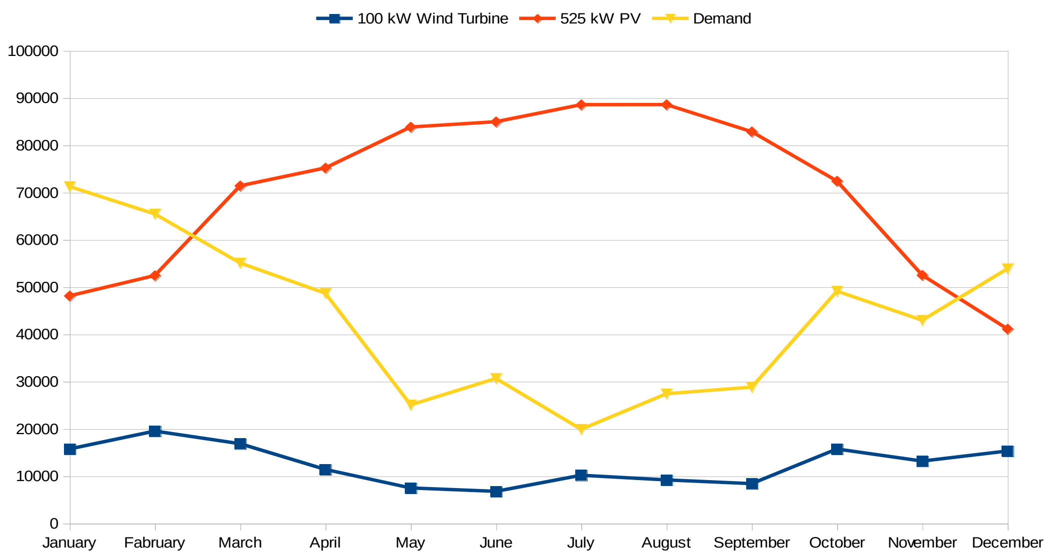


Figure 5.10. Urban Area Energy Consumption and Energy Generation by each Resource for Configuration-1 by Homer

In case of no energy supplier system will be installed for sample house, total energy cost will be 61.938,0USD yearly, and 1.238.760,0 USD for 20 years.

Table 5.20. Urban Area - Produced and Demanded Energy Difference in kW and in USD for Homer Configuration-1

	Difference Produced-Demanded (kW)	**Difference Produced-Demanded (USD)**
January	-7.923,7	-950,8
February	4.653,2	465,3
March	34.983,0	3.498,3
April	38.513,8	3.851,4
May	65.949,1	6.594,9
June	61.899,2	6.189,9
July	78.756,1	7.875,6
August	71.591,4	7.159,1
September	63.068,1	6.306,8
October	38.858,2	3.885,8
November	22.295,8	2.229,6
December	3.138,3	313,8
Total	**475.782,5**	**47.419,8**
20 Years Total	**9.515.650,5**	**948.395,6**

Energy system investment should be assessed for 20 years. With this approach, 20 years operational cost should be added to installation cost of the proposed wind solar hybrid energy system. As it has been mentioned in Section 5, total investment cost is calculated for the proposed configuration below:

100 kW Wind Turbine installation cost	:	220.000 $
100 kW Wind Turbine operational cost	:	220.000 $
525 kW Solar PV Panel installation cost	:	892.500 $
525 kW Solar PV Panel operational cost	:	446.250 $
20 Years Total Investment Cost	:	1.778.750 $

Total expense is not only the investment costs of this configuration when concerned with the monthly energy selling or buying from the installed facility. This aspect should be included in the total expense calculations.

20 Years Total Energy Expense	:	- 948.395,6 $
20 Years Total Investment Cost	:	1.778.750,0 $
20 Years Total Expense for this configuration	:	830.354,4 $

Difference between energy cost in case of no energy supplier system is installed and total expense in case of this investment is installed and operated should be calculated in order to understand the system benefit or loss.

20 Years Total Energy Cost without hybrid system	:	1.238.760,0 $
20 Years Total Expense for this configuration	:	830.354,4 $
20 Years total benefit or loss	:	- 408.405,6 $

According to the final result, this configuration will bring in 948.395,6 $ in 20 years, however when we consider energy cost that will be paid for this consumption, the system will be unprofitable as 408.405,6 $ for 20 years.

Final energy cost per kW at the end of 20 years can be calculated dividing 20 Years Total Expense by 20 Years Energy Demand;

20 Years Energy Demand	:	10.323.000 kW
20 Years Total Expense for this configuration	:	830.354,4 $
Energy Cost for per kW for 20 Years Investment	:	0.080 $

Profit volume ratio can be also calculated dividing 20 years total benefit or loss by 20 years total investment cost. This ratio ;

20 Years total benefit or loss	:	- 408.405,6 $
20 Years Total Investment Cost	:	1.778.750,0 $
Profit volume ratio	:	22,96%

5.2.2.2. Results of Configuration-2 for SHUA with HOMER

750 kW (100 kW WTG + 650 kW PV)

Configuration-2 calculated by Homer for sample house includes one 100 kW wind turbine and 650 kW solar PV panels.

Table 5.21. Urban Area Monthly Energy Production of Configuration-2 by Homer

	1 Wind Turbine (100kW)	650 kW PV Panels	Energy Demand (kW)	Difference between Produced and Demanded Energy Amount
	750 kW			
January	75.336,5		71.800,0	3.536,5
February	84.437,6		67.300,0	17.137,6
March	105.288,7		53.300,0	51.988,7
April	104.518,5		48.100,0	56.418,5
May	111.313,5		25.400,0	85.913,5
June	111.980,1		29.850,0	82.130,1
July	119.845,8		20.000,0	99.845,8
August	118.886,1		26.200,0	92.686,1
September	110.995,9		28.200,0	82.795,9
October	105.401,1		49.300,0	56.101,1
November	78.200,9		43.400,0	34.800,9
December	66.229,6		53.300,0	12.929,6
Total	**1.192.434,3**		**516.150,0**	**676.284,3**

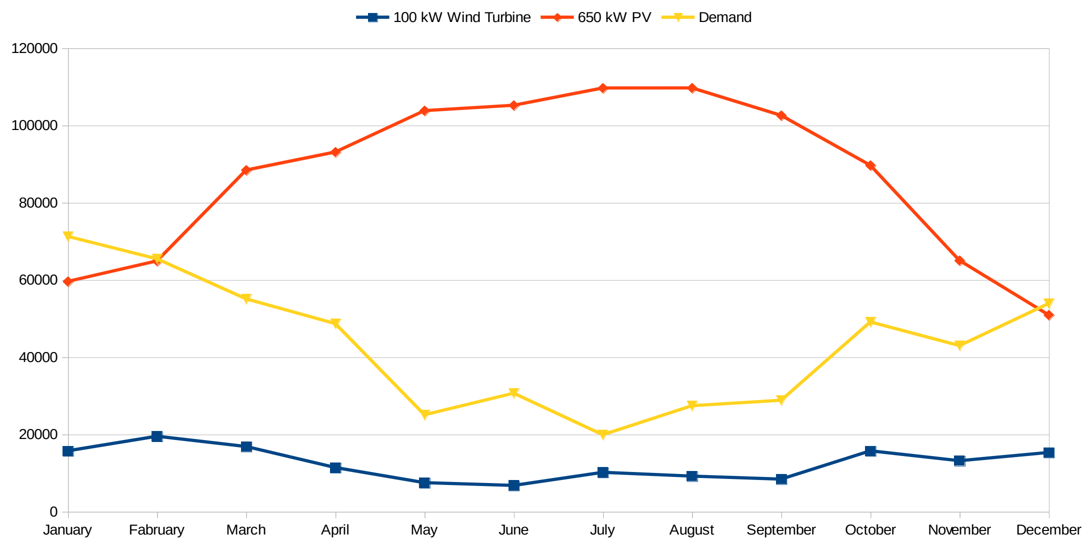


Figure 5.11. Urban Area Energy Consumption and Energy Generation by each Resource for Configuration-2 by Homer

In case of no energy supplier system will be installed for sample house, total energy cost will be 61.938,0USD yearly, and 1.238.760,0 USD for 20 years.

Table 5.22. Urban Area - Produced and Demanded Energy Difference in kW and in USD for Homer Configuration-2

	Difference Produced-Demanded (kW)	**Difference Produced-Demanded (USD)**
January	3.536,5	353,7
February	17.137,6	1.713,8
March	51.988,7	5.198,9
April	56.418,5	5.641,9
May	85.913,5	8.591,3
June	82.130,1	8.213,0
July	99.845,8	9.984,6
August	92.686,1	9.268,6
September	82.795,9	8.279,6
October	56.101,1	5.610,1
November	34.800,9	3.480,1
December	12.929,6	1.293,0
Total	**676.284,3**	**67.628,4**
20 Years Total	**13.525.686,7**	**1.352.568,7**

Energy system investment should be assessed for 20 years. With this approach, 20 years operational cost should be added to installation cost of the proposed wind solar hybrid energy system. As it has been mentioned in Section 5, total investment cost is calculated for the proposed configuration below:

100 kW Wind Turbine installation cost	:	220.000 $
100 kW Wind Turbine operational cost	:	220.000 $
650 kW Solar PV Panel installation cost	:	1.105.000 $
650 kW Solar PV Panel operational cost	:	552.500 $
20 Years Total Investment Cost	:	2.097.500 $

Total expense is not only the investment costs of this configuration when concerned with the monthly energy selling or buying from the installed facility. This aspect should be included in the total expense calculations.

20 Years Total Energy Expense	:	- 1.352.568,7 $
20 Years Total Investment Cost	:	2.097.500,0 $
20 Years Total Expense for this configuration	:	744.931,3 $

Difference between energy cost in case of no energy supplier system is installed and total expense in case of this investment is installed and operated should be calculated in order to understand the system benefit or loss.

20 Years Total Energy Cost without hybrid system	:	1.238.760,0 $
20 Years Total Expense for this configuration	:	744.931,3 $
20 Years total benefit or loss	:	- 493.828,7 $

According to the final result, this configuration will bring in 1.352.568,7 $ in 20 years, however when we consider energy cost that will be paid for this consumption, the system will be unprofitable as 493.828,7 $ for 20 years.

Final energy cost per kW at the end of 20 years can be calculated dividing 20 Years Total Expense by 20 Years Energy Demand;

20 Years Energy Demand	:	10.323.000 kW
20 Years Total Expense for this configuration	:	744.931,3 $
Energy Cost for per kW for 20 Years Investment	:	0.072 $

Profit volume ratio can be also calculated dividing 20 years total benefit or loss by 20 years total investment cost. This ratio ;

20 Years total benefit or loss	:	- 493.828,7 $
20 Years Total Investment Cost	:	2.097.500,0 $
Profit volume ratio	:	23,54%

5.2.2.3. Results of Configuration-3 for SHUA with HOMER

500 kW (100 kW WTG + 400 kW PV)

Configuration-3 calculated by Homer for sample house includes one 100 kW wind turbine and 400 kW solar PV panels.

Table 5.23. Urban Area Monthly Energy Production of Configuration-3 by Homer

	1 Wind Turbine (100kW)	400 kW PV Panels	Energy Demand (kW)	Difference between Produced and Demanded Energy Amount
	500 kW			
January	52.416,1		71.800,0	-19.383,9
February	59.468,8		67.300,0	-7.831,2
March	71.277,2		53.300,0	17.977,2
April	68.709,0		48.100,0	20.609,0
May	71.384,8		25.400,0	45.984,8
June	71.518,2		29.850,0	41.668,2
July	77.666,3		20.000,0	57.666,3
August	76.696,7		26.200,0	50.496,7
September	71.540,3		28.200,0	43.340,3
October	70.915,4		49.300,0	21.615,4
November	53.190,7		43.400,0	9.790,7
December	46.647,0		53.300,0	-6.653,0
Total	**791.430,7**		**516.150,0**	**275.280,7**

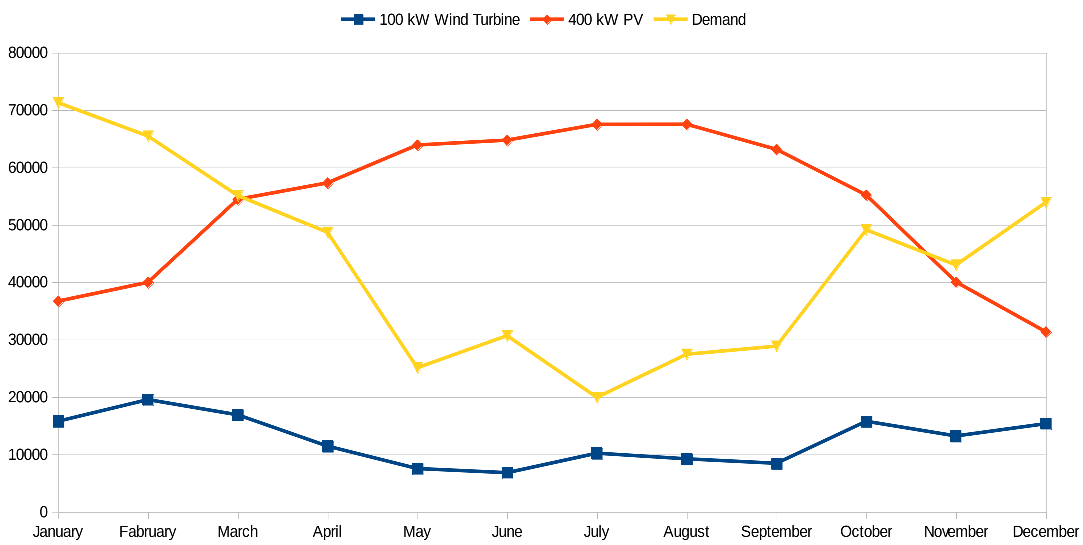


Figure 5.12. Urban Area Energy Consumption and Energy Generation by each Resource for Configuration-3 by Homer

In case of no energy supplier system will be installed for sample house, total energy cost will be 61.938,0USD yearly, and 1.238.760,0 USD for 20 years.

Table 5.24. Urban Area - Produced and Demanded Energy Difference in kW and in USD for Homer Configuration-3

	Difference Produced-Demanded (kW)	**Difference Produced-Demanded (USD)**
January	-19.383,9	-2.326,1
February	-7.831,2	-939,7
March	17.977,2	1.797,7
April	20.609,0	2.060,9
May	45.984,8	4.598,5
June	41.668,2	4.166,8
July	57.666,3	5.766,6
August	50.496,7	5.049,7
September	43.340,3	4.334,0
October	21.615,4	2.161,5
November	9.790,7	979,1
December	-6.653,0	-798,4
Total	**275.280,7**	**26.850,7**
20 Years Total	**5.505.614,3**	**537.014,2**

Energy system investment should be assessed for 20 years. With this approach, 20 years operational cost should be added to installation cost of the proposed wind solar hybrid energy system. As it has been mentioned in Section 5, total investment cost is calculated for the proposed configuration below:

100 kW Wind Turbine installation cost	:	220.000 $
100 kW Wind Turbine operational cost	:	220.000 $
400 kW Solar PV Panel installation cost	:	680.000 $
400 kW Solar PV Panel operational cost	:	340.000 $
20 Years Total Investment Cost	:	1.460.000 $

Total expense is not only the investment costs of this configuration when concerned with the monthly energy selling or buying from the installed facility. This aspect should be included in the total expense calculations.

20 Years Total Energy Expense	:	- 537.014,2 $
20 Years Total Investment Cost	:	1.460.000,0 $
20 Years Total Expense for this configuration	:	922.958,8 $

Difference between energy cost in case of no energy supplier system is installed and total expense in case of this investment is installed and operated should be calculated in order to understand the system benefit or loss.

20 Years Total Energy Cost without hybrid system	:	1.238.760,0 $
20 Years Total Expense for this configuration	:	922.958,8 $
20 Years total benefit or loss	:	- 315.774,2 $

According to the final result, this configuration will bring in 537.014,2 $ in 20 years, however when we consider energy cost that will be paid for this consumption, the system will be unprofitable as 315.774,2 $ for 20 years.

Final energy cost per kW at the end of 20 years can be calculated dividing 20 Years Total Expense by 20 Years Energy Demand;

20 Years Energy Demand	:	10.323.000 kW
20 Years Total Expense for this configuration	:	922.958,8 $
Energy Cost for per kW for 20 Years Investment	:	0.089 $

Profit volume ratio can be also calculated dividing 20 years total benefit or loss by 20 years total investment cost. This ratio ;

20 Years total benefit or loss	:	- 315.774,2 $
20 Years Total Investment Cost	:	1.460.000,0 $
Profit volume ratio	:	21,63%

5.3. Uncertainty Results

According to Section 4.2.3, explanations of uncertainties for this study have been done. Each individual uncertainty value has been identified with its minimum and maximum values. Based on the equations 4.2.2, 4.2.3 and 4.2.4, and considering rule of Root of Mean Square (RMS), total uncertainty values have been calculated for the scenarios of Mechanical Engineering Building and Sample House located in urban area. All individual uncertainty values and total uncertainty values calculated as minimum and maximum for each scenario are presented below.

Table 5.25. Uncertainty values of configurations for MEB calculated with HOT

		Configurations for MEB calculated with HOT	
		Min (%)	Max (%)
Wind	Measurement Uncertainty	-2,5	2,5
	Vertical Extrapolation Uncertainty	4,7	4,7
	Air Density	-1,0	1,0
	Annual Variability Uncertainty	-2,0	2,0
	Power Curve Uncertainty	5,2	7,8
Solar	Solar Radiation Uncertainty	-25,0	25,0
	Cell Efficiency Uncertainty	0,0	10,0
	Annual Variability Uncertainty	-6,7	4,7
Total Uncertainty		-27,0	29,0

Table 5.26. Uncertainty values of configurations for MEB calculated with Homer Pro

		Configurations for MEB calculated with Homer Pro	
		Min (%)	Max (%)
Wind	Measurement Uncertainty	-2,5	2,5
	Vertical Extrapolation Uncertainty	4,7	4,7
	Air Density	-1,0	1,0
	Annual Variability Uncertainty	-2,0	2,0
	Power Curve Uncertainty	5,2	7,8
Solar	Solar Radiation Uncertainty	-22,7	22,7
	Cell Efficiency Uncertainty	0,0	10,0
	Annual Variability Uncertainty	-6,7	4,7
Total Uncertainty		-24,9	27,1

According to calculated uncertainty results in Table 5.25 and Table 5.26, for configurations of MEB calculated with HOT, total uncertainty range is -27,0% , +29,0%. And the total uncertainty range is -24,9% - +27,1% for MEB configurations calculated by Homer Pro.

Table 5.27. Uncertainty values of configurations for SHUA calculated with HOT

		Configurations for SHUA calculated with HOT	
		Min (%)	Max (%)
Wind	Measurement Uncertainty	-4,0	4,0
	Vertical Extrapolation Uncertainty	2,9	2,9
	Air Density	-1,0	1,0
	Annual Variability Uncertainty	-2,0	2,0
	Power Curve Uncertainty	5,2	7,8
Solar	Solar Radiation Uncertainty	-25,0	25,0
	Cell Efficiency Uncertainty	0,0	10,0
	Annual Variability Uncertainty	-6,7	4,7
Total Uncertainty		-27,0	28,9

Table 5.28. Uncertainty values of configurations for SHUA calculated with Homer Pro

		Configurations for SHUA calculated with Homer Pro	
		Min (%)	Max (%)
Wind	Measurement Uncertainty	-3,5	3,5
	Vertical Extrapolation Uncertainty	2,9	2,9
	Air Density	-1,0	1,0
	Annual Variability Uncertainty	-2,0	2,0
	Power Curve Uncertainty	5,2	7,8
Solar	Solar Radiation Uncertainty	-22,7	22,7
	Cell Efficiency Uncertainty	0,0	10,0
	Annual Variability Uncertainty	-6,7	4,7
Total Uncertainty		-24,8	26,9

According to calculated uncertainty results in Table 5.27 and Table 5.28, for configurations of SHUA calculated with HOT, total uncertainty range is -27,0% , +28,9%. And the total uncertainty range is -24,8% - +26,9% for SHUA configurations calculated by Homer Pro.

The calculated uncertainty values are high for energy production uncertainty values in general. In order to reduce total uncertainties, some each individual uncertainty should be evaluated and required actions should be taken. For instance, in this study, the main reason to get high uncertainty value is solar radiation uncertainty. This value can be decreased using high resolution data set, or the absolute solution is to use measured data. By this way, total uncertainty will be reduced significantly. In addition to that using well calibrated, well mounted anemometers, selecting terrains which are about flat, using measured power curve of wind turbine will decrease total uncertainty considerably. That will show level of feasibility of project.

5.4. Comparison of the Results

Based on the results given in previous Sections 5.1 and 5.2, comparisons have been conducted in this part of the study. Each configuration which have been assessed by HOT, and have been calculated by Homer Pro in order to see the accuracy of the results of HOT.

Table 5.29. Comparison of HOT and HOMER for MEB - Configuration 1

MEB - Configuration 1	**HOT**	**HOMER**	**Relative Error**
1-year Energy Production (kW)	494628,4	582386,0	84,9%
20-years Total Profit (USD)	38276,2	226287,3	16,9%
20-years Energy Cost (USD)	0,091	0,072	126,4%
20-years Profit Volume Ratio (%)	30,16	50,41	59,8%

Table 5.30. Comparison of HOT and HOMER for MEB - Configuration 2

MEB - Configuration 2	**HOT**	**HOMER**	**Relative Error**
1-year Energy Production (kW)	620435,4	651555,4	95,2%
20-years Total Profit (USD)	298841,4	364856,8	81,9%
20-years Energy Cost (USD)	0,074	0,066	112,1%
20-years Profit Volume Ratio (%)	42,79	51,81	82,6%

Results for the Mechanical Engineering Building of IZTECH have been presented in Table 5.29 and Table 5.30. According to these tables, HOT has calculated less energy production and less profit, consequently, high energy cost and low profit volume ratio have been calculated. It is expected to calculate values which are close to Homer results. Once the results calculated by HOT divided by the results calculated by Homer, proportion of each result set is calculated. Values are expected to be in the vicinity of 100,0% for each result. These results are acceptable for these configurations since the differences are not so high. In this scenario, measured wind speed data have been used for the wind energy calculation and NASA solar data which have been measured in large distance nodes as 1 by 1 degree latitude-longitude, have been used for the solar energy calculation. The useof measured data for HOT and Homer at the same time, has provided computing similar results. For this reason, it has been proved that measured data is of great importance when conducting energy analysis. Only measured data are the wind data for this study, because of this, the results calculated by HOT are close to the results calculated by Homer.

Table 5.31. Comparison of HOT and HOMER for SHUA - Configuration 1

SHUA - Configuration 1	**HOT**	**HOMER**	**Relative Error**
1-year Energy Production (kW)	730344,2	991932,5	73,6%
20-years Total Profit (USD)	390021,5	948395,6	41,1%
20-years Energy Cost (USD)	0,137	0,080	171,3%
20-years Profit Volume Ratio (%)	-9,67	22,96	-42,1%

Table 5.32. Comparison of HOT and HOMER for SHUA - Configuration 2

SHUA - Configuration 2	**HOT**	**HOMER**	**Relative Error**
1-year Energy Production (kW)	879442,2	1192434,3	73,8%
20-years Total Profit (USD)	697377,2	1352568,7	51,6%
20-years Energy Cost (USD)	0,138	0,072	191,7%
20-years Profit Volume Ratio (%)	-8,80%	23,54%	-37,4%

Table 5.33. Comparison of HOT and HOMER for SHUA - Configuration 3

SHUA - Configuration 3	**HOT**	**HOMER**	**Relative Error**
1-year Energy Production (kW)	565551,7	791430,7	71,5%
20-years Total Profit (USD)	44411,0	537014,2	8,3%
20-years Energy Cost (USD)	0,136	0,089	152,8%
20-years Profit Volume Ratio (%)	-11,49%	21,63%	-53,1%

Results for the sample house located on urban area have been presented in Table 5.31, Table 5.32 and Table 5.33. These tables show that HOT has calculated less energy production and less profit, consequently, with high energy cost and low even negative profit volume ratio. It expected to calculate the values which are close to the Homer results. Once the results calculated by HOT are divided by the results calculated by

Homer, proportions of each result are calculated. Values are expected to be close to 100,0% for each result. These results are not acceptable for these configurations since the differences are higher. In these scenarios, the measured data have not been used for the energy calculations. The datasets used in this analysis are obtained from the NASA wind and solar databases which are driven by data from large distance nodes as 1 by 1 degree latitude-longitude. This resolution is not acceptable to calculate accurate energy generation. Also, comparisons between using hourly and monthly data can be seen in this scenario clearly. No measured data have been used in these calculations. Given the hourly data which are directly used in HOT calculations. While Homer have calculated hourly energy production against the energy consumption, HOT have only calculated the monthly energy production.

In the first scenario of MEB, measured wind speed data have been converted to monthly data and inserted in Homer for calculations. In this way consistency has been protected. However, in the other scenario which considers SHUA, the NASA hourly data directly have been used in Homer calculation and monthly mean wind speed values have been inserted in HOT for calculations. For this reason differences between HOT and Homer results are considerable. It has been noticed that Homer has calculated higher amounts of energy via the use of the NASA datasets. Based on the calculations done individually with the same data but with different variables like different loss factors, different hub heights, it has been observed that Homer has calculated higher amounts of energy. That should be investigated in detailed and the energy calculations should be handled accordingly in the future assessments.

According to the results of Homer, it should be noted that Homer model can give more accurate results via the use of measured data. However, in the urban areas with low resolution data, Homer results are not reliable for energy production analysis.

It can be seen that the Developed Hybrid Optimisation Tool - HOT - has provided reliable results with the measured data sets in regards to the above comparisons.

CHAPTER 6

DISCUSSION

The main focus of this study is to develop a tool to evaluate hybrid energy systems which aims to provide a preliminary result to assess the feasibility of a wind-solar hybrid energy system. In order to find an optimum solution for the hybrid systems, wind and solar data, as explained in Section 3 and Section 4, should be obtained and entered into the developed tool. During the study, various criteria regarding the sensitivity of the results have been determined and added to this section in order to inform the users and to emphasise the importance of them in the energy assessments which in turn contributes in the feasibility of the proposed projects.

As discussed above these criteria are of importance in the energy calculation of the hybrid energy systems, however accessibility of these criteria is difficult.

- Sensitivity difference between hourly and monthly data,
- Variety of resource capacities due to the measurement locations,
- Wind farm site selection criteria,
- Selection of the base energy resource,
- Selection of the energy supply system unit capacity,

Measured wind data which were available for the URLA Wind Farm located in the west of IZTECH campus, have been provided by the ENDA Enerji[108]. Data have been measured in the campus of IZTECH, and an agreement has been signed between the Institute and ENDA Enerji in order to use the data for the projects which will be done within the Institute. This data have been recorded in every ten minutes, however in our model these data were converted to the monthly data as input. To do so, the 10-min data have been converted first to hourly data, and then to monthly data. Consequently, Homer software provides monthly re-analysis data which have been recorded by NASA. In order to be consistent with the Homer software, the NASA data have been used in this thesis. Energy consumption has been entered to the developed tool and Homer on a monthly-basis data. It should be noted that, daily profiles of energy consumption has different values in different periods of the day as well as the energy resources capacities vary. Due to these varieties, monthly data has a low sensitivity for results. The use of the hourly data for both energy consumption and energy resources would be more sensitive and more reliable. Thus, it could enable us to be informed on the hourly response of the designed energy system to the energy consumption. In the future, this developed tool can be evaluated and re-developed in order to provide more accurate results.

During this study, variety of resource capacities regarding the data location has been observed and assessed for discussion. NASA solar data have resolution of 1 by 1 degree of latitude-longitude equal angle grid [109]. Due to this resolution of grid, the places of interest in this thesis (Mechanical Engineering Building of IZTECH and sample house in Urla town) are located in the same grid, and therefore their solar data have been provided with same values. PV panels can be located in any area with a suitable angle on the ground in order to get maximum amount of solar radiation. However, once the location of the measurement changes, even in meters, the wind speed will be affected. Especially in Turkey, most of the wind farms are located in complex terrains. Due to the variation on altitudes, obstacles surrounding the location of interest, the ground cover and many other factors can affect the measured wind data. This point has been considered in this thesis and the importance of the measured data has been mentioned in Section 3. In the future, in case of a development for this study would be performed, measured solar and wind data usage should be considered. If this would not be possible as it has been in our study, high resolution grid data should be accessed and should be used in the calculations in order to find more accurate and optimistic solutions for the wind-solar hybrid energy systems by this developed tool.

Based on the measured data at the met mast, wind farm location is chosen. Once the measured wind speed is low, investment cannot be feasible and the investor would not like to spend money on the wind farm. However, once the measured wind speed is high enough, the investment would be actualized in short time. This is the reason why wind turbines are located far away from the city centers. Tall or dense buildings, roads with high amount of cars, with all other constructions located in the city center would affect the wind. Turbulence would occur, and the steady wind cannot be achievable. Therefore, all of the wind farms in the world have been installed out of city centers. This situation is different for solar energy due to its steady radiation for all locations. Therefore, the wind speeds on the sample house location are lower than the measured wind speed at the IZTECH area. This shows that investments on the wind power systems are more feasible in areas which has not been surrounded by constraints

Base energy resource selection should be roughly considered before calculation. Wind has more capacity for the area of Urla region. However, it could change for other locations in Turkey. For example, it is known that solar energy capacity is at the highest level in Antalya and Konya together with the less wind energy capacity in Turkey. For these and similar cities, PV system should be the base energy resource. It is possible that the use of wind turbines could increase the energy cost significantly, and could cause the project to be infeasible for such locations. Therefore, the powerful resource should be the base energy resource for a location and the other resource should be supplementary for the hybrid energy system in order to generate the required energy. With this approach, unit energy costs per kW should be calculated considering the lifetime of the hybrid energy system, and the lowest unit energy cost providing system should be the base energy resource for the hybrid energy system.

Once the number of wind turbines and PV panels have been calculated in any tool or software, the total installed capacity of each component in wind turbine and PV panel should be evaluated and if it is possible, larger units should be used in practice due to the lower investment costs per kW in such units. For instance, instead of 2 units of 100 kW capacity wind turbine, 1 unit of 200 kW capacity wind turbine should be preferred. That selection would decrease the investment cost around 10% due to using the same crane, laying a little bit larger foundation, increasing hub height less than two times larger than 100 kW wind turbine's hub height, and some other small but important components. Especially, for the larger energy systems around 1 MW, this method will decrease the costs considerably.

In addition to above discussion points, economical discussion should be done for this study. Due to the variation on resource capacities and energy consumption, for a constant number of wind turbines and PV panels, energy production has been different on a monthly basis. Energy production could be lower or higher than the energy consumption in some of the months. In this case, the system needs to buy energy from the grid or needs to sell energy to the grid. Selling electricity would be beneficial in terms of earning money while energy consumption has been met. However, investment cost should be evaluated for the feasibility of the project. In order to produce more energy, high capacity components should be used in the hybrid energy system. That will increase the investment cost, which in turn extends the pay-back duration of the investment. In order to reduce the investment costs of the hybrid energy systems, the design in the developed tool has been made considering the average numbers of wind turbines and PV panels for each month. This approach has provided us to produce energy more than the demand for some of the months and less than the demand for the other months. In this way, the system would provide less energy and the consumer would need to buy the required energy amount from the grid; however, in the mean time, the system would provide enough energy and would sell surplus energy to the grid. Thus, the designed hybrid energy system will decrease the cost of the energy production and the pay-back duration will be shorter than the other systems.

CHAPTER 7

CONCLUSION

It is expected that in near future, hybrid energy systems will be more popular in Turkey for small and micro scale energy generation applications. This expectation will create new requirements for the energy market. In order to investigate and find a quick solution to small energy production application calculations, this study has been driven.

A tool (HOT) has been developed in this study in order to calculate wind-solar hybrid energy systems. The main approach to develop a tool for hybrid energy system calculations is to have an idea before project development stage and decrease investment cost of desired project. There are already professional and commercial software which have been doing detailed calculations of hybrid energy systems in the world, however these software can be achievable via buying. HOT has been developed considering minimum data input and required output by using common equations and assumptions. One of the most important goals of the study is to find HOT results close to Homer Pro results. Considering Homer Pro as a commercial and one of the most common software on hybrid energy area in the world, it is not expected to find the same results with Homer. These findings have been explained in Section 5.3.

Based on the comparison of the results found via HOT and Homer for the same energy consumption and the same data, the main goal of the thesis have been succeeded. Results of HOT are close to Homer results. That has been expected to have a difference between results due to using monthly data on HOT instead of hourly data using in Homer. That is the most important and effective point regarding difference between the results. Using monthly means of hourly wind and solar data, accuracy of energy results have been low.

It has been observed in the calculations and results of this study, since data measured at the met mast located in IZTECH campus area have been used in HOT and Homer, energy generation of wind turbines are considerably close to each other. That shows us the measured data are more reliable than the data provided by Homer downloading from NASA. Except Configuration 1 and Configuration 2 done by HOT and Homer, Configurations 1, 2, and 3 have been calculated using data provided by

Homer. And difference between the results are not as close as expected for HOT and Homer. This has been caused for using hourly data directly in Homer calculations, however monthly mean of the hourly data in HOT.

HOT should be developed for the next generation studies and market requirements, and should calculate more accurate results with monthly data. Since achievability of hourly data is not easy for any location in the world, this tool should support users with the easiest way to calculate energy generation before project development stages.

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