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Planning a Renewable Power System in Texas as an Introduction to Smart Power Grid

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PLANNING A RENEWABLE POWER SYSTEM IN TEXAS AS AN INTRODUCTION TO SMART POWER GRID

A Thesis

by

GHALEB S. AL DUHNI

Submitted to the Graduate College of
The University of Texas Rio Grande Valley
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PLANNING A RENEWABLE POWER SYSTEM IN TEXAS AS AN INTRODUCTION TO SMART POWER GRID

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May 2021

ABSTRACT

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Design electrical systems from six renewable energy sources: photovoltaic, wind energy, geothermal, concentrated solar energy, biomass energy, and hydropower in addition to a storage system in the state of Texas, This power system converts the electric system in Texas into a 100 % renewable energy power system. Optimization technique has applied to the results to make the system economical and reduce the wasting resources, this system is considered as decentralized as well which is a great advantage for achieving the smart grid technology compared with the conventional plants where the generation parts are deposed in a small part of the grid, this design makes each part of the grid have two roles as a generator as well as load. The storage system relies on the heat storage of traditional batteries and concentrated solar power plants. Hence this power system could reduce the greenhouse gases by more than 90 %, the annual electricity bill in Texas could be decreased by amount form 10-20 billion dollars yearly, and finally, achieve a higher level of security and reliability of the system by applying the smart grid concept.

DEDICATION

The completion of my master's studies would not have been possible without the love and support of my family. My father, Saleh AL Duhni, my mother, Jihan Aboumerhi, my brother, Omar Al Duhni, and my sisters, Rana AL Duhni, and Suha AL Duhni, wholeheartedly inspired, motivated, and supported me by all means to accomplish this degree. Thank you for your love and patience.

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CHAPTER I

PURPOSE AND SIGNIFICANCE OF THE STUDY

1.1 Introduction

Energy has a great impact on human life's it has changed the normal life which the first human had and it is now under huge risks due to the depletion of the conventional resources of energy (Coal, Gas, and oil). Since the beginning of the industrial revolution, humans have begun to consume more fossil fuels to improve their living standards, almost all of our life routine depends on electricity, therefore, it directly depends on fossil fuel which forms the main source of electricity. Owing to the short age of fossil resources, these living standards are now at risk. Fossil fuel takes millions of years of special conditions to form. At one day, the traditional fuels are going to be extinct, All Fossil fuels are on their way to run out as Coal, Oil, and gas by the end of 2090,2052, 2060 respectively 'Kuo,2019', so switching to other energy sources it is mandatory to keep living on this planet with the current level of luxury.

Renewable energy can be defined as a resource that can replenish energy at a comparable rate or higher than the rate it is consumed. The sun is one of the most important energy sources and it is responsible for many forms of energy starting with solar energy which can be simply defined as the amount of energy received from the incident sunlight, which has energy many times more than human consumption of electricity ‘Gulaliyev et al,2020’. This solar energy can be converted into electrical energy through two well-known technologies, the first is the so-called photovoltaic (PV) and the other is concentrated solar energy (CSP). The energy conversion efficiency for the PV power plants reaches up to 25% based on a single PV junction and more than 45% for multiple band junction ‘Zebarjadi et al,2011’. CSP power plant has less energy conversion efficiency which varies as well based on the technology, however, it is in the range of 20 % ‘Zebarjadi et al,2011’.

The difference in temperature between the different layer on the earth due to the sunlight results in the wind the motion which also is another important resource for energy and the most known technology for generating electricity from wind energy is known as a wind turbine, which has many forms and could be on land or in the sea which is known by offshore and onshore wind turbines. There are other forms, such as aircraft power and vibration technology to generate electricity, but unfortunately, compared with the efficiency of wind turbines, the energy conversion efficiency of the wind turbine is more than 40% ‘Zebarjadi et al,2011’.

Due to the heat from the sun, the vaporization of water in the ocean plays an important role in rainfall or the water cycle. Water Energy is used nowadays to generate electricity in a lot of countries from the technology known as hydropower with big dams or fast flow water rate, hydropower has great efficiency and the minimum losses in the conversion process and it could reach up to 90% ‘Zebarjadi et al,2011’.

Geothermal energy is one of the lowest energies in which the sun has not played role in existed. Geothermal energy comes from the high pressure of the outer layers of the earth toward its center, which forms a great source of energy simply as a form of heat which could convert to electricity with the same principle of the thermal power plants. Hence, due to that, it is possible to convert the thermal power plants into geothermal power plants. As a result, this reduces the installation cost of building new power plants and completely shifts to renewable resources. Geothermal power plants have a great availability with a very high capacity factor that could reach up to 90% 'Falahati et al,2012'.However, the energy conversion efficiency of geothermal power plants is between 10-20% 'Zebarjadi et al,2011'.

Since solar energy plays an important role in the photosynthesis of plants, biomass energy is another form of solar energy. Biomass can simply burn organic plants such as corn and soybeans and use the heat to generate electricity. In addition, it may depend on other materials, such as animal and human waste. The energy conversion efficiency is in the range of 20-40 % 'Zebarjadi et al,2011'. The capacity factor of biomass power plants is very high in a range between 75-85 % 'Falahati et al,2012'.

Energy resources considered Renewable resources if it applies two conditions, the first one is the ability to replenish itself by a natural process with a higher rate or compatible rate compared with the consumption rate, and the second condition is if the energy resource is eco-friendly. There are many different terminologies sharing the same concept with renewable energy like clean energy which does not have any harmful effect on the environment like releasing greenhouse gases such as (NOx, COx, SOx, …) and the famous example of this type of energy is nuclear energy. Another term is so-called sustainable energy, which applies the first condition of renewable energy, but violates the second condition, such as wasted energy.

However, in this work, all sources that achieve the first condition and have a less bad effect on the environment compared with the traditional power plants are used to plan a renewable energy power system.

1.2 Renewable Energy In The World

According to the Global Energy Statistics Yearbook 2020, electricity consumption in 2019 is approximately 23,500 TWh And because of the growth of the world's population and the development of technology, it has increased year by year. Figure 1 shows the global electricity consumption and linear growth. Most of the electricity load is mainly concentrated in Asia and North America, accounting for about 70% of the total electricity consumption. China, the United States, and India It accounts for 40% of the world's total electricity consumption. As shown in Figure 1.1‘Electricity domestic consumption,2020’.

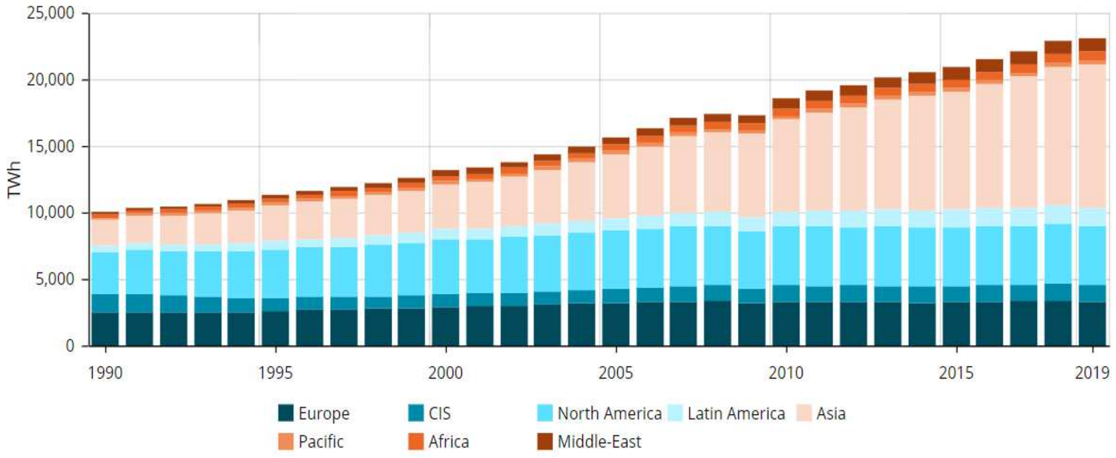


Figure 1. 1: Global electricity consumption

Figure 1.2 illustrates the share of renewable energy in the total electricity generation in 2019. Renewable energy forms around 25% in the best statistics records as it is clear in Figure 1.2 ‘Ritchie and Roser,2020’, all renewable energy resources generate around 7,000 TWh and the Hydropower generates 4,000 TWh making the largest proportion of the renewable energy resources for electricity consumption. At the same time, Wind and Solar energy have grown rapidly in recent years with 1,417 and 711 TWh annual generation respectively. However, the other renewable resources do not generate more than 1,000 TWh yearly. The growth in solar and wind energy could be due to two main factors: The first is the new technology of photovoltaic models and wind turbines. Second, moving in the direction of the microgrid concept.

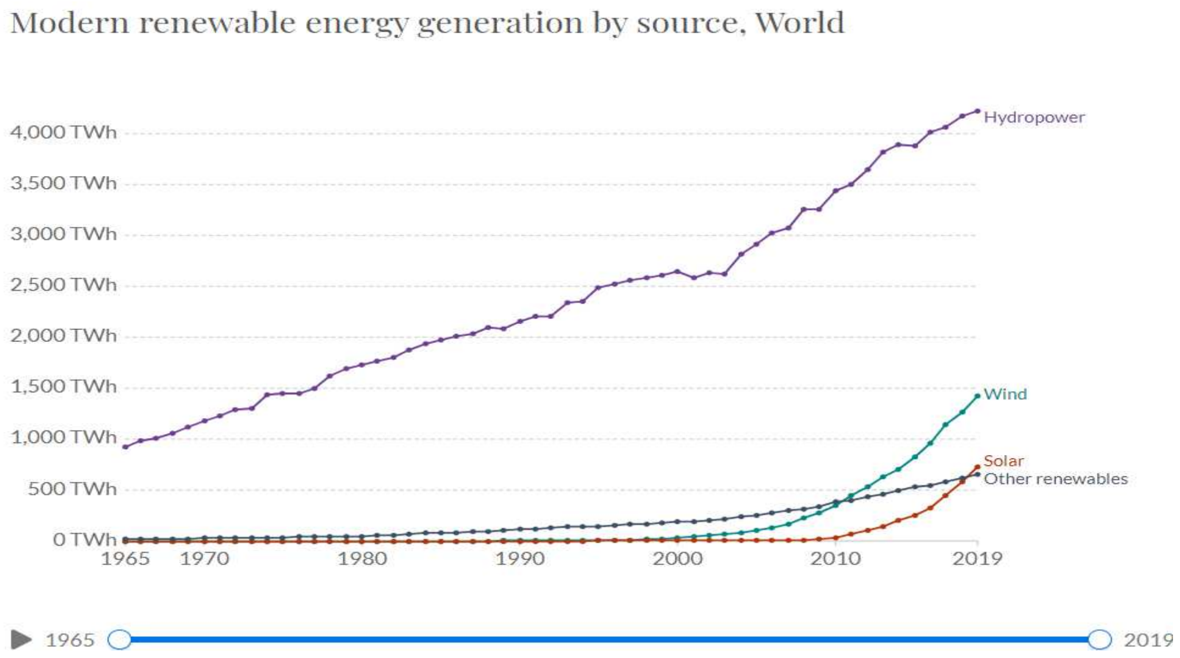
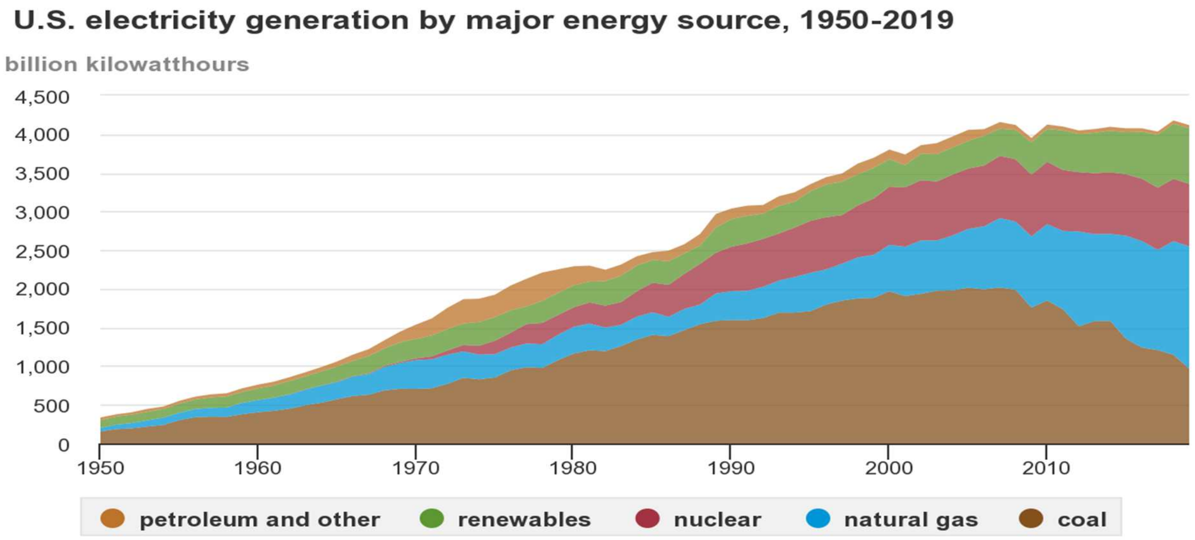


Figure 1. 2: Global renewable energy generation

1.2.1 Renewable Energy In The US

Based on the US energy information administration ‘What is U.S. electricity generation by energy source?,2021’, the electricity consumption in the US was about 4,120TWh in 2019, only around 18% came from renewable energy resources which are less than the average global percentage, which is 25% as mentioned before. Wind energy is the largest renewable energy source is used in the US, accounting for 7.3% of power generation, followed by hydropower, accounting for 6.6%, then solar energy, accounting for 1.8%, biomass accounting for 1.4%, and finally geothermal energy, accounting for 0.4%. Figure 1.3 ‘Electricity explained,2021’ shows how fossil fuel power plants have become the main source of electricity generation in the United States, and the percentage of renewable energy generation has gradually increased over the past few decades. Hydropower was the main source of renewable energy, and in the past ten years, wind energy has become the largest renewable energy source. As shown in Figure 1.4 ‘Electricity explained,2021’, solar power plants are increasing dramatically. In the past ten years, there seems to be no development in the biomass and geothermal fields, and their capacity is constant, so the integration of renewable energy resources is mainly concentrated on solar and wind energy.



U.S. electricity generation by major energy source, 1950-2019

Note: Electricity generation from utility-scale facilities.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 7.2a, March 2020 and *Electric Power Monthly*, February 2020, preliminary data for 2019

Figure 1. 3: Electricity generation by different sources in the US

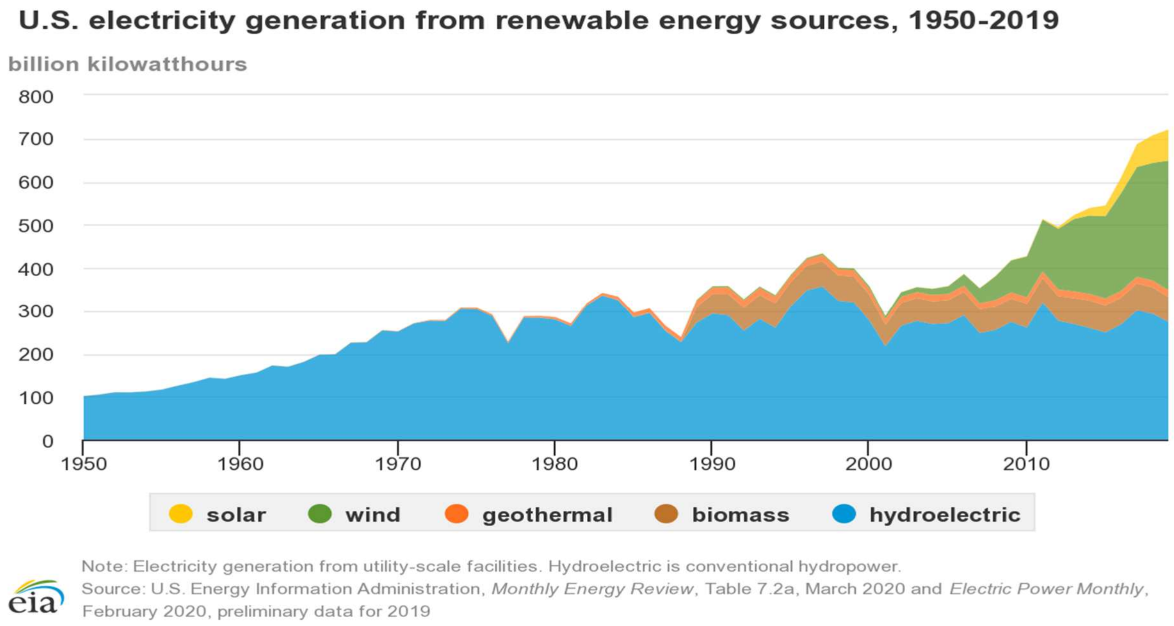


Figure 1. 4: Electricity generation from renewable energy sources

1.2.2 Renewable Energy In Texas State

Texas consumes 483 TWh ‘Texas Electricity Profile 2019,2020’ which forms 10% of the total consumption in the US. The Electric Reliability Council of Texas (ERCOT) is the main operator of the Texas power grid. ERCOT represents 90% of the electrical load in Texas and it is responsible for providing electricity to more than 26 million Texans based on ERCOT data ‘About ERCOT,n.d’. Like most other states in the United States, Texas also uses fossil fuels as the main source of power generation, especially natural gas, as shown in Figure 1.5 ‘Electricity Sources Influence Electric Vehicle Upstream Emissions,2020’.

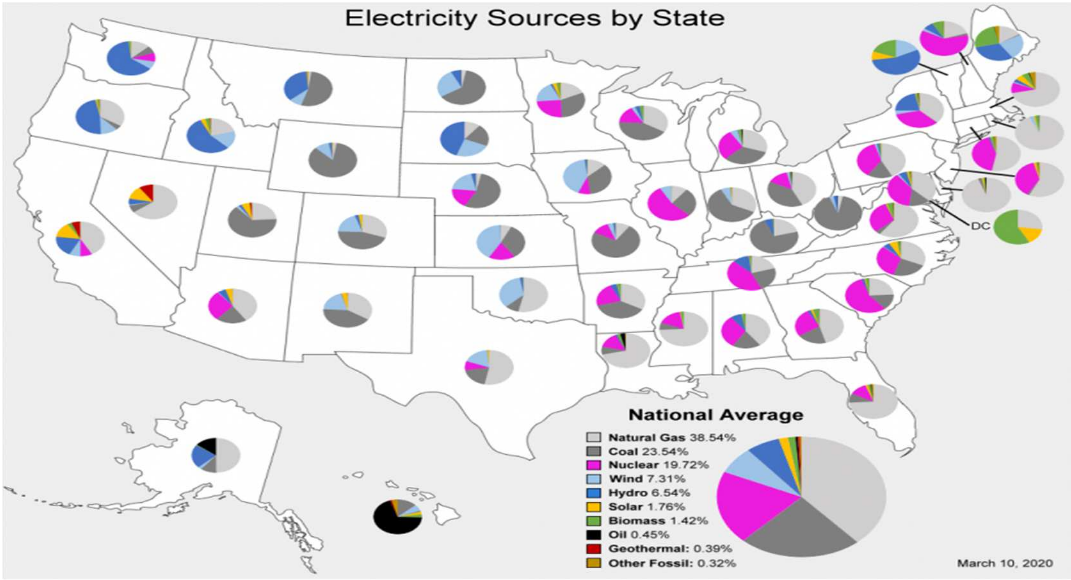


Figure 1. 5: Electricity source by state

In ERCOT, wind energy resources form around 20% of the electricity generation in the ERCOT grid, however, Fossil fuel is still the dominant source of electricity generation by 67.5%.On the contrary to the highest percentage of electricity generation from the wind, the electricity generation from the other resources such as solar, biomass, and hydropower does not exceed 2% as is clear in Figure 1.6 ‘Sakelaris,2020’.

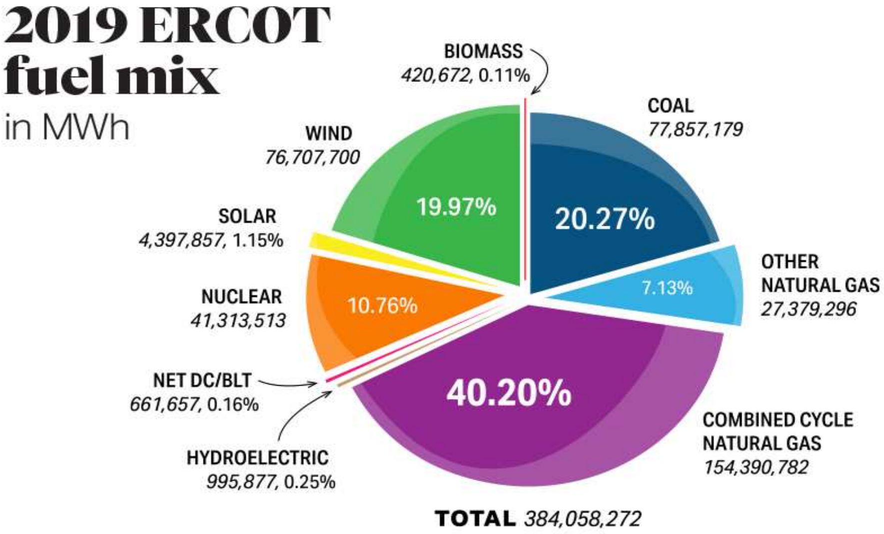


Figure 1. 6: Electricity generation in ERCOT by source

1.3 COVID Effect On Energy

1.3.1 Impact Of COVID-19 Crisis Globally

At the end of 2019, the Covid-19 virus appeared and broke out on a global scale and hit every country in the world. It caused a lot of loss of life and money, The governments have developed many plans to stop the outbreak, such as working remotely, converting teaching from face-to-face classrooms to fully online, imposing curfews at night, closing restaurants and stadiums, and ending with a complete lockdown. All these plans have had a huge impact in many areas, such as the oil, transportation, and energy sectors. Compared with the past three years, the total global investment in energy in 2020 has dropped by 20%. As shown in Figure 1.7 'IEA,2017-2020', the main reason for the decline is the decline in the growth of fuel supply projects, while the growth in the power sector and energy efficiency has not changed much.

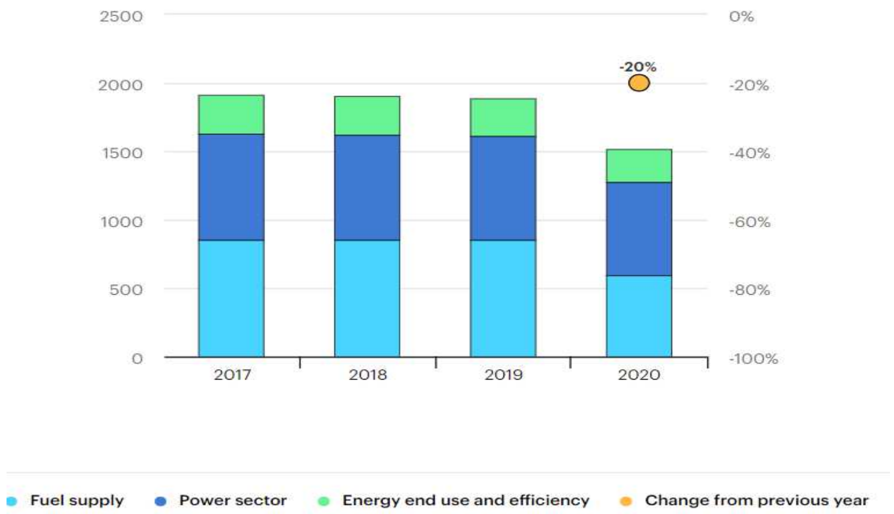


Figure 1. 7: Total global energy investment, 2017-2020

In 2020, global investment in renewable energy and clean energy reached 56.78 billion U.S. dollars, compared with 63.58 billion U.S. dollars in 2019, a decrease of approximately

10.6%. This reduction comes from a reduction in investment in renewable energy projects, as shown in Figure 1.8 ‘IEA,2015-2020’.

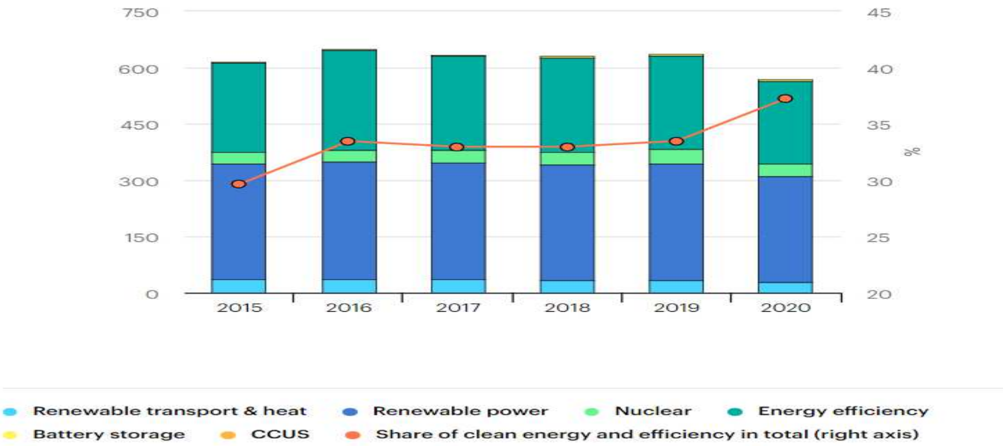


Figure 1. 8: Global investment in clean energy and share in total investment, 2015-2020

1.3.2 Impact Of COVID-19 Crisis In The US

The US as the other countries has been affected by this pandemic in all fields and in the energy sector as well, the petroleum sector has been hit badly, and that caused the West Texas Intermediate oil prices to were below zero according to EIA as shown in Figure 1.9 ‘Low liquidity and limited available storage pushed WTI crude oil futures prices below zero,2020’.

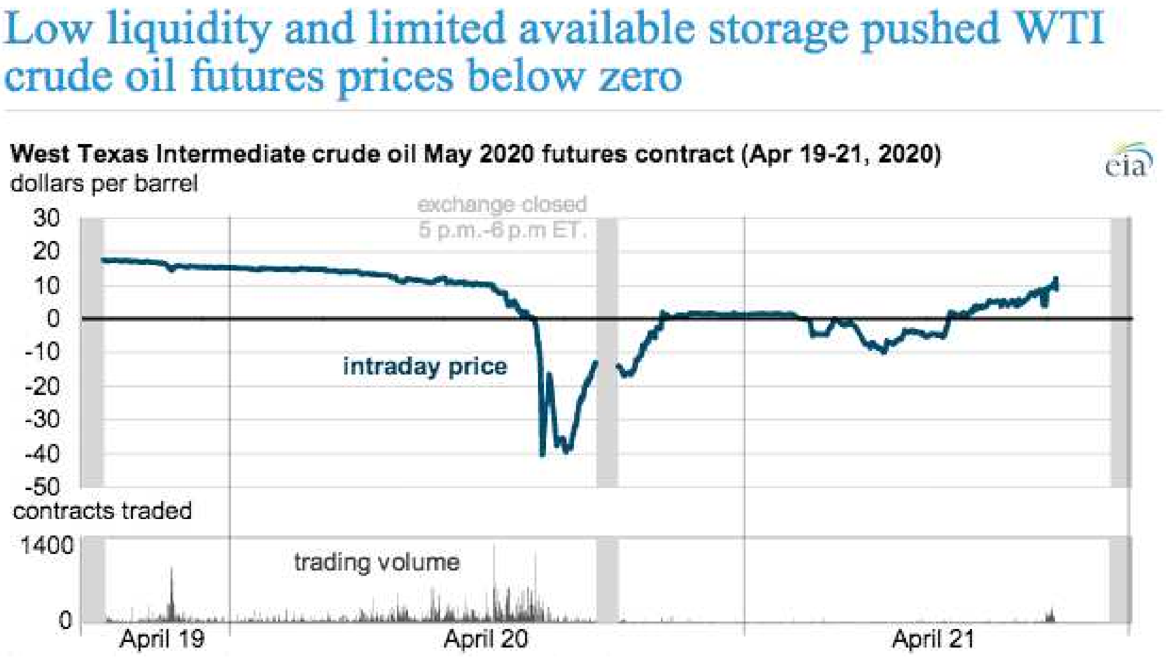


Figure 1. 9: Oil prices during COVID -19 pandemic

The transportation section is another sector that has had a lot of losses due to this pandemic, Fuel demand dropped from 16 million barrels a day to 11 million barrels by about a 30% decrease compared with the same intervals in 2019 as shown in Figure 1.10 ‘Low transportation fuel demand and low profitability drive refinery run declines,2020’. Electricity demand has as well been affected by COVID, daily weekday electricity demand has decreased by 9-13% in the central region of the US compared with the expected demand in the period from March 2020 to April 2020 as seen in Figure 1.11 ‘Daily electricity demand impacts from COVID-19 mitigation efforts differ by region,2020’.

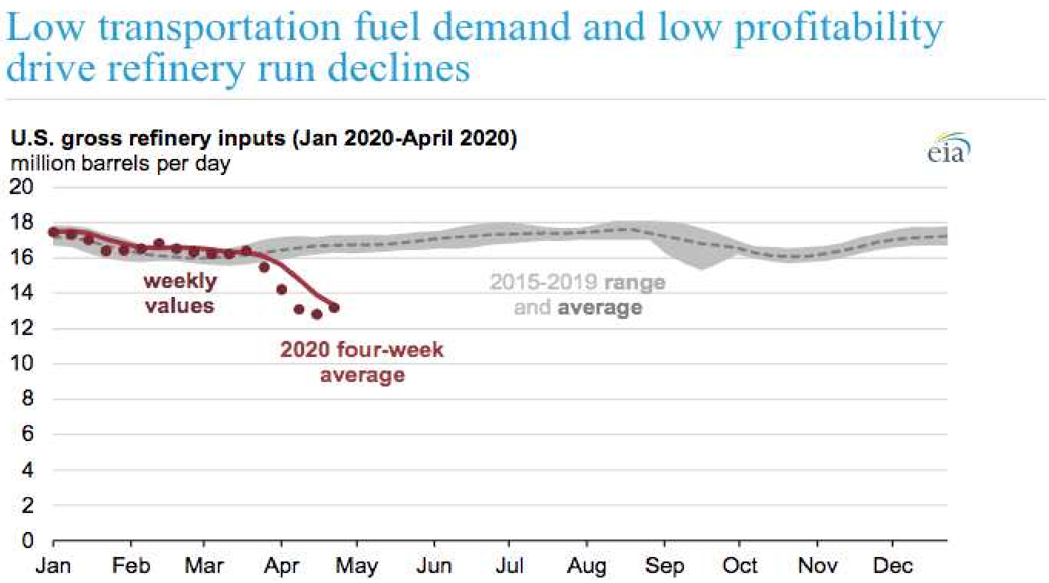


Figure 1. 10: COVID effect on the transportation sector

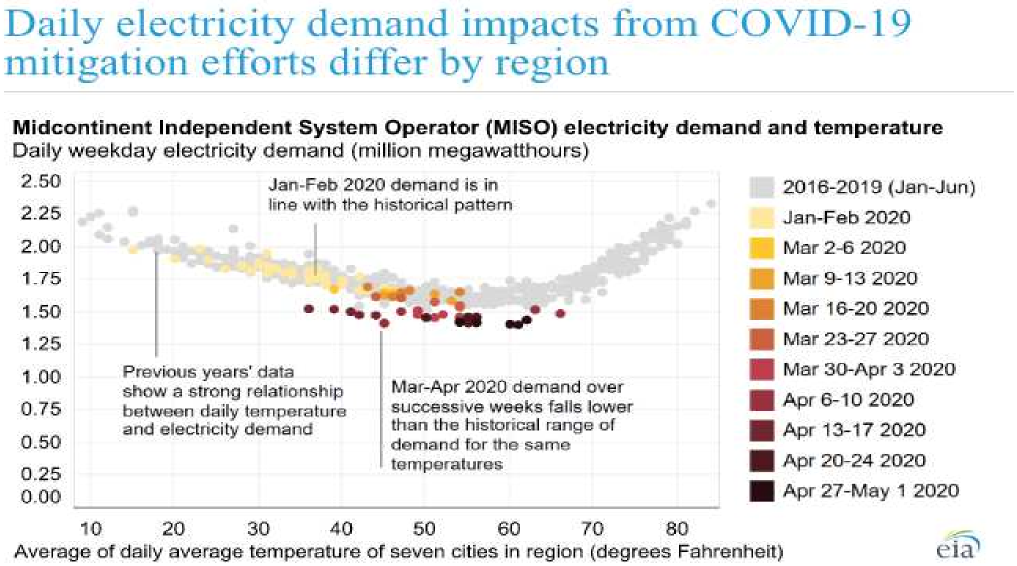


Figure 1. 11: Electricity demand between March and April 2020

1.4 Thesis Statement

Renewable energy is the future of the new industrial revolution. In one of the pessimistic studies, All Fossil fuels are on their way to run out as Coal, Oil, and gas by the end of

2090,2052, 2060 respectively 'Kuo,2019', Moreover according to a study based on the known reserves of fossil fuel left, The coal will last for 114 years as the longest fossil fuel, however, the natural gas and oil will last for only 52.8 and 50.7 years, respectively 'Ritchie and Roser,2017' as shown in Figure 1.12 ‘Ritchie and Roser, 2017’. The previous two studies have almost the same expected year for running out of oil and natural gas, but different expectations for coal. Although the extinction of fossil fuel could be a debatable argument, the decrease in the reservoirs for fossil fuel is a fact, and that has a lot of impacts due to the shortage of energy resources such increase in the cost of fossil fuel.

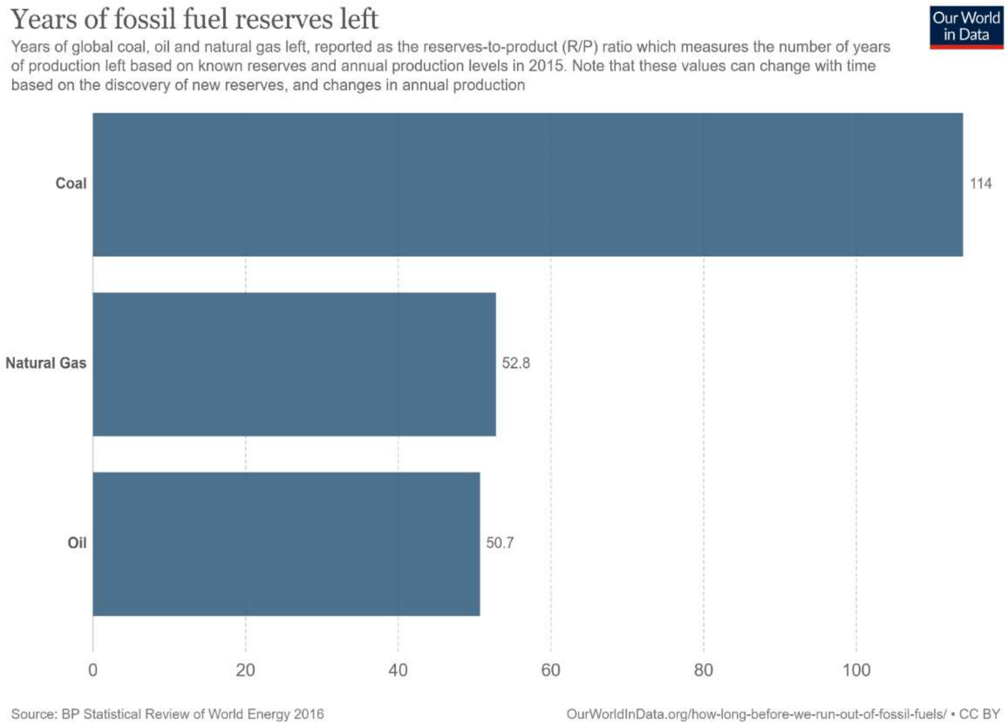


Figure 1. 12: Years of fossil fuel reserves left

In addition to the expectation that fossil fuels will be exhausted by the end of the century or at least the shortage of fossil fuel storage and its impact on global prices. The distribution of fossil fuel depots is uneven on the earth. Figure 1.13 ‘Ritchie and Roser, 2017’shows known natural gas reservoirs, most of which are located in the Middle East, the United States, Russia, and China. As shown in Figure 1.14 ‘Ritchie and Roser, 2017’, the oil situation is no different. Most oil depots are located in the Middle East, Canada, Russia, and Brazil. The shortage of fossil fuel resources and the limited supply will lead to price instability, which is another problem faced by the power sector.

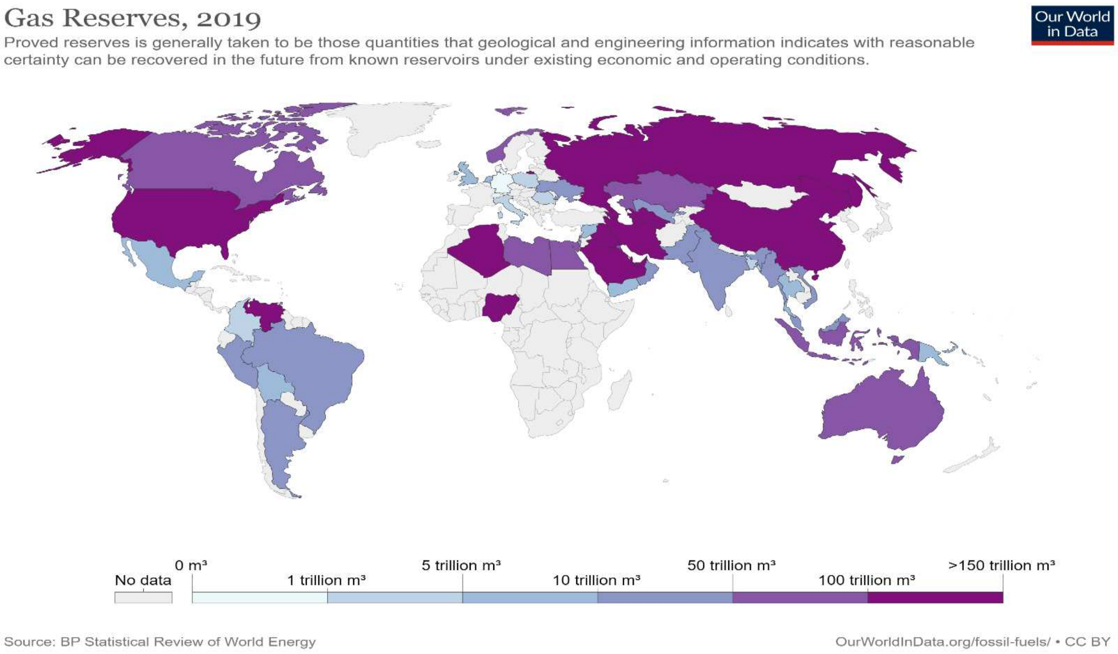
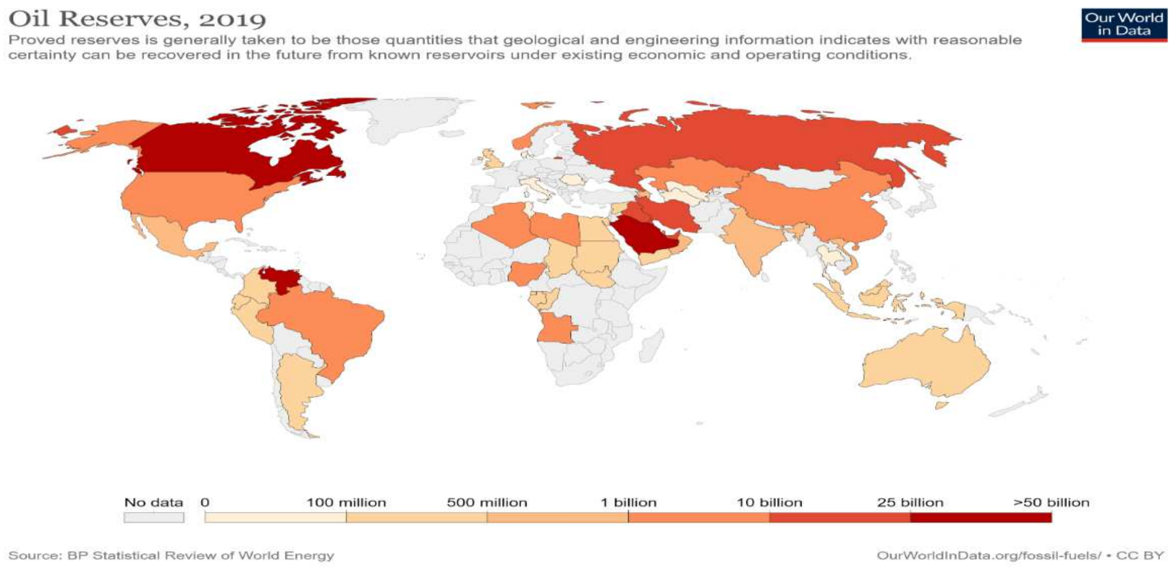


Figure 1. 13: Gas reserves in 2019 worldwide


Oil Reserves, 2019

Proved reserves is generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions.

Source: BP Statistical Review of World Energy

OurWorldInData.org/fossil-fuels/ • CC BY

Figure 1. 14: Gas reserves in 2019 worldwide

Figure 1.15 ‘IEA,2019’ illustrates the change in the price of fossil fuel such as diesel, gasoline, and oil in the period 2005-2019, The price of each fuel has changed from one year to another based on many factors such as catastrophic environmental, wars, and political issues. This indicates the instability of the fossil fuel market and the potential for price spikes at any time.

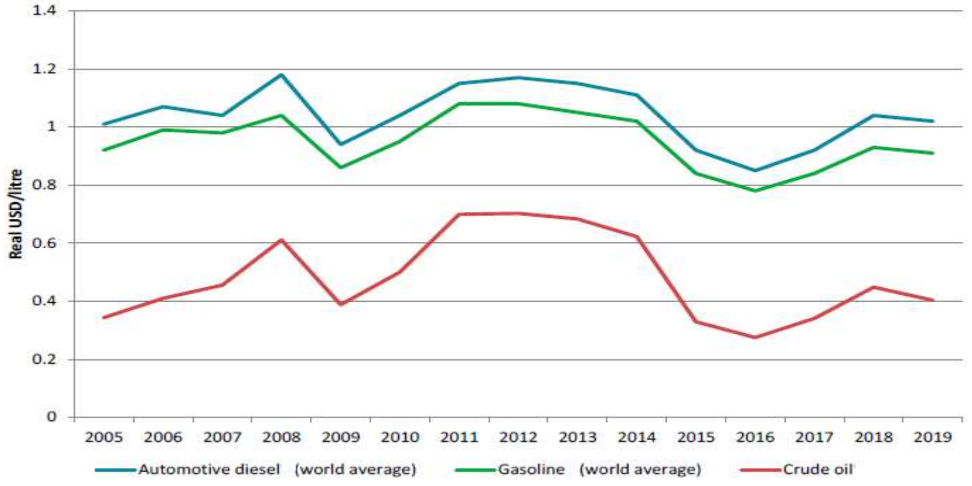


Figure 1. 15: Fluctuations in cost of fossil fuel in the period (2005-2019)

Global warming and greenhouse gases are one of the most important factors threatening life on earth. Fossil fuels are responsible for 10 million metric tons of carbon emissions ‘Boden et al, 2017’. Figure 1.16 ‘Boden et al, 2017’ shows the increase in carbon emissions from fossil fuels during the period 1900-2014, and to make matters worse, the emissions increased day by day. To understand the threat that fossil fuels for humanity, according to ‘Lelieveld et al,2019’ an average of 3.6 million people every year could be saved if we stop using fossil fuels due to the emissions released from them. The number of death due to the emissions of fossil fuel and all anthropogenic emissions in a general is more in countries like the US, Europe, India, and China due to the high use of fossil fuels in that region of the world as shown in Figure 1.17 ‘Lelieveld et al ,2019’.

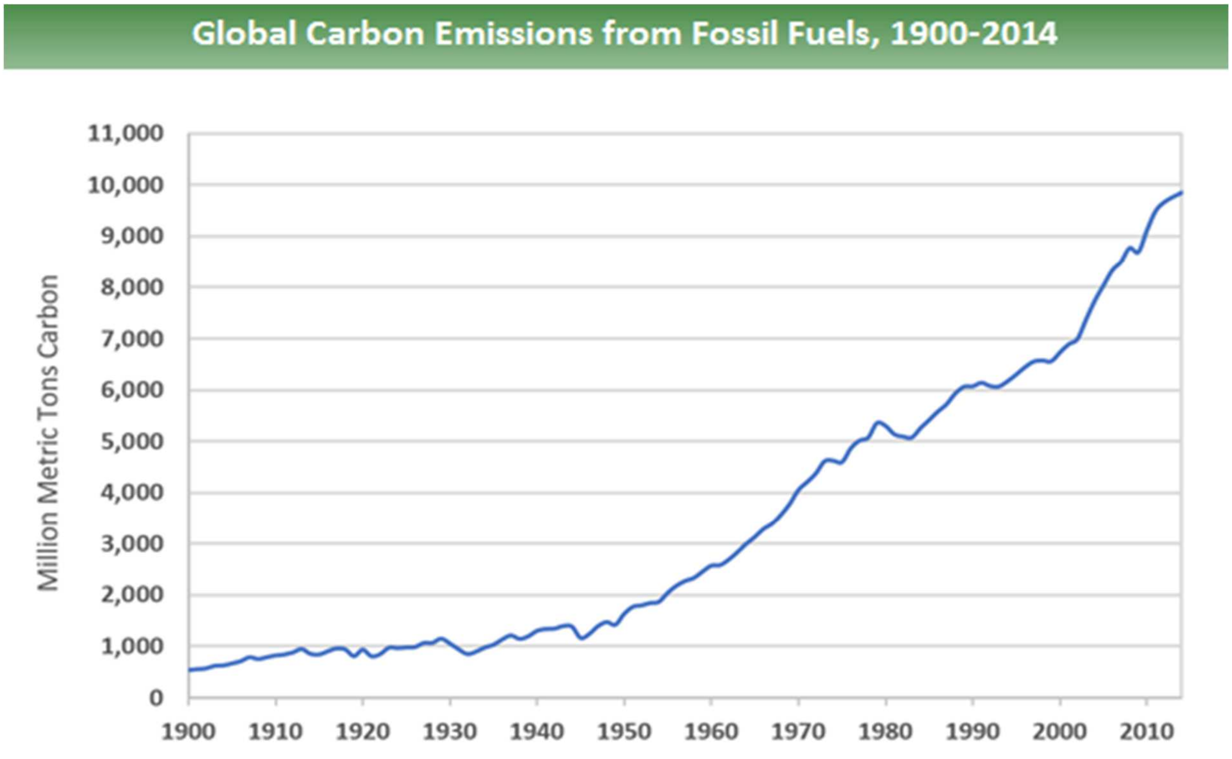


Figure 1. 16: Global Carbon Emissions from fossil fuels in period 1900-2014

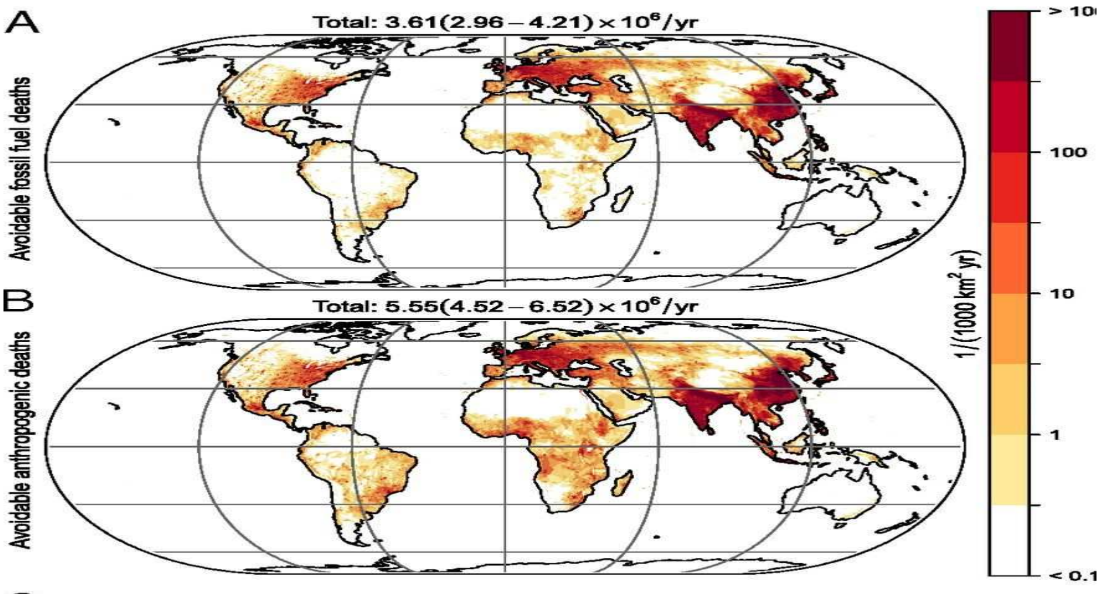


Figure 1. 17: Excess death avoided by emissions of fossil fuels

So, based on the previous reasons, the tendency to depend more on the sustainable energy sector by using renewable resources such as solar, wind, hydro, biomass, and geothermal as the main source of electricity is mandatory. Hence, these resources should be used in the best way. This article proposes potential designs for grid optimization using renewable energy (RES), including photovoltaic (PV), concentrated solar (CSP), geothermal, wind, biomass, hydropower, and energy storage systems. As for the importance of renewable energy, because it is both sustainable and a clean resource, it encourages us to use it in the best way.

In this work, the state of Texas is the case study because it is one of the biggest electric market in the US and it is a large scale system, so, turning the power system in Texas into 100% clean will prove the possibility of reaching 100% renewable energy at any power system at any places in the world. . In addition, in this work, the power system will take the form of a smart grid, so it will show the availability of concept benefits that can be applied to small countries that do not have a large amount of renewable energy.

The power load of the proposed power system is equal to the power demand of Texas in 2019. The system is connected to the electric grid in the state of Texas but the main and only source of electricity is from renewable energy resources while the current power plants depend mainly on fossil plants, as shown in Figure 1.18. The goal is to convert the electric grid in Texas to be completely dependent on renewable energy resources to achieve independence from Fossil market fluctuations and also in the fact of the extinction of fossil fuels which form one of the biggest problems for the whole of humanity, global warming, and greenhouse gases are another reason why a 100% renewable energy power system is very important.

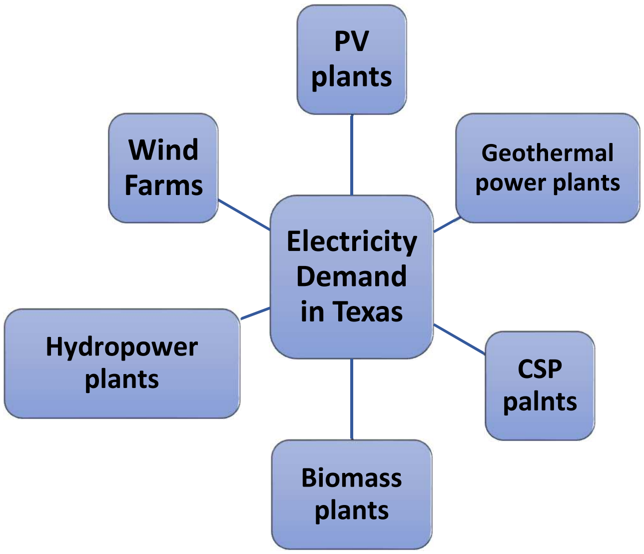


Figure 1. 18: Proposed electrical grid

The second goal of this work after designing many electrical power systems from six types of renewable energy resources is to combine the six renewable resources in one smart system by designing the optimal size from each source in order to decrease the electricity bill and to generate electricity in the lowest electric price, to apply the optimization technique, linear programming has applied using MATLAB software. After that, an energy storage system has been added to transfer excess power generation from off-peak load time to peak time load, and from the maximum power generation time to the minimum power generation time as a way of load management. The main purpose of the storage system is to maintain the balance between the power generation side and the load side and to avoid power outages in the entire system. The last goal of this work is to achieve the smart grid concept by converting the power system into 9 main zones on one track and into 254 power systems on another track by designing a renewable power system for each county in Texas. The four main goals of this work are shown in Figure 1.19.

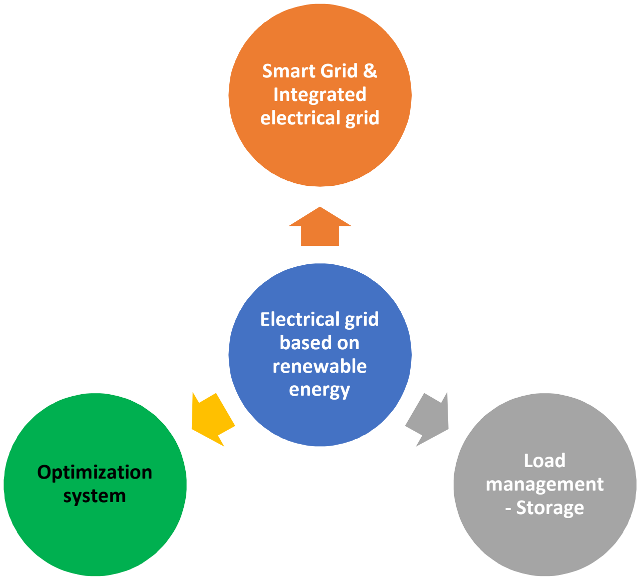


Figure 1. 19: Thesis goals

1.4.1 Optimization Power System

There are different methods for this work. The first approach designing a power system from six types of renewable energy from each source separately if that is applicable, so the designing has many approaches starting from depending on the availability of the renewable resource alone to feed the load, which is the total electricity load in 2019 on Texas. Hence, this idea means there are six separate systems each one of them is based on different renewable sources, the power system number one depends completely on photovoltaic energy as a source of generations, the only source of generation, and power system number two depends fully on wind energy as the main source of generation, power system number three depends only on concentrated solar power, power system number four is only from Geothermal energy plants as well as The fifth power system only comes from hydroelectric power, and finally, the sixth power system depends on biomass. Some of these renewable resources are rare and limited by many factors, so the main goal is to determine the available resources for each renewable resource in Texas.

The second task is to make the combination between the six prospective design systems to make one electric power system from the previous six systems and to design the optimal size for each system, the linear programming technique is applied using MATLAB software, the objective goal is to reduce the electricity cost under consideration of two main constraints, the generation of electricity should be equal to the electric demand at all times, and the availability of resources due to geographical limitations on Texas state. Later, the storage system was applied to the final design to improve results and reduce electricity bills and the area required for renewable energy plants. In addition, the main reason for the storage system is to avoid power outages.

The decision variables in Formula 1.1 are the size of the photovoltaic solar power plant, the size of wind farms, the size of geothermal power plants, the size of the concentrated solar power plant, the size of hydropower plants, and the size of biomass power plants, and the size of the storage system. In this system, there are many decision parameters, such as global solar radiation, wind speed, gradient thermal conductivity, direct solar radiation, water storage, and power demand. Formula No. 1.2 shows the constraints required in the optimization system, as shown in Figure 1.20.

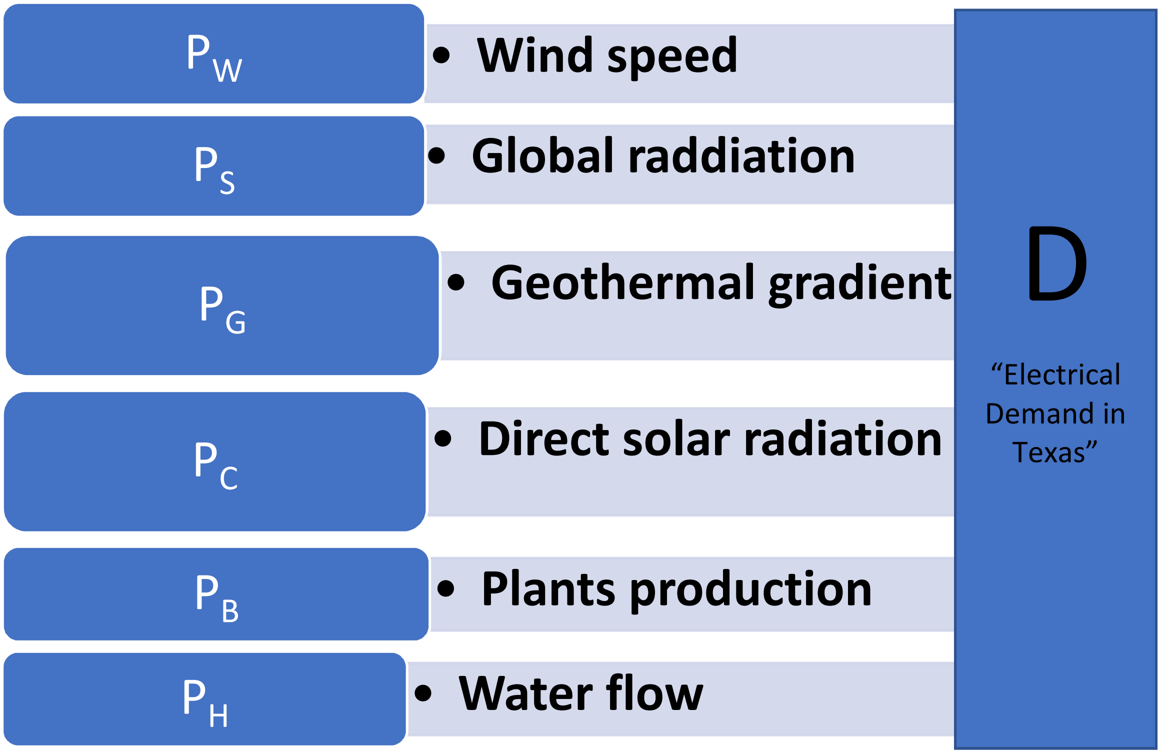


Figure 1. 20: Decision variables and parameters for the proposed electrical grid

$\min F = A_W P_W + A_S P_S + A_C P_C + A_G P_G + A_B P_B + A_H P_H$ 1.1

subject to

$P_W + P_S + P_C + P_G + P_B + P_H = D$ 1.2

Where:

P_W: wind power size in GW

P_S: Photo-voltaic power plant size in GW

P_C: Concentrated solar power plant size in GW

P_G: Geothermal power plant size in GW

P_H: Hydropower power plant size in GW

P_B: Biomass power plant size in GW

A_W is the Levelized cost of energy for the wind system in \$/MWh

A_S is the Levelized cost of energy for the photo-voltaic system in \$/MWh

A_C is the Levelized cost of energy for the concentrated solar power system in \$/MWh

A_G is the Levelized cost of energy for the geothermal system in \$/MWh

A_H is the Levelized cost of energy for the hydropower system in \$/MWh

A_B is the Levelized cost of energy for the biomass system in \$/MWh

1.4.2 Managing Load And Generation

One of the biggest renewable energy drawbacks is the availability of generation at all day time, capacity factor terminology is used to measure the percentage among power generation to power rates. The capacity factor depends on site conditions, therefore, there is no fixed percentage and it varies from one land to another. The capacity factor for solar on average is between 10-30 %, for wind, it varies from 20- 40%, However, for the biomass power plant, the capacity factor is in range from75-85% ‘Falahati et al,2012’. Moreover, Solar energy for instance generates more electricity at noon while wind, on the other hand, tends to produce more electricity at night time compared with day time and even more it tends to produce electricity more in warm-season more than cold ‘Power generation is blowing in the wind,2012'. From all of that, it is difficult to design a power system depending only on one form of renewable resources without oversizing the system in order to avoid load shedding or any power outage due to the lack of generation. The storage system has the magic key to achieve the combination of renewable resources as well as avoiding oversizing by storing the energy at the maximum time generation in order to feed the demand at the minimum time generation.

The storage system has two main components: bidirectional power converter/inverter and battery system, the size of the battery bank is usually away larger than the size of the bidirectional power converter/inverter and for the large scale has a power transformer as seen in Figure 1.21. The battery is used to compensate for the difference between the load side and the power generation side by charging the battery when the power generation side is larger than the load or discharging it when the load side is larger than the power generation side. A bidirectional power converter/inverter converts direct current to alternating current and vice versa, In addition, it also controls the charging and discharging process of the battery bank.

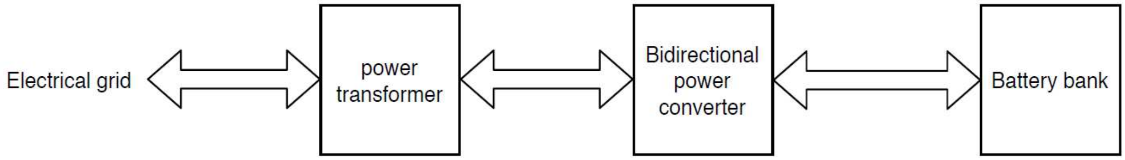


Figure 1. 21: Electrical storage system schematic

The working principle of the storage system is to charge the battery in different situations, for example, when the power generation is too much, or in another situation where the power demand is very low. Discharge the battery when the electricity demand is at the peak or when the power generation is at the minimum status due to any reason. Generally, the battery is charged when the power generation is greater than the demand, and then the battery bank is discharged when the electrical load is greater than the power generation. The working principle is shown in Figure 1.22.

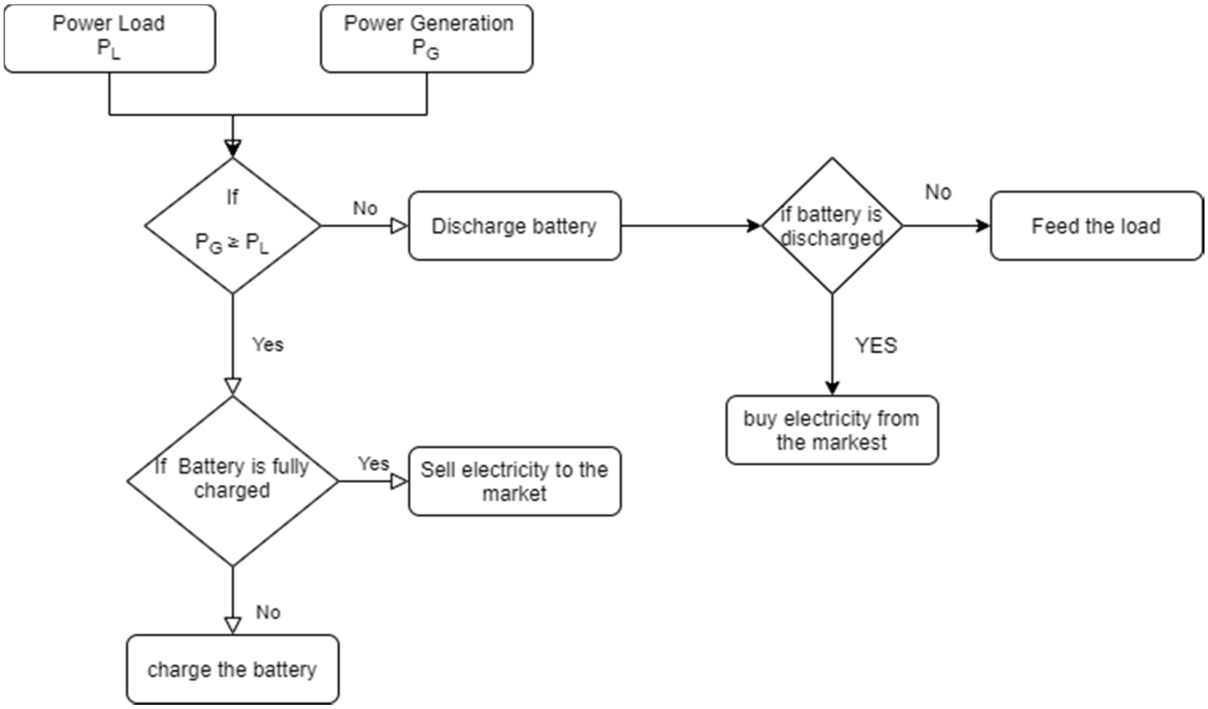


Figure 1. 22: Energy storage system flow chart

Although the traditional storage system was shown before. The storage system in this work relies on renewable energy, especially infinite energy sources, such as PV, CSP, and wind turbines. Take the photovoltaic system as an example. Its components include power inverters. Therefore, the use of photovoltaics in storage systems will reduce the cost of power inverters/converters. However, there must be a battery pack to store energy.

1.4.3 Smart Grid

The smart grid is a new technology that can transform a conventional grid that has specific locations for power generation plants and other locations for power load sites into many small grids or regions where the power generation and power load is not specified at certain locations. Each part of it has its power generation part and load part. Owing to the following facts from ERCOT, ERCOT's current grid is far from a smart grid. ERCOT's grid has 80 GW capacity and around 650 power generating plants, and they vary in their capacity from several megawatts up to thousands of megawatts, So, Therefore, more or less each plant will generate 123 megawatts, and for ERCOT, each megawatt can power 200 Texas houses, so any outage of any power plant will cause many customers to a power outage 'Fact sheets ERCOT,2020'.

In this work, there are two proposed systems that can realize the concept of a smart grid and improve the reliability and safety of the power system, thereby avoiding power outages caused by insufficient power generation. The first track is based on the current load zone in Texas, dividing the entire power system into 9 zones, and designing a renewable energy system for each zone based on electrical energy consumption. The second track is to achieve a higher level of security by going from 9 zones to 254 zones, each zone represents each county in the state of Texas, thus by this system the overall capacity of the renewable power system will be higher, but the reliability of the total power system will be higher and the regional electricity price will be lower.

1.5 Expected Benefits

The expected benefits of this work would be in many forms: reducing greenhouse gases emissions, eco-friendly system, independence of the power system from the global price of the fossil fuel, independence of the power system of the circumstances of export of fossil fuels, reducing electricity bill cost, increase the security and the reliability of the power system, and moving to the smart power system and microgrid.

Renewable energy power plants reduce greenhouse gas emissions. Hence, using a 100 % renewable power system rather than the traditional power system, which based on the fossil fuel power plants will lead to reducing greenhouse emissions in a sufficient percentage, moreover to help in the global warming, which correlated with the percentage of emissions. In addition, because environmentally friendly power systems with extremely low carbon emissions can reduce pollution, many lives can be saved.

The cost of electricity in the traditional power system directly depends on the price of fossil fuels, so it depends on the exporters of fossil fuels and their circumstances. Hence, a 100% renewable power system will achieve higher level of independence because of the availability of renewable energy resources within the land of the power system. Through the use of renewable energy, the total cost of electricity can be reduced, because renewable energy technologies continue to develop and prices continue to fall. Therefore, over time, people will be able to obtain cheaper electricity

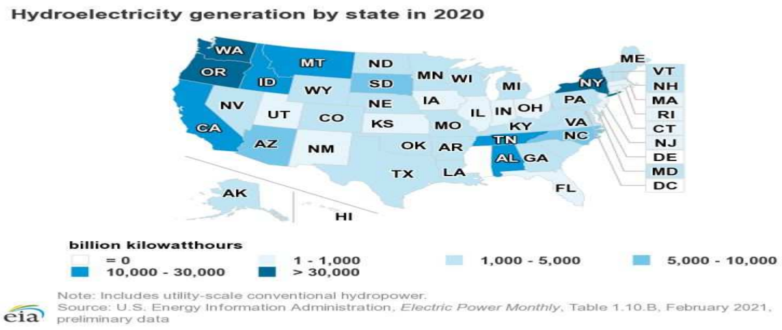
The smart power systems will increase the security of the power system in the state of Texas. Reliability of the system by converting into many zones and all of it has its own resources of renewable energy resources, therefore that would avoid power outages in all regions in Texas due to this system, moreover, the microgrid system will make more than 254 system instead of one power system. Hence, it would make every power system a backup for the other, thereby that will achieve higher security for the power system in the state of Texas in terms of the availability of power generation by having 254 power systems could feed the electrical demand at any of those systems in case of lack of energy in it.

CHAPTER II

BACKGROUND

2.1. Hydroelectric Power

Hydroelectric power generation depends on converting the kinetic and potential energy of water flow into electrical energy. Hydroelectric power plants mainly for large projects could be classified into two main technologies the storage system, which depends on huge storage water and dams based on the potential energy of the water and the second technology is known as the run of river (ROR) which depends on the kinetic energy. The total capacity of hydroelectric power plants in the US is 80 GW , as shown in Figure 2.1 ‘Hydropower explained,2020’ the variation in the capacity of hydropower plants from one state to another. Some states such as Washington and California have more than 10 GW of power capacity, while Texas has less than 1 GW of power capacity of hydropower plants. However, as shown in Figure 2.2 ‘Friedrich et al,2018’, the water reservoirs are distributed regularly in all states.



Note: Includes utility-scale conventional hydropower.
Source: U.S. Energy Information Administration, *Electric Power Monthly*, Table 1.10.B, February 2021, preliminary data

Figure 2. 1: Hydroelectricity generation by state in the US

Figure 2. 2: Water reservoirs in the US

2.2. Geothermal Energy

On the contrary of the other renewable energy resources, Geothermal energy is available almost at all times during the day and night and throughout the year at all seasons ‘Watrak et al., 2017’. The average heat conversion efficiency for geothermal power plants is 12% and it depends on the design of the plants if it uses single flash, double side, or binary cycle. ‘Zarrouk et al.,2014’. Geothermal plants are considered very expensive plants based on their capital costs, even so, a study for 55 MW Gedongsongo Geothermal Power Plant Project shows the economic impact of this project with an electricity tariff of around 11.4 cents per kWh which is an acceptable price ‘Wirawan and Pramudiohadi,2017’. Geothermal energy has many forms and the most popular one is called hydropower, the detection ways for the availability of geothermal reservoir requires a drilling process for high depth, so it is a very expensive method. ‘Tousif and Taslim, 2011'. There are some important factors to decide if a site is suitable to implement a geothermal power plant starting from the temperature of the reservoir, its depth, and the percentage of mineralization in the water ‘Watrak et al., 2017’The globe geothermal capacity hit 15.406 GW, The US leads electricity market from a geothermal power plant in the world with a capacity of around 3.67 GW, followed by Indonesia, Philippines, Turkey, and New Zealand by 2.133,1.918,1,526 and 1.005 GW respectively as shown in Figure 2.3 ‘Richter,2020’.

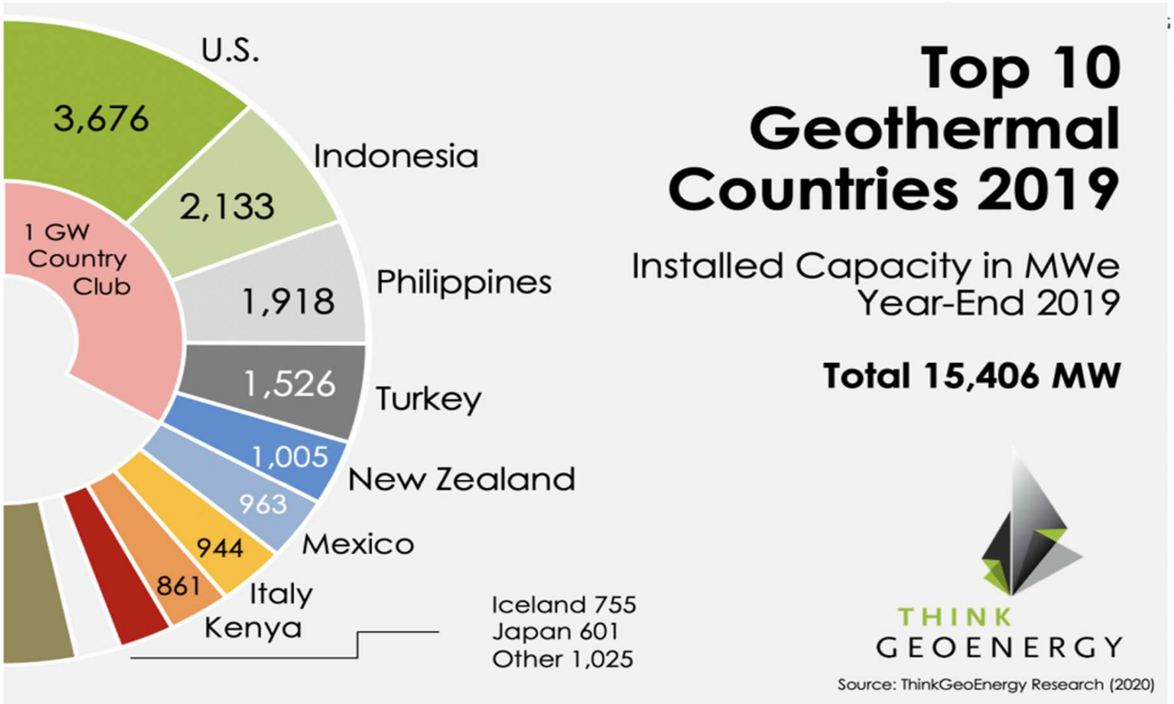


Figure 2. 3: Top 10 geothermal countries based on the installed geothermal power plants

One of the largest projects for producing electricity from geothermal energy is located in Hawaii with a capacity reaching 500 MW ‘Fesmire,1991'. Iceland is one of the pioneer countries in geothermal energy technology, electricity generation from geothermal forms 25% of the electricity generation, and that comes from the natural geography of Iceland, which has a lot of volcanos ‘Hreinsson,2016’. Geothermal energy could use to produce electricity at average temperature by using binary cycle generators such as Kalina and Rankine ‘Setel et al.,2015'. Hydroelectric power and hot springs are old forms of geothermal energy. Although they seem to be rare, another technology has been developed, which is later known by heat and dry rock, and has been transformed into an engineered enhancement system (EGS) ‘Jelacic and Renner,2008'. EGC can power baseload even in places where a natural geothermal resource is not available, EGC concept simple extracting heat from artificial wells by injecting water in high depth beneath the ground and make fractures between rocks to increase heat exchange between layers ‘Azim et al.,2010’. EGS needs highly depth wells, which could reach 3 Km up to 5 Km in order of reaching a temperature of around 200 □ to produce electricity. ‘Moore and Simmons ,2013’. Using supercritical carbon dioxide, S_2CO_2 instead of water in EGS is attractive due to its properties in transfer heat through different layers of rocks, and the predictability of the fracturing it makes. ‘Avanthi Isaka and Ranjith,2020'. Scientists expect geothermal energy could produce 100 GW in this century in the US and EGS has the main reason for that. ‘Tester et al.,2006.’ Northwest Geysers is one of the most important EGS projects in the US and it has two wells with 3,058 m and 3,396 m depth and temperature degree at the bottom around 400 □ ‘Gracia et al.,2016’. Newberry Volcano is another project of EGS in the US with a depth of around 3,500 m and a temperature of 320□ ‘Cladouhos et al ,2018’. According to the BHT well temperature of the American Society of Petroleum Geologists, most thermal wells are available in the central United States, especially in southern Texas, but geothermal data is available Located in the western United States, as shown in Figure 2.4 ‘Blackwell et al,2006’.

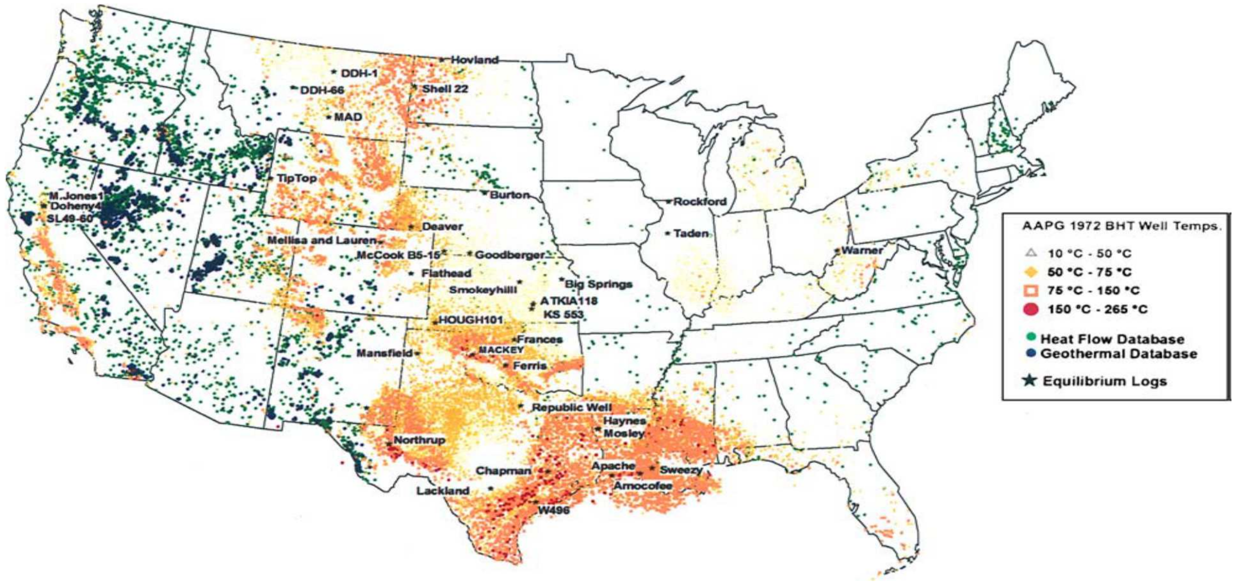
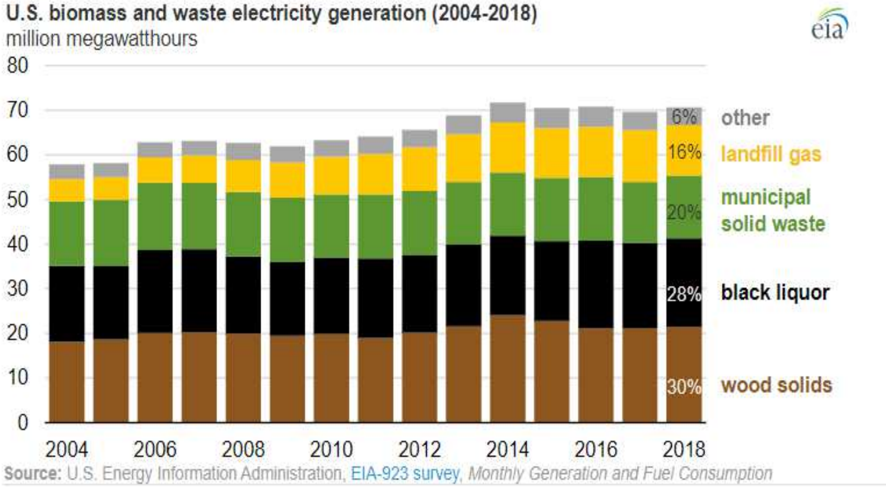


Figure 2. 4: American Association Petroleum Geologists BHT well temperature

2.3. Biomass Energy

Biomass energy is based on the two main technologies of the anaerobic digester and direct combustion to generate electricity. Biomass energy has many resources, such as livestock waste, wastewater, agricultural residues, and solid waste. Biomass energy is a renewable energy source for two main reasons: the ability to replenish itself at a very high compatible rate and also the low percentage of emissions of the energy produced from biomass power plants compared with the fossil fuel power plants. In 2019, biomass power plants generated 589 TWh globally and it is expected to reach up to 1,168 TWh by the end of this decade ‘IEA,2020’. In 2018, the annual electricity generation from biomass power plants in the US was 70.6 TWh, which equals 2% of the total electricity consumption in us. The electricity production comes from different sources such as wood, municipal solid waste, etc with variation in generation as shown in Figure

2.5 ‘Increases in electricity generation from biomass stop after a decade of growth,2019’. By the end of 2019, the US has a 178 biomass power plant with a total capacity of 6,347 MW, and only 2 biomass power plants in total capacity of 164 MW are installed in Texas ‘U.S. Biomass Power Plants,2019’.



Source: U.S. Energy Information Administration, EIA-923 survey, *Monthly Generation and Fuel Consumption*

Figure 2. 5: Biomass power plants production in the US

Based on NERL, in the United States, biomass resources vary from state to state. Some counties have enough resources to produce more than 500 thousand tons in the year while some other counties have resources less than 50 thousand tons per year, the mid-east and far west counties in the US have the most resources of biomass renewable energy however, the east part and the northern part of Texas have an average of 200 thousand tons per year while the majority of the state produces less than 50 tons per year as shown in Figure 2.6. ‘Biomass For Electricity Generation,2016’.

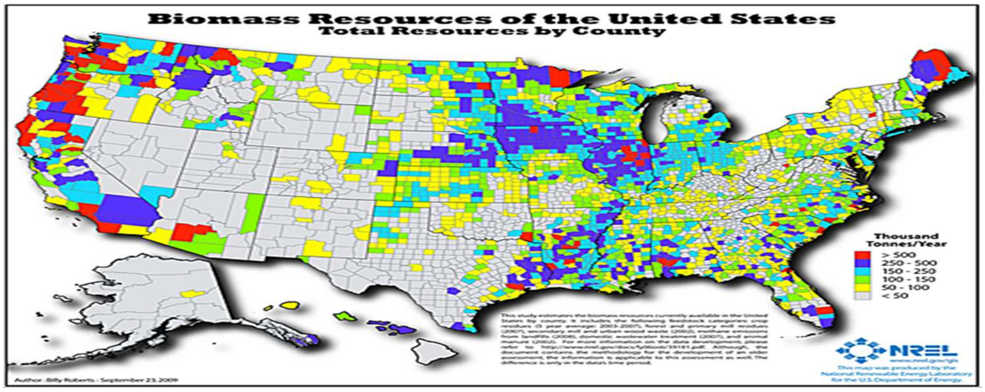
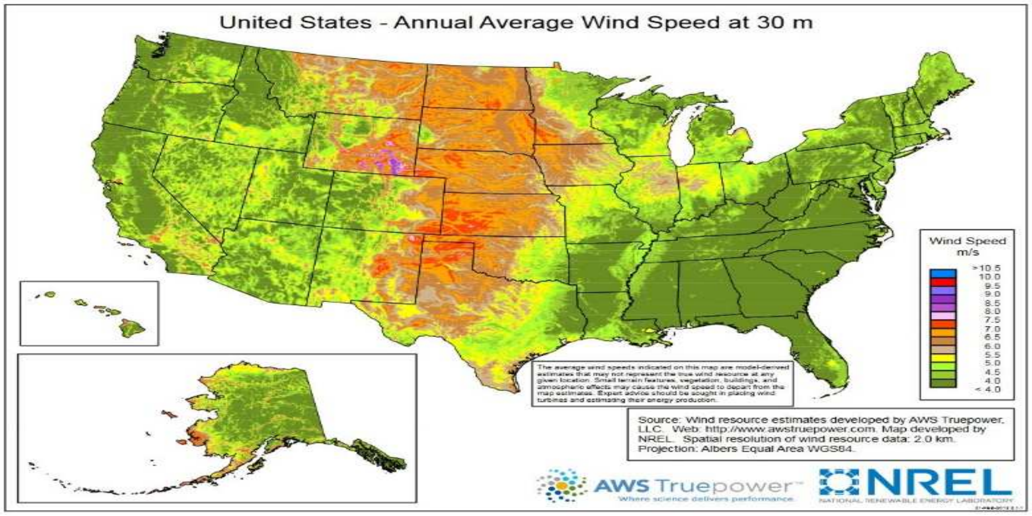


Figure 2. 6: Biomass resources of the US

2.4. Wind Energy

Wind turbine defines as a machine to convert wind energy into electrical power, and it forms the modern way while the windmill converts wind energy into mechanical power, which used to pumping water and grinding grains especially in moderate age till the beginning of the 19th century. ‘Manwell et al,2006’.A wind turbine can be categorized by its rotation axis to horizontal wind turbine axis (HWTA) and vertical wind turbine axis (VWTA). There are many types of VWTA, such as a blade, two-bladed, three-bladed, multiple-bladed... etc, HWTA, can also be used in many designs, such as Darrieus, Savonius, etc. ‘Eldridge, 1978’. Horizontal wind turbines are the most popular wind turbines, especially the three-blade rotor has the highest efficiency among other types of wind turbines ‘Sahim et al, 2018’. Based on the global wind energy council (GWEC), the capacity of wind energy globally is 651 GW at the end of 2019 by increasing by 10% compared to 2018. Although, of the COVID-19 pandemic, a new record is predicted at the end of 2020 with a new installation of 76 GW ‘Global Wind Report 2019,2020’.Based on the American wind energy association (AWES) in the second-quarter report 2020, the USA has 110 GW from the wind turbine, ‘Wind Power America second-quarter report 2020,202’. Based on ‘Wind explained,2021’, wind turbines generated 300 TWh in 2019 by forming 7.3% of the electricity load in the US.

The average wind speed in the US varies from one state to another in an average of less than 4 m/s to more than 10 m/s, the states that lie in the middle of the US have the highest average wind speed including the northern part of that state of Texas as shown in Figure 2.7 ‘NREL-annual average wind speed,2011’. Hence, the implementation of wind turbines in these states has a higher potential.



Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.

Figure 2. 7: Annual Average wind speed in the US

The state of Texas is the leading state in the US for a wind turbine with an installed capacity of around 24.2 GW which almost three times bigger than the second state in the US which is Iowa as shown in Figure 2.8 ‘Texas ranks first in U.S.-installed wind capacity and number of turbines,2019’. As of the end of 2018, Texas had installed 13,180 wind turbines, which is nearly 1.7 times the number of wind turbines installed in California, the second-largest state in the United States as shown in Figure 2.8 ‘Texas ranks first in U.S.-installed wind capacity and number of turbines,2019’.

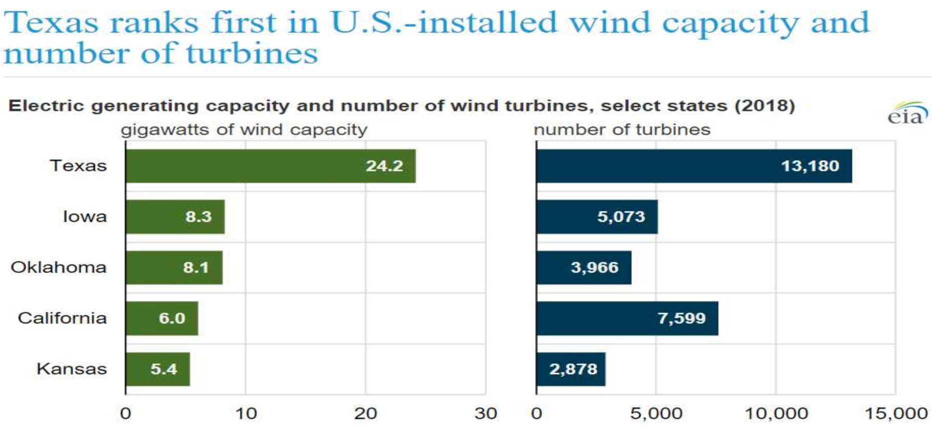


Figure 2. 8: Texas wind turbine capacity compared with the other states in the US

The price of electricity-generation using wind turbines in the ERCOT zone in Texas varies from 5$/MWh to 20 $/MWh and the lowest prices are in the northwest in Texas 'Hui et al, 2012'.

2.5. Solar Energy

Solar energy is energy in the form of heat from the sun. However, in order to convert solar energy into electricity, there are two main technologies that are photovoltaic technology (PV) and concentrated solar energy (CSP). The output power of photovoltaic systems based on the photoelectric effect is in the form of DC and depends on solar irradiance. PV systems depend on global horizontal solar irradiance (GHSI). According to NREL, the GHSI in the United States ranges from less than 4 kWh per m^2 per day in some areas to more than 5.75 kWh per m^2 per day in some areas. As shown in Figure 2.9 'NREL-Global Horizontal solar irradiance,2018', the GHSI is highest in the southern part of the western United States, including western Texas.

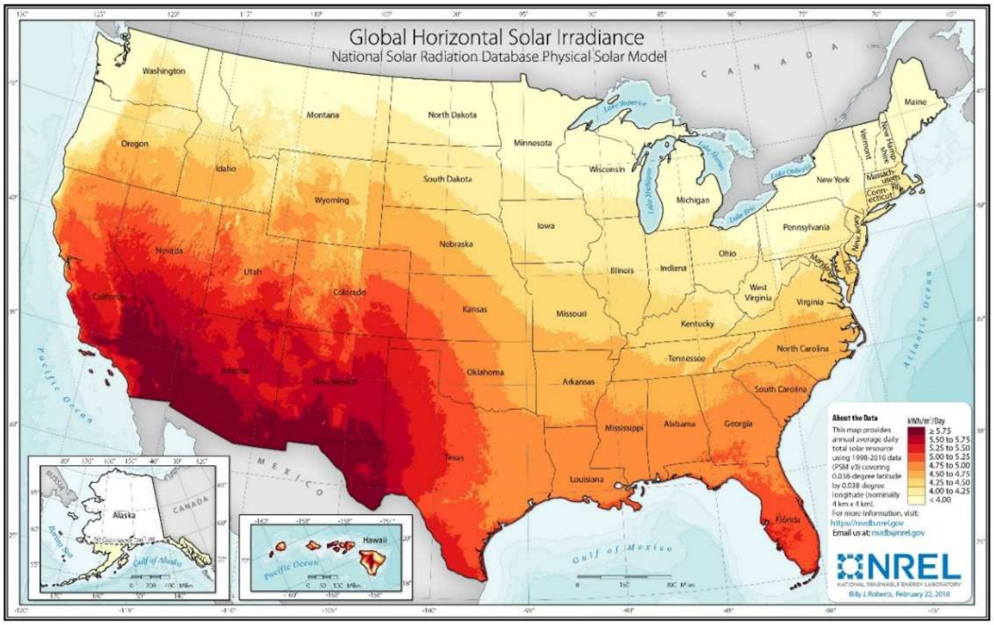


Figure 2. 9: Global Horizontal Solar Irradiance in the US

In 2021, the total PV installed capacity in the US reached 97.7 GW ‘SEIA-US,2021’. In terms of installed capacity, Texas ranks second with 7.7 GW of installed capacity ‘Texas Solar ,2020’.

CSP systems depend on direct solar irradiance (DSI). According to NERL, The difference in DSI between one state and another in the United States ranges from less than 4 kWh per m^2 day in one state to more than 7.5 kWh per m^2 per day in one state. As shown in Figure 2.10 ‘NREL- direct normal solar irradiance,2018’, the highest DSI is located in the southwestern states of the United States, including the far western counties of Texas.

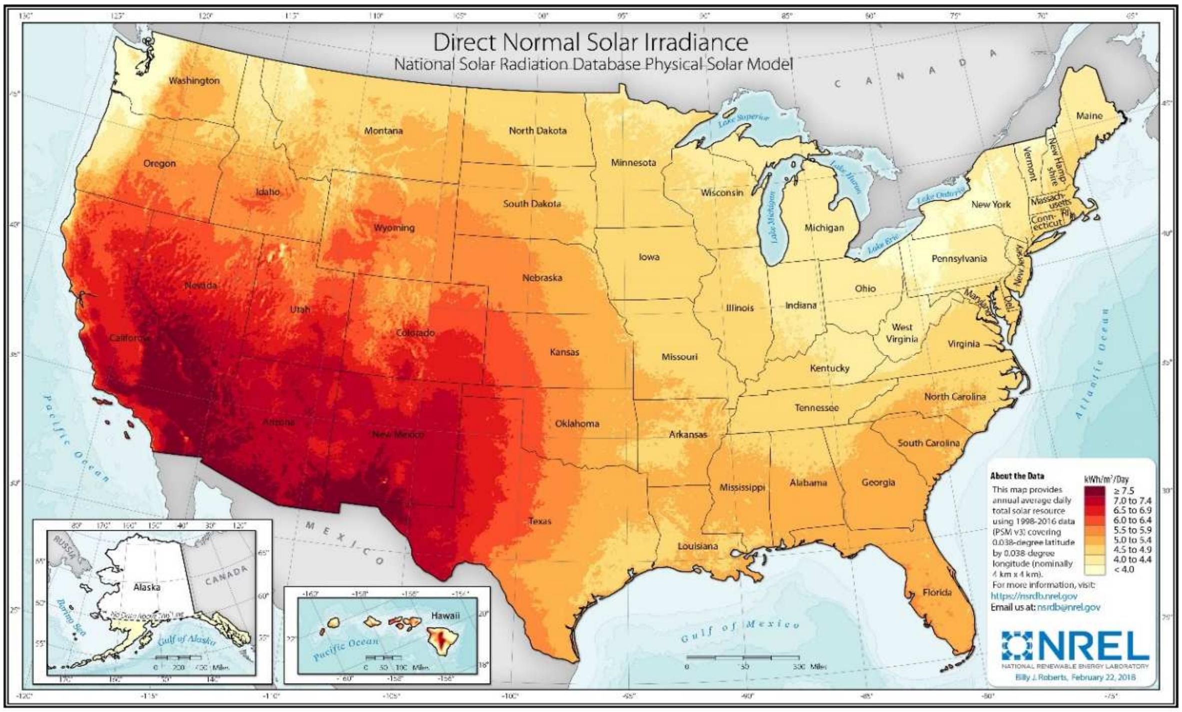


Figure 2. 10: Direct normal solar irradiance in the US

The CSP system has four main technologies: solar thermal tower, parabolic trough, linear Fresnel, and dish tower. The total capacity of the CSP projects in the USA is 1.8 GW 'Concentrating Solar Power, n.d'. However, most of the projects are located in California. Therefore, Texas does not have that many projects of CSP.

2.6. Renewable Power System

There are many studies talking about renewable energy as a source of power generation, some of which come from one energy source, and some from a combination of multiple energy sources, as shown below:

Design small hydroelectric power plants in the agricultural sector to supply electricity to rural and remote areas; In addition to reducing greenhouse gas emissions 'Chacón et al,2021'.

Run of river hydropower technology is an innovative way to install renewable energy power plants to reduce electricity prices and be eco-friendly, and it has more resources available than large dam ‘Basso et al,2020’. Cross-boundary dams represent large hydroelectric power plants due to their large storage capacity and high gate height, so they generate large amounts of electricity ‘Llamosas and Sovacool,2021’. The construction of hydropower plants is complex, so smart design is needed to expand the scope of hydropower use on a domestic scale ‘Yu and Jiang, 2018’. It is possible to add wastewater treatment facilities to small hydroelectric power plants to reduce power by combining waste reduction and water energy, but this type of power plant is smaller in scale ‘Pecha et all, 2014’.

Design a small geothermal power plant based on the organic fluid in the Rankine cycle turbine and by injecting it into the well again, using the same fluid over and over again ‘Gabbrielli,2012’. The organic fluid in the Rankine cycle can work in the temperature range of 80 to 180°C ‘Chagnon-Lessard,2020’. Through the combination of geothermal energy and solar energy for retrofit design to extend the life of geothermal wells, especially during peak periods by using solar power to increase the life of geothermal wells ‘Li et al,2020’. The assessment of geothermal energy varies from country to country. In Germany, according to the new assessment of geothermal resources, 9-16 PWh of electricity can be generated annually ‘Eyerer et al,2020'. The total thermal energy stored in the US in the range of depth between 3-10 km is around 14 $*10^6$ EJ, while the electrical consumption in the US in 2005 is 100 EJ, thus the thermal energy storage in the US is 140,000 times more than electrical consumption in the US, in 2005 ‘Tester et al,2006’.

Biomass power plants, especially small-scale biomass power plants with a scale of no more than 100 kW, are a high-efficiency power generation method based on gasifier technology, with an efficiency of up to 30% ‘Perna et al,2015’.140,000 tons of solid waste produce 62 GWh of electricity yearly and in addition to reducing 40,500 tons of co2 annually ‘Mallaki and Fatehi, 2014’.Biomass power plants based on surplus food may be a good idea, especially in rural and remote areas, so it can reduce carbon emissions by 2% compared to other types of power plants ‘Kabir et al, 2017’.Combining the microalgal and coal firing in a biomass power plant could reduce the emissions of co_2 by 10 %, however, the electricity price could increase due to this combination by 5% ‘Lee and Lee,2019’. Biomass power plants have the advantages of the low cost and low carbon emissions compared with other power plants, thus improving the drying process would help to increase the overall efficiency of the biomass power plant by 10 % compared with non-dried biomass fuel power plants ‘Gebreegziabher et al,2014’.

A vertical axis wind turbine (VAWT) is a good way to produce electricity especially for the small scale in the remote area, VAWT has a hybrid design from the Savonius, which has self-starting, and the Darrieus model which has higher efficiency 'Chandrashekhar et al, 2019'. Wind turbines should be compatible with grid requirements that will affect the load of wind turbines and therefore have a significant impact on the challenges faced by wind turbines ‘Hansen et al,2009’. Innovation design of wind turbines and battery storage to control the variation in the power, which happens due to wind speed fluctuations, this design helps to reduce the surplus generation from wind turbine especially at night when electricity demand is low ‘Such and Hill,2012’. There are a lot of studies for planning wind farms are determined the power output of the wind farms based on the wind speed, mean, and wind speed distribution, hence, the simple payback time could determine based on those studies ‘Yi Zhang, & Ula,2007’. There are a lot of challenges due to the connection between large scale wind turbines with the electrical grid such as the active power, frequency control, reactive power, and voltage level, however, there are some solutions to avoid all of that problem like accurate forecasting of the power generation from wind turbines and smart storage system of the turbines ‘Yao and Yao,2010’.

Photovoltaic systems are used a lot in the last two decades on large or small scales, designing an electrical system from PV and energy storage connected to the grid to reduce the dependence on the normal grid for buildings ‘Harzli et al,2016’. Renewable energy systems are used for small grids in a rural area and also it is very popular in the absence of the grid where it is called grid off system, a smart combination of PV and systems with distributed energy resources consist a smart system for charging electric vehicles, which forms a great application for an Eco-friendly system 'Nizam and Wicaksono,2018'. PV systems inject in the low voltage part of the distribution grid to feed residential loads such as charging electric vehicles and air heat pump where they consider as fluctuations load as well as the generation from the PV ' Al Essa and Cipcigan,2016'.PV plants are the best solution for remote land without any access to electricity, and it forms the main block to design a mini-grid, solar power pump systems are great applications of the integration between resource water and solar and it is very useful for water well, farmlands, rural and island areas ' Puati Zau and Chowdhury,2018'.Mini-grids are the option for rural loads, remote lands, islands, places with harsh environmental conditions. Solar farms with storage systems are an economical option and it is almost available everywhere ‘Khan et al,2009’.

CSP is an attractive system, especially after the new technology of thermal storage and the new technology of CSP, therefore, all prices of kWh produced from CSP can reach $0.09 ‘Abaza et al,2020’. The parabolic trough CSP system is very popular and commercialized, and the 50 MW CSP system based on the parabolic trough can generate electricity at the price of 90.4 $/MWh ‘Boukelia et al,2014’. In addition to being used for electricity, CSP systems can also be used for heating and cooling applications. However, compared with PV systems with very large storage capacity, its economic impact is small ‘Zhou et al,2019’. CSP plants based on parabolic trough power output may be different in one region from another, so the efficiency and conversion factor will be different, such as in the Middle East The efficiency of 100 MW CSP is as high as 14.35%, and the net conversion rate is 81.1% 'Praveen et al,2018'.The solar power tower is one of the best technologies of CSP plants, 1 MW of solar tower plant could reach up to 80 % efficiency at the design point and optical efficiency of 71.36% 'Zhang et al., 2021'.

2.7. Combination Renewable Power Systems

There are a lot of systems that combine among many forms of renewable energy in one power system, however, most of them are from wind and solar energy, moreover, it is usually in small scales as shown as the following:

A smart generation system consists of PV solar and wind systems on a large scale project to achieve the load demand in a long term plan to replace the conventional power plants with renewable energy systems and use the higher solar radiation, which available there ‘Aljahdali and Abbod,2018’. Combination of renewable resources such as wind Turbine and PV and conventional ones like Diesel and besides the storage system has a great effect to reduce the disadvantages of renewable resources due to the electric grid performance and stability as well as reduce the higher costs of the fossil fuel ‘Pan et al,2009’.A hybrid renewable energy system (HRES) is an ideal model for remote or rural areas and it forms a mini-grid system that offers an economical solution for electricity generation from the environment besides fossil sources for emergency cases and storage systems to help the grid in the absence of sun or required wind speed ‘Nagaraj,2012’.HRES is the first step for moving toward 100 % electricity from renewable energy resources, systems depend on renewable resources such as wind and PV as the main source and diesel generator, battery bank, and energy from the grid as a backup system are more realistic and economically as well ‘Foroutan and Gazafrudi,2019’.Converting a large electric grid depends mainly on fossil power plants into renewable energy by integrating specific sizes for wind and PV farms and study the forecasting in demands besides the renewable resources such as the solar irradiation and wind speed, based on decentralized basic by dividing the whole grid to several small zones to achieve the microgrid concept ‘Awaja et al,2014’. The mini-grid concept is the first block on turning toward 100% electricity generation from clear resources, the mini-grid system consists of PV and wind farms besides battery storage bank to feed electric vehicles charging station ‘Verma et al ,2019’.Although all the environments attached to Fossil fuels such as global warming and greenhouse gases, dispensing fossil fuel as an important electric source for generation is away from reality. Integration between renewable resources and oil wells by enhancing oil recovery from HRES by impelling heat shows one of the smart applications for renewable resources ‘Ermar et al,2019’. CSP power plants and wind farm plants could complete each other based on their drawbacks, using a wind turbine to produce electricity and feed the load, however, CSP compensates for the lack of generation in the absence of the wind ‘Aliyu and Agee,2016’.

2.8. Optimization Renewable Power Systems

However, to make the power system more ideal, it should be a way to determine the best design or size of each system. There are many studies discussing how to design a combination of renewable energy systems by applying optimization techniques as shown below:

Designing a HRES from a combination of biomass, PV solar, and energy storage, to determine the optimal size of the system, the optimization technique has been applied using HOMER software ‘Muhamad et al,2014’. One of the famous optimization techniques is Linear programming is used to design the optimal size of a HRES consists of PV and Wind for charging and discharging electric vehicles for residential consumers ‘Melhem et al,2016’. Design the proper size for HRES is very critical and to optimize it, a global optimization technique has been applied such as Particle Swarm ‘Bharti et al ,2019’. Optimal designs for renewable energy resources due to specific constraints such as electricity demand and area obstacles, to decrease the electricity bills. Software like HOMER is used to achieve that for the HRES ‘Moazzami et al,2017’.Design an optimal HRES system consisting of wind, solar and energy storage to use HOMER software to generate electricity to meet demand, especially in remote and rural areas ‘Helal et al,2012’.Designing optimal HRES using real-time pricing and loss of energy concepts in order to determine the size of the wind, solar, and battery components ‘Tobaru et al,2016’.Hydropower can be used as an energy storage system with solar and wind energy to maintain the balance between load and power generation ‘Ekoh et al,2016’.Renewable energy systems are composed of PV, wind, and hydropower to maintain the balance between power generation and load. In addition, linear programming is used to achieve the best design of these components ‘Kusakana et al,2012’.HOMER software is used to select the best design for photovoltaic, wind energy and battery pack systems, and even more for more components, such as diesel generators ‘Lamnadi et al, 2016’.HRES can be connected to the grid through PV and Wind to avoid the use of storage systems ‘Nacer et al,2015’.HRES can be connected to the Texas grid to reduce annual electricity bills, and linear programming techniques are also used to select the best design ‘Abuelrub and Singh,2017’.Taking into account future changes in electricity prices, use LINGO software to design the best design and storage system of HRES for wind farms and solar power plants ‘Wang et al,2021’.The complex HRES consists of PV, CSP, batteries and hydropower and is connected to the grid to reduce the sense of disqualification in fossil fuels by choosing the best design for each system ‘Wang et al,2021’.Complex renewable energy systems (including combustion and digestion technologies based on PV, wind, and biomass) can reduce more than 2,000 tons of carbon dioxide emissions per day ‘Li et al,2019’. HRES is composed of biomass, photovoltaics, and wind energy, In addition to The storage is designed using HOMER software to select the best design to make it a new system rather than a traditional power system based on fossil fuels ‘Krishnamoorthy et al,2020’.By using genetic algorithm optimization technology, more technologies can be used to determine the optimal size of HRES from wind, photovoltaic, and batteries ‘Fulzele,2018’.By using particle swarm optimization technology, in addition to diesel generator sets, HRES systems for photovoltaic, wind energy, and battery packs can also be selected as the best design, thereby reducing electricity prices ‘Abdelshafy et al,2018’.Based on the guaranteed convergence particle swarm optimization with Gaussian mutation, another technology that selects the optimal design of HRES includes photovoltaics, wind energy, battery packs and diesel generators ‘Abedini et al,2016’.

2.9. 100% Renewable Power System

There are a lot of studies for designing electrical grid to reach 100% renewable energy electricity as the following: Biomass and CSP are renewable resources that could form a large-scale electric grid up to 110 GW to form a 100% low carbon power system and Costs ranges from 6-8 $/MWh ‘Li et al,2020’. Reaching to 100% renewable energy electrical grid from the traditional fossil fuel-based on the wind, water, solar, and storage systems, moreover, that is applied for everywhere and for heat application ‘Jacobson,2020’.100% renewable energy electrical grid have been achieved from an electric grid system, consists of hydro, wind and solar. Electrical generation from 100% renewable resources happened in Portugal for 107 hours in 2016 and 67 hours in 2018 without any electricity generation from fossil fuel ‘Yang et al,2019'. Iceland could reach up to 100% of electricity from geothermal energy, moreover, Norway, Costa Rica, Brazil, and Canada reach up to 97%,93%,,76%, and 62% respectively of electricity from water energy ‘Kroposki et al,2017’. The renewable electrical grid in Germany from PV, Wind, and storage to reach 56 % of the total electricity from renewable energy, however, it is not economical efficient ‘Weinand et al,2020’. Reaching 100% renewable energy electricity for a smart grid or small load is very reachable, and it could achieve based on the HRES of wind and solar in addition to storage ‘Rousan et al,2018’. Sweden tends to reach 100% renewable energy electricity from wind and hydropower in 2040 ‘Zhong et al,2021’. Ireland plans to reach 100 % electricity from renewable energy from biomass, wind, and hydropower in 2050 ‘Yue et al,2020’.100 % renewable energy electricity could reach based on CSP and wind turbine system, using linear programming to achieve the optimal design of the system ‘Wang et al ,2021’.

As shown in previous studies, achieving 100% renewable energy power generation systems and optimization systems are always separate. However, in this work, the optimization technique and 100 % renewable energy concepts are combined together in order to reach 100 % renewable energy with very low carbon energy and very effective economical price of electricity to reduce the overall electricity bill in the state of Texas. The optimization technique is used in this work is Linear programming by MATLAB software. Moreover, all optimization studies are for small-scale, or usually support for the main system and it connected with the traditional power system as well as the renewable energy system, In contradicting that, this work uses renewable energy resources as the main source and the optimization technique for large scale more than 100 GW and even for small scales less than 1 Gw. This work shows the ability to reach a 100 % renewable power system from small cities and large countries as well in order to achieve the smart power system concept starting from rearranging the power generation sources among the grid and not restricted in few places and depend on renewable energy resources. Finally, all previous studies were focused on solar, water, and wind energy, and in very few of them in biomass energy, while this work focuses on 6 types of renewable energy: solar based on PV, Solar based on CSP, Wind energy, Biomass energy, Geothermal energy, hydropower plants in one system. The design size of the previous system depends on the regional cost and available resources of all of that renewable energy in the state of Texas when the study for all Texas and inside each county when the study talks about the small scale inside counties by taking two tracks to achieve the microgrid concept and the smart power system at the same time in order to increase the reliability and security of the 100 % power renewable power system.

CHAPTER III

HYDROELECTRIC ENERGY

3.1 Hydroelectric Energy

Hydroelectric energy is a form of kinetic and potential energy based on the elevation of water. The fallen water from high altitudes has potential energy due to its height. The potential energy converts into kinetic energy based on the water flow rate from the high elevation of the head to the hydroelectric turbine. The kinetic energy is used to turn the turbine, which is connected with an electric generator. The electric generator converts the mechanical energy from the turbine into electricity. The amount of electricity generation from hydropower plants is determined by the water flow rate and the height of the head.

The major components of hydroelectric power plants are the same for all hydropower plant types. Intake is the gate of the water inflow into the turbine, hence, it determines the height of the head. The next important part is the Penstock, which is responsible for the acceleration of the water flow. The hydroelectric turbine technology changes based on the type of power plant but in general, it turns the generator by the kinetic energy of the water. The electric generator is the same part in all hydropower plant types. All previous components are shown in Figure 3.1 ‘Hydroelectric Power, n.d’ which represents the simple scheme for any hydropower plants.

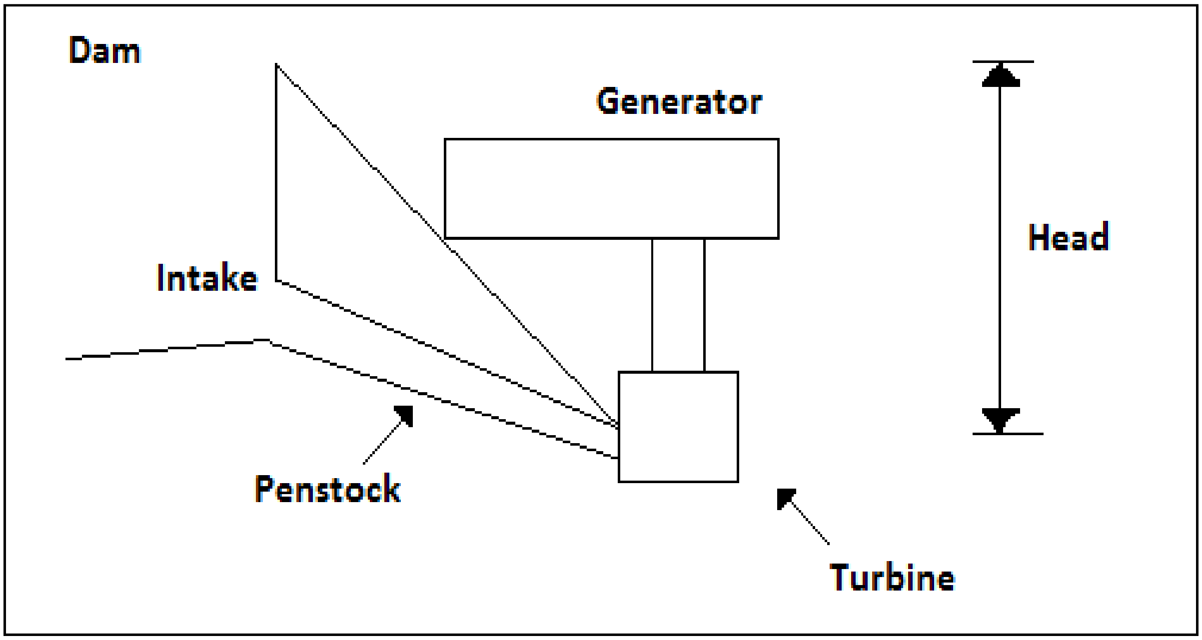


Figure 3. 1: Hydropower plants components

Hydroelectric power plants are the most used power plants among renewable energy power plants in the world. Hydroelectric power plants are the most efficient plants among the renewable energy plants with efficiency up to 90%‘ Letcher,2018'. Contrasted with traditional power plants, hydroelectric power plants are cost-effective and competitive in generating electricity varies from 0.02-0.05 $ per kWh ‘Letcher,2018’.

3.2 Hydroelectric Power Plants Types

Hydroelectric power plants can be classified into many categories based on many things such as the power plant technology, the size of hydropower plants, the height of the head, and the water flow rate.

3.2.1 Storage Hydropower Plants

This type of hydropower plant depends on the water reservoir and it is called impounded water hydropower plants ‘IPPC,2012’. This type of power plant requires a huge reservoir, so it is the largest hydroelectric power plant, a traditional type of power plant. The water storage allows this type of plant to be completely dispatchable and completely controllable since the water flow is predictable based on the water storage ‘IPPC,2012’. The components of the hydropower dam are shown in Figure 3.2 ‘How Hydroelectric Power Works ,n.d’. They are as follows:

1- Reservoir

Dams usually represent the reservoir in the traditional hydropower plants, however, could be any other water storage.

2- Intake

It is the gate connected between the reservoir and the turbine.

3-Penstock

Tubes transmit the water from the intake to the turbine

4-Turbine

It is the main component at any hydropower plant, it is responsible for converting the kinetic energy into mechanical energy.

5-Generator

The electric generator is responsible for converting mechanical energy produced from the turbine into electricity.

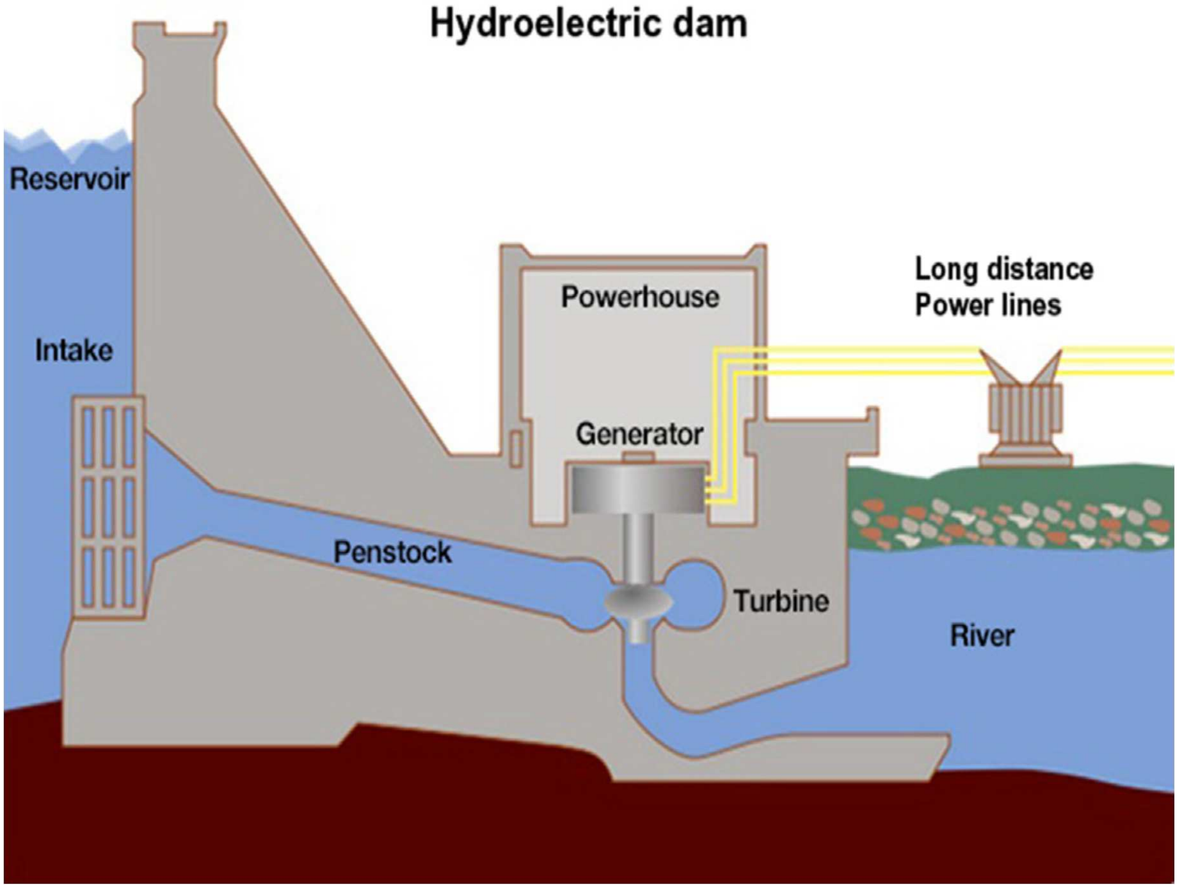


Figure 3. 2: Storage hydropower plants components

3.2.2 Run Of River

This type of hydropower plant does not have water storage, or it has a small water reservoir. This type depends on the flow of water, so it is usually placed on a river, stream or waterfall, so the water flow will fluctuate and it is uncontrollable, thus generation varies based on the season winter or summer, and also it varies from day to day due to the rainfall and the wind speed which could control the flow rate of the water 'Letcher,2018'. Due to insufficient power generation continuity, this type of power plant is used to power peak and medium loads. Compared with dam hydroelectric power plants, this type of power plant is usually classified as a small power plant.

Run of river hydropower plants share the same components with the storage hydropower plants such as turbine, generator and the Penstock, Run of river hydropower plant does not have head and Instead, a canal was placed by the river and the excess water was removed after the turbine passed It is discharged into the river again, as shown in Figure 3.3 ‘Hydropower Overview, n.d’.

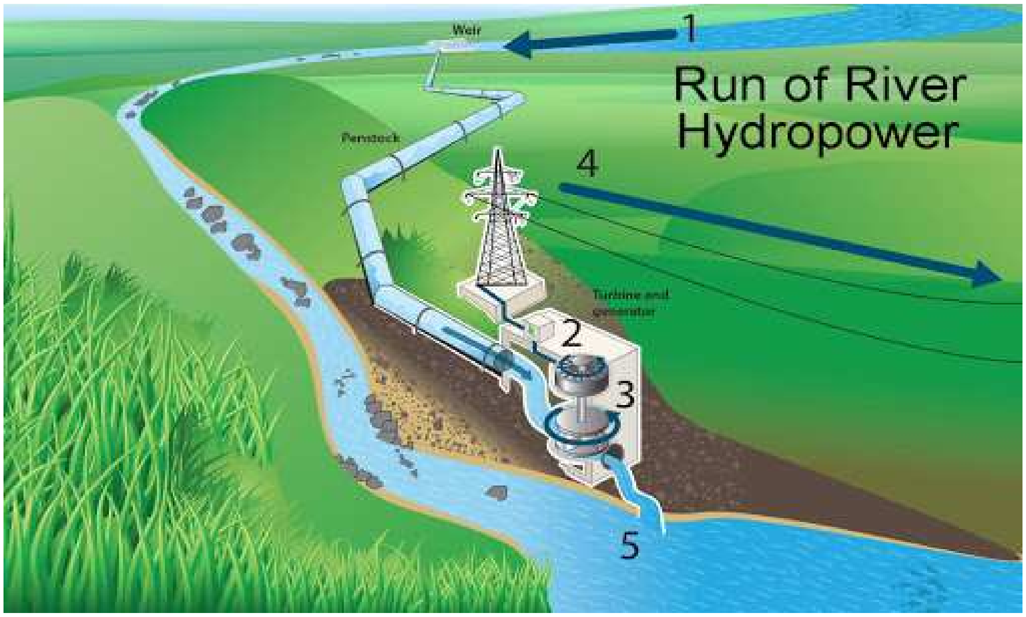


Figure 3. 3: Run of river hydropower plant

[1:river water,2: turbine,3:electric generator,4:electrical transmission.5:discharge channel]

3.2.3 Pumped Storage Hydropower Plant

In this type, water is pumped from lower storage into upper storage using an electric pump to fill the tank then discharge it through a turbine to generate electricity ‘Letcher,2018’.The idea of these hydropower plants is to fill the storage with water when there is an excess of electric generation then discharging it through the hydropower turbine to produce electricity when the load at the peak or there is a lack of generation. The round trip efficiency of this process of pumping the water and discharge it to turn the turbine varies between 75-85% ‘Letcher,2018’.

Pumped storage hydroelectric power plants are built next to major power plants such as fossil and nuclear power plants ‘Letcher,2018’. As auxiliary energy, their working principle is exactly the same as that of a traditional energy storage system (battery system). Because of that, the size of pumped storage hydropower plants is classified as small power plants. Owing to the features of this type of power plants, it is cost-effective if it is used with wind and solar energy as a storage system to exploit the extra generation at the noontime on the solar system and when there is the higher wind speed at night and increase the efficiency of those systems ‘Letcher,2018’.

Pumped storage hydropower plant has two types as shown in Figure 3.4, the closed-loop which is based on two separate reservoirs and they are not connected to the natural water body while the other type is the open-loop, which has one water reservoir and is connected to the natural water body ‘Pumped-Storage Hydropower, n.d’ The operation run of the river and the pumped-storage power station are combined to use the energy stored in the reservoir to compensate for the fluctuation of the river's water flow. Therefore, this not only improves the efficiency of the power plant, it also makes it dispatchable and can be used to provide base load at peak loads.

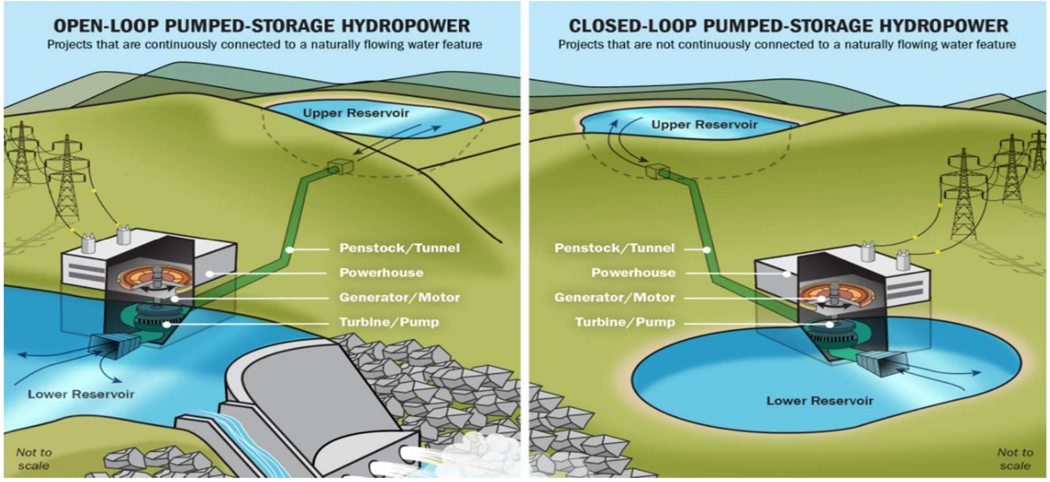


Figure 3. 4: Pumped storage hydropower

3.2.4 In-Stream (Hydro-kinetic) Hydropower

In contrast to All the previous types, which depend on the potential energy based on the difference in the elevation from the lowest point and the highest point in the Penstock, the hydro-kinetic hydropower plants depend on the kinetic energy by placing their devices directly in the stream of the flowing water ‘Letcher,2018’. Hydroelectric power plants could be classified by their capacities into small, mini, and micro, it is usually defined as plants less than 10 MW,2 MW, and 100 kW ‘Yuksel et al,2018’ and the large hydropower plants are considered larger than 100 MW ‘Letcher,2018’. Table 3.1 shows a comparison of all previous hydroelectric power plants based on scale and technology.

Types of Hydropower plants	Category of the size	Extracted energy	Water storage
Storage Hydropower plant	Larger	Potential energy	Needs a huge water body such as dams
Run of river	Small	Potential energy	No need for water storage or small water reservoir
Pumped storage	Mini or micro	Potential energy	Small water reservoir
In-stream Hydro-kinetic	Mini or micro	Kinetic energy	No need for a water reservoir

Table 3. 1: Comparison between different types of hydropower plants

3.3 Hydroelectric Power Plants Turbine Types

Water turbines are also called hydraulic turbines, which convert the potential and kinetic energy of water into mechanical energy ‘Water turbine, n.d’. There are two main types of turbines used in hydroelectric power plants, namely impulse turbines and reaction turbines.

3.3.1 Impulse Turbine

In a Impulse turbine, the speed of the water flow moves the flow path, and the water flow hits each blade once, as shown in Figure 3.5 ‘Hydroelectric Power, n.d’. The impulse turbine is usually used for high head and low water flow ‘Types of Hydropower Turbines, n.d’ are two main types of pulse turbines, they are Pelton wheel and cross flow.

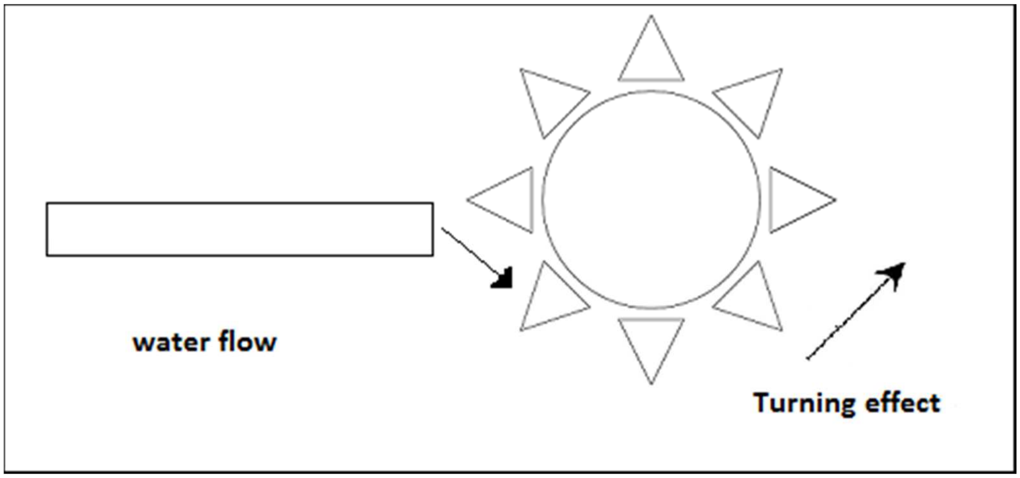


Figure 3. 5: Work principle of impulse turbine

3.3.2 Reaction Turbine

In the reaction turbine, on the contract of impulse turbine, the water flow hits all parts of turbine at once, the power is generated by the combination of pressure and water flow ‘Types of Hydropower Turbines, n.d’. As shown in Figure 3.6 ‘Hydroelectric Power, n.d’, the reaction turbine is placed directly on the water flow because the turbine is designated for high water flow and low head. There are three main types of reactive turbines, which are propeller, Francis, and free-fall turbines.

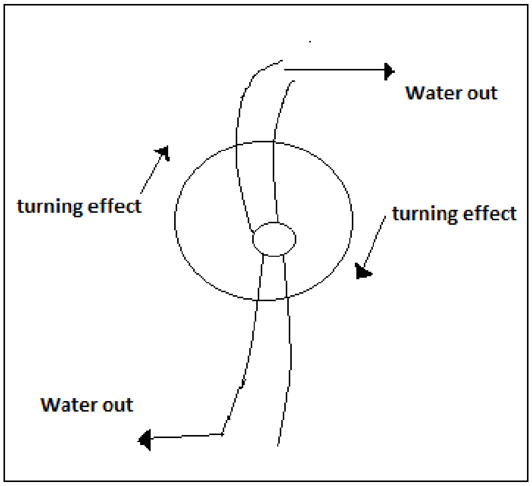


Figure 3. 6: Work principle of reaction turbine

There are a lot of factors that are determined for chosen turbines should be used such as water flow, head height, cost, depth, and efficiency. Figure 3.7 ‘Hydropower production, n.d’ shows the different types of turbines and the optimal operating range determined based on the water flow, head height, and hydropower plant size.

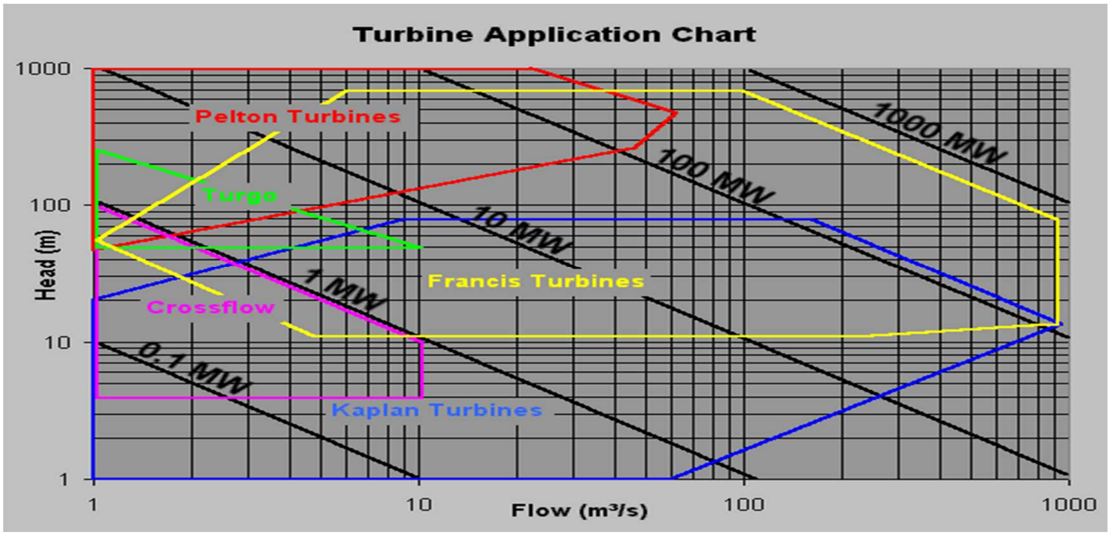


Figure 3. 7: Turbine Applications

3.4 Hydropower Generation Theory

Hydroelectric power generation is determined based on many factors such as water flow, the head height, and turbine efficiency as shown in Equation 3.1.The power generation based on the potential energy and kinetic energy representing in Equation 3.1 ‘Yuksel et al,2018’ by the head height factor and the water flow factor respectively.

$P = H * Q * g * \rho * \eta$ …….3.1

Where:

P: hydroelectric power generation in kW.

H: the height of the head in m.

Q: water flow in m^3/s

g: Gravitational acceleration constant ≈9.81 m^2/s

η: efficiency of the hydroelectric turbine.

According to ‘Engineering ToolBox,203’, Water density varies based on the temperature of the water and it is from 1000 kg/m^3 at 0℃ to 958.35 kg/m^3 at 100℃ .

H could be calculated from the pressure as shown in Equation 3.2 ‘Zainuddin et al, 2009’

$H = 0.74 * pressure$…………3.2

The water flow is determined by the velocity of water and the area as shown in Equation 3.3

$Q = V * A$…….3.3

V: velocity of water in m/s

A: area of the water in m^2

Energy generation from hydroelectric power depends on the life span of the power plants and the power generation as shown in Equation 3.4.

$E = P * life - span$……3.4

Where

E=:Energy generation from hydropower electric plant in Wh

Life-span: the time in hours

3.5 Methodology

In this work, a proposed system is designed based on the available hydroelectric energy in Texas. Hydroelectric power plants have four main forms; storage, run of river, pumped storage, and hydro-kinetic hydropower plants. The pumped storage hydropower plants are the best option as a backup power plant, so they are secondary power plants and always attached to other power plants. Because of all of that this type of hydropower plant is not considered in this work. The hydro-kinetic power plant is a micro power plant, while this work focuses on the large systems, thus it is not considered in this work as well. In this proposed system, two approaches are designed based on the impoundment water reservoirs and water rivers in Texas.

In this work, the first method is called Scenario #1, which is based on the technology of storage hydropower stations. Scenario # 1 depends on the height of the water level in the main reservoirs and dams in Texas, which depends on the storage technology, which depends on the height of the water level and the low water flow. Scenario # 2 is based on the operation Run of river technology, which is designed for high water flows and is suitable for major rivers in

Texas. In both cases, Equations 3.1 and 3.4 are applied based on data from the Texas Water Resources Development Commission. The flowchart of the design of both scenarios is shown in Figure 3.8.

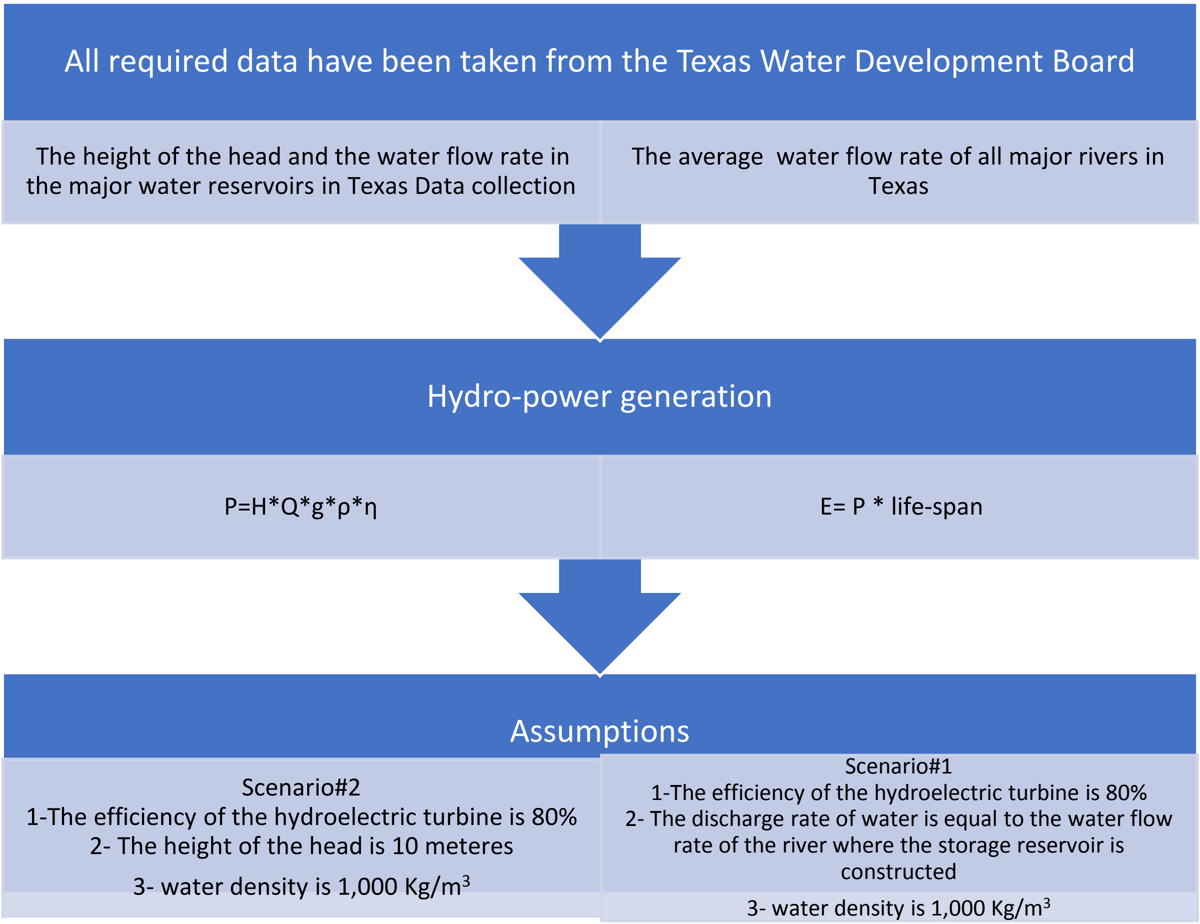
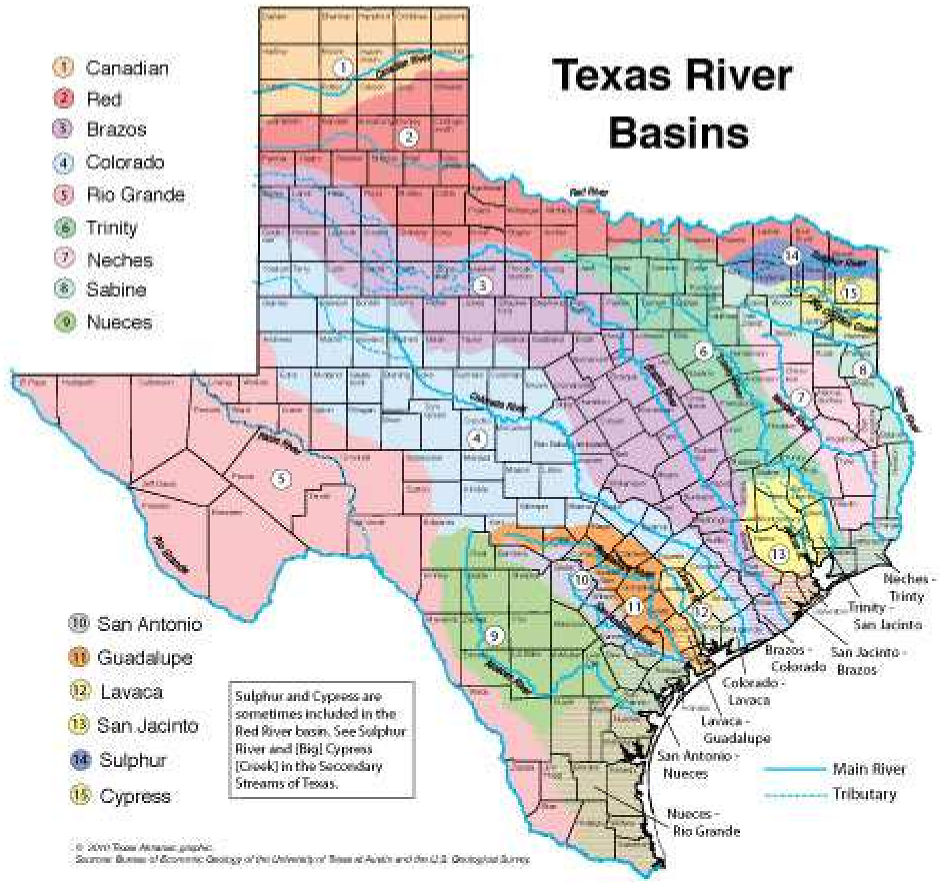


Figure 3. 8: Flow chart of the hydropower plants designs

3.6 Water Resources In Texas

The annual average precipitation in Texas is estimated at 733.298 mm, it varies among Texas's counties from 1538.478 mm in some counties like Jasper and Liberty to 245 mm in counties like El Paso and Loving. 'Texascounties-precipitation, 2020'. Texas has 15 major river basins and 8 coastal basins as shown in Figure 3.9 'SECONDARY STREAMS OF TEXAS,2018'.



© 2011 Texas Almanac graphic.
Sources: Bureau of Economic Geology of the University of Texas at Austin and the U.S. Geological Survey.

Figure 3. 9: Texas’s rivers

Based on the Texas water department's board, Texas has 122 water reservoirs among all counties in Texas as shown in Figure 3.10 ‘Burns,2013’. The total conservation capacity of all reservoirs is 31,316,346 acre-feet ‘Texas Reservoirs,2021’and they are distributed based on the major river basins.

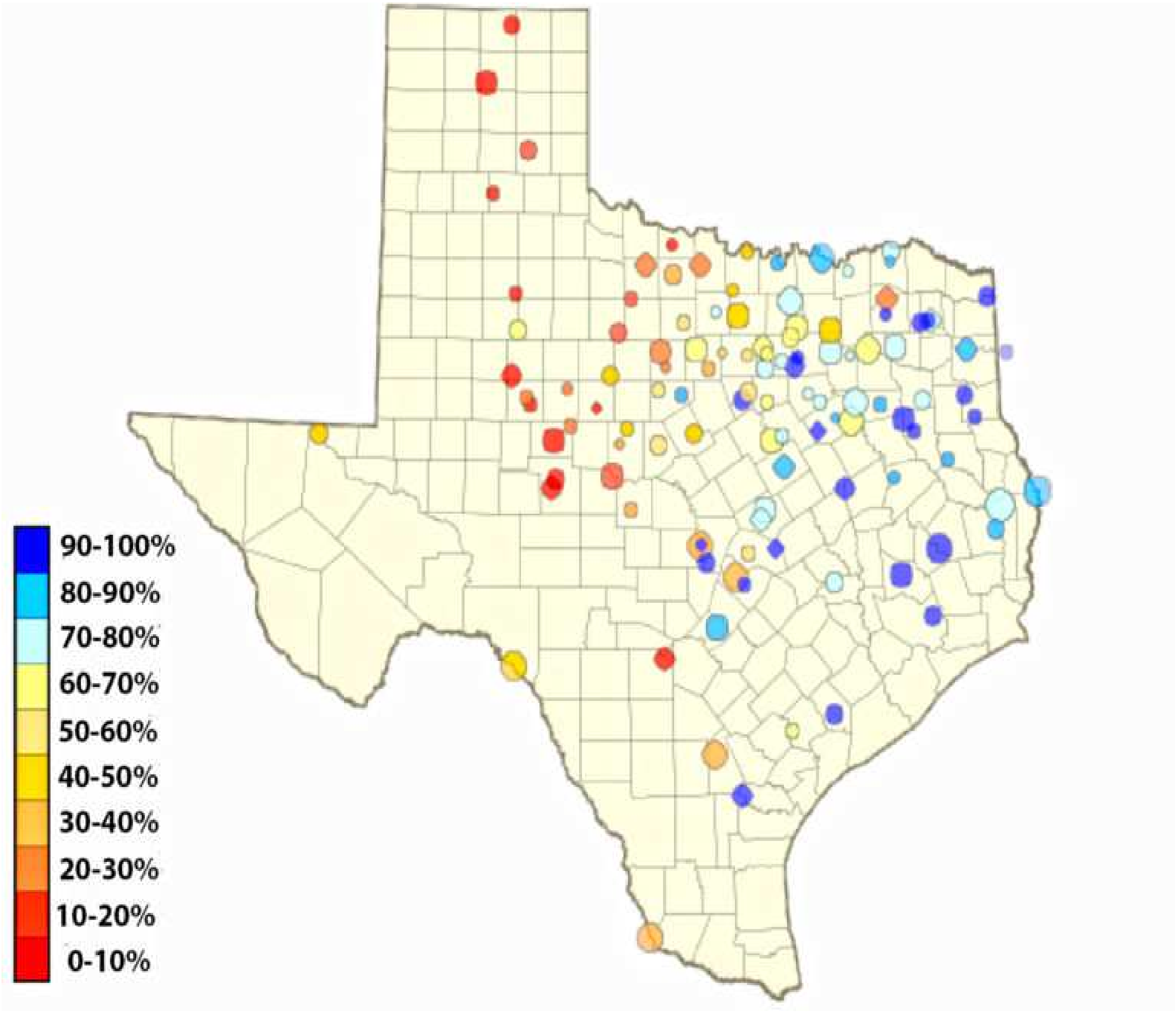


Figure 3. 10: Texas's reservoirs

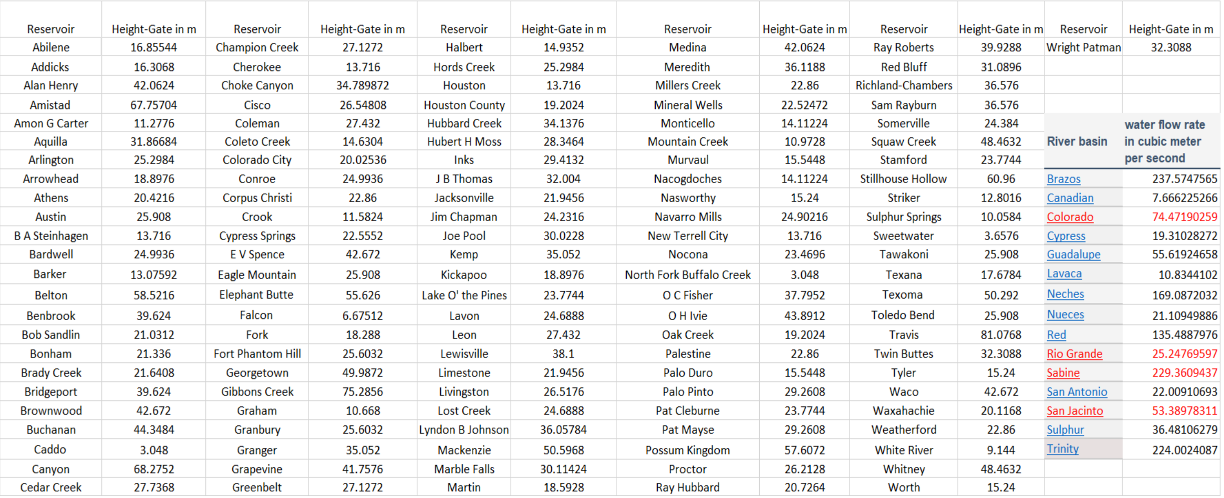
3.7 Prospected Electrical System From Hydroelectric Energy

In this proposed system, there are two scenarios; The first approach is based on the height of the head of water reservoirs and the second approach is about the water flow rate.

3.7.1 Storage: Scenario#1

Storage hydroelectric power plants are traditional power plants based on hydroelectric power generation. It is usually related to reservoirs and dams. The storage hydropower plant depends on the height of the head; the difference between the top point and the lowest point in the reservoir. In addition, the power generation of hydroelectric power plants depends on the flow of water.

The height of the gate in Texas's dams varies from 3 m in the small water reservoirs such as Caddo and Sweetwater up to 81 m in Travis dam. All the water reservoirs are constructed on lakes and rivers, so the flow rate of water in those water reservoirs depends on the flow rate of the river basin connected to them as well as the discharge rate of water into the customers. The water flow in the river is higher than the discharge flow, so the change in power generation due to the fluctuation of the water flow is negligible. The height and flow rate of the water storage tank are shown in Figure 3.11 'Texas Reservoirs,2021', 'Completed Surveys & Data, n.d' & 'River Basins n.d'.



Reservoir	Height-Gate in m	Reservoir	Height-Gate in m	Reservoir	Height-Gate in m	Reservoir	Height-Gate in m	Reservoir	Height-Gate in m	Reservoir	Height-Gate in m
Abilene	16.85544	Champion Creek	27.1272	Halbert	14.9352	Medina	42.0624	Ray Roberts	39.9288	Wright Patman	32.3088
Addicks	16.3068	Cherokee	13.716	Hords Creek	25.2984	Meredith	36.1188	Red Bluff	31.0896		
Alan Henry	42.0624	Choke Canyon	34.789872	Houston	13.716	Millers Creek	22.86	Richland-Chambers	36.576		
Amistad	67.75704	Cisco	26.54808	Houston County	19.2024	Mineral Wells	22.52472	Sam Rayburn	36.576		
Amon G Carter	11.2776	Coleman	27.432	Hubbard Creek	34.1376	Monticello	14.11224	Somerville	24.384	**River basin**	**water flow rate in cubic meter per second**
Aquilla	31.86684	Coleto Creek	14.6304	Hubert H Moss	28.3464	Mountain Creek	10.9728	Squaw Creek	48.4632		
Arlington	25.2984	Colorado City	20.02536	Inks	29.4132	Murvaul	15.5448	Stamford	23.7744		
Arrowhead	18.8976	Conroe	24.9936	J B Thomas	32.004	Nacogdoches	14.11224	Stillhouse Hollow	60.96	Brazos	237.5747565
Athens	20.4216	Corpus Christi	22.86	Jacksonville	21.9456	Nasworthy	15.24	Striker	12.8016	Canadian	7.666225266
Austin	25.908	Crook	11.5824	Jim Chapman	24.2316	Navarro Mills	24.90216	Sulphur Springs	10.0584	Colorado	74.47190259
B A Steinhagen	13.716	Cypress Springs	22.5552	Joe Pool	30.0228	New Terrell City	13.716	Sweetwater	3.6576	Cypress	19.31028272
Bardwell	24.9936	E V Spence	42.672	Kemp	35.052	Nocona	23.4696	Tawakoni	25.908	Guadalupe	55.61924658
Barker	13.07592	Eagle Mountain	25.908	Kickapoo	18.8976	North Fork Buffalo Creek	3.048	Texana	17.6784	Lavaca	10.8344102
Belton	58.5216	Elephant Butte	55.626	Lake O' the Pines	23.7744	O C Fisher	37.7952	Texoma	50.292	Neches	169.0872032
Benbrook	39.624	Falcon	6.67512	Lavon	24.6888	O H Ivie	43.8912	Toledo Bend	25.908	Nueces	21.10949886
Bob Sandlin	21.0312	Fork	18.288	Leon	27.432	Oak Creek	19.2024	Travis	81.0768	Red	135.4887976
Bonham	21.336	Fort Phantom Hill	25.6032	Lewisville	38.1	Palestine	22.86	Twin Buttes	32.3088	Rio Grande	25.24769597
Brady Creek	21.6408	Georgetown	49.9872	Limestone	21.9456	Palo Duro	15.5448	Tyler	15.24	Sabine	229.3609437
Bridgeport	39.624	Gibbons Creek	75.2856	Livingston	26.5176	Palo Pinto	29.2608	Waco	42.672	San Antonio	22.00910693
Brownwood	42.672	Graham	10.668	Lost Creek	24.6888	Pat Cleburne	23.7744	Waxahachie	20.1168	San Jacinto	53.38978311
Buchanan	44.3484	Granbury	25.6032	Lyndon B Johnson	36.05784	Pat Mayse	29.2608	Weatherford	22.86	Sulphur	36.48106279
Caddo	3.048	Granger	35.052	Mackenzie	50.5968	Possum Kingdom	57.6072	White River	9.144	Trinity	224.0024087
Canyon	68.2752	Grapevine	41.7576	Marble Falls	30.11424	Proctor	26.2128	Whitney	48.4632		
Cedar Creek	27.7368	Greenbelt	27.1272	Martin	18.5928	Ray Hubbard	20.7264	Worth	15.24		

Figure 3. 11: Head height and water flow rate of Texas's water reservoirs

In order to design an energy storage hydropower station based on the flow of each river, in this method, it is proposed to build an energy storage hydropower station in each major reservoir in Texas. A model was designed for this by applying Equations 3.1, 3.2, 3.3, and 3.4. Water flow rate and the height of the head for all water reservoirs are shown in Figure 3.11. In addition to all of that, there are three assumptions taken into consideration; the water flow rate of water reservoirs is the same as the water flow rate of the river basin ,the efficiency of the hydroelectric turbine is 80% and the water density is 1,000 Kg/m^3.

After applied the proposed model, each hydroelectric power plant in the proposed system has a capacity that varies from 0.935 to 140.369 MW as the following:

$$P\ @Gibbins\ Creek = H * Q * g * \eta * \rho$$

$$P\ @Gibbins\ Creek\ \ = 75.28 * 237.5 * 9.8 * .8 * 1000$$

$$P\ @Gibbins\ Creek\ \ \approx 140\ MW$$

In this model, the highest hydropower plant size is on Gibbons Creek dam which is located on the Brazos river while the smallest one is Palo Duro dam which located in the Canadian River. All hydropower plants from this model could power up to 4,094 MW from 121 hydropower plants on all main water reservoirs in Texas. 23 water reservoirs have enough water flow rate and head height to power more than 50 MW and a total of 1,770.827 MW. 75 water reservoirs have enough water flow rate and head height to power more than 10 MW and a total of 2,216.214 MW. Only 23 water reservoirs could be categorized as small hydropower plants with a water flow rate and head height enough to power less than 10 MW and more than 0.935 MW. All previous classifications are shown in Figure 3.12.

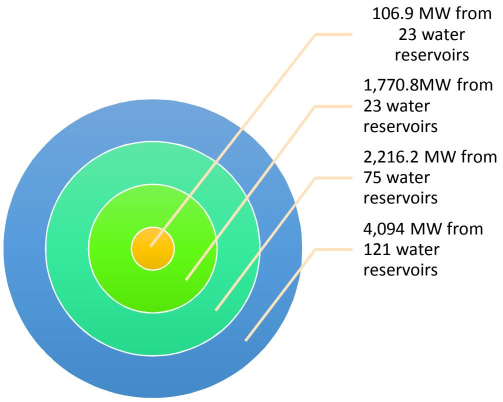


Figure 3. 12: Scenario#1 results

In this scenario, Texas could produce electricity from water reservoirs distributed in 94 counties as shown in Figure 3.13. The size of storage hydropower plants varies from 222.77 to .72 MW. Texas has 9 counties where has enough resources from hydroelectric energy to produce more than 100 MW from each county and a total of 1,431.56 MW. There are 17 counties that have enough resources to produce between 50-100 MW and a total of 1,254.18 MW. Regarding scenario #1, there are 43 counties that produce between 10-50 MW and a total of 1,293.52 MW. Only 25 counties could be considered as poor based on their hydroelectric energy with enough resources less than 10 MW and a total of 109.58 MW.

County	Power size in Mw	County	Power size in Mw	County	Power size in Mw	County	Power size in Mw
Bell	222.77	Tom Green	49.88	Brown	24.94	East Mont	5.75
Tarrant	204.06	Comanche	48.87	Polk	23.31	Franklin	4.48
Palo Pinto	203.97	Jones	47.74	Fannin	22.69	Bandera	3.63
Williamsor	158.55	Hunt	46.64	Archer	20.09	Medina	3.63
Denton	140.39	Newton	46.64	Clay	20.09	Marion	3.6
Grimes	140.37	Dallas	45.99	Nacogdoches	18.73	Harrison	3.24
Hood	138.1	Somervell	45.46	Scurry	18.7	Wichita	3.24
Collin	122.7	Cherokee	45.19	Harris	18.47	Titus	3.2
Eastland	100.65	Montague	44.79	Crosby	17.05	Hopkins	2.88
Ellis	96.89	Haskell	44.33	Austin	15.14	Jackson	1.5
Navarro	90.56	Johnson	44.33	Leon	13.64	Zapata	1.32
Bosque	90.36	Purdon	43.78	Limestone	13.64	Camp	1.06
Hendersor	83.44	Lamar	43.43	Robertson	13.64	Randall	0.94
Burnet	82.18	Parker	40.19	McCulloch	12.65	Hutcginsor	0.72
Hill	80.49	Coleman	39.37	El Paso	11.02	Moore	0.72
Baylor	79.89	Coke	36.16	Montgomery	10.47	Potter	0.72
McLennan	79.56	Houston	33.76	Val Verde	10.27		
Garza	78.42	Kaufman	33.22	Bowie	9.25		
Wise	69.66	Wood	32.92	Rockwall	9.11		
Travis	67.09	Cooke	30.14	Concho	8.55		
Jasper	66.74	Comal	29.8	Runnels	8.55		
Rusk	66.65	Panola	27.98	Anderson	7.58		
Stephens	63.65	Smith	27.8	Cooper	6.94		
Briscoe	53.8	Mitchell	27.55	Nolan	6.82		
Grayson	53.48	San Jacinto	27.1	Goliad	6.39		
Taylor	51.32	Llano	25.92	Live Oak	5.76		

Figure 3. 13: Results by counties from scenario #1

3.7.2 Run of River: Scenario#2

Texas has 15 major rivers as shown in the map in Figure 3.9, the water flow varies from one river to another, moreover, it varies inside the river itself based on the season of the year and the time of the day, because of the fluctuations in the water flow make it could opt for a run of river hydropower plant type hence, it does not depend on the height head more than the water flow. There are five rivers in Texas that have a water flow of more than 100 m^3/s and they are Brazors, Neches, Red, Sabine, and Trinity As shown in Table 3.2 'River Basins, n.d', in more than 10 counties in Texas, 9 out of every 15 rivers intersect, which is considered a good source of hydropower for power generation. Moreover, all high-flow rivers flow through more than 10 counties in Texas, which will improve the operating efficiency of Run of river hydroelectric power plants.

Major Rivers	Average flow (acre feet per year)	Average flow in m^3/s	Number of counties that cross by the river
Brazos	6,074,000	237.4	29
Canadian	196,000	7.6	5
Colorado	1,904,000	74.4	23
Cypress	493,700	19.2	7
Guadalupe	1,422,000	55.5	8
Lavaca	277,000	10.8	3
Neches	4,323,000	168.9	14
Nueces	539,700	21.1	11
Red	3,464,000	135.4	17
Rio Grande	645,500	25.2	20
Sabine	5,864,000	229.2	13
San Antonio	562,700	21.9	5
San Jacinto	1,365,000	53.3	6
Sulphur	932,700	36.4	11
Trinity	5,727,000	223.8	26

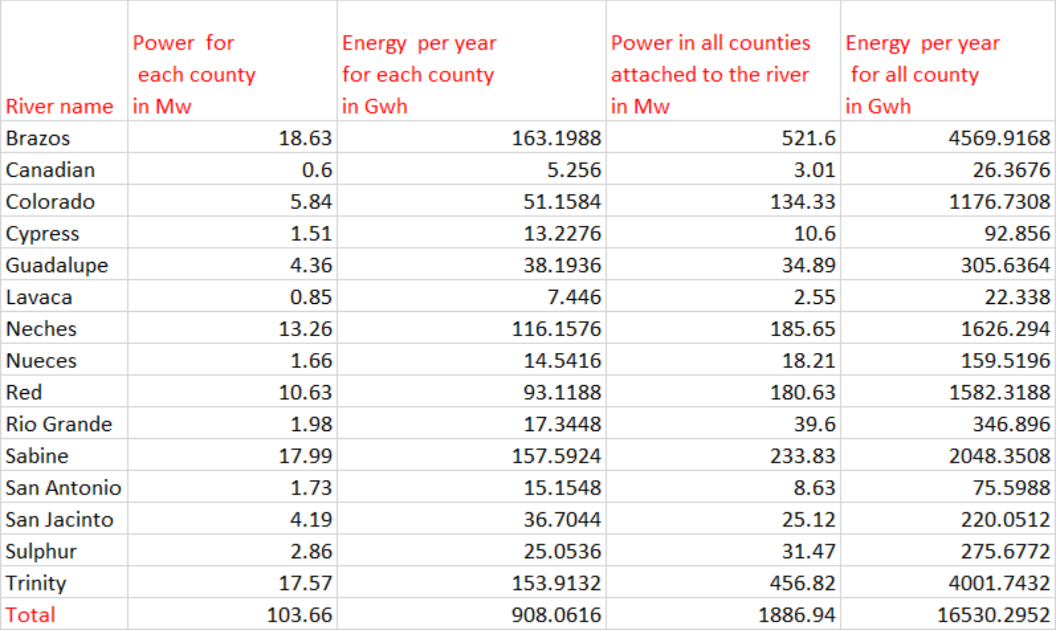
Table 3. 2: Major rivers in Texas and their average water flow

To design run of river hydropower plants based on the water flow in every river, in this approach, A run of a river hydropower plant is proposed to construct at every county that the river crosses through it. A model has designed for that by applying Equations 3.1,3.2,3.3, and 3.4 and the water flow from Table 3.2. In addition to all of that, there are three assumptions taken into consideration and they are the height of the head is 10 meters, the efficiency of the turbine is 80% and the water density is 1,000 kg/m^3.After applied the proposed model, each hydroelectric power plant in the proposed system has a capacity that varies from 0.6 to 18.63 MW, and for all counties attached to each river from 3.01 to 540.31 MW. In this model, hydroelectric power plants could power up to 521.6 MW from only the Brazos river. The second biggest rive is Trinity river with a maximum power of 456.82 MW, then Sabine, Neches, Red, Colorado rivers with maximum capacity up to 233.83,185.65,180.63, and 134.33 MW respectively. The previous 6 rivers have enough capacity in this model to power 1,731.57 MW, while all 15 rivers up to 1,886.395 MW as shown in Figure 3.14. The estimated capacity of the hydropower plants based on the river are determined as the following:

$$P\ @every\ hydropower\ plant\ in\ Brazos\ river = H * Q * g * \eta * \rho$$

$$P\ @every\ hydropower\ plant\ in\ Brazos\ river = 10 * 237.5 * 9.8 * .8 * 1000$$

$$P\ @every\ hydropower\ plant\ in\ Brazos\ river \approx 18.63\ MW$$



River name	Power for each county in Mw	Energy per year for each county in Gwh	Power in all counties attached to the river in Mw	Energy per year for all county in Gwh
Brazos	18.63	163.1988	521.6	4569.9168
Canadian	0.6	5.256	3.01	26.3676
Colorado	5.84	51.1584	134.33	1176.7308
Cypress	1.51	13.2276	10.6	92.856
Guadalupe	4.36	38.1936	34.89	305.6364
Lavaca	0.85	7.446	2.55	22.338
Neches	13.26	116.1576	185.65	1626.294
Nueces	1.66	14.5416	18.21	159.5196
Red	10.63	93.1188	180.63	1582.3188
Rio Grande	1.98	17.3448	39.6	346.896
Sabine	17.99	157.5924	233.83	2048.3508
San Antonio	1.73	15.1548	8.63	75.5988
San Jacinto	4.19	36.7044	25.12	220.0512
Sulphur	2.86	25.0536	31.47	275.6772
Trinity	17.57	153.9132	456.82	4001.7432
Total	103.66	908.0616	1886.94	16530.2952

Figure 3. 14: Run of river model results

The previous 15 rivers pass through 170 counties among Texas, some counties have more than one river so, therefore, they have more resources compared to other counties based on the run of river model. The power capacity varies from one county to another from 36.19-0.601MW. 86 counties have enough resources to power more than 10 MW and only 7 counties power less than 1 MW as shown in Figure 3.15.

county	Power size (Mw)	county	Power size (Mw)	county	Power size (Mw)	county	Power size (Mw)	county	Power size (Mw)	county	Power size (Mw)	county	Power size (Mw)
parker	36.19	fort bend	18.63	dallas	17.56	briscoe	10.62	san saba	5.84	cameron	1.98	jimwekks	1.65
orange	31.24	garza	18.63	denton	17.56	childresss	10.62	scurry	5.84	crane	1.98	la salle	1.65
smith	31.24	hale	18.63	eliss	17.56	clay	10.62	terry	5.84	crlcke	1.98	mcmullen	1.65
vanzandt	31.24	hood	18.63	freeson	17.56	deafsmith	10.62	travis	5.84	el paso	1.98	nueces	1.65
anderson	30.82	kent	18.63	jack	17.56	hademan	10.62	wharton	5.84	hidalgo	1.98	oliveoak	1.65
henderson	30.82	Knox	18.63	kaufman	17.56	hall	10.62	yoakum	5.84	hudsprth	1.98	real	1.65
houston	30.82	lamb	18.63	leon	17.56	randall	10.62	cass	4.37	jeff davis	1.98	uvalde	1.65
polk	30.82	lubbock	18.63	madison	17.56	wichta	10.62	franklin	4.37	kinney	1.98	zavala	1.65
cooke	28.18	nclennan	18.63	navarro	17.56	wilbarger	10.62	morris	4.37	loving	1.98	san patricio	1.65
gravson	28.18	palopinto	18.63	rockwall	17.56	fayette	6.69	callhoon	4.36	maveririck	1.98	camp	1.51
montague	28.18	parmer	18.63	tarrant	17.56	bastrop	5.84	comal	4.36	pecos river	1.98	marion	1.51
liberty	21.75	robertison	18.63	trinity	17.56	borden	5.84	dewitt	4.36	presidio	1.98	jackson	0.85
san jacinto	21.75	stonewall	18.63	walker	17.56	burnet	5.84	gonzalea	4.36	reeves	1.98	Lavaca	0.85
harrison	19.49	through morton	18.63	wise	17.56	coke	5.84	guadalupe	4.36	starr	1.98	hemphil	0.601
upshur	19.49	washintton	18.63	bowie	13.48	coleman	5.84	kendall	4.36	terrel	1.98	huthcinson	0.601
austin	18.63	young	18.63	fannin	13.48	colorado	5.84	Kerr	4.36	val verde	1.98	oldham	0.601
baily	18.63	gregg	17.98	lamar	13.48	Dawson	5.84	vitoria	4.36	ward	1.98	potter	0.601
Baylor	18.63	newton	17.98	redriver	13.48	howard	5.84	grimes	4.19	webb	1.98	roberts	0.601
bosque	18.63	panola	17.98	angelina	13.26	lampasas	5.84	Harris	4.19	zapata	1.98		
brazoria	18.63	rains	17.98	cherokee	13.26	liano	5.84	walker	4.19	bexar	1.72		
burleson	18.63	rusk	17.98	hardiln	13.26	martin	5.84	montgomery	4.19	goliad	1.72		
castro	18.63	sabine	17.98	jasper	13.26	matagorda	5.84	delta	2.86	karnes	1.72		
crosby	18.63	shelby	17.98	jefferson	13.26	mcculloch	5.84	fitus	2.86	refugio	1.72		
falls	18.63	wood	17.98	trinity	13.26	mills	5.84	hopkins	2.86	wilson	1.72		
fisher	18.63	champers	17.56	tyler	13.26	mitchell	5.84	hunt	2.86	dimmit	1.65		
floyd	18.63	collin	17.56	amstrong	10.62	runnels	5.84	brewster	1.98	edwards	1.65		

Figure 3. 15: Run of River design by counties

3.8 Results

The results from the perspective model from storage hydropower plants (scenario#1) are 4,094 MW, and the results from the run of river hydropower plants (scenario#2) are 1886.4 MW. The total power that could be generated from water resources in Texas is 5,980.4 MW from 198 counties as shown in Figure 3.16.

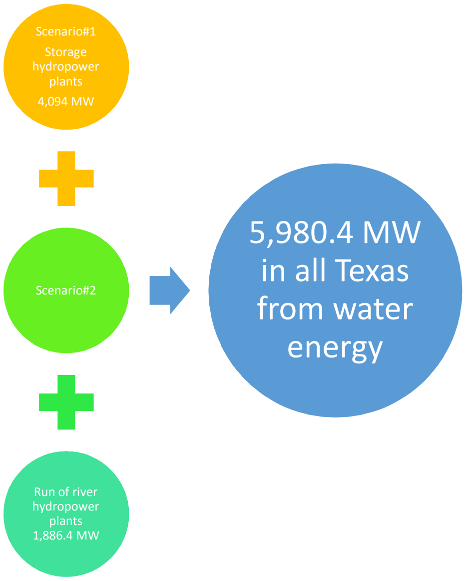


Figure 3. 16: Results from hydropower plants in the proposed system

There are 13 counties in Texas that have enough resources from water reservoirs and rivers to power more than 100 MW and a total of 1,971.51 MW, hence those counties considered rich counties of hydroelectric energy resources. Texas has 25 counties that have enough resources from water reservoirs and rivers to power between 50-100 MW and a total of 1,760.1MW, thus those counties can be categorized as a good option for small hydropower plants.82 counties in Texas have enough resources from water reservoirs and rivers to power from 10-50 MW and a total of 1,980.021 MW, therefore those counties are the best option for mini-hydropower plants.78 counties in Texas have enough resources from water reservoirs and rivers to power from 0.5-10MW and a total of 275.984 MW, therefore those counties are the best option for micro-hydropower plants. There are only 56 counties in Texas that do not have any water resources for hydropower plants. All results from both scenarios are shown in Figure 3.17.

County	Power size (Mw)	County	Power size (Mw)	County	Power size (Mw)	County	Power size (Mw)	County	Power size (Mw)	County	Power size (Mw)	County	Power size (Mw)	County	Power size (Mw)
Bell	222.77	Houston	64.58	Crosby	35.68	Castro	18.63	Wichita	13.86	Howard	5.84	Zapata	3.3	Dimmit	1.65
Palo Pinto	222.6	Briscoe	64.42	Comal	34.16	Falls	18.63	Limestone	13.64	Lampasas	5.84	Titus	3.2	Edwards	1.65
Tarrant	221.62	Stephens	63.65	Austin	33.77	fisher	18.63	Redriver	13.48	martin	5.84	delta	2.86	Jimwekks	1.65
Williamson	158.55	Dallas	63.55	Mitchell	33.39	floyd	18.63	Angelina	13.26	matagorda	5.84	fitus	2.86	la salle	1.65
Denton	157.95	Smith	59.04	Robertson	32.871	fort bend	18.63	Hardiln	13.26	Mills	5.84	Camp	2.57	Mcmullen	1.65
Hood	156.73	Cherokee	58.45	Llano	31.76	Hale	18.63	Jefferson	13.26	san saba	5.84	Brewster	1.98	nueces	1.65
Grimes	144.56	Cooke	58.32	orange	31.24	kent	18.63	tyler	13.26	terry	5.84	cameron	1.98	oliveoak	1.65
Collin	140.26	Lamar	56.91	vanzandt	31.24	Knox	18.63	El Paso	13	wharton	5.84	crane	1.98	Real	1.65
Ellis	114.45	Polk	54.13	Leon	31.2	Lamb	18.63	val verde	12.25	Yoakum	5.84	crlcke	1.98	uvalde	1.65
Henderson	114.26	Taylor	51.32	trinity	30.82	lubbock	18.63	Randall	11.56	Live Oak	5.76	Hidalgo	1.98	Zavala	1.65
Bosque	108.99	Wood	50.9	Clay	30.71	Nclennan	18.63	Childresss	10.62	st Montgom	5.75	Hudsprth	1.98	Hutcginson	1.321
Navarro	108.12	kaufman	50.78	Donley	28.84	parmer	18.63	deafsmith	10.62	Hopkins	5.74	Jeff davis	1.98	Potter	1.321
Eastland	100.65	Tom Green	49.88	Rockwall	26.67	stonewall	18.63	Hademan	10.62	Marion	5.11	kinney	1.98	Lavaca	0.85
Baylor	98.52	Hunt	49.5	Brown	24.94	through morton	18.63	Hall	10.62	Cass	4.37	loving	1.98	Moore	0.72
Garza	97.05	Comanche	48.87	Scurry	24.54	Washintton	18.63	Wilbarger	10.62	Morris	4.37	maveririck	1.98	Hemphil	0.601
Burnet	88.02	Jones	47.74	Harrison	22.73	Young	18.63	Montgomery	10.47	callhoon	4.36	pecos river	1.98	oldham	0.601
Wise	87.22	Panola	45.96	Bowie	22.73	McCulloch	18.49	Franklin	8.85	Dewitt	4.36	presidio	1.98		
Rusk	84.63	Somervell	45.46	Harris	22.66	Gregg	17.98	Concho	8.55	Gonzalea	4.36	Reeves	1.98		
Grayson	81.66	Coleman	45.21	liberty	21.75	Rains	17.98	Goliad	8.11	Guadalupe	4.36	starr	1.98		
Hill	80.49	San Jacinto	45.06	Archer	20.09	sabine	17.98	Cooper	6.94	kendall	4.36	terrel	1.98		
Jasper	80	Haskell	44.33	Jackson	19.91	shelby	17.98	Nolan	6.82	Kerr	4.36	Ward	1.98		
McLennan	79.56	Johnson	44.33	upshur	19.49	Champers	17.56	fayette	6.69	Vitoria	4.36	Webb	1.98		
Parker	76.38	Purdon	43.78	Nacogdoches	18.73	Freeson	17.56	bastrop	5.84	Walker	4.19	bexar	1.72		
Montague	72.97	Coke	42	baily	18.63	madison	17.56	borden	5.84	San Patricio	3.79	karnes	1.72		
Travis	72.93	Anderson	38.4	Brazoria	18.63	Walker	17.56	Colorado	5.84	Bandera	3.63	Refugio	1.72		
Newton	64.62	Fannin	36.17	Burleson	18.63	Runnels	14.39	Dawson	5.84	Medina	3.63	Wilson	1.72		

Figure 3. 17: Results from both scenarios by counties

3.9 Hydropower Generation Technology And The Environment

Constructing huge dams may cause some negative impact on the environment such as obstruct fish immigration, moreover, it could change the natural temperature of the water, and the chemistry of water as well ‘Hydropower and the environment, 2020’. The impact of hydroelectric power plants depends in some respects on land use, the impact of wildlife and life cycle global warming emissions. Creating huge dams and reservoir water in result destroy forests, wildlife, and agriculture land ‘Environmental Impacts of Hydroelectric Power, 2013’. Installed the Three Gorges Dams in China has a great impact and all the community besides the dam and force them to relocate their position ‘Yardley,2007’. Figure 3.18 ‘Disadvantages, n.d’ shows the environmental impact of the three Three Gorges dams, and the erosion rate is increasing year by year. The green color is decreased by a huge rate from 1987 to 2004 which shows the negative impact of the hydropower plants for the surrounding environment.

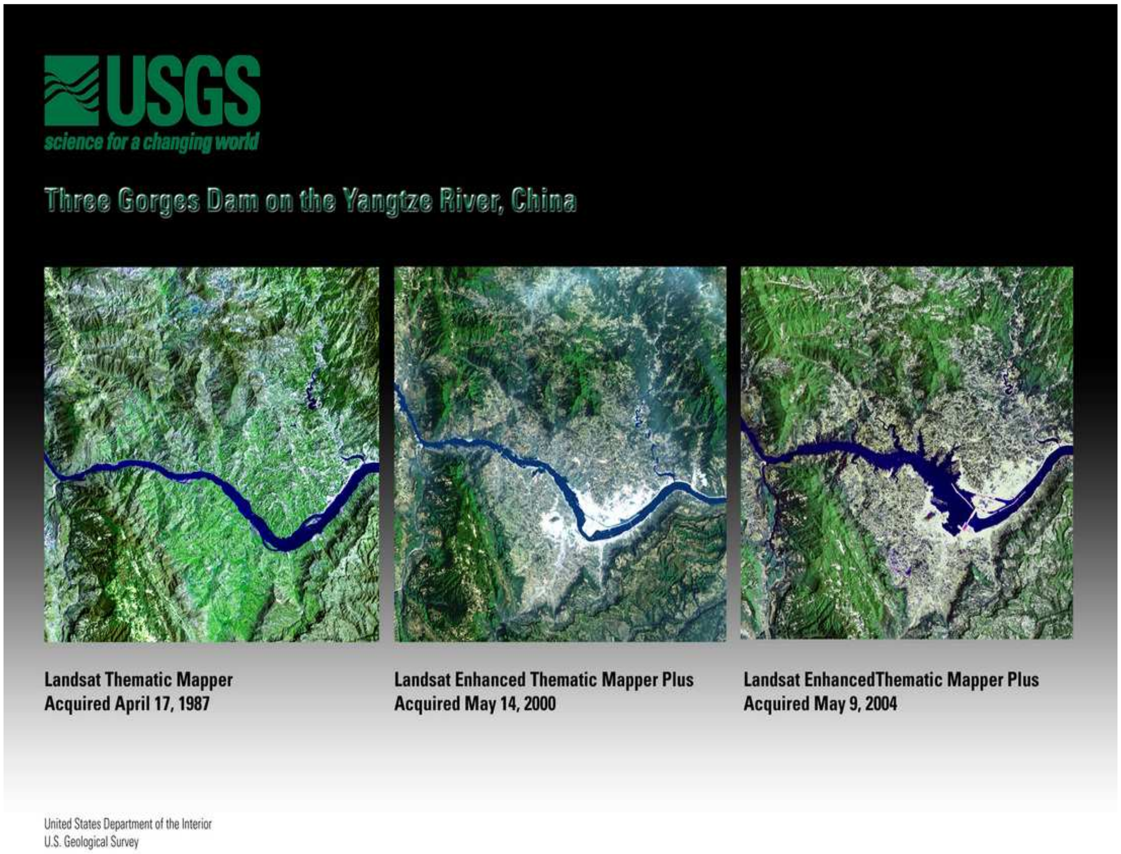


Figure 3. 18: The Three Gorges Dam in China

CHAPTER IV

GEOTHERMAL ENERGY

4.1 Geothermal Energy

Geothermal energy is the energy of the earth's heat. It involves extracting the thermal energy of the earth in order to use it in some applications such as heating systems and power plants. The temperature of the earth’s center is almost equal to the temperature of the sun's surface around 6,000 degrees Celsius ‘European Synchrotron Radiation Facility,2013’. According to the 'Layers of the earth, n.d', Earth has four main layers; The inner core layer depth is around 1,278 Km and its temperature is 5,505□, the outer core depth is around 2200 Km and its temperature is 4,400□, the mantle layer is the thickest layer of earth and its depth is almost 2,800 Km and its temperature varies between 300-500 □, the crust is the thinnest layer and its depth varies between 5-60 Km and its temperature varies from 200-400 □ as shown in Figure 4.1.

Figure 4. 1: Earth’s layers

Even if the replenishment rate is higher than other renewable energy sources such as solar and wind energy, geothermal energy is still regarded as a renewable energy source In places that are updated daily, geothermal energy requires more time, which may take up to 100 years to restore the internal temperature of the rock itself But it depends on the rate at which energy has been extracted from the geothermal reservoir from the beginning of the project era. Therefore, by controlling the extraction rate of the energy we could preserve it for a long time and avoid depletion ‘Tester al et,2006’.

4.2 Geothermal Energy Resources

Geothermal energy has many resources or forms, as shown below:

1- Hydrothermal resources

Hydrothermal resources are the traditional form of natural resources and geothermal energy, and it is limited to certain areas of the earth. As shown in Figure 4.2 ‘DiPippo,2012’, the five goals should be achieved in an area that should be regarded as a hydrothermal resource, and they are a large hear source, reliable charge mechanism, permeable reservoir, supply of water, and overlying of layers impervious rock.

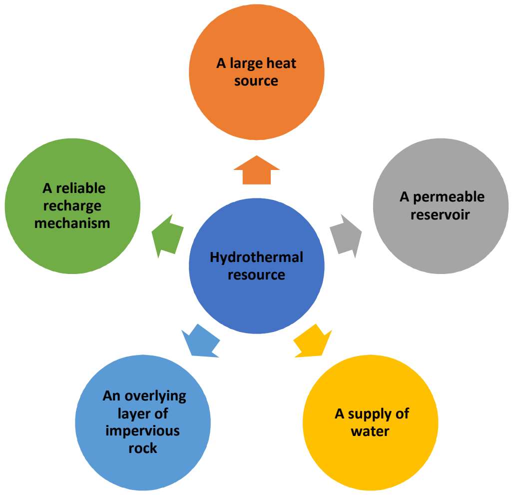


Figure 4. 2: Hydrothermal resource conditions

2- Magma energy

It is the high energy, which available in the form of very high-temperature heat could reach up to 1,000□ ‘Pearce, 2016’. Magma energy is available at different depths in the earth’s crust.

3-Geopressured

Geopressured has three important features that make it a potential source of energy and they are: very high pressure, very high temperature, and dissolved methane ‘ DiPippo,2012’.

4- Hot and dry rock

All previous resources were restricted to certain areas of the earth, and dry hot rock is a new technology that allows geothermal energy resources to be used anywhere on the earth regardless of geographic conditions. It is also called an Enhanced geothermal system ‘Blackwell et al,2011’, the idea of this technology simply to inject water into a specific depth to reach the required temperature and pump it out as steam or dry vapor to drive a turbine linked to an electric generator. The availability of water now is achieved by the injection of cold water and that water should be injected under a certain pressure to open the channels between the rock layers above the constructed geothermal reservoir, However, in some places, Geothermal wells may reach high depths in order to reach the required temperature. As shown in Figure 4.3 ‘Tester et al,1979’ the components of the hot and dry rock power plant.

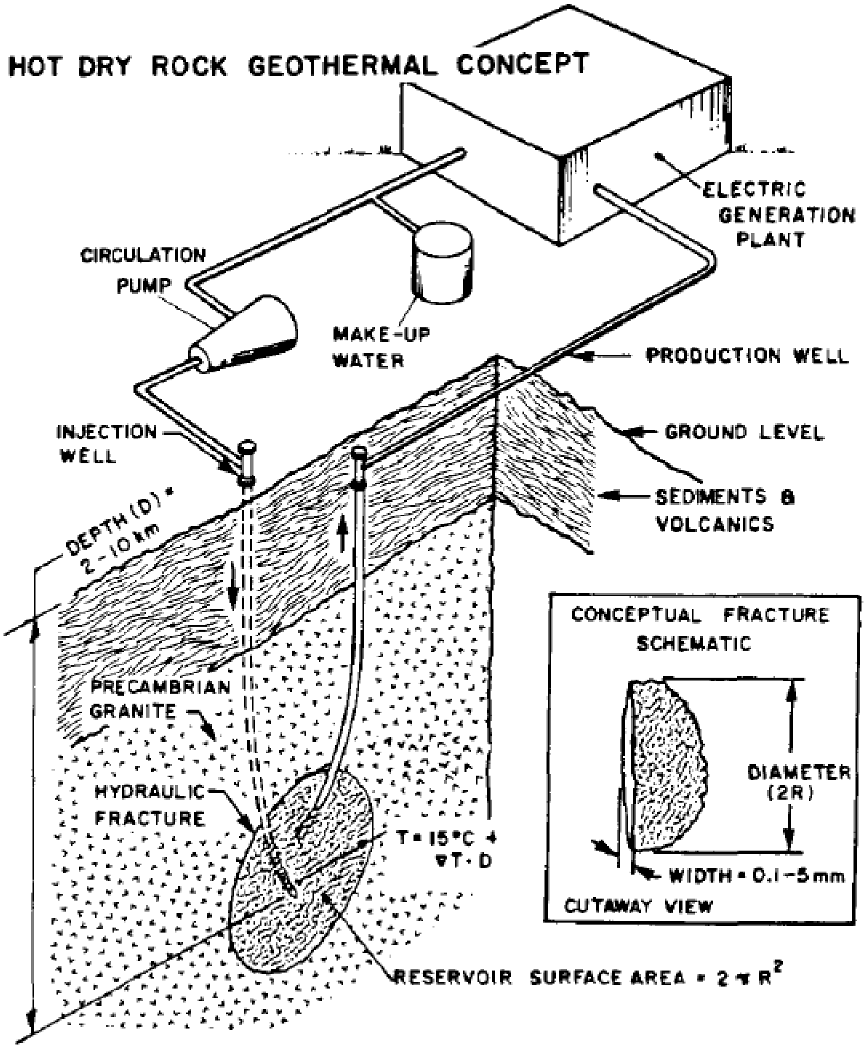


Figure 4. 3: Hot and Dry rock schematic representation

4.3 Geothermal Energy Power Plants Types

Geothermal power plants can be categorized based on the type of fluid used to drive the turbine, the main fluid will be water and could appear in dry steam form or combination form between hot water and steam, and also could use another fluid in parallel with the main fluid water. There are dry-type and flash-type geothermal power plants, where water is the only fluid in the above two forms, and finally there are binary cycle geothermal power plants that use two fluids.

4.3.1 Dry-Steam Geothermal Power Plant

It is the most efficient geothermal power plant, it works where dry steam is available from the geothermal well, it is necessary to be stable without any water in liquid form. Also, the temperature of the steam should be higher than 235 'DiPippo,2012'. Hence, it is limited to certain places. One of the most important features of the geothermal power plant is the simplification of the structure, as shown in Figure 4.4 'Kulasekara and Seynulabdeen,2019'.

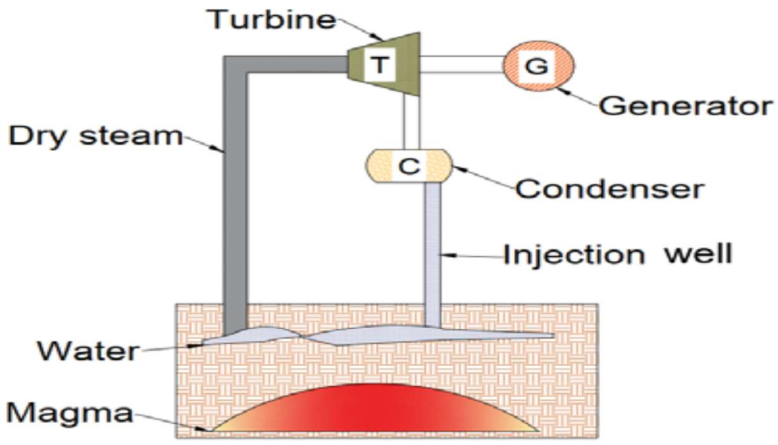


Figure 4. 4: Dry-steam geothermal power plant

4.3.2 Flashed Power Plants

It is the most common geothermal power plant in which hot water is drawn from a geothermal well. It is called flash power plants due to the nature of hot water, which is mixed of steam and water with a temperature degree that varies between 150-235 □ ‘ DiPippo,2012’. Due to the presence of steam and water, a separator is installed in the flashed power plant, as shown in Figure 4.5 ‘Kulasekara and Seynulabdeen,2019’.

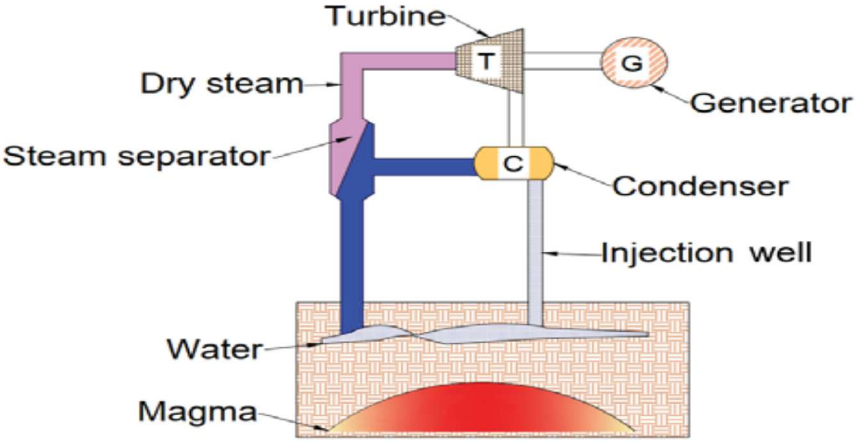


Figure 4. 5: Flash-steam geothermal power plant

4.3.3 Binary Cycle Power Plants

If the fluid temperature is lower than 150□ then, it is not applicable to be used in the previous two types of geothermal power plants ‘DiPippo,2012’. The binary cycle power plant relies on the use of two different fluids. The first fluid is steam from a geothermal reservoir, and the temperature varies between 50-150°C. The heat is then transferred to another fluid (such as isobutane) that has a lower boiling point than water. Transfer the heat is achieved by heat-exchanger as shown in Figure 4.6 ‘Kulasekara and Seynulabdeen,2019’.

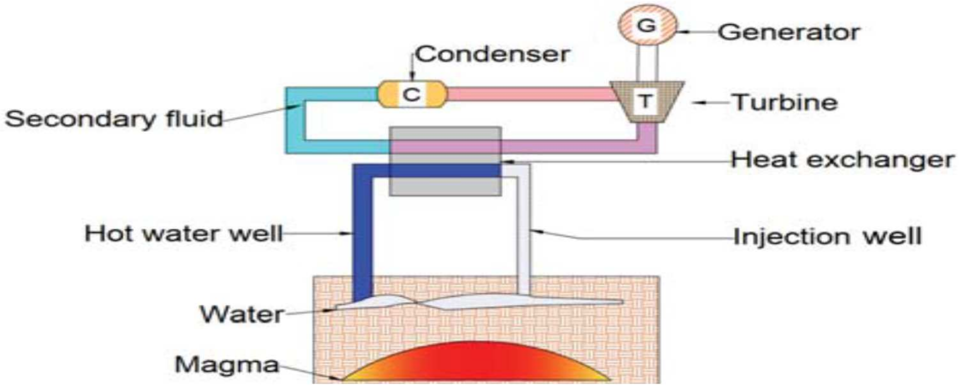


Figure 4. 6: Binary cycle geothermal power plant

4.4 Geothermal Power Plant Components

Geothermal power plants have three main components: the main component is the production well which has the hot water fluid extracted from the geothermal reservoir, the second component is the power plant and it is the core of any electric power plant where has the turbine and electric generator. Finally, the last part is the reinjection well. This part is of great significance for reinjecting the cold water in the power plant to avoid depletion, and for achieving the sustainability of the power plant. All components are shown in Figure 4.7 'Tousif and Taslim, 2011'.

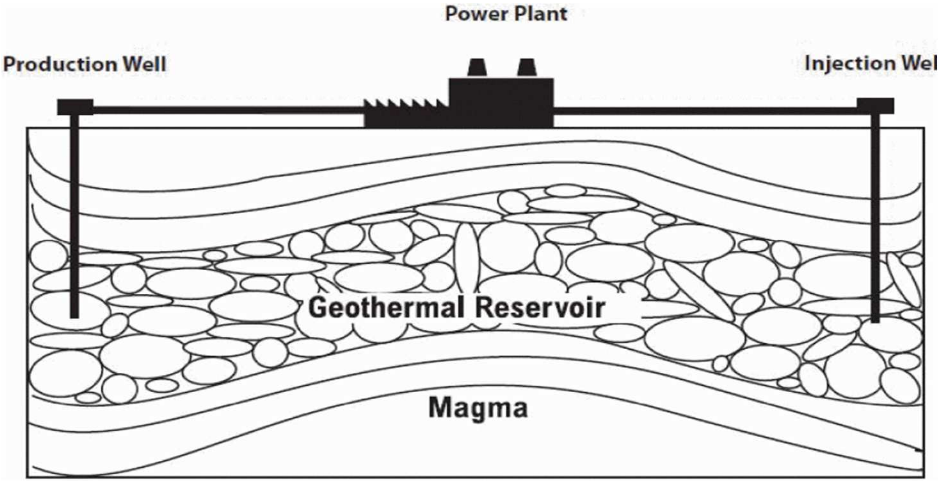


Figure 4. 7: Geothermal power plant components

4.5 Prospected Electrical System From Geothermal Energy

In this work, an electrical system has designed from geothermal energy resources in Texas depending on the estimation of the thermal energy storage in the earth in Texas counties, three scenarios have been addressed; the first covers all counties in Texas, the second one focuses on abandoned oil and gas wells in Texas, and the last one is for replacing all coal power plants into geothermal power plants.

All scenarios share the same method for designing starting with the estimation of thermal energy storage in the prospected place of power plants then applying the conversion rules from thermal energy into electricity. Temperature maps at different depths are taken from SMU geothermal lab 'Blackwell et al,2011'. Figure 4.8 shows the methodology of the prospected geothermal electrical systems.

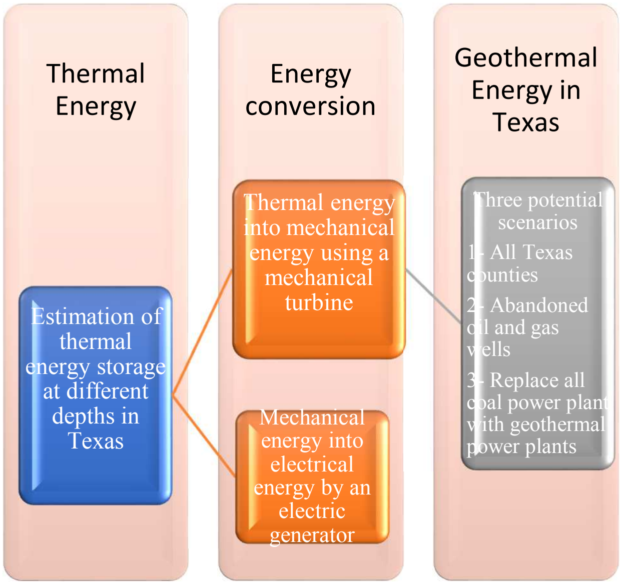


Figure 4. 8: Methodology of the prospected geothermal electrical system

4.6 Estimation Method Of Thermal Energy Storage

The method of estimation of the energy stored in the geothermal reservoir has been used in many studies such as ‘ Franco and Donatini, 2017’, ‘ Blackwell et al,2011’ and, ‘Williams,2004’. This method is based on the hot and dry rock systems, consequently, it depends on the density of rocks and the heat capacity, plus the volume of the reservoir, which is technically the volume of the geothermal fluid (water or steam), in addition to the difference in temperature between the geothermal reservoir and the surface as shown in Equation 4.1 ‘ Franco and Donatini, 2017’.

$E_S = \rho * C * V * (T_R - T_S) \dots\dots\dots\dots\dots .4.1$

Where :

E_S: The storage energy in the geothermal reservoir in joules

P: rock density in Kg/m^3

C: specific heat in J/°C.kg

V: volume of the reservoir in Km^3

T_R: reservoir temperature in □

T_S : surface temperature in □

Rock density (P) varies from 1600- 3500 Kg/Km^3 ‘Sharma,1997’, the specific heat capacity (C) is 2000 J/°C/kg ‘Bralower and Bice,2020’.

E_S represents the stored energy in the geothermal reservoir but that does not mean all of that energy is accessible and could be extracted due to many reasons such s the availability of geothermal fluid and porosity of rocks ‘Franco and Donatini, 2017’.The recovery factor represents the ratio between the energy that could be extracted from the geothermal reservoir to the stored energy in it, as shown in Equation 4.2 ‘ Franco and Donatini, 2017’.

$$Rf = \frac{E_X}{E_S} \text{ ....4.2}$$

Where :

Rf: recovery factor

E_X: extracted energy in Joules

$$E_e = \frac{E_X * \eta_{heat\ engine} * \eta_{mechanical\ turbine}}{3600} \text{......4.3}$$

Where:

E_e : Electrical energy in kWh

$\eta_{heat\ engine}$: efficiency of heat engine

$\eta_{mechanical\ turbine}$: efficiency of the mechanical turbine

However, Joule is not a commonly used unit of electrical energy, so it is best to convert it to kWh, therefore it is divided by 3600 as shown in Equation 4.3

$$E_A = \frac{E_e}{Life-span} \text{..........................4.4}$$

Where:

E_A: Annual energy in kWh.

Life-span: the expected age of the geothermal power plant

The recovery factor value depends on the reservoir characteristics, so the value range is 0.05-0.25 ‘Franco and Donatini, 2017’. The extracted thermal energy is converted into mechanical energy using a heat engine whose efficiency varies between 30-50% ‘Donev et al,2018.’ to drive a mechanical turbine with efficiency varies between 80-90% ‘Buecker,2007’is connected with an electric generator to produce electricity as shown in Figure 4.9.

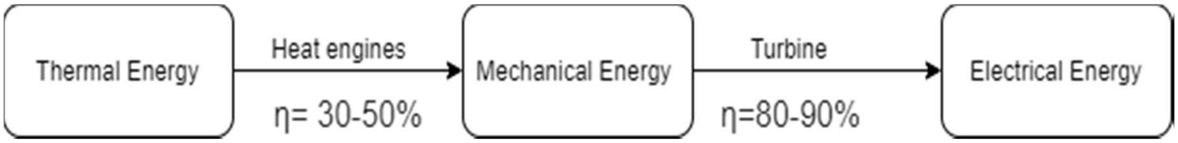


Figure 4. 9: Energy conversion efficiency

Design a model to calculate the electrical energy (E_E) that can be generated from the geothermal reservoir according to Equations 4.1, 4.2, 4.3, and 4.4. Coupled with the efficiency of converting thermal energy into electrical energy, the result will appear in the form of energy, so when converting it into electrical power, time should be considered. The efficiency of geothermal power plants based on this model varies between 1.2-11.25%, as shown in Figure 4.10.

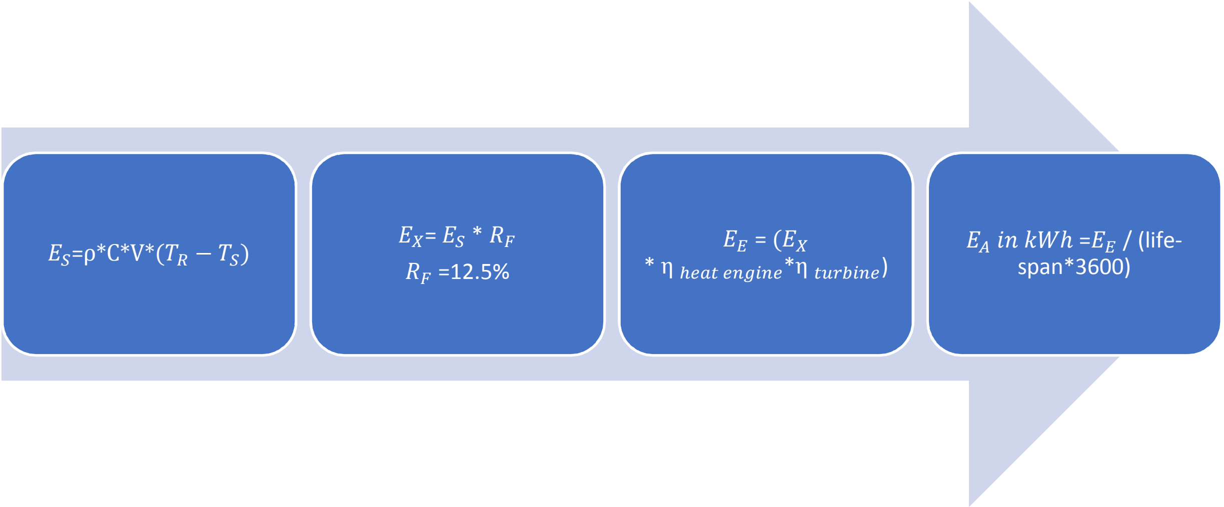


Figure 4. 10: Flowchart of geothermal power plant design

4.7 Temperature Maps In Texas

According to the SMU Geothermal Laboratory, the temperature of the earth increases in proportion to the depth of the earth, and it is applicable to any place, but the gradient will vary with location. Temperature gradient is the change of temperature with depth. In addition to temperature gradient, there is also thermal conductivity, which depends on the type of rock and soil. Both the temperature gradient and the thermal conductivity are determined by the heat flow which is the most important factor for the geothermal power plant ‘Richards,2008’. As shown in Figure 4.11 ‘Blackwell et al,2011’, the temperature degree in Texas increases when the depth increases. At 3.5 km, the temperature degree varies from 25-150 while it is at 10 km varies from 175-350 ‘Blackwell et al,2011’.

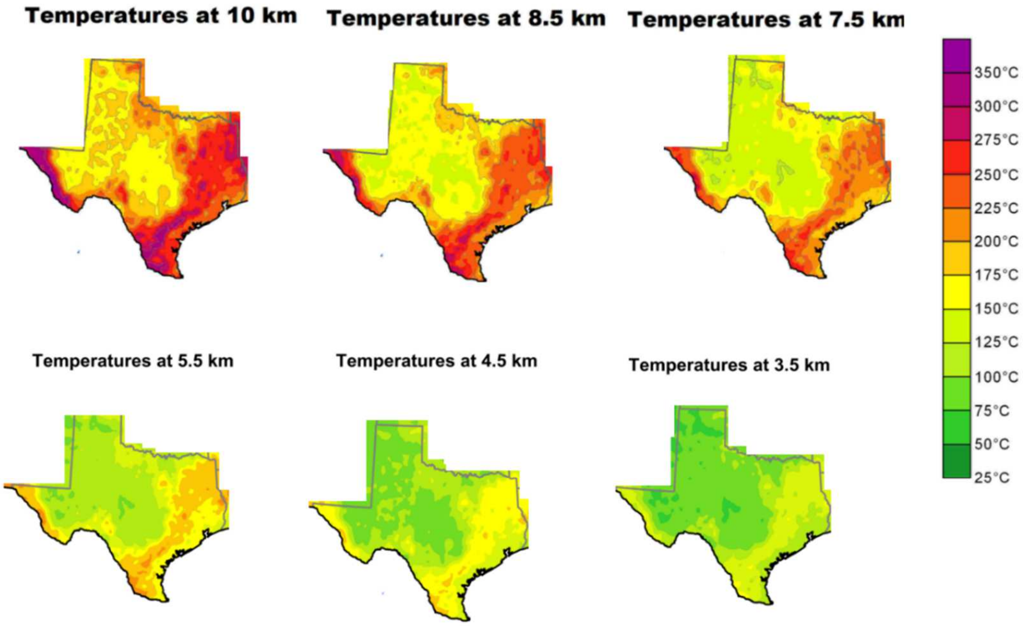


Figure 4. 11: The temperature degree at different depths in Texas

At a depth of 10 km, more energy can be extracted due to the high temperature, but unfortunately, this requires higher drilling techniques and more expensive techniques. When the depth is 3.5 Km, the power generation will be relatively low due to the low temperature. Hence, in this work, all designs use a temperature map of 5.5 Km.

At a depth of 5.5 kilometers, all counties in Texas have temperatures above 50°C, which means that it is theoretically possible to generate electricity from geothermal power plants based on binary cycle power generation, especially enhanced geothermal systems. However, the temperature ranges from 50 to 225, and there are 8 counties where the temperature ranges from 200 to 225 degrees Celsius, there are 36 counties in Texas with temperatures between 175-200 degrees Celsius, 45 counties with temperatures between 150-175 degrees Celsius, and 6 counties in Texas with temperatures between 12-150 degrees Celsius, 154 Counties The temperature is between 100-125 degrees Celsius, Only 5 counties have temperatures below 75 degrees Celsius and above 50 degrees Celsius. Based on all of that, Texas counties could be classified into six classes due to their temperature at 5.5 km depth as shown in Table 4.1.

Classification	number of counties	Min Temperature (□)	Max Temperature (□)
1	8	200	225
2	36	175	200
3	45	150	175
4	6	125	150
5	154	100	125
6	5	50	75

Table 4. 1: Classification of Texas counties based on the temperature at 5.5 km depth

4.8 Hypothetical Geothermal System

In this hypothetical model, the maximum electrical energy that might be generated by the enhanced geothermal system in Texas was calculated. The maximum energy mainly depends on the total area, the reservoir temperature (in this case a depth of 5.5 km). Geothermal energy is a renewable resource which means it has the ability to replenish itself, and it does not deplete, Although, it needs time to replenish itself as mentioned before, thus the life span in this model is considered as 100 years to allow the rock to restore its heat and do not deplete completely 'Tester al et,2006'.

There are some assumptions as of the following:

1- Using the temperature at 5.5 Km depth

2- The recovery factor is equal to 15%

3- The mechanical turbine efficiency is equal to 40%

4- The electrical generator efficiency is equal to 85%

5- Surface temperature for all Texas =25□

6- Lifespan of the geothermal reservoir is 100 years

7- The reservoir temperature is the average temperature neither the maximum nor the minimum.

8- The volume of the geothermal reservoir is 1 km * total area

9- The density of the rock is an average 2550 Kg/Km^3

10- The specific heat capacity is 2000 J/°C/kg

Using Equations 4.1, 4.2, 4.3 and 4.4, calculate the annual power generation according to the following formula:

$$E_S\ at\ Brewster = \rho * C * V * (T_R - T_S)$$

$$E_S\ at\ Brewster = 2550 * 2000 * 16037.98 * 10^9 * (162.5 - 25)$$

$$E_x at\ Brewster = 1.12 * 10^{22} \text{ Joule}$$

$$E_x at\ Brewster = RF * E_S$$

$$E_x at\ Brewster = 0.15 * 1.12 * 10^{22}$$

$$E_x at\ Brewster = 1.68 * 10^{21} \text{ Joule}$$

$$E_e at\ Brewster = \frac{E_x * \eta_{heat\ engine} * \eta_{mechanical\ turbine}}{3600}$$

$$E_e at\ Brewster = \frac{1.68 * 10^{21} * 0.4 * 0.85}{3600}$$

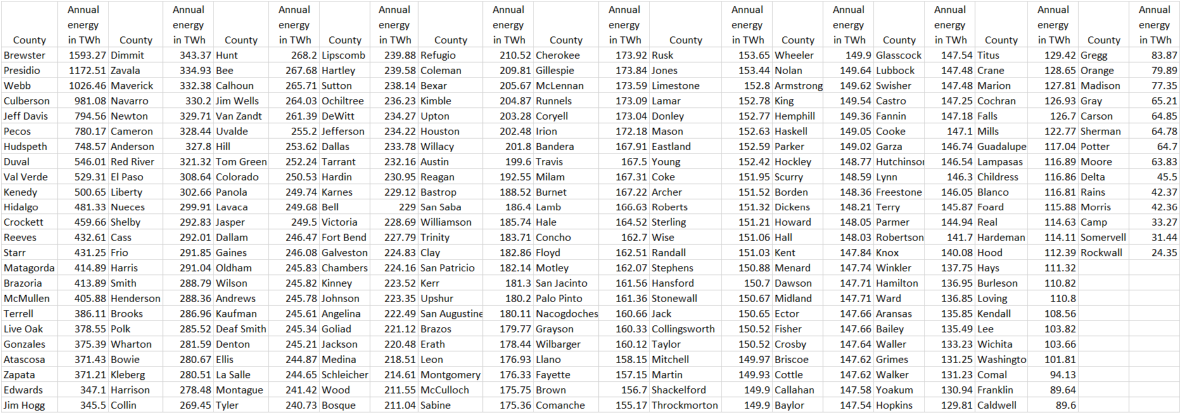
$$E_e at\ Brewster = 1.59 * 10^{17} \text{ Wh}$$

$$E_A at\ Brewster = \frac{E_e}{Lifespan}$$

$$E_A at\ Brewster = \frac{1.59 * 10^{17}}{100}$$

$$E_A at\ Brewster = 1593.27 \text{ TWh}$$

In this hypothetical model, Texas can provide up to 55.6 PWh of electricity per year, which is almost 10 times the total electricity consumption of the United States. The generation varies from one county to another based on two main factors; the reservoir temperature and the total area. The power generation of each county varies from 1.5 PWh to 24.35 TWh, as shown in Figure 4.12.



County	Annual energy in TWh	County	Annual energy in TWh	County	Annual energy in TWh	County	Annual energy in TWh	County	Annual energy in TWh	County	Annual energy in TWh	County	Annual energy in TWh	County	Annual energy in TWh	County	Annual energy in TWh	County	Annual energy in TWh	County	Annual energy in TWh
Brewster	1593.27	Dimmit	343.37	Hunt	268.2	Lipscomb	239.88	Refugio	210.52	Cherokee	173.92	Rusk	153.65	Wheeler	149.9	Glasscock	147.54	Titus	129.42	Gregg	83.87
Presidio	1172.51	Zavala	334.93	Bee	267.68	Hartley	239.58	Coleman	209.81	Gillespie	173.84	Jones	153.44	Nolan	149.64	Lubbock	147.48	Crane	128.65	Orange	79.89
Webb	1026.46	Maverick	332.38	Calhoun	265.71	Sutton	238.14	Bexar	205.67	McLennan	173.59	Limestone	152.8	Armstrong	149.62	Swisher	147.48	Marion	127.81	Madison	77.35
Culberson	981.08	Navarro	330.2	Jim Wells	264.03	Ochiltree	236.23	Kimble	204.87	Runnels	173.09	Lamar	152.78	King	149.54	Castro	147.25	Cochran	126.93	Gray	65.21
Jeff Davis	794.56	Newton	329.71	Van Zandt	261.39	DeWitt	234.27	Upton	203.28	Coryell	173.04	Donley	152.77	Hemphill	149.36	Fannin	147.18	Falls	126.7	Carson	64.85
Pecos	780.17	Cameron	328.44	Uvalde	255.2	Jefferson	234.22	Houston	202.48	Irion	172.18	Mason	152.63	Haskell	149.05	Cooke	147.1	Mills	122.77	Sherman	64.78
Hudspeth	748.57	Anderson	327.8	Hill	253.62	Dallas	233.78	Willacy	201.8	Bandera	167.91	Eastland	152.59	Parker	149.02	Garza	146.74	Guadalupe	117.04	Potter	64.7
Duval	546.01	Red River	321.32	Tom Green	252.24	Tarrant	232.16	Austin	199.6	Travis	167.5	Young	152.42	Hockley	148.77	Hutchinsoı	146.54	Lampasas	116.89	Moore	63.83
Val Verde	529.31	El Paso	308.64	Colorado	250.53	Hardin	230.95	Reagan	192.55	Milam	167.31	Coke	151.95	Scurry	148.59	Lynn	146.3	Childress	116.86	Delta	45.5
Kenedy	500.65	Liberty	302.66	Panola	249.74	Karnes	229.12	Bastrop	188.52	Burnet	167.22	Archer	151.52	Borden	148.36	Freestone	146.05	Blanco	116.81	Rains	42.37
Hidalgo	481.33	Nueces	299.91	Lavaca	249.68	Bell	229	San Saba	186.4	Lamb	166.63	Roberts	151.32	Dickens	148.21	Terry	145.87	Foard	115.88	Morris	42.36
Crockett	459.66	Shelby	292.83	Jasper	249.5	Victoria	228.69	Williamson	185.74	Hale	164.52	Sterling	151.21	Howard	148.05	Parmer	144.94	Real	114.63	Camp	33.27
Reeves	432.61	Cass	292.01	Dallam	246.47	Fort Bend	227.79	Trinity	183.71	Concho	162.7	Wise	151.06	Hall	148.03	Robertson	141.7	Hardeman	114.11	Somervell	31.44
Starr	431.25	Frio	291.85	Gaines	246.08	Galveston	224.83	Clay	182.86	Floyd	162.51	Randall	151.03	Kent	147.84	Knox	140.08	Hood	112.39	Rockwall	24.35
Matagorda	414.89	Harris	291.04	Oldham	245.83	Chambers	224.16	San Patricio	182.14	Motley	162.07	Stephens	150.88	Menard	147.74	Winkler	137.75	Hays	111.32		
Brazoria	413.89	Smith	288.79	Wilson	245.82	Kinney	223.52	Kerr	181.3	San Jacinto	161.56	Hansford	150.7	Dawson	147.71	Hamilton	136.95	Burleson	110.82		
McMullen	405.88	Henderson	288.36	Andrews	245.78	Johnson	223.35	Upshur	180.2	Palo Pinto	161.36	Stonewall	150.67	Midland	147.71	Ward	136.85	Loving	110.8		
Terrell	386.11	Brooks	286.96	Kaufman	245.61	Angelina	222.49	San Augustine	180.11	Nacogdoches	160.66	Jack	150.65	Ector	147.66	Aransas	135.85	Kendall	108.56		
Live Oak	378.55	Polk	285.52	Deaf Smith	245.34	Goliad	221.12	Brazos	179.77	Grayson	160.33	Collingsworth	150.52	Fisher	147.66	Bailey	135.49	Lee	103.82		
Gonzales	375.39	Wharton	281.59	Denton	245.21	Jackson	220.48	Erath	178.44	Wilbarger	160.12	Taylor	150.52	Crosby	147.64	Waller	133.23	Wichita	103.66		
Atascosa	371.43	Bowie	280.67	Ellis	244.87	Medina	218.51	Leon	176.93	Llano	158.15	Mitchell	149.97	Briscoe	147.62	Grimes	131.25	Washingto	101.81		
Zapata	371.21	Kleberg	280.51	La Salle	244.65	Schleicher	214.61	Montgomery	176.33	Fayette	157.15	Martin	149.93	Cottle	147.62	Walker	131.23	Comal	94.13		
Edwards	347.1	Harrison	278.48	Montague	241.42	Wood	211.55	McCulloch	175.75	Brown	156.7	Shackelford	149.9	Callahan	147.58	Yoakum	130.94	Franklin	89.64		
Jim Hogg	345.5	Collin	269.45	Tyler	240.73	Bosque	211.04	Sabine	175.36	Comanche	155.17	Throckmorton	149.9	Baylor	147.54	Hopkins	129.81	Caldwell	89.6		

Figure 4. 12: Results from Hypothetical model based on enhanced geothermal in Texas

However, the previous model is not practical because it depends on all land in the state of Texas, which is not applicable to apply. Based on ‘Brain Post: Map of Where NOBODY Lives in the USA | 47% of the USA is Uninhabited,2014’. around 47 % of the land in the US is unhabituated by people. Therefore, in order to obtain more realistic results, a factor of 0.47 is included in the results. Based on this, Texas can provide up to 26.13 PWh, which is still enough to power the entire United States.

4.9 Electrical Proposal System Based On Enhanced Geothermal Technology

In this electrical proposal system based on the enhanced geothermal technology, three scenarios are addressed; the first one is based on all Texas counties. The second is based on depleted oil and natural gas wells in Texas, so these wells have been drilled to deeper depths, so This is a great potential for geothermal power plants. The last scenario is based on converting all coal-fired power plants to geothermal power plants, which is also a good potential due to the similarity of components between geothermal power plants and coal-fired power plants.

4.9.1 Scenario#1

In this scenario, a geothermal power plant proposed to be constructed in every county in Texas. All geothermal reservoirs have the same dimensions which are 1 Km *1 Km *1 Km, which is considered as a small geothermal reservoir 'Franco and Donatini,2017' by using the temperature maps in Figure 4.11 from SMU Geothermal labs and applying the Equations in the flowchart in Figure 4.10 and taking into consideration the general assumption in the hypothetical model in the calculation is the following:

$E_S\ at\ Gonzales = \rho * C * V * (T_R - T_S)$

$E_S\ at\ Gonzales = 2550 * 2000 * 1 * 10^9 * (212.5 - 25)$

$E_S\ at\ Gonzales = 9.56 * 10^{17}$ Joule

$E_x at\ Gonzales = RF * E_S$

$E_x at\ Gonzales = 0.15 * 9.56 * 10^{17}$

$E_x at\ Gonzales = 1.43 * 10^{17}$ Joule

$E_e at\ Gonzales = \frac{E_x * \eta_{heat\ engine} * \eta_{mechanical\ turbine}}{3600}$

$$E_e at\ Gonzales = \frac{1.43 * 10^{17} * 0.4 * 0.85}{3600}$$

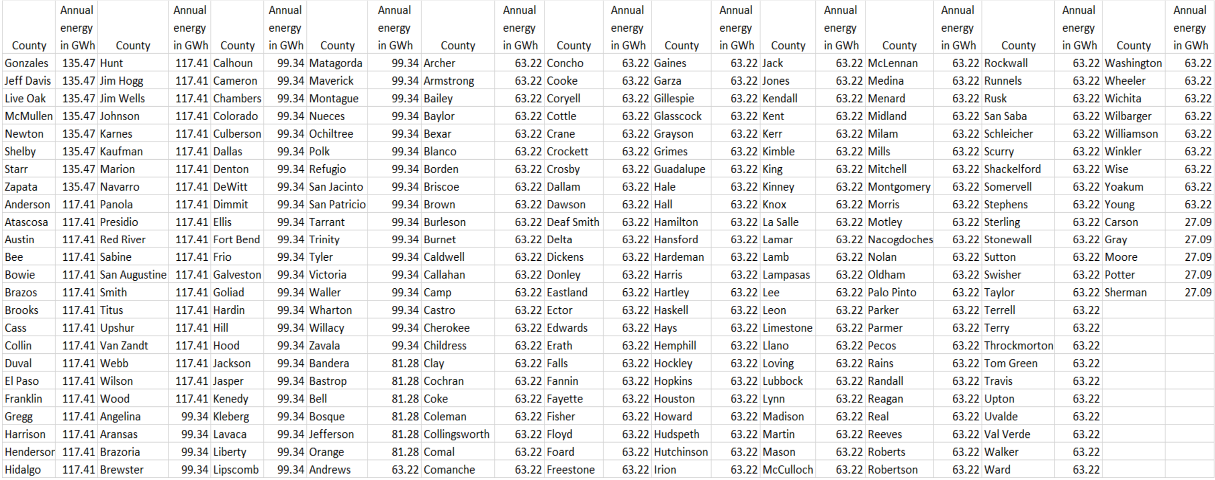
$E_e at\ Gonzales = 1.35 * 10^{13}$ Wh

$$E_A at\ Gonzales = \frac{E_e}{Lifespan}$$

$$E_A at\ Gonzales = \frac{1.35 * 10^{13}}{100}$$

$$E_A at\ Gonzales = 135.468 \text{ GWh}$$

Texas can produce up to 20.139 TWh from this scenario. The annual generation varies from one county to another, the range is from 135.47 to 27.09 GWh.



County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh
Gonzales	135.47	Hunt	117.41	Calhoun	99.34	Matagorda	99.34	Archer	63.22	Concho	63.22	Gaines	63.22	Jack	63.22	McLennan	63.22	Rockwall	63.22	Washington	63.22
Jeff Davis	135.47	Jim Hogg	117.41	Cameron	99.34	Maverick	99.34	Armstrong	63.22	Cooke	63.22	Garza	63.22	Jones	63.22	Medina	63.22	Runnels	63.22	Wheeler	63.22
Live Oak	135.47	Jim Wells	117.41	Chambers	99.34	Montague	99.34	Bailey	63.22	Coryell	63.22	Gillespie	63.22	Kendall	63.22	Menard	63.22	Rusk	63.22	Wichita	63.22
McMullen	135.47	Johnson	117.41	Colorado	99.34	Nueces	99.34	Baylor	63.22	Cottle	63.22	Glasscock	63.22	Kent	63.22	Midland	63.22	San Saba	63.22	Wilbarger	63.22
Newton	135.47	Karnes	117.41	Culberson	99.34	Ochiltree	99.34	Bexar	63.22	Crane	63.22	Grayson	63.22	Kerr	63.22	Milam	63.22	Schleicher	63.22	Williamson	63.22
Shelby	135.47	Kaufman	117.41	Dallas	99.34	Polk	99.34	Blanco	63.22	Crockett	63.22	Grimes	63.22	Kimble	63.22	Mills	63.22	Scurry	63.22	Winkler	63.22
Starr	135.47	Marion	117.41	Denton	99.34	Refugio	99.34	Borden	63.22	Crosby	63.22	Guadalupe	63.22	King	63.22	Mitchell	63.22	Shackelford	63.22	Wise	63.22
Zapata	135.47	Navarro	117.41	DeWitt	99.34	San Jacinto	99.34	Briscoe	63.22	Dallam	63.22	Hale	63.22	Kinney	63.22	Montgomery	63.22	Somervell	63.22	Yoakum	63.22
Anderson	117.41	Panola	117.41	Dimmit	99.34	San Patricio	99.34	Brown	63.22	Dawson	63.22	Hall	63.22	Knox	63.22	Morris	63.22	Stephens	63.22	Young	63.22
Atascosa	117.41	Presidio	117.41	Ellis	99.34	Tarrant	99.34	Burleson	63.22	Deaf Smith	63.22	Hamilton	63.22	La Salle	63.22	Motley	63.22	Sterling	63.22	Carson	27.09
Austin	117.41	Red River	117.41	Fort Bend	99.34	Trinity	99.34	Burnet	63.22	Delta	63.22	Hansford	63.22	Lamar	63.22	Nacogdoches	63.22	Stonewall	63.22	Gray	27.09
Bee	117.41	Sabine	117.41	Frio	99.34	Tyler	99.34	Caldwell	63.22	Dickens	63.22	Hardeman	63.22	Lamb	63.22	Nolan	63.22	Sutton	63.22	Moore	27.09
Bowie	117.41	San Augustine	117.41	Galveston	99.34	Victoria	99.34	Callahan	63.22	Donley	63.22	Harris	63.22	Lampasas	63.22	Oldham	63.22	Swisher	63.22	Potter	27.09
Brazos	117.41	Smith	117.41	Goliad	99.34	Waller	99.34	Camp	63.22	Eastland	63.22	Hartley	63.22	Lee	63.22	Palo Pinto	63.22	Taylor	63.22	Sherman	27.09
Brooks	117.41	Titus	117.41	Hardin	99.34	Wharton	99.34	Castro	63.22	Ector	63.22	Haskell	63.22	Leon	63.22	Parker	63.22	Terrell	63.22		
Cass	117.41	Upshur	117.41	Hill	99.34	Willacy	99.34	Cherokee	63.22	Edwards	63.22	Hays	63.22	Limestone	63.22	Parmer	63.22	Terry	63.22		
Collin	117.41	Van Zandt	117.41	Hood	99.34	Zavala	99.34	Childress	63.22	Erath	63.22	Hemphill	63.22	Llano	63.22	Pecos	63.22	Throckmorton	63.22		
Duval	117.41	Webb	117.41	Jackson	99.34	Bandera	81.28	Clay	63.22	Falls	63.22	Hockley	63.22	Loving	63.22	Rains	63.22	Tom Green	63.22		
El Paso	117.41	Wilson	117.41	Jasper	99.34	Bastrop	81.28	Cochran	63.22	Fannin	63.22	Hopkins	63.22	Lubbock	63.22	Randall	63.22	Travis	63.22		
Franklin	117.41	Wood	117.41	Kenedy	99.34	Bell	81.28	Coke	63.22	Fayette	63.22	Houston	63.22	Lynn	63.22	Reagan	63.22	Upton	63.22		
Gregg	117.41	Angelina	99.34	Kleberg	99.34	Bosque	81.28	Coleman	63.22	Fisher	63.22	Howard	63.22	Madison	63.22	Real	63.22	Uvalde	63.22		
Harrison	117.41	Aransas	99.34	Lavaca	99.34	Jefferson	81.28	Collingsworth	63.22	Floyd	63.22	Hudspeth	63.22	Martin	63.22	Reeves	63.22	Val Verde	63.22		
Hendersor	117.41	Brazoria	99.34	Liberty	99.34	Orange	81.28	Comal	63.22	Foard	63.22	Hutchinson	63.22	Mason	63.22	Roberts	63.22	Walker	63.22		
Hidalgo	117.41	Brewster	99.34	Lipscomb	99.34	Andrews	63.22	Comanche	63.22	Freestone	63.22	Irion	63.22	McCulloch	63.22	Robertson	63.22	Ward	63.22		

Figure 4. 13: Annual Energy by county from scenario 1

Based on the results shown in Figure 4.13, Texas's counties could be classified into six categories, the largest one generates 135.47 GWh and it is available in 8 counties. The smallest county can reach 27.09 GWh, which is the case of 5 counties. Most counties in Texas can supply 63.22 GWh from 154 counties. The change in power generation comes from temperature fluctuations among counties in Texas, as shown in Figure 4.14.

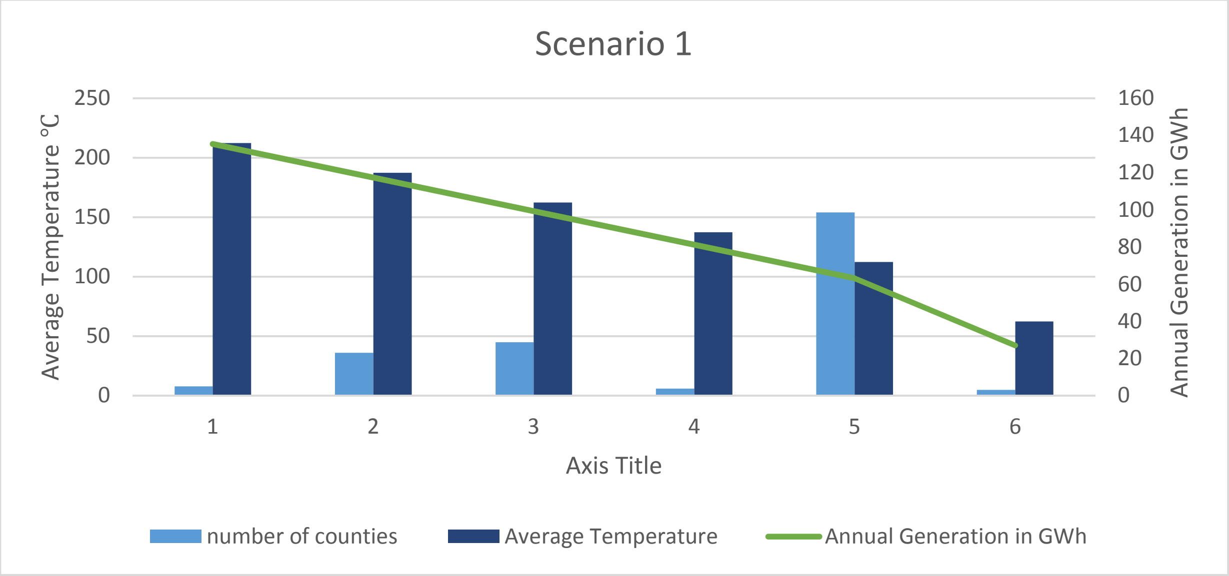


Figure 4. 14: Scenario #1 results based on Temperature classification

4.9.2 Scenario#2

In this case, the design has been implemented based on the oil and gas fields in Texas, which is called the oil state of the United States. In 2019, more than 40 % of the oil production came from Texas, and a quarter of the natural gas production as well 'Texas state energy profile,2020'. The depths of oil and gas wells vary from a hundred feet up to several thousand feet. Every extracted oil barrel produces up to gallons of water 'Texas moves ahead on discharging oil wastewater,2020', thus, every oil and gas well has a water source which is very important for a geothermal plant. From all of that, construct a geothermal power plant at every depleted oil and gas wells will reduce the capital cost due to the availability of the required depth and water, which makes this project economical and require fewer time constructions, besides, using the depleted wells to generate electricity.

According to data from the Texas Railroad Commission, Texas has 6,139 depleted natural gas and oil wells 'Orphan Well Query for January 2019,2019', distributed among 197 counties in Texas. Therefore, as mentioned earlier, due to the following three main factors, every depleted gas and oil well is a good potential for geothermal power plants. First, due to the formation of oil and gas wells, the availability of water. Second, the land and infrastructure need to be improved, but it is not bare land. Third, and finally, the depth of the well reaches thousands of feet, very close to the depth of the proposed system.

In this scenario. Under the same general assumptions, a geothermal power plant is designed on each well, but the size of the geothermal reservoir is 5.179 Km^2 * 100 m, which means the volume size is 0.5179 Km^3, the 5.179 Km^2 comes from the normal distance between the gas and oil wells 'Kemp,2013'. By using the temperature maps in Figure 4.11 from SMU Geothermal labs and applying the Equations in the flowchart in Figure 4.10 and taking into consideration the general assumption in the hypothetical model in the calculation is the following:

$E_S\ at$ Hutchinson $= \rho * C * V * (T_R - T_S)$

$E_S\ at\ Gonzales = 2550 * 2000 * 0.5179 * 10^9 * (112.5 - 25)$

$=2.311 * 10^{17}$ Joule

$E_x at\ Gonzales = RF * E_S$

$E_x at\ Gonzales = 0.15 * 2.311 * 10^{17}$

$E_x at\ Gonzales = 3.466 * 10^{16}$ Joule

$E_e at\ Gonzales = \frac{E_x * \eta_{heat\ engine} * \eta_{mechanical\ turbine}}{3600}$

$$E_e at\ Gonzales = \frac{3.466 * 10^{16} * 0.4 * 0.85}{3600}$$

$E_e at\ Gonzales = 3.274 * 10^{12}$ Wh

$$E_A at\ Gonzales = \frac{E_e}{Lifespan}$$

$$E_A at\ Gonzales = \frac{3.274 * 10^{12}}{100}$$

$E_A at\ Gonzales = 3.274 * 10^{10}$=32.74 GWh

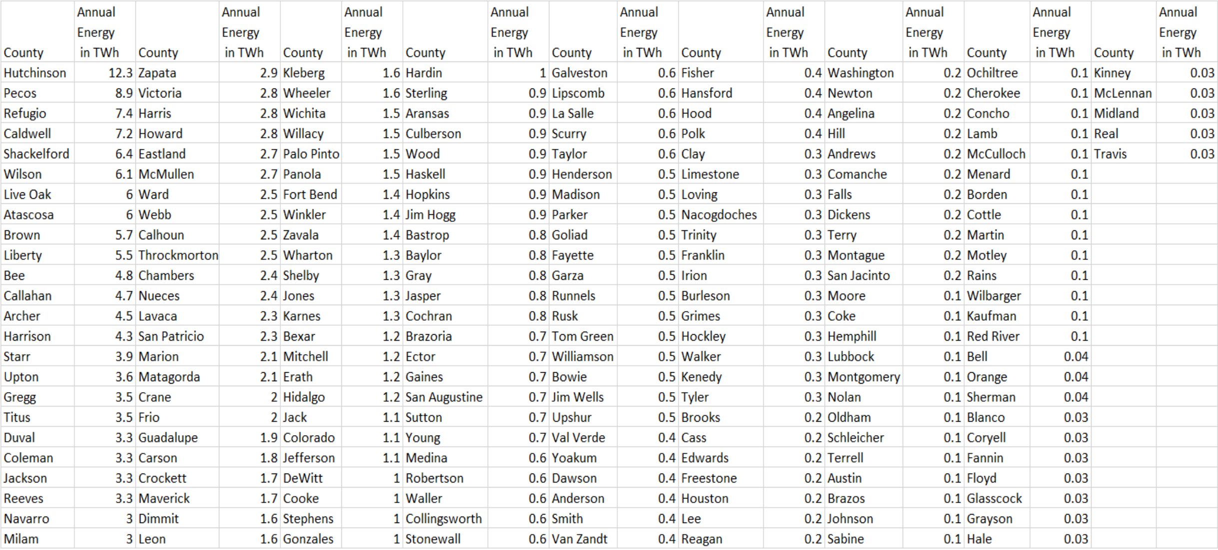
$Total\ E_A at\ Gonzales$= $E_A at\ Gonzales\ *$

$number\ of\ depleted\ oil\ and\ gas\ wells\ in\ Gonzales$

$Total\ E_A at\ Gonzales$ = 32.74 GWh * 375

$Total\ E_A at\ Gonzales$ = 12.27 TWh

In this case, Texas can produce 251 TWh. The annual generation varies from one county to another, the range is from 12.27 to 0.032 TWh. 71 counties in Texas have enough resources based on this scenario to produce more than 1 TWh per year. 98 counties have enough resources based on this scenario to generate more than 100 GWh and less than 1 TWh. According to this situation, only 28 counties have insufficient resources of less than 100 GWh. As shown in Figure 4.15.



County	Annual Energy in TWh	County	Annual Energy in TWh	County	Annual Energy in TWh	County	Annual Energy in TWh	County	Annual Energy in TWh	County	Annual Energy in TWh	County	Annual Energy in TWh	County	Annual Energy in TWh	County	Annual Energy in TWh
Hutchinson	12.3	Zapata	2.9	Kleberg	1.6	Hardin	1	Galveston	0.6	Fisher	0.4	Washington	0.2	Ochiltree	0.1	Kinney	0.03
Pecos	8.9	Victoria	2.8	Wheeler	1.6	Sterling	0.9	Lipscomb	0.6	Hansford	0.4	Newton	0.2	Cherokee	0.1	McLennan	0.03
Refugio	7.4	Harris	2.8	Wichita	1.5	Aransas	0.9	La Salle	0.6	Hood	0.4	Angelina	0.2	Concho	0.1	Midland	0.03
Caldwell	7.2	Howard	2.8	Willacy	1.5	Culberson	0.9	Scurry	0.6	Polk	0.4	Hill	0.2	Lamb	0.1	Real	0.03
Shackelford	6.4	Eastland	2.7	Palo Pinto	1.5	Wood	0.9	Taylor	0.6	Clay	0.3	Andrews	0.2	McCulloch	0.1	Travis	0.03
Wilson	6.1	McMullen	2.7	Panola	1.5	Haskell	0.9	Henderson	0.5	Limestone	0.3	Comanche	0.2	Menard	0.1		
Live Oak	6	Ward	2.5	Fort Bend	1.4	Hopkins	0.9	Madison	0.5	Loving	0.3	Falls	0.2	Borden	0.1		
Atascosa	6	Webb	2.5	Winkler	1.4	Jim Hogg	0.9	Parker	0.5	Nacogdoches	0.3	Dickens	0.2	Cottle	0.1		
Brown	5.7	Calhoun	2.5	Zavala	1.4	Bastrop	0.8	Goliad	0.5	Trinity	0.3	Terry	0.2	Martin	0.1		
Liberty	5.5	Throckmorton	2.5	Wharton	1.3	Baylor	0.8	Fayette	0.5	Franklin	0.3	Montague	0.2	Motley	0.1		
Bee	4.8	Chambers	2.4	Shelby	1.3	Gray	0.8	Garza	0.5	Irion	0.3	San Jacinto	0.2	Rains	0.1		
Callahan	4.7	Nueces	2.4	Jones	1.3	Jasper	0.8	Runnels	0.5	Burleson	0.3	Moore	0.1	Wilbarger	0.1		
Archer	4.5	Lavaca	2.3	Karnes	1.3	Cochran	0.8	Rusk	0.5	Grimes	0.3	Coke	0.1	Kaufman	0.1		
Harrison	4.3	San Patricio	2.3	Bexar	1.2	Brazoria	0.7	Tom Green	0.5	Hockley	0.3	Hemphill	0.1	Red River	0.1		
Starr	3.9	Marion	2.1	Mitchell	1.2	Ector	0.7	Williamson	0.5	Walker	0.3	Lubbock	0.1	Bell	0.04		
Upton	3.6	Matagorda	2.1	Erath	1.2	Gaines	0.7	Bowie	0.5	Kenedy	0.3	Montgomery	0.1	Orange	0.04		
Gregg	3.5	Crane	2	Hidalgo	1.2	San Augustine	0.7	Jim Wells	0.5	Tyler	0.3	Nolan	0.1	Sherman	0.04		
Titus	3.5	Frio	2	Jack	1.1	Sutton	0.7	Upshur	0.5	Brooks	0.2	Oldham	0.1	Blanco	0.03		
Duval	3.3	Guadalupe	1.9	Colorado	1.1	Young	0.7	Val Verde	0.4	Cass	0.2	Schleicher	0.1	Coryell	0.03		
Coleman	3.3	Carson	1.8	Jefferson	1.1	Medina	0.6	Yoakum	0.4	Edwards	0.2	Terrell	0.1	Fannin	0.03		
Jackson	3.3	Crockett	1.7	DeWitt	1	Robertson	0.6	Dawson	0.4	Freestone	0.2	Austin	0.1	Floyd	0.03		
Reeves	3.3	Maverick	1.7	Cooke	1	Waller	0.6	Anderson	0.4	Houston	0.2	Brazos	0.1	Glasscock	0.03		
Navarro	3	Dimmit	1.6	Stephens	1	Collingsworth	0.6	Smith	0.4	Lee	0.2	Johnson	0.1	Grayson	0.03		
Milam	3	Leon	1.6	Gonzales	1	Stonewall	0.6	Van Zandt	0.4	Reagan	0.2	Sabine	0.1	Hale	0.03		

Figure 4. 15: Annual Energy by county from scenario 2

4.9.3 Scenario#3

Texas has 15 coal power plants ‘List of power stations in Texas, n.d’. Replacing all coal power plants with geothermal power plants has many advantages starting from reducing the gas emission from the coal power plants and also reduce the capital cost of installing a new geothermal power plant because the coal plant and geothermal power plants have the same components. In this scenario, a geothermal power plant is designed at every coal power plants under the same general assumption except the size of the geothermal reservoir, which is reduced to 2.58 *1 km^3 due to the normal area of the coal power plant which is 640 acre ‘Nace,2010’. By using the temperature maps in Figure 4.11 from SMU Geothermal labs and applying the Equations in the flowchart in Figure 4.10 and taking into consideration the general assumption in the hypothetical model in the calculation is the following:

$$E_S \, at \text{ Oleto creek} = \rho * C * V * (T_R - T_S)$$

$$E_S \, at \text{ Oleto creek} = 2550 * 2000 * 2.58 * 10^9 * (162.5 - 25)$$

E_S at Oleto creek $=1.80 * 10^{18}$ Joule

$E_x at$ Oleto creek $= RF * E_S$

$E_x at$ Oleto creek $= 0.15 * 1.8 * 10^{18}$

$E_x at$ Oleto creek $= 2.71 * 10^{17}$ Joule

$E_e at$ Oleto creek$= \frac{E_x * \eta_{heat\ engine} * \eta_{mechanical\ turbine}}{3600}$

$$E_e at \text{ Oleto creek} = \frac{2.71 * 10^{17} * 0.4 * 0.85}{3600}$$

$E_e at$ Oleto creek $= 2.56 * 10^{13}$ Wh

$$E_A at \text{ Oleto creek} = \frac{E_e}{Lifespan}$$

$$E_A at \text{ Oleto creek} = \frac{2.56 * 10^{13}}{100}$$

$E_A at$ Oleto creek $= 2.56 * 10^{11}$=256.30 GWh

Texas can produce up to 2.865 TWh from this scenario. The annual generation varies from one plant to another, the range is from 69.9 to 302.91 GWh, as shown in Table 4.2.

Coal Power Plant	Annual Energy in GWh
Oleto Creek	256.3
Fayette	163.1
Gibbons Creek	163.1
Harrington	69.9
Limestone	163.1
Martin Lake	163.1

Oak Grove	163.1
Pirkey	302.9
Sandy Creek	163.1
J.K. Spruce	163.1
Tolk	163.1
Major Oak Power	163.1
W. A. Parish	163.1
Welsh	302.9
San Miguel lignite powerplant	302.9
New capacity	2,865.9

Table 4. 2: Annual Energy by county from scenario 3

4.10 Results

From the above three scenarios, Texas can provide up to 274TWh of power, as shown in Figure 4.16. Most of the annual output comes from scenario 2. However, Scenario 2 and 3 are based on the limited resources of depleted oil and gas wells and coal-fired power plants. Contrasted with Scenario 2 and 3, Scenario 1 is not restricted and has a lot of resources based on the land area and temperature of Texas. Although this is a very expensive system, it is not economically efficient.

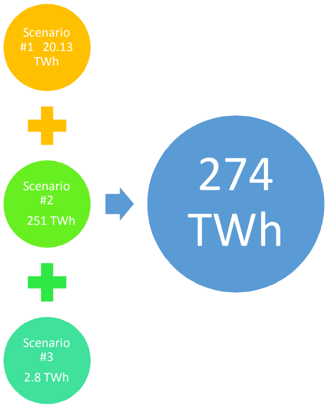


Figure 4. 16: Geothermal results from three scenarios

All counties in Texas have sufficient geothermal energy resources to provide at least 63 GWh of electricity for the above scenarios. The annual power generation between counties varies from 12.3 TWh to 63 GWh. 78 counties in Texas have sufficient resources to use enhanced geothermal systems to produce more than 1 TWh of electricity. 36 counties can supply more than 500 GWh of electricity each year, up to 1 TWh. 76 counties in Texas have sufficient resources to provide up to 500 GWh and more than 100 GWh of electricity. 64 counties in Texas have sufficient resources to provide up to 100 GWh and more than 50 GWh of electricity All results are shown in Figure 4.17.

County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Hutchinson	12341	Milam	3075.4	Kleberg	1694.3	Hardin	1076.9	Medina	685.3	Hood	459.5	Freestone	292.4	Schleicher	194.2	Dallas	99.3	Castro	63.2	Llano	63.2
Pecos	8968.8	Harris	3009.3	Wheeler	1634.8	Wood	1029.5	Galveston	665.3	Polk	459.5	Houston	292.4	Terrell	194.2	Denton	99.3	Childress	63.2	Lynn	63.2
Refugio	7456.7	Victoria	2929.1	Willacy	1591.4	Aransas	1025.4	Lipscomb	665.3	Dawson	456.1	Lee	292.4	Kaufman	178.2	Ellis	99.3	Comal	63.2	Mason	63.2
Caldwell	7233.5	Howard	2813.5	Panola	1576.7	Culberson	1025.4	Henderson	664.7	Fisher	423.4	Reagan	292.4	Red River	178.2	Tarrant	99.3	Crosby	63.2	Mills	63.2
Shackelford	6447.7	McMullen	2801.5	Wichita	1569.3	Sterling	1012.7	Collingsworth	652.6	Hansford	423.4	Washington	292.4	Moore	167.4	Potter	97	Dallam	63.2	Morris	63.2
Atascosa	6379.2	Eastland	2780.7	Fort Bend	1539.9	Robertson	1011.5	Stonewall	652.6	Franklin	421.4	Andrews	259.7	Cherokee	161.4	Blanco	96	Deaf Smith	63.2	Parmer	63.2
Wilson	6258.7	Webb	2610.4	Zavala	1539.9	Jim Hogg	968.7	La Salle	619.8	Trinity	408	Comanche	259.7	Concho	161.4	Coryell	96	Delta	63.2	Randall	63.2
Live Oak	6169.2	Ward	2584.3	Palo Pinto	1536.6	Haskell	947.2	Scurry	619.8	Clay	390.6	Falls	259.7	McCulloch	161.4	Fannin	96	Donley	63.2	Roberts	63.2
Brown	5792.9	Calhoun	2568.9	Winkler	1503.8	Bastrop	923.2	Taylor	619.8	Limestone	390.6	McLennan	259.1	Menard	161.4	Floyd	96	Foard	63.2	Rockwall	63.2
Liberty	5553.1	Throckmorton	2518.8	Shelby	1468.5	Hopkins	914.5	Bowie	603.8	Loving	390.6	Montague	253.7	Jeff Davis	135.5	Glasscock	96	Gillespie	63.2	San Saba	63.2
Bee	4921	Chambers	2466	Bexar	1437.7	Baylor	881.7	Jim Wells	603.8	Nacogdoches	390.6	San Jacinto	253.7	Borden	128.7	Grayson	96	Hall	63.2	Somervell	63.2
Callahan	4777.9	Nueces	2466	Wharton	1437	Jasper	871.1	Upshur	603.8	Brooks	360.6	Austin	239	Cottle	128.7	Hale	96	Hamilton	63.2	Swisher	63.2
Harrison	4737.5	Lavaca	2414.6	Karnes	1394.3	Goliad	870.2	Madison	587.1	Cass	360.6	Brazos	239	Martin	128.7	Kinney	96	Hardeman	63.2	Uvalde	63.2
Archer	4581.5	San Patricio	2414.6	Jones	1340.1	Brazoria	819.6	Parker	587.1	Irion	357.9	Johnson	239	Motley	128.7	Midland	96	Hartley	63.2	Wise	63.2
Starr	4064.4	Marion	2184.8	Mitchell	1274.6	Cochran	816.3	Garza	554.3	Kenedy	356.6	Sabine	239	Rains	128.7	Real	96	Hays	63.2		
Titus	3886.2	Matagorda	2157.3	Hidalgo	1272.7	Gray	812.9	Runnels	554.3	Tyler	356.6	Dickens	226.9	Wilbarger	128.7	Travis	96	Hudspeth	63.2		
Upton	3632	Crane	2093.2	Erath	1241.9	San Augustine	786.3	Tom Green	554.3	Newton	345.9	Terry	226.9	Bell	123.4	Bandera	81.3	Kendall	63.2		
Gregg	3583.3	Frio	2054.4	Colorado	1231.2	Ector	783.5	Williamson	554.3	Burleson	325.1	Ochiltree	202.2	Orange	123.4	Bosque	81.3	Kent	63.2		
Duval	3461.7	Guadalupe	1929.5	Jack	1209.2	Gaines	750.8	Val Verde	488.9	Hockley	325.1	Coke	194.2	Collin	117.4	Sherman	69.2	Kerr	63.2		
Coleman	3402.8	Leon	1830.6	Jefferson	1133.7	Sutton	718	Yoakum	488.9	Walker	325.1	Hemphill	194.2	El Paso	117.4	Armstrong	63.2	Kimble	63.2		
Jackson	3392.1	Carson	1823.2	DeWitt	1128.3	Young	718	Grimes	488.2	Lamb	324.5	Lubbock	194.2	Hunt	117.4	Bailey	63.2	King	63.2		
Reeves	3337.3	Crockett	1798.5	Gonzales	1117.7	Fayette	717.4	Anderson	482.2	Angelina	305.1	Montgomery	194.2	Presidio	117.4	Briscoe	63.2	Knox	63.2		
Navarro	3157.6	Maverick	1797.2	Cooke	1078.2	Rusk	717.4	Smith	482.2	Hill	305.1	Nolan	194.2	Brewster	99.3	Burnet	63.2	Lamar	63.2		
Zapata	3082.2	Dimmit	1745.7	Stephens	1078.2	Waller	716.7	Van Zandt	482.2	Edwards	292.4	Oldham	194.2	Cameron	99.3	Camp	63.2	Lampasas	63.2		

Figure 4. 17: Geothermal energy results by counties in Texas from all scenarios

Geothermal energy resources vary from one county to another inside Texas, based on that Texas's counties can be categorized into four main groups, the first one is about all counties have enough resources to generate more than 1 TWh, Texas has 78 counties in this group. The second categorize is for all counties that have enough resources to produce more than 500 TWh and less than 1,000 GWh, Texas has 36 counties in this category. In the third category, there are 76 counties, and they have enough geothermal energy resources to power more than 100 GWh and less than 500 GWh. In the last category, there are 64 counties, and they have enough geothermal energy resources to power more than 50 GWh and less than 100 GWh. All categories are shown in Figure 4.18.

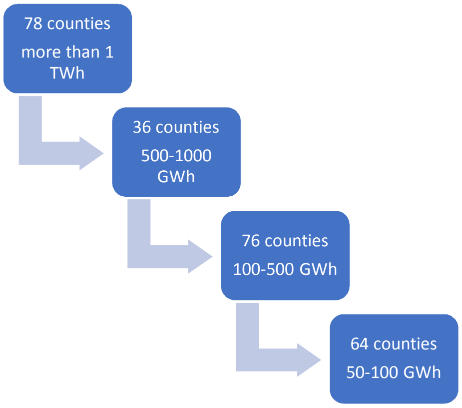


Figure 4. 18: Geothermal power plants categorization in Texas

4.11 Cost

The enhanced geothermal systems are very expensive system and the capital cost vary from 9,000-11,000 $/KW 'Belyakov,2019'. Of all renewable energy sources, this capital cost may be the most expensive, and even more expensive in all types of storage or traditional power plants. In 'Black & Veatch,2012' predicted the capital cost to be 9,625 $/kW in 2020 and to reach 8,420 $/kW in 2050. The investment cost of an enhanced geothermal system comes from different sources, such as wells, heat exchangers, owners, turbines, etc., as shown in Figure 4.19 ‘Black & Veatch,2012’.

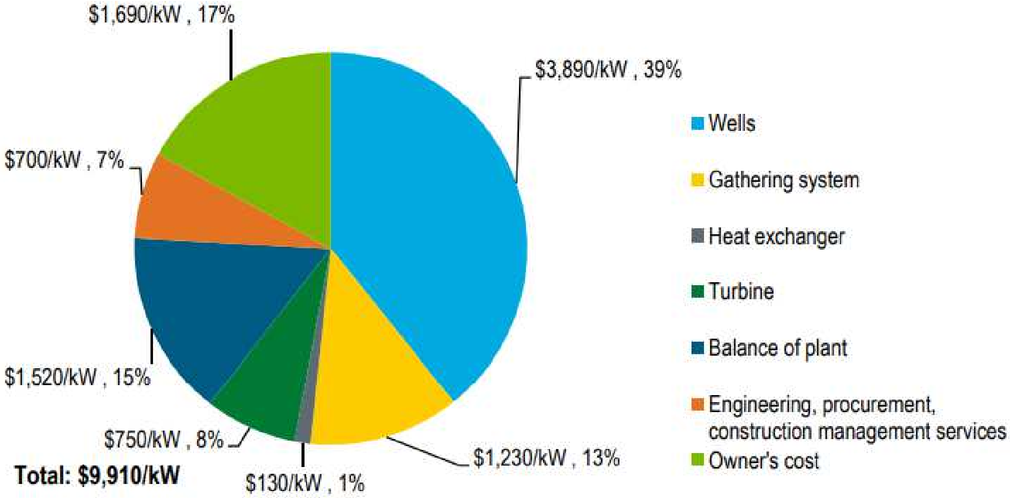


Figure 4. 19: Capital cost of Enhanced Geothermal system

Converting a depleted oil well into a geothermal power plant could be useful for two purposes; avoid the decommissioning cost of the well's infrastructure plus the cost of drilling and exploration ‘Soldo and Alimonti,2015’. The cost of drilling and installing the power plants besides the exploration of the field is 80% of the capital cost of the enhanced geothermal system ‘Soldo and Alimonti,2015’.Moreover, if we compare the cost of converting a depleted oil into a geothermal power plant based on the chart shown in Figure 4.19, the cost could be less by 77% of the capital cost due to saving of cost from many factors such as drilling, Gathering system, Heat exchanger, construction management service and owner's cost. Therefore, the capital cost of scenario 2 is 77-80% less than scenario 1.

Scenario 3 is proposed based on the coal power plant, which means the cost of the turbine, owners, and the construction management services, which is almost around 33 % of the capital cost of the enhanced geothermal systems are saved as shown in Figure 4.19. Therefore the capital cost of scenario 3 is 33% less than scenario 1. However, in some references such 'IRENA, 2017' the saving cost could reach up to 49 %. The capital costs of all scenarios are shown in Table 4.3.

	Capital cost $/kW	Average capital cost $/kW
Scenario 1	9,000-11,000 ‘Belyakov,2019’	10,000
Scenario 2	Less77-80% of Scenario 1	2,000 ‘Soldo and Alimonti,2015’
Scenario 3	Less 33-49% of Scenario 1	5,100 ‘IRENA, 2017’

Table 4. 3: Capital costs of all scenarios.

CHAPTER V

BIOMASS ENERGY

5.1 What Is The Biomass Energy

Biomass is renewable organic energy that comes from animals, plants, and humans ‘EIA-Biomass explained,2020’. Biomass energy is the modern name of the older technology of burning organic material to extract heat ‘Biomass,2020’. Biomass comes from the sun, because the process of photosynthesis plays an important role in all organic materials. Hence, it is considered to be another form of solar energy.

Biomass has many resources, first of all, agricultural residues, such as corn, rice, and cotton, and then solid or liquid sewage in municipal waste. In addition, biomass can be collected from cow dung and manure. All of the biomass resources are permanent and have a comparable rate of replenishment and that is why it is considered a renewable energy resource. Biomass resources consume carbon dioxide during its production, and then release carbon dioxide when burned. Hence, it is less harmful to the environment and is considered a clean and renewable energy source. The utilization of biomass energy has a wide range of applications, from large-scale and small-scale heating systems, liquid fuels such as ethanol to power generation ‘Fei,2012’, as shown in Figure 5.1.

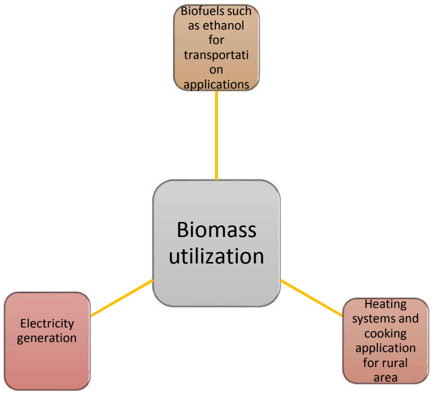


Figure 5. 1: Biomass application

5.2 Biomass Into Electricity

There are three technologies for extracting energy from biomass resources; first, Thermochemical conversion, which is based on burning biomass resources to produce heat by an excess of air in the combustion technique, and partial air on gasification for producing bio-gases or without air in Pyrolysis technology. Secondly, biologic conversion or biochemical conversion depends on using a special type of bacteria to produce liquids or gases by using two main technology as Fermentation and Anaerobic digestion, the latter technology based on fresh plants by squeeze it to produce oil and it is known as a physical conversion as shown in Figure 5.2 ‘Biomass, n.d’.

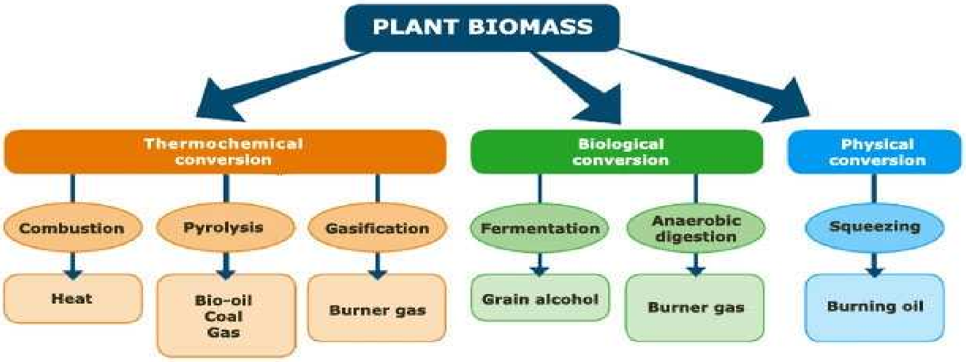


Figure 5. 2: Biomass energy conversion

The components of a biomass power plant are exactly the same as those of a thermal power plant. Hence, they have the same working principle, which is, only use hot steam to turn a turbine connected to a generator to generate electricity. The main four components for any biomass and fossil power plants are boiler, turbine, condenser, and generator as shown in Figure 5.3 ‘Jorgenson et al,2011’, the difference is in the boiler design and that is due to the difference in the heat value of the biomass fuel, which is lower than coal and for the ash remaining ‘Fei,2012’.

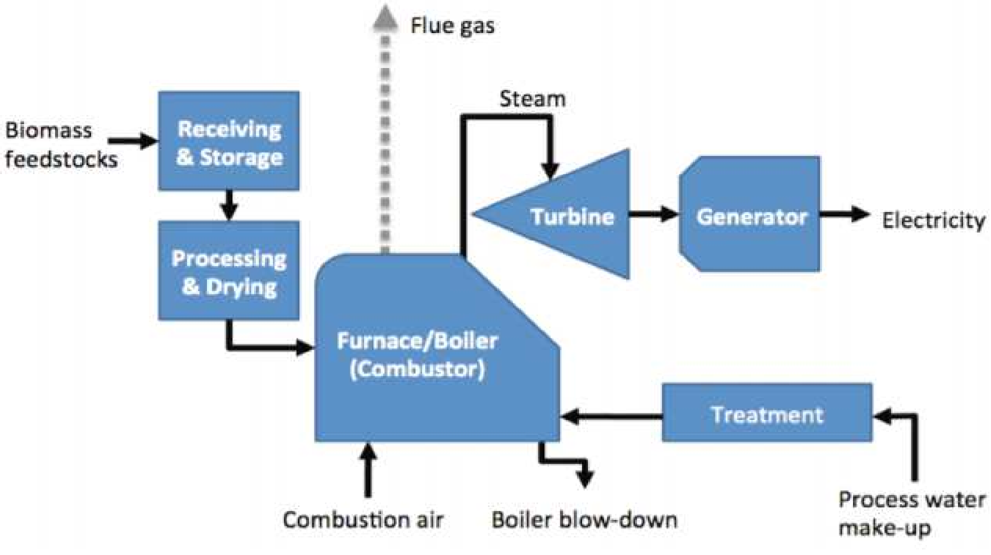


Figure 5. 3: Biomass power plant components

5.3 Methodology

In this work, a prospective biomass system is designed based on the available biomass resources in Texas from four main sources: Livestock, wastewater, municipal solid waste, and agricultural crops, the method of the design is achieved by three major steps; firstly, gathering the required information of cattle, crop production and municipal waste from Texas department of agriculture, Texas Commission environmental quality and any available website. Second, the field of study is on all Texas counties and their resources. Finally, the observation results of biomass projects in the United States and global projects based on direct combustion technology and anaerobic digester are combined with the existing biomass resources in Texas. The method of the proposed system is shown in Figure 5.4.

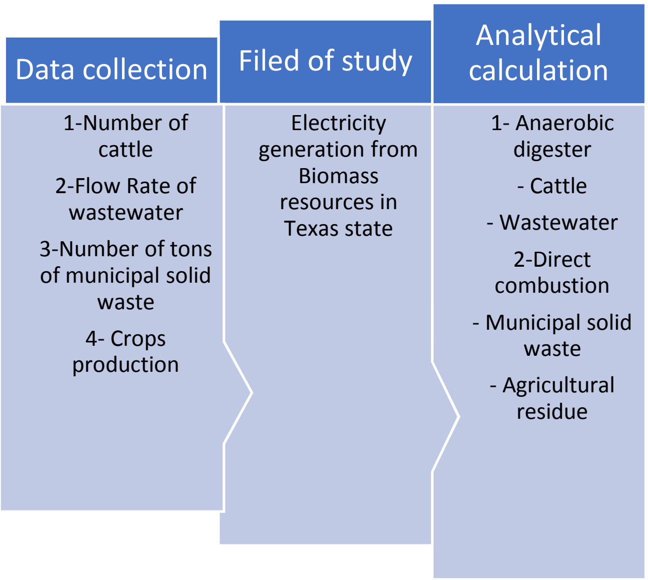


Figure 5. 4: Methodology flowchart

5.4 Biomass Resources In Texas

5.4.1 Livestock

Based on Texas counties website in 2017 ‘Texas Counties: Cattle Population in 2017,2017’, Texas has around 12,573,876 cattle and they are distributed among the state as shown in Figure 5.5 ‘County Estimate Map – Cattle,2020’. Deaf Smith county has the most number of cattle in Texas with around 600,000. most of the cattle are in the north part of Texas, especially in northern High Plains.

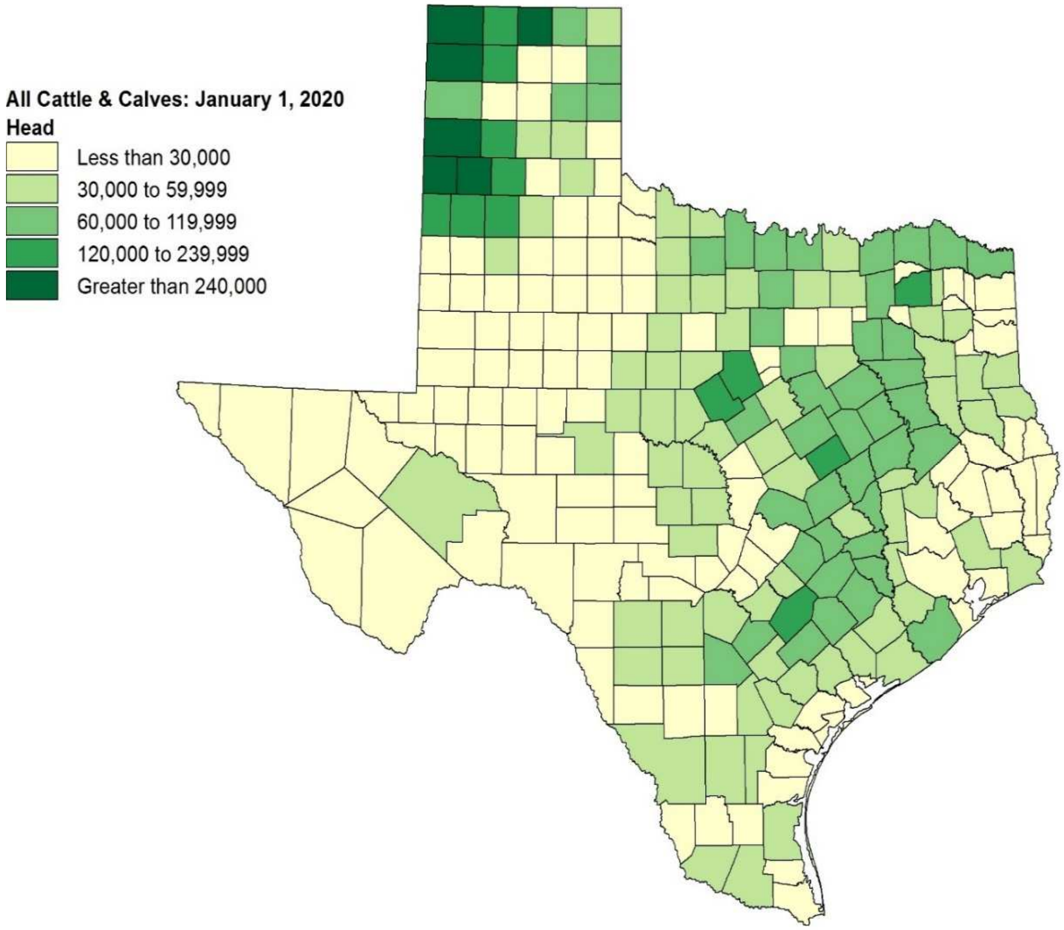


Figure 5. 5: Cattle in Texas

5.4.2 Wastewater Plants

Texas has more than 2,500 wastewater treatment plants and most of them are located in the eastern and southern part near to the sea, The biggest wastewater treatment plants where the flow rate is over 50 million gallons per day are in the biggest city such as Houston, Austin, Dallas, Fort Worth and San Antonio and that is due to the higher population on these cities. As shown in Figure 5.6 'Stillwell et al., 2010'.

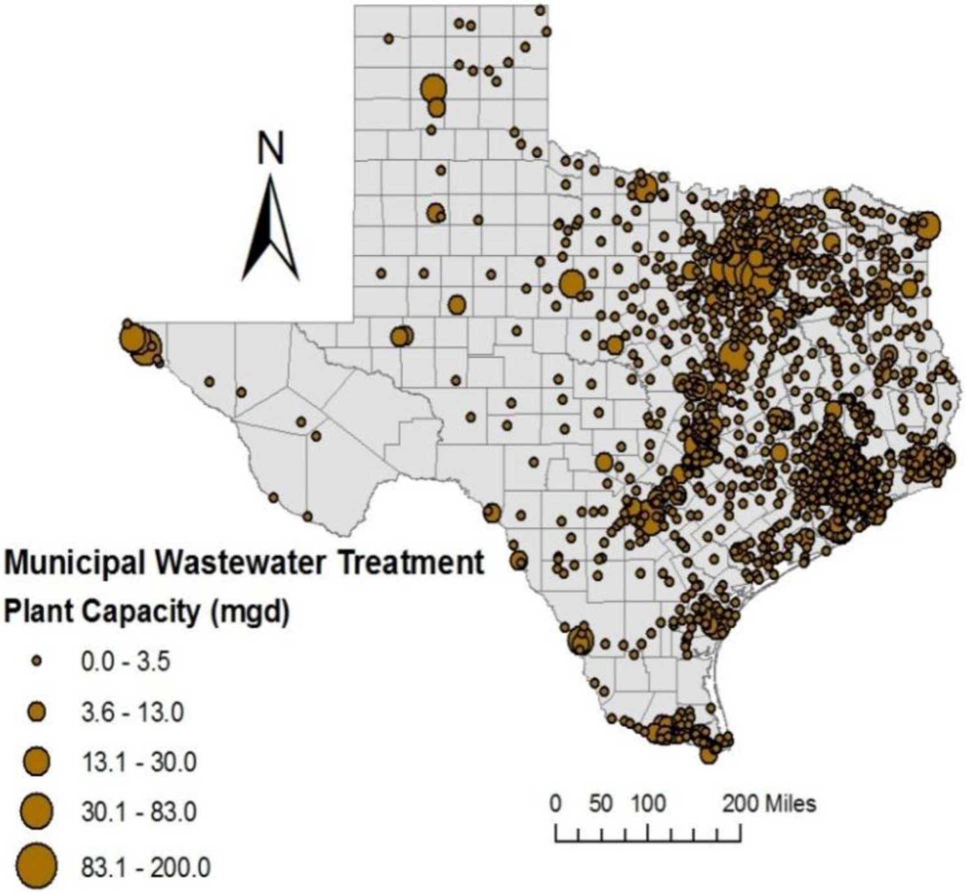


Figure 5. 6: Wastewater treatment plants in Texas

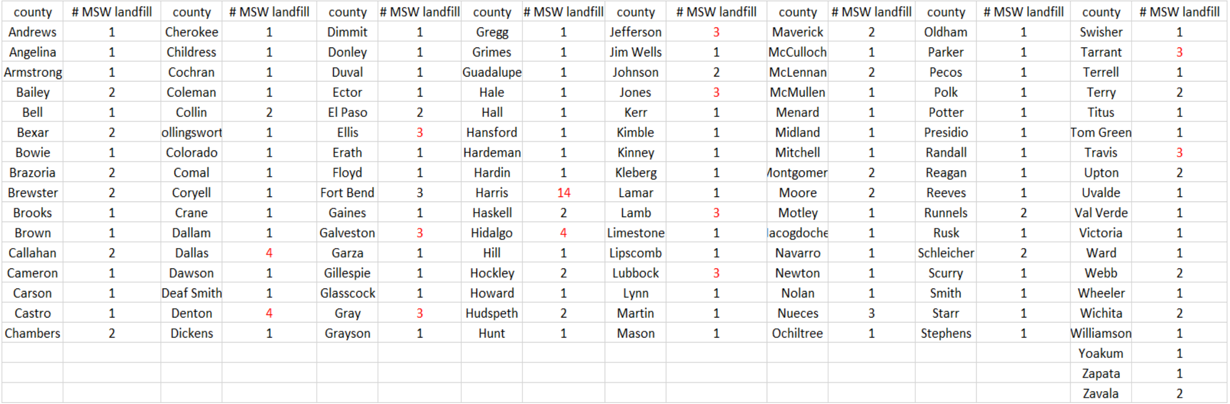
Houston has 39 wastewater treatment and treats an average of 250 million gallons daily 'Dunne, n.d' and with a capacity of up to 564 million gallons daily 'Wastewater Treatment Facilities, 2018'. San Antonio wastewater treatment plant capacity is around 225 million gallons daily ‘SAWS Water Recycling Facts 2021’.Dallas wastewater treatment plant capacity is around 280 million gallons daily ‘ Dallas Water Utilities,2020’.

5.4.3 Municipal Solid Waste

Based on the Texas Commission on environmental quality (TCEQ) in 2019, Texas has around 198 Municipal solid waste (MSW) landfills ‘Data on Municipal Solid Waste Facilities in Texas,2020’. They are located in different counties in the state of Texas, some of them serve only one county, some serve more than one county, covering up to 20 counties in Texas, there are 123 counties do not have MSW landfills, so they cannot generate electricity based on direct burning of waste biomass, but 131 counties in Texas have MSW landfills, so this method applies to them. Table 5.1‘Data on Municipal Solid Waste Facilities in Texas,2020’ shows the distribution of MSW landfills in Texas, and Figure 5.7 ‘Data on Municipal Solid Waste Facilities in Texas,2020’ shows the name of counties that have MSW landfills and as shown Harris has the most number of MSW landfills in Texas with 14 landfills followed by Dallas, Denton, and Hidalgo with 4 MSW landfills for each.

Number of Landfills	**Number of counties**
71	1
58	2-5
49	6-10
8	11-15
7	16-20
5	>20

Table 5. 1: Number of landfills in Texas



county	# MSW landfill	county	# MSW landfill	county	# MSW landfill	county	# MSW landfill	county	# MSW landfill	county	# MSW landfill	county	# MSW landfill	county	# MSW landfill
Andrews	1	Cherokee	1	Dimmit	1	Gregg	1	Jefferson	3	Maverick	2	Oldham	1	Swisher	1
Angelina	1	Childress	1	Donley	1	Grimes	1	Jim Wells	1	McCulloch	1	Parker	1	Tarrant	3
Armstrong	1	Cochran	1	Duval	1	Guadalupe	1	Johnson	2	McLennan	2	Pecos	1	Terrell	1
Bailey	2	Coleman	1	Ector	1	Hale	1	Jones	3	McMullen	1	Polk	1	Terry	2
Bell	1	Collin	2	El Paso	2	Hall	1	Kerr	1	Menard	1	Potter	1	Titus	1
Bexar	2	ollingswort	1	Ellis	3	Hansford	1	Kimble	1	Midland	1	Presidio	1	Tom Green	1
Bowie	1	Colorado	1	Erath	1	Hardeman	1	Kinney	1	Mitchell	1	Randall	1	Travis	3
Brazoria	2	Comal	1	Floyd	1	Hardin	1	Kleberg	1	Montgomer	2	Reagan	1	Upton	2
Brewster	2	Coryell	1	Fort Bend	3	Harris	14	Lamar	1	Moore	2	Reeves	1	Uvalde	1
Brooks	1	Crane	1	Gaines	1	Haskell	2	Lamb	3	Motley	1	Runnels	2	Val Verde	1
Brown	1	Dallam	1	Galveston	3	Hidalgo	4	Limestone	1	acogdoche	1	Rusk	1	Victoria	1
Callahan	2	Dallas	4	Garza	1	Hill	1	Lipscomb	1	Navarro	1	Schleicher	2	Ward	1
Cameron	1	Dawson	1	Gillespie	1	Hockley	2	Lubbock	3	Newton	1	Scurry	1	Webb	2
Carson	1	Deaf Smith	1	Glasscock	1	Howard	1	Lynn	1	Nolan	1	Smith	1	Wheeler	1
Castro	1	Denton	4	Gray	3	Hudspeth	2	Martin	1	Nueces	3	Starr	1	Wichita	2
Chambers	2	Dickens	1	Grayson	1	Hunt	1	Mason	1	Ochiltree	1	Stephens	1	Williamson	1
														Yoakum	1
														Zapata	1
														Zavala	2

Figure 5. 7: MSW landfills number at each county in Texas

Based on TCWQ in 2019 ‘Municipal Solid Waste in Texas: A Year in Review,2020’, every person in Texas produced 7 pounds of waste and the total amount was around 37 million tons among Texas as shown in Figure 5.8 ‘Municipal Solid Waste in Texas: A Year in Review,2019’.

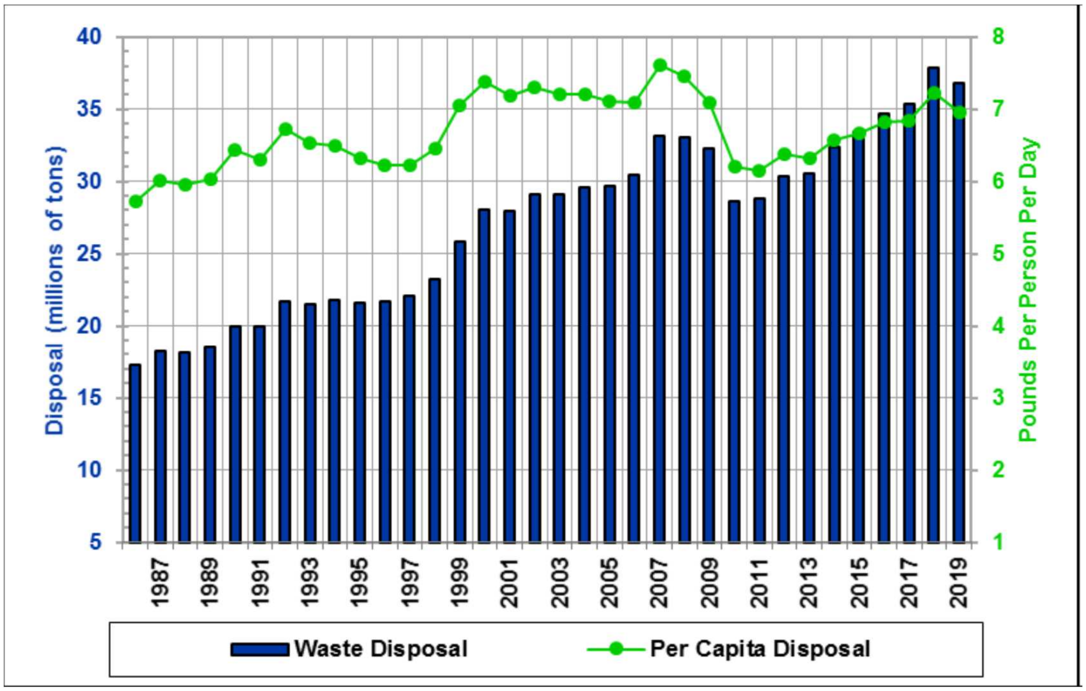


Figure 5. 8: Texas MSW Landfill

5.4.4 Agriculture Crops

Texas leads all other states in the number of farms and ranches. While the primary crops of Texas are cotton, corn, feed grains (sorghum, milo, etc.), rice and wheat 'Crop Information - Planting & Harvesting, n.d'.

5.4.4.1 Rice

In 2019, Texas produced 11.028 million deadweight tons (560,247 metric tons) of rice as shown in Figure 5.9 'Texas Rice Yield and Production,2021', only seven counties produce almost 82% of the rice in Texas as shown in Table 5.2 'Quick Stats, n.d'.

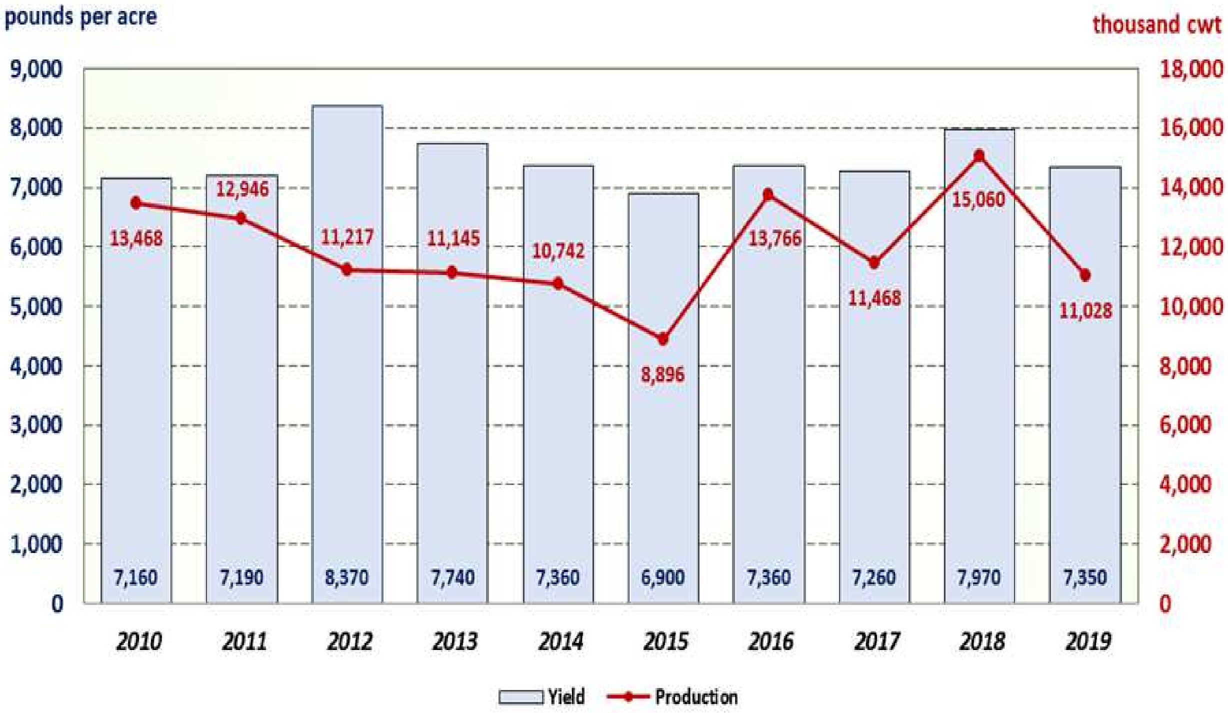


Figure 5. 9: Texas's production of rice from 2010-2019

County	Production of rice in cwt
Colorado	2,125,000
Brazoria	1,375,000
Chambers	647,000
Jackson	828,000
Jefferson	604,000
Matagorda	905,000
Wharton	2,520,000
Other counties	2,024,000
Total production	11,028,000

Table 5. 2: Top seven counited in Texas for rice production

5.4.4.2 Cotton

Texas upland cotton production totaled 6.320 million bales, most of the production comes as shown in Table 5.3 ‘ANNUAL COTTON REVIEW,2020’.

District	Production in bales
Northern High Plains	908,300
Southern High Plains	2,136,700
Northern Low Plains	411,800
Southern Low Plains	353,300
Cross Timbers	14,400
Blacklands	189,900
North East	14,300
South East	64,600
Trans-Pecos	49,200
Edwards Plateau	278,200
South Central	176,000
Coastal Bend	726,400
Upper Coast	555,200
South	102,700
Lower Valley	339,000
Texas	6,320,000

Table 5. 3: Texas’s production of Cotton in 2019

5.4.4.3 Corn

Texas corn production totaled 287 million bushels and it is distributed among Texas as shown in Figure 5.10 ‘County Estimate Map – Corn,2020’.Figure 5.11‘Quick Stats, n.d’ Shows the top 52 corn-producing counties in Texas, accounting for 72% of the total corn production in Texas

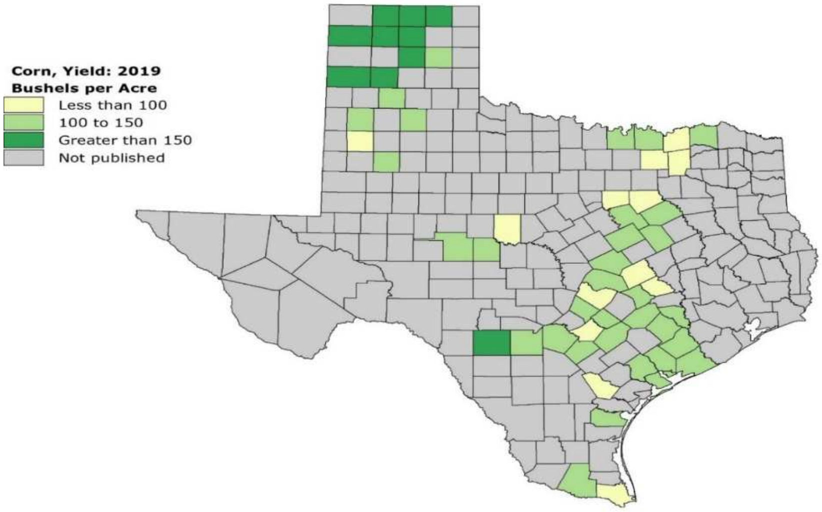
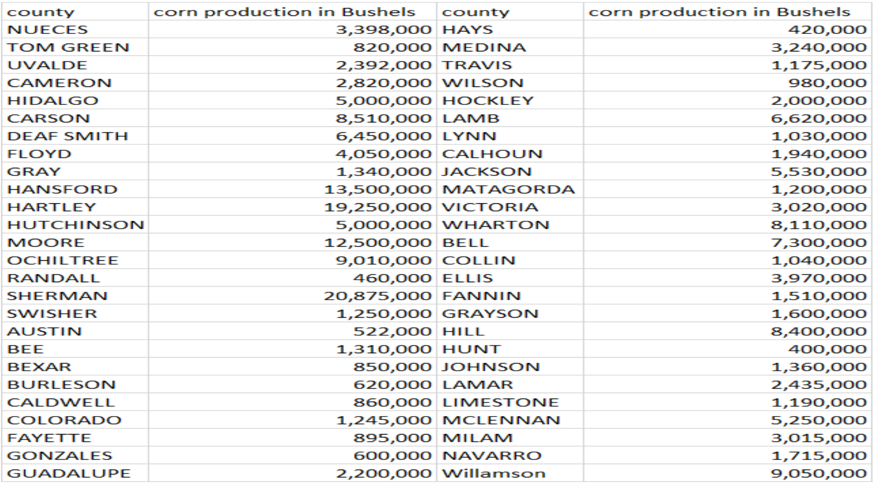


Figure 5. 10: Corn production in Texas on 2019



county	corn production in Bushels	county	corn production in Bushels
NUECES	3,398,000	HAYS	420,000
TOM GREEN	820,000	MEDINA	3,240,000
UVALDE	2,392,000	TRAVIS	1,175,000
CAMERON	2,820,000	WILSON	980,000
HIDALGO	5,000,000	HOCKLEY	2,000,000
CARSON	8,510,000	LAMB	6,620,000
DEAF SMITH	6,450,000	LYNN	1,030,000
FLOYD	4,050,000	CALHOUN	1,940,000
GRAY	1,340,000	JACKSON	5,530,000
HANSFORD	13,500,000	MATAGORDA	1,200,000
HARTLEY	19,250,000	VICTORIA	3,020,000
HUTCHINSON	5,000,000	WHARTON	8,110,000
MOORE	12,500,000	BELL	7,300,000
OCHILTREE	9,010,000	COLLIN	1,040,000
RANDALL	460,000	ELLIS	3,970,000
SHERMAN	20,875,000	FANNIN	1,510,000
SWISHER	1,250,000	GRAYSON	1,600,000
AUSTIN	522,000	HILL	8,400,000
BEE	1,310,000	HUNT	400,000
BEXAR	850,000	JOHNSON	1,360,000
BURLESON	620,000	LAMAR	2,435,000
CALDWELL	860,000	LIMESTONE	1,190,000
COLORADO	1,245,000	MCLENNAN	5,250,000
FAYETTE	895,000	MILAM	3,015,000
GONZALES	600,000	NAVARRO	1,715,000
GUADALUPE	2,200,000	Willamson	9,050,000

Figure 5. 11: Corn production in Texas counties

5.5 Prospected Electrical System From Biomass Energy

In this work, two biomass power plant scenarios are designed, the first one is from the direct combustion of the thermochemical technology from municipal solid waste and agriculture residue and the other one is from the biologic conversion based on anaerobic technology from the wastewater and cattle waste as shown in Figure 5.12.

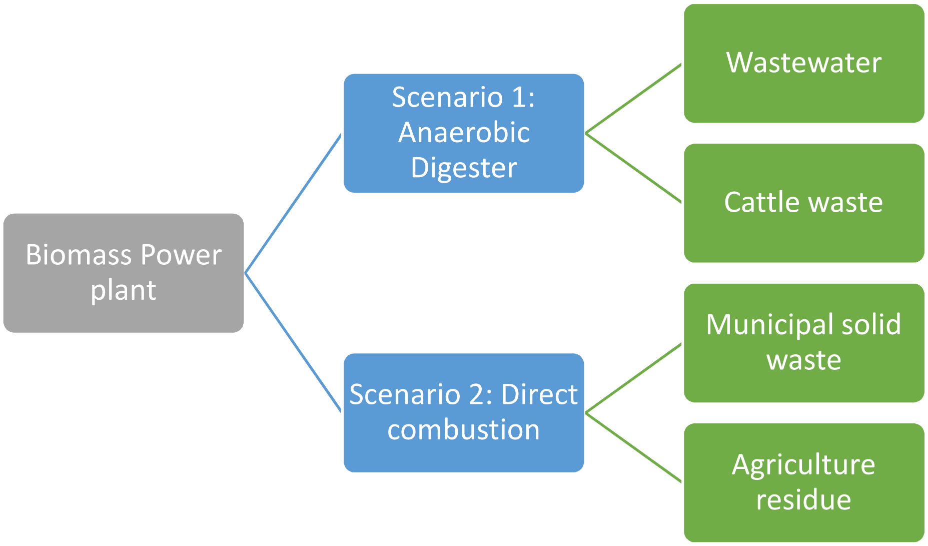


Figure 5. 12: Proposed system from biomass energy

In anaerobic technology, many forms of biomass energy sources can be used such as livestock waste, crops residue, wastewater, and food waste, all of that organic material is stored in a special digester with special types of bacteria to produce methane gas as a steam drive a turbine connected with an electrical generator as seen in Figure 5.13 'Tanigawa,2017'.

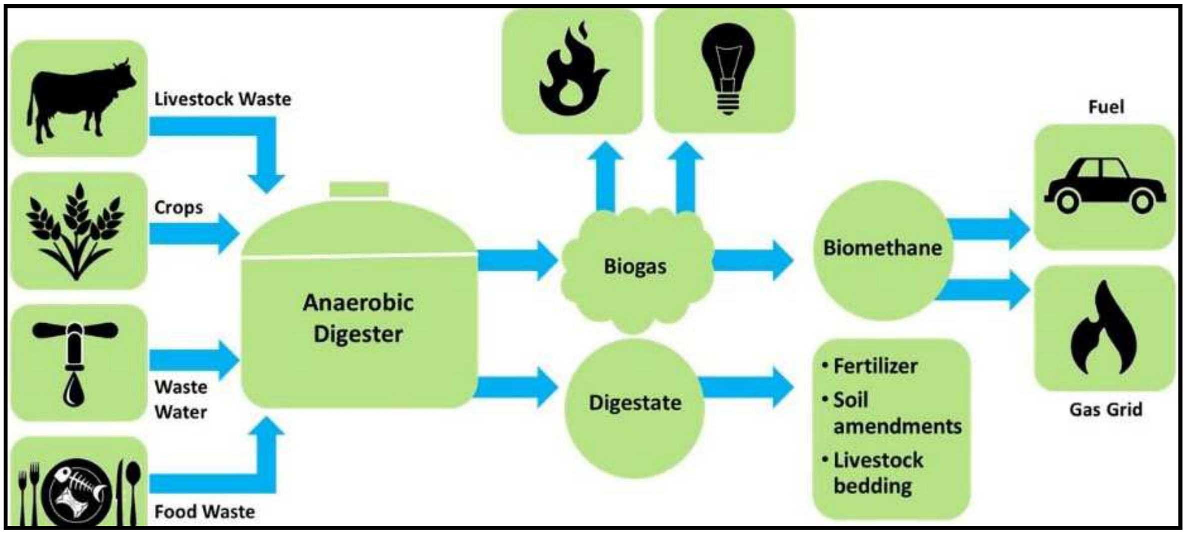


Figure 5. 13: Anaerobic Digester- scenario 1

In the second scenario, municipal solid waste and agriculture residues are collected and sorted, then burned in a boiler to produce steam based on direct combustion technology as shown in Figure 5.14 'Khan and Hoque ,2010'.

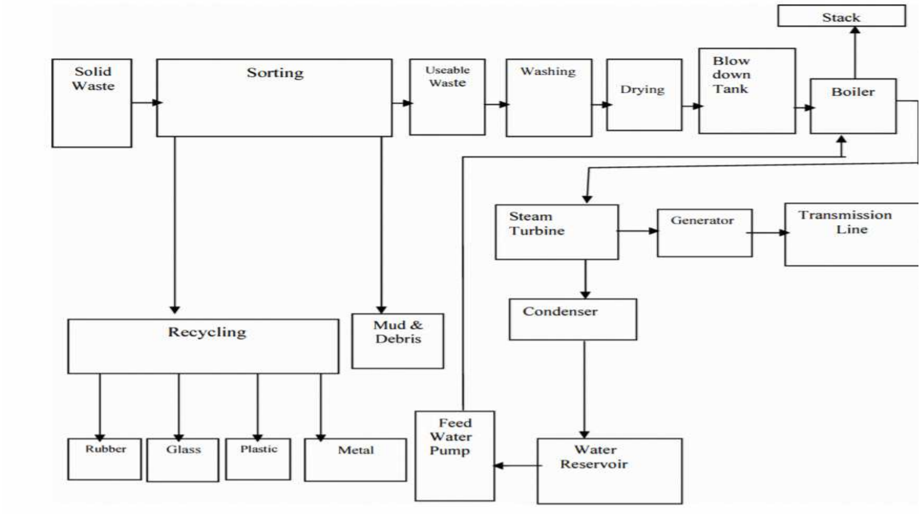


Figure 5. 14: Direct combustion-scenario 2

5.5.1 Live-Stock

Based on energy central model observation, every cow could generate 850 kWh/year, in other words, 100 W for each cow which means 10,000 cows produce 1 MW from their manure in anaerobic digester ‘Konrad,2009’. By using the observation from ‘Konrad,2009’, the output power that could produce from cattle is shown in Equation 5.1‘Konrad,2009’.

$E_c = N_c * 850 \ldots\ldots 5.1$

Where:

E_C: Annual Energy from cattle in kWh

N_C: Number of cattle

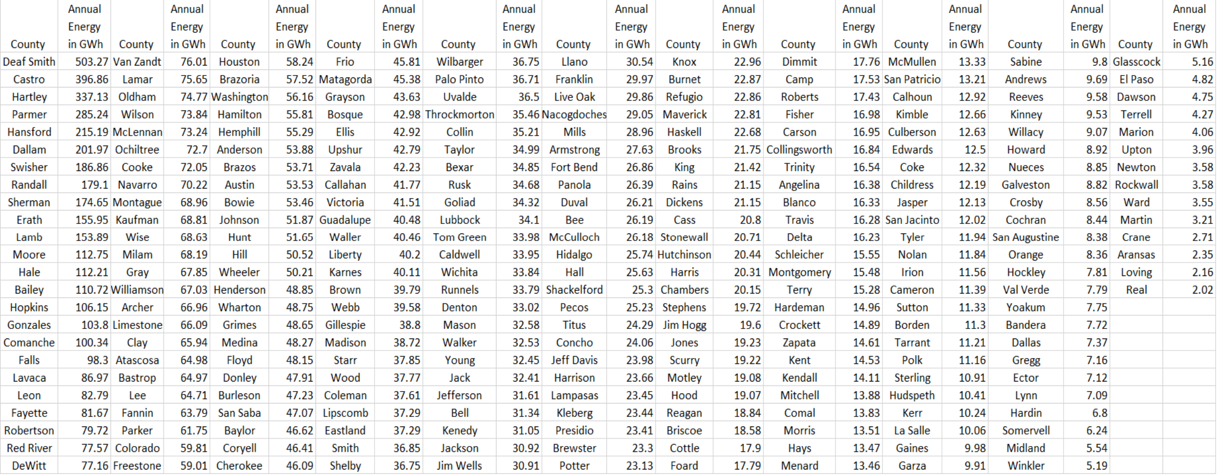
Overall Texas has around 12.5 million cattle ‘Texas Counties: Cattle Population in 2017,2017’, which means theoretically could power 1250 MW daily from all of those cattle, practically there is no way to collect all animal waste in 254 counties in Texas so for that, the best solution is to apply the smart grid concept by constructing multiple biomass power plants at each county. The annual power generation of the cattle in Texas can reach 10.6 TWh per year. The annual energy generation varies from one county to another in the range between 503 to 2 GWh. Based on Texas counties website, 19 counties in Texas have more than 100,000 cattle per. Hence, the annual energy generation in all 19 counties could reach up to 3.6 TWh. 60 counties in Texas have more than 50,000 up to 100,000 cattle in each, therefore, 3.5 TWh could be powered every year from all of those 60 counties. 146 counties have more than 10,000 cattle and less than 50,000 cattle, hence, could power up to 3.3 TWh every year. Only 29 counties in Texas have less than 10,000 cattle per, however, all 29 counties could power up to 159 GWh per year. All results are determined by using Equation 5.1 as the following:

$$E_C at\ Deaf\ Smith = N_C * 850$$

$$E_C at\ Deaf\ Smith = 592{,}078 * 850$$

= 503.27 GWh

All results in Texas counties based on live-stock resources are shown in Figure 5.15.



County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Deaf Smith	503.27	Van Zandt	76.01	Houston	58.24	Frio	45.81	Wilbarger	36.75	Llano	30.54	Knox	22.96	Dimmit	17.76	McMullen	13.33	Sabine	9.8	Glasscock	5.16
Castro	396.86	Lamar	75.65	Brazoria	57.52	Matagorda	45.38	Palo Pinto	36.71	Franklin	29.97	Burnet	22.87	Camp	17.53	San Patricio	13.21	Andrews	9.69	El Paso	4.82
Hartley	337.13	Oldham	74.77	Washington	56.16	Grayson	43.63	Uvalde	36.5	Live Oak	29.86	Refugio	22.86	Roberts	17.43	Calhoun	12.92	Reeves	9.58	Dawson	4.75
Parmer	285.24	Wilson	73.84	Hamilton	55.81	Bosque	42.98	Throckmorton	35.46	Nacogdoches	29.05	Maverick	22.81	Fisher	16.98	Kimble	12.66	Kinney	9.53	Terrell	4.27
Hansford	215.19	McLennan	73.24	Hemphill	55.29	Ellis	42.92	Collin	35.21	Mills	28.96	Haskell	22.68	Carson	16.95	Culberson	12.63	Willacy	9.07	Marion	4.06
Dallam	201.97	Ochiltree	72.7	Anderson	53.88	Upshur	42.79	Taylor	34.99	Armstrong	27.63	Brooks	21.75	Collingsworth	16.84	Edwards	12.5	Howard	8.92	Upton	3.96
Swisher	186.86	Cooke	72.05	Brazos	53.71	Zavala	42.23	Bexar	34.85	Fort Bend	26.86	King	21.42	Trinity	16.54	Coke	12.32	Nueces	8.85	Newton	3.58
Randall	179.1	Navarro	70.22	Austin	53.53	Callahan	41.77	Rusk	34.68	Panola	26.39	Rains	21.15	Angelina	16.38	Childress	12.19	Galveston	8.82	Rockwall	3.58
Sherman	174.65	Montague	68.96	Bowie	53.46	Victoria	41.51	Goliad	34.32	Duval	26.21	Dickens	21.15	Blanco	16.33	Jasper	12.13	Crosby	8.56	Ward	3.55
Erath	155.95	Kaufman	68.81	Johnson	51.87	Guadalupe	40.48	Lubbock	34.1	Bee	26.19	Cass	20.8	Travis	16.28	San Jacinto	12.02	Cochran	8.44	Martin	3.21
Lamb	153.89	Wise	68.63	Hunt	51.65	Waller	40.46	Tom Green	33.98	McCulloch	26.18	Stonewall	20.71	Delta	16.23	Tyler	11.94	San Augustine	8.38	Crane	2.71
Moore	112.75	Milam	68.19	Hill	50.52	Liberty	40.2	Caldwell	33.95	Hidalgo	25.74	Hutchinson	20.44	Schleicher	15.55	Nolan	11.84	Orange	8.36	Aransas	2.35
Hale	112.21	Gray	67.85	Wheeler	50.21	Karnes	40.11	Wichita	33.84	Hall	25.63	Harris	20.31	Montgomery	15.48	Irion	11.56	Hockley	7.81	Loving	2.16
Bailey	110.72	Williamson	67.03	Henderson	48.85	Brown	39.79	Runnels	33.79	Shackelford	25.3	Chambers	20.15	Terry	15.28	Cameron	11.39	Val Verde	7.79	Real	2.02
Hopkins	106.15	Archer	66.96	Wharton	48.75	Webb	39.58	Denton	33.02	Pecos	25.23	Stephens	19.72	Hardeman	14.96	Sutton	11.33	Yoakum	7.75		
Gonzales	103.8	Limestone	66.09	Grimes	48.65	Gillespie	38.8	Mason	32.58	Titus	24.29	Jim Hogg	19.6	Crockett	14.89	Borden	11.3	Bandera	7.72		
Comanche	100.34	Clay	65.94	Medina	48.27	Madison	38.72	Walker	32.53	Concho	24.06	Jones	19.23	Zapata	14.61	Tarrant	11.21	Dallas	7.37		
Falls	98.3	Atascosa	64.98	Floyd	48.15	Starr	37.85	Young	32.45	Jeff Davis	23.98	Scurry	19.22	Kent	14.53	Polk	11.16	Gregg	7.16		
Lavaca	86.97	Bastrop	64.97	Donley	47.91	Wood	37.77	Jack	32.41	Harrison	23.66	Motley	19.08	Kendall	14.11	Sterling	10.91	Ector	7.12		
Leon	82.79	Lee	64.71	Burleson	47.23	Coleman	37.61	Jefferson	31.61	Lampasas	23.45	Hood	19.07	Mitchell	13.88	Hudspeth	10.41	Lynn	7.09		
Fayette	81.67	Fannin	63.79	San Saba	47.07	Lipscomb	37.29	Bell	31.34	Kleberg	23.44	Reagan	18.84	Comal	13.83	Kerr	10.24	Hardin	6.8		
Robertson	79.72	Parker	61.75	Baylor	46.62	Eastland	37.29	Kenedy	31.05	Presidio	23.41	Briscoe	18.58	Morris	13.51	La Salle	10.06	Somervell	6.24		
Red River	77.57	Colorado	59.81	Coryell	46.41	Smith	36.85	Jackson	30.92	Brewster	23.3	Cottle	17.9	Hays	13.47	Gaines	9.98	Midland	5.54		
DeWitt	77.16	Freestone	59.01	Cherokee	46.09	Shelby	36.75	Jim Wells	30.91	Potter	23.13	Foard	17.79	Menard	13.46	Garza	9.91	Winkler	5.19		

Figure 5. 15: Biomass energy from livestock in Texas counties

5.5.2 Wastewater Plants

Electricity could produce from wastewater based on biogas technology using the anaerobic digester could be calculated using Equation 5.2 'Opportunities for Combined Heat and Power at Wastewater Treatment Facilities, 2011'.

$$P_{anaerobic} = F * 26 \ldots\ldots.5.2$$

Where

$P_{anaerobic}$ is the power capacity in kW

F is the water flow rate in the wastewater plant in million gallons per day (mgd).

Based on USEPA, every person is responsible for about 50-70 gallon of wastewater flow per day.‘USEPA,20’, Texas population is around 30 million so by using Equation (5.2) and the previous numbers, the maximum power generation from wastewater based on Anaerobic digester technology will be between 39-54 MW in the whole Texas and it will be between 6.2 -8.7 MW in Harris county, and between 3.5-4.9 MW in Dallas county, in Bexar county will be between 2.7-3.7 MW and finally in Travis county between 1.7-2.4 MW as shown in Figure 5.16. The calculations are determined as the following:

$p\ @\ Texas = F * 26$

$p\ @\ Texas = Number\ of\ population * 60 * 26/1000000$

$p\ @\ Texas = 30000000 * 60 * 26/1000000$

$p\ @\ Texas$ = 46,800 kW

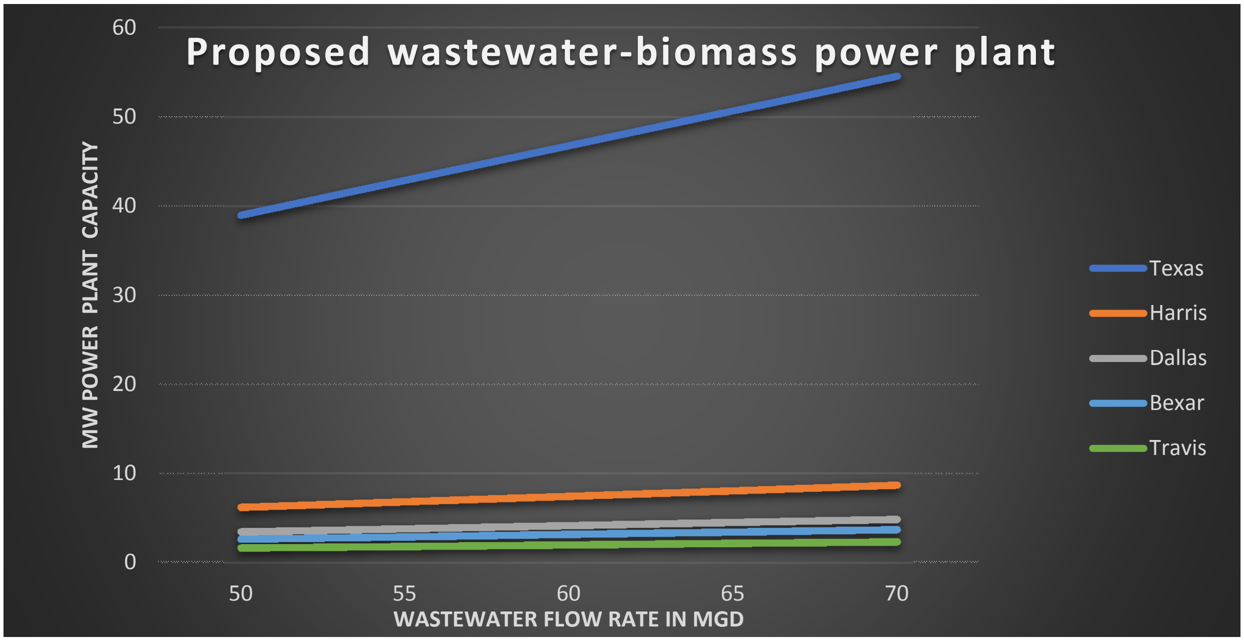


Figure 5. 16: Power generation from an anaerobic digester based on wastewater in Texas

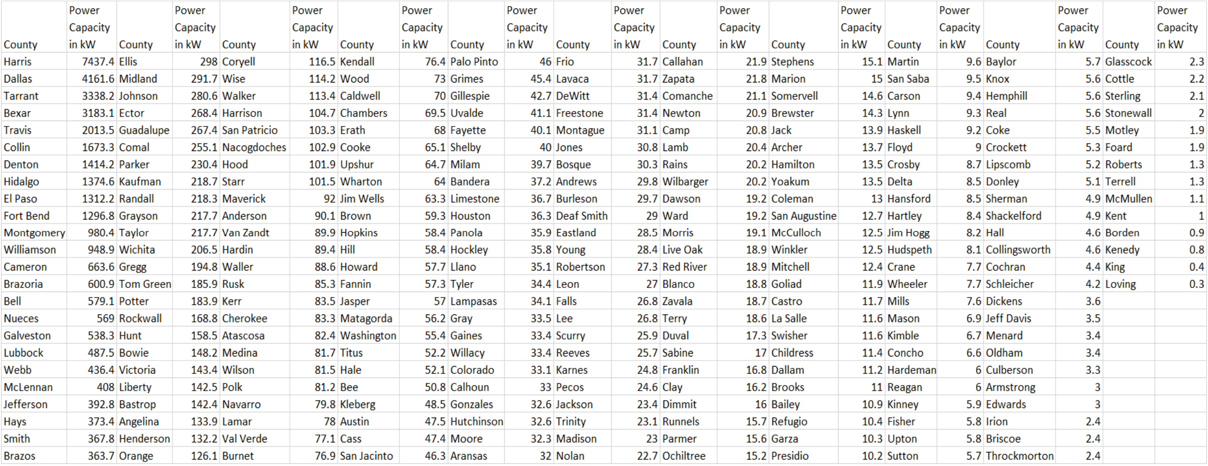
By applying Equation 5.2 at all counties in Texas based on their population from 'Population of Counties in Texas 2021,2021', and assuming the average gallons per person daily is 60 gallons, the proposed system for wastewater biomass power plant for each county is shown in Figure 5.17.The calculations are determined as the following:

$$p\ @\ Harris = F * 26$$

$$p\ @\ Harris = Number\ of\ population * 60 * 26/1000000$$

$$p\ @\ Harris = 4767540 * 60 * 26/1000000$$

$$p\ @\ Harris = 7{,}437.4\ \text{kW}$$



County	Power Capacity in kW	County	Power Capacity in kW	County	Power Capacity in kW	County	Power Capacity in kW	County	Power Capacity in kW	County	Power Capacity in kW	County	Power Capacity in kW	County	Power Capacity in kW	County	Power Capacity in kW	County	Power Capacity in kW	County	Power Capacity in kW
Harris	7437.4	Ellis	298	Coryell	116.5	Kendall	76.4	Palo Pinto	46	Frio	31.7	Callahan	21.9	Stephens	15.1	Martin	9.6	Baylor	5.7	Glasscock	2.3
Dallas	4161.6	Midland	291.7	Wise	114.2	Wood	73	Grimes	45.4	Lavaca	31.7	Zapata	21.8	Marion	15	San Saba	9.5	Knox	5.6	Cottle	2.2
Tarrant	3338.2	Johnson	280.6	Walker	113.4	Caldwell	70	Gillespie	42.7	DeWitt	31.4	Comanche	21.1	Somervell	14.6	Carson	9.4	Hemphill	5.6	Sterling	2.1
Bexar	3183.1	Ector	268.4	Harrison	104.7	Chambers	69.5	Uvalde	41.1	Freestone	31.4	Newton	20.9	Brewster	14.3	Lynn	9.3	Real	5.6	Stonewall	2
Travis	2013.5	Guadalupe	267.4	San Patricio	103.3	Erath	68	Fayette	40.1	Montague	31.1	Camp	20.8	Jack	13.9	Haskell	9.2	Coke	5.5	Motley	1.9
Collin	1673.3	Comal	255.1	Nacogdoches	102.9	Cooke	65.1	Shelby	40	Jones	30.8	Lamb	20.4	Archer	13.7	Floyd	9	Crockett	5.3	Foard	1.9
Denton	1414.2	Parker	230.4	Hood	101.9	Upshur	64.7	Milam	39.7	Bosque	30.3	Rains	20.2	Hamilton	13.5	Crosby	8.7	Lipscomb	5.2	Roberts	1.3
Hidalgo	1374.6	Kaufman	218.7	Starr	101.5	Wharton	64	Bandera	37.2	Andrews	29.8	Wilbarger	20.2	Yoakum	13.5	Delta	8.5	Donley	5.1	Terrell	1.3
El Paso	1312.2	Randall	218.3	Maverick	92	Jim Wells	63.3	Limestone	36.7	Burleson	29.7	Dawson	19.2	Coleman	13	Hansford	8.5	Sherman	4.9	McMullen	1.1
Fort Bend	1296.8	Grayson	217.7	Anderson	90.1	Brown	59.3	Houston	36.3	Deaf Smith	29	Ward	19.2	San Augustine	12.7	Hartley	8.4	Shackelford	4.9	Kent	1
Montgomery	980.4	Taylor	217.7	Van Zandt	89.9	Hopkins	58.4	Panola	35.9	Eastland	28.5	Morris	19.1	McCulloch	12.5	Jim Hogg	8.2	Hall	4.6	Borden	0.9
Williamson	948.9	Wichita	206.5	Hardin	89.4	Hill	58.4	Hockley	35.8	Young	28.4	Live Oak	18.9	Winkler	12.5	Hudspeth	8.1	Collingsworth	4.6	Kenedy	0.8
Cameron	663.6	Gregg	194.8	Waller	88.6	Howard	57.7	Llano	35.1	Robertson	27.3	Red River	18.9	Mitchell	12.4	Crane	7.7	Cochran	4.4	King	0.4
Brazoria	600.9	Tom Green	185.9	Rusk	85.3	Fannin	57.3	Tyler	34.4	Leon	27	Blanco	18.8	Goliad	11.9	Wheeler	7.7	Schleicher	4.2	Loving	0.3
Bell	579.1	Potter	183.9	Kerr	83.5	Jasper	57	Lampasas	34.1	Falls	26.8	Zavala	18.7	Castro	11.7	Mills	7.6	Dickens	3.6		
Nueces	569	Rockwall	168.8	Cherokee	83.3	Matagorda	56.2	Gray	33.5	Lee	26.8	Terry	18.6	La Salle	11.6	Mason	6.9	Jeff Davis	3.5		
Galveston	538.3	Hunt	158.5	Atascosa	82.4	Washington	55.4	Gaines	33.4	Scurry	25.9	Duval	17.3	Swisher	11.6	Kimble	6.7	Menard	3.4		
Lubbock	487.5	Bowie	148.2	Medina	81.7	Titus	52.2	Willacy	33.4	Reeves	25.7	Sabine	17	Childress	11.4	Concho	6.6	Oldham	3.4		
Webb	436.4	Victoria	143.4	Wilson	81.5	Hale	52.1	Colorado	33.1	Karnes	24.8	Franklin	16.8	Dallam	11.2	Hardeman	6	Culberson	3.3		
McLennan	408	Liberty	142.5	Polk	81.2	Bee	50.8	Calhoun	33	Pecos	24.6	Clay	16.2	Brooks	11	Reagan	6	Armstrong	3		
Jefferson	392.8	Bastrop	142.4	Navarro	79.8	Kleberg	48.5	Gonzales	32.6	Jackson	23.4	Dimmit	16	Bailey	10.9	Kinney	5.9	Edwards	3		
Hays	373.4	Angelina	133.9	Lamar	78	Austin	47.5	Hutchinson	32.6	Trinity	23.1	Runnels	15.7	Refugio	10.4	Fisher	5.8	Irion	2.4		
Smith	367.8	Henderson	132.2	Val Verde	77.1	Cass	47.4	Moore	32.3	Madison	23	Parmer	15.6	Garza	10.3	Upton	5.8	Briscoe	2.4		
Brazos	363.7	Orange	126.1	Burnet	76.9	San Jacinto	46.3	Aransas	32	Nolan	22.7	Ochiltree	15.2	Presidio	10.2	Sutton	5.7	Throckmorton	2.4		

Figure 5. 17: A proposed system for all counties in Texas from wastewater

In fact, it is very difficult to use all Texas wastewater in these proposed systems, so focusing on the largest wastewater treatment plant in Texas is the best option. As shown in Figure 5.17, with the exception of the largest county in Texas, most counties do not have enough wastewater resources to produce more than 1 megawatt of water. Based on the maximum capacity for wastewater treatment plants in Houston, Dallas, and San Antonio. As shown in Table 5.4, the power of these three cities can reach 14.7 MW, 7.3 MW and 5.9 MW respectively.

City	Maximum capacity of wastewater treatment in mgd	MW power plant capacity
Houston	564	14.664
Dallas	280	7.28
San Antonio	225	5.85

Table 5. 4: A proposed system for Houston, Dallas, and San Antonio

5.5.3 Municipal Solid Waste

Based on TCEQ in 2019, Texas produced 36,804,463 MSW tons, and 100,834 MSW tons as an average per day, in 2018 and based on EIA, every 85% of each ton of MSW used in waste to energy power plants produced 534 kWh 'Biomass explained,2020'so based on the results are published in EIA, Equation 5.3 'Biomass explained,2020' shows the power output from the MSW.

$E_{MSW} = MSW * 0.85 * 534 \ldots\ldots 5.3$

Where:

E_{MSW} : the potential energy in MSW in kWh,

MSW : the municipal solid waste in Tons

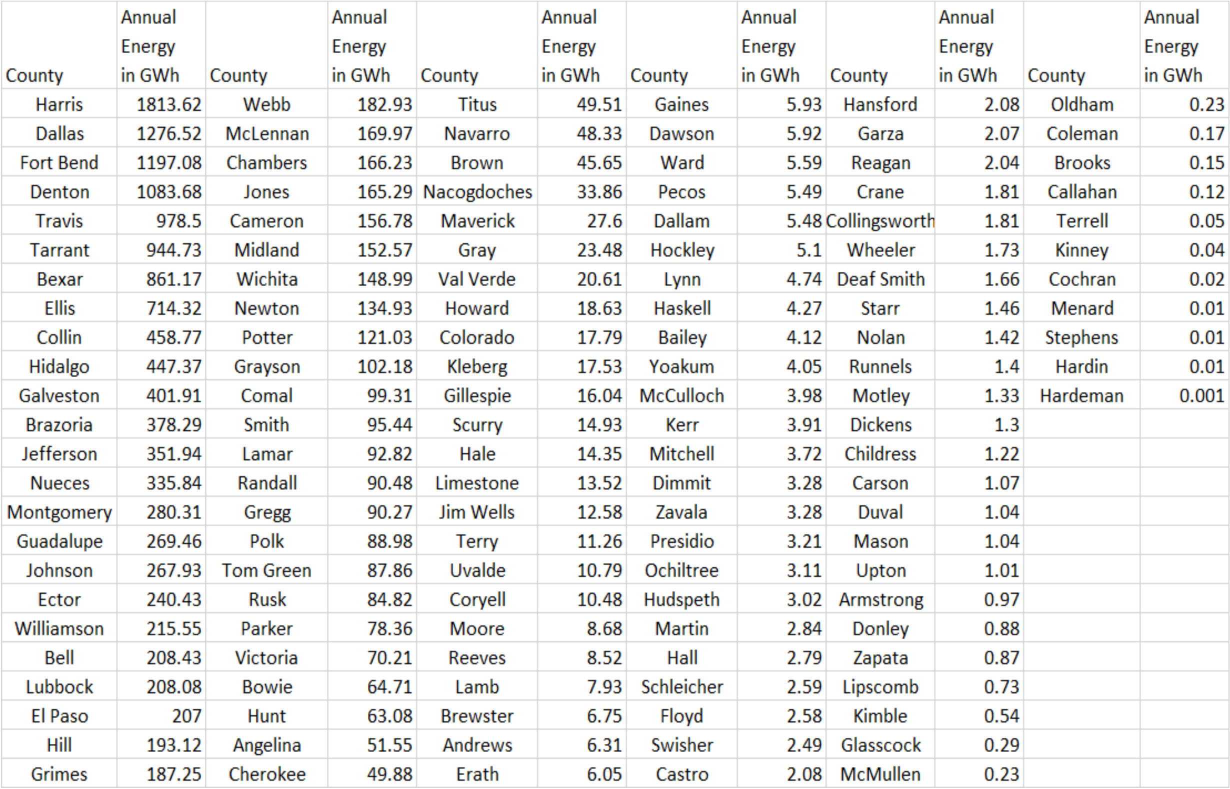
Texas can power around 16.705 TWh from 131 counties in Texas and annual generation varies from one county to another in the range of 1,813 GWh to 1.8 MWh. The results are determined using Equation 5.3 as the following:

$E_{MSW}\ at\ Harris = MSW * 0.85 * 534$

$E_{MSW}\ at\ Harris = 3{,}995{,}632 * 0.85 * 534$

$E_{MSW}\ at\ Harris$ =1813.6 GWh

All results based on MSW in Texas counties are shown in Figure 5.18.

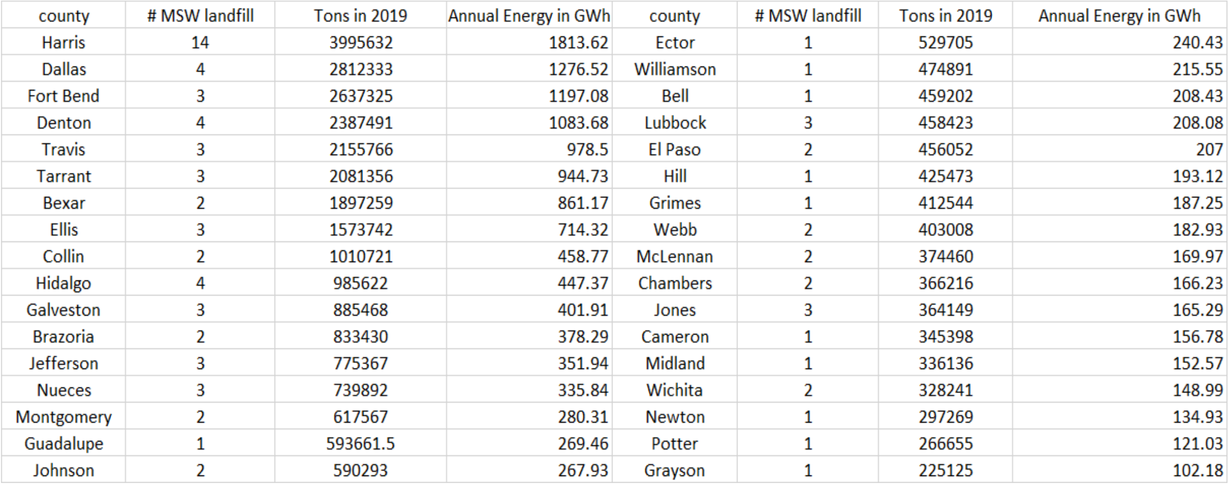


County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Harris	1813.62	Webb	182.93	Titus	49.51	Gaines	5.93	Hansford	2.08	Oldham	0.23
Dallas	1276.52	McLennan	169.97	Navarro	48.33	Dawson	5.92	Garza	2.07	Coleman	0.17
Fort Bend	1197.08	Chambers	166.23	Brown	45.65	Ward	5.59	Reagan	2.04	Brooks	0.15
Denton	1083.68	Jones	165.29	Nacogdoches	33.86	Pecos	5.49	Crane	1.81	Callahan	0.12
Travis	978.5	Cameron	156.78	Maverick	27.6	Dallam	5.48	Collingsworth	1.81	Terrell	0.05
Tarrant	944.73	Midland	152.57	Gray	23.48	Hockley	5.1	Wheeler	1.73	Kinney	0.04
Bexar	861.17	Wichita	148.99	Val Verde	20.61	Lynn	4.74	Deaf Smith	1.66	Cochran	0.02
Ellis	714.32	Newton	134.93	Howard	18.63	Haskell	4.27	Starr	1.46	Menard	0.01
Collin	458.77	Potter	121.03	Colorado	17.79	Bailey	4.12	Nolan	1.42	Stephens	0.01
Hidalgo	447.37	Grayson	102.18	Kleberg	17.53	Yoakum	4.05	Runnels	1.4	Hardin	0.01
Galveston	401.91	Comal	99.31	Gillespie	16.04	McCulloch	3.98	Motley	1.33	Hardeman	0.001
Brazoria	378.29	Smith	95.44	Scurry	14.93	Kerr	3.91	Dickens	1.3		
Jefferson	351.94	Lamar	92.82	Hale	14.35	Mitchell	3.72	Childress	1.22		
Nueces	335.84	Randall	90.48	Limestone	13.52	Dimmit	3.28	Carson	1.07		
Montgomery	280.31	Gregg	90.27	Jim Wells	12.58	Zavala	3.28	Duval	1.04		
Guadalupe	269.46	Polk	88.98	Terry	11.26	Presidio	3.21	Mason	1.04		
Johnson	267.93	Tom Green	87.86	Uvalde	10.79	Ochiltree	3.11	Upton	1.01		
Ector	240.43	Rusk	84.82	Coryell	10.48	Hudspeth	3.02	Armstrong	0.97		
Williamson	215.55	Parker	78.36	Moore	8.68	Martin	2.84	Donley	0.88		
Bell	208.43	Victoria	70.21	Reeves	8.52	Hall	2.79	Zapata	0.87		
Lubbock	208.08	Bowie	64.71	Lamb	7.93	Schleicher	2.59	Lipscomb	0.73		
El Paso	207	Hunt	63.08	Brewster	6.75	Floyd	2.58	Kimble	0.54		
Hill	193.12	Angelina	51.55	Andrews	6.31	Swisher	2.49	Glasscock	0.29		
Grimes	187.25	Cherokee	49.88	Erath	6.05	Castro	2.08	McMullen	0.23		

Figure 5. 18: Prospected biomass power plant based on MSW

Counties can be divided into many groups based on their municipal solid waste resources: starting from the four richest counties, the municipal solid waste in these four counties is enough to generate more than 1,000 GWh of electricity. The second group of counties, namely 30 counties, can generate more than 100 GWh and less than 1000 GWh. Then, good counties based on MSW production, specifically 32 counties, which are enough to generate electricity more than 10 GWh and less than 100 GWh, Finally, ending with very poor 65 counties with resources lower Fewer than 10 GWh and more than 1 MWh.

There are 36,804,463 tons of municipal solid waste in Texas, and 34 counties generate enough municipal solid waste to generate 15 TWh, which accounts for almost 90% of the total power generation of all counties in this model. There are 4 counties with sufficient resources to provide more than 1,000 GWh of electricity, Harris County can generate up to 1,813 GWh, and it is the richest county in Texas due to municipal solid waste. Figure 5.19 shows the top 34 counties of Texas and their municipal solid waste and the expected annual energy generated from it.



county	# MSW landfill	Tons in 2019	Annual Energy in GWh	county	# MSW landfill	Tons in 2019	Annual Energy in GWh
Harris	14	3995632	1813.62	Ector	1	529705	240.43
Dallas	4	2812333	1276.52	Williamson	1	474891	215.55
Fort Bend	3	2637325	1197.08	Bell	1	459202	208.43
Denton	4	2387491	1083.68	Lubbock	3	458423	208.08
Travis	3	2155766	978.5	El Paso	2	456052	207
Tarrant	3	2081356	944.73	Hill	1	425473	193.12
Bexar	2	1897259	861.17	Grimes	1	412544	187.25
Ellis	3	1573742	714.32	Webb	2	403008	182.93
Collin	2	1010721	458.77	McLennan	2	374460	169.97
Hidalgo	4	985622	447.37	Chambers	2	366216	166.23
Galveston	3	885468	401.91	Jones	3	364149	165.29
Brazoria	2	833430	378.29	Cameron	1	345398	156.78
Jefferson	3	775367	351.94	Midland	1	336136	152.57
Nueces	3	739892	335.84	Wichita	2	328241	148.99
Montgomery	2	617567	280.31	Newton	1	297269	134.93
Guadalupe	1	593661.5	269.46	Potter	1	266655	121.03
Johnson	2	590293	267.93	Grayson	1	225125	102.18

Figure 5. 19: Top 34 counties based on MSW resources

According to the previous classification, Texas can generate annually 16.7 TWh from 131 counties, which is the maximum energy produced by Texas municipal solid waste. 66 counties could generate up to 16.5 TWh based on municipal solid waste, which means that 98.8% of the energy only comes from 66 counties. The 51 counties can produce up to 16.2, which constitutes 97% of the maximum energy. As well. only 41 counties in Texas have enough MSW to power up to 15 TWh that represents around 90 % of the total energy in the state. There are even 25 counties with MSW sufficient to power 13.7 TWh, which is 82% of the maximum energy in the model. Only 6 counties in Texas have 43% of the state's MSW, which can generate 7.2 TWh per year. All the results are shown in Figure 5.20.

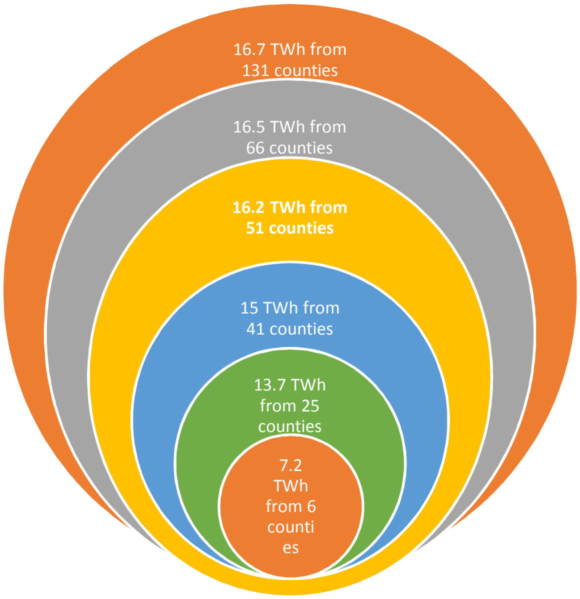


Figure 5. 20: Prospected Energy from MSW-scenario#2

5.5.4 Agriculture Residue

There are residues on any crop. In this design, three main agricultural residues are considered, namely cotton stalk, rice straw, and corn stalk. To determine the potential energy in the agriculture residue, there are three main steps based on the model offered by 'Gojiya and Deb,2017'.

Step1:

Determine the Gross agriculture residue using Equation 5.4 'Gojiya and Deb,2017'

$GAR = AC_p * RPR$ ….5.4

Where GAR is the gross agriculture residue in tons, AC_p is the annual crop production in tons, and the RPR is the residue production ration.

Step2:

Determine the surplus residue using Equation 5.5 ‘Gojiya and Deb,2017’

$SR = GAR * A_C$……5.5

Where SR is the surplus residue and A_C is the accessibility factor

Step3:

Determine energy potential from agriculture residue using Equation 5.6 ‘Gojiya and Deb,2017’

$E_P = \frac{SR}{FCV}$ …………5.6

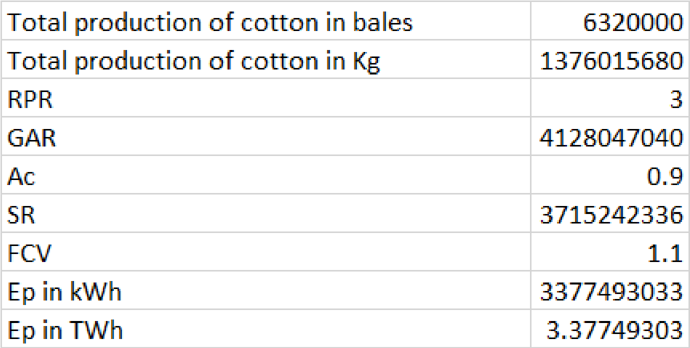
Where E_P is the energy potential from agriculture residue and FCV is the fuel consumption value which is 1.1Kg/kWh ‘Morris,2000’.The accessibility factor depends on the competing uses of the residue ‘Gojiya and Deb,2017’, the values of the A_C and RPR for cotton, rice and maize are given in Table 5.5 ‘Singh,2016’.

Crop	RPR (kg/kg)	Accessibility (%)
Rice	1.5	80
Maize	2	80
Wheat	1.5	30
Cotton	3	90

Table 5. 5: RPR and A_C values

5.5.4.1 Energy Potential From Cotton Stalk

By applying Equations 5.4,5.5, and 5.6, plus the value of the accessibility factor and residue produce ratio given in Table 5.5, a model on excel is prepared as shown in Figure 5.21.



Total production of cotton in bales	6320000
Total production of cotton in Kg	1376015680
RPR	3
GAR	4128047040
Ac	0.9
SR	3715242336
FCV	1.1
Ep in kWh	3377493033
Ep in TWh	3.37749303

Figure 5. 21: Excel model for energy potential from cotton stalk

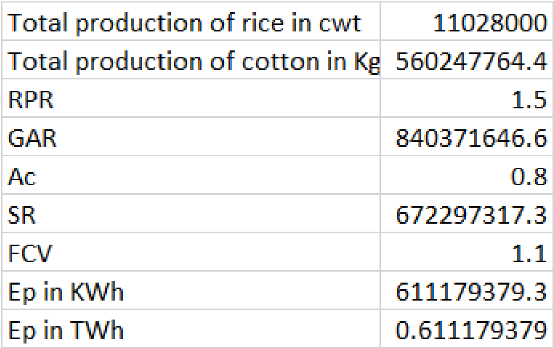
By using the above model, Texas could power up to 3.38 TWh annually, The annual generation varies from one district to another among the state of Texas, as shown in Table 5.6.

District	Total production of cotton in Kg	Energy potential in TWh
Northern High Plains	908,300	0.49
Southern High Plains	2,136,700	1.14
Northern Low Plains	411,800	0.22
Southern Low Plains	353,300	0.19
Cross Timbers	14,400	0.01
Blacklands	189,900	0.1
North East	14,300	0.01
South East	64,600	0.03
Trans-Pecos	49,200	0.03
Edwards Plateau	278,200	0.15
South Central	176,000	0.09
Coastal Bend	726,400	0.39
Upper Coast	555,200	0.3
South	102,700	0.05
Lower Valley	339,000	0.18
Texas	6,320,000	3.38

Table 5. 6: Energy potential from the cotton stalk in Texas

5.5.4.2 Energy Potential From Rice Straw

By applying Equations 5.5,5.6, and 5.7, plus the value of the accessibility factor and residue produce ratio given in Table 5.5, a model on excel is prepared as shown in Figure 5.22.



Total production of rice in cwt	11028000
Total production of cotton in Kg	560247764.4
RPR	1.5
GAR	840371646.6
Ac	0.8
SR	672297317.3
FCV	1.1
Ep in KWh	611179379.3
Ep in TWh	0.611179379

Figure 5. 22: Excel model for energy potential from rice straw

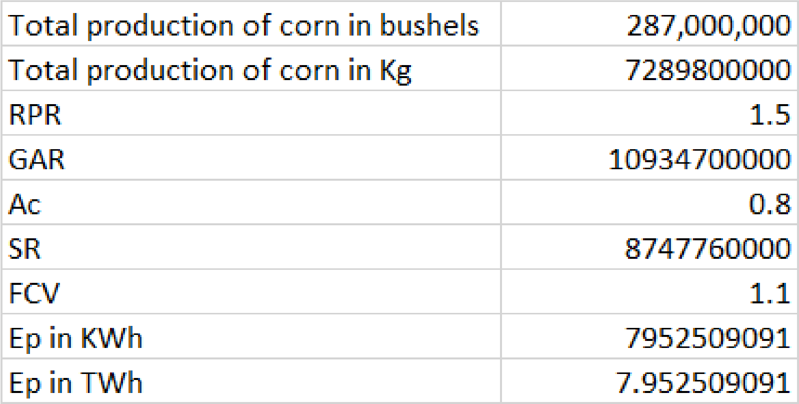
By using the above model, Texas could power up to 611 GWh annually, seven counties could produce around 80 % of the total amount could Texas generate, and Colorado county alone could produce around 118 GWh as seen in Table 5.7.

County	Production of rice in cwt	Energy potential in GWh
Colorado	2125000	117.77
Brazoria	1375000	76.2
Chambers	647000	35.86
Jackson	828000	45.89
Jefferson	604000	33.47
Matagorda	905000	50.16
Wharton	2520000	139.66
Other counties	2024000	112.17
Total production	11028000	611.18

Table 5. 7: Energy potential from the rice straw in Texas

5.5.4.3 Energy Potential From Corn Straw

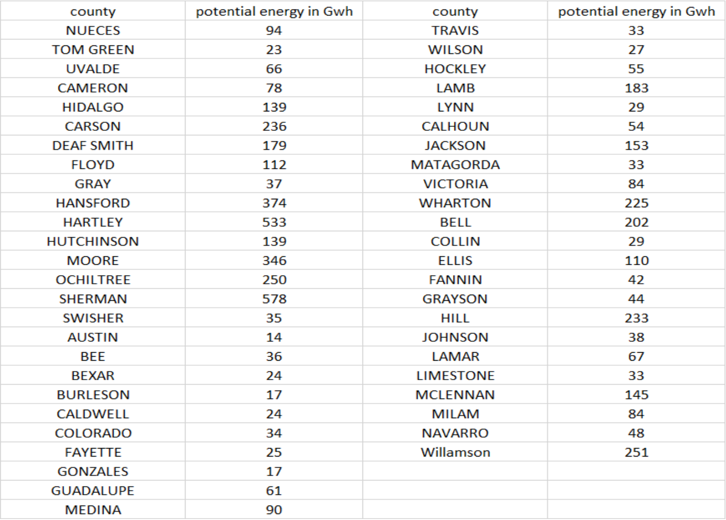
By applying Equations 5.5,5.6, and 5.7, plus the value of the accessibility factor and residue produce ratio given in Table 5.5, a model on excel is prepared as shown in Figure 5.23.



Total production of corn in bushels	287,000,000
Total production of corn in Kg	7289800000
RPR	1.5
GAR	10934700000
Ac	0.8
SR	8747760000
FCV	1.1
Ep in KWh	7952509091
Ep in TWh	7.952509091

Figure 5. 23: Excel model for energy potential from maize straw

By using the above model, Texas could power up to 8 TWh annually, 52 counties are responsible for about 60% of that as shown in Figure 5.24.



county	potential energy in Gwh	county	potential energy in Gwh
NUECES	94	TRAVIS	33
TOM GREEN	23	WILSON	27
UVALDE	66	HOCKLEY	55
CAMERON	78	LAMB	183
HIDALGO	139	LYNN	29
CARSON	236	CALHOUN	54
DEAF SMITH	179	JACKSON	153
FLOYD	112	MATAGORDA	33
GRAY	37	VICTORIA	84
HANSFORD	374	WHARTON	225
HARTLEY	533	BELL	202
HUTCHINSON	139	COLLIN	29
MOORE	346	ELLIS	110
OCHILTREE	250	FANNIN	42
SHERMAN	578	GRAYSON	44
SWISHER	35	HILL	233
AUSTIN	14	JOHNSON	38
BEE	36	LAMAR	67
BEXAR	24	LIMESTONE	33
BURLESON	17	MCLENNAN	145
CALDWELL	24	MILAM	84
COLORADO	34	NAVARRO	48
FAYETTE	25	Willamson	251
GONZALES	17		
GUADALUPE	61		
MEDINA	90		

Figure 5. 24: Energy potential from the maize straw in Texas

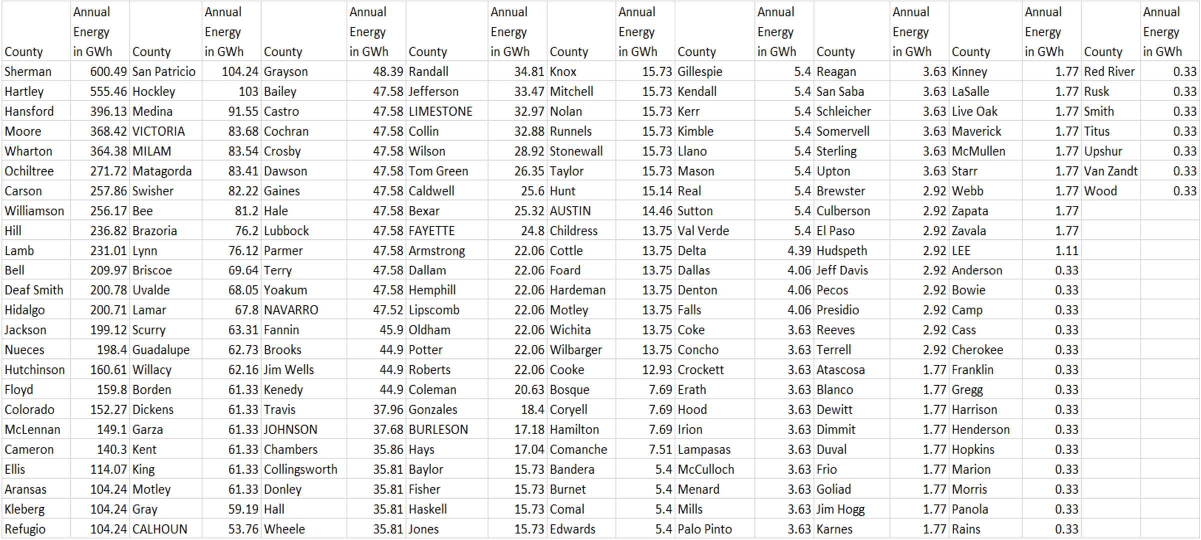
5.5.5.4 Summary

Texas can produce approximately 11.93 TWh from the agricultural residues of the first three crops of cotton, rice, and corn, each of which produces 3.37, 0.61, and 7.95 TWh, respectively. As shown in Table 5.8.

Agriculture residue	The potential energy in TWh
Cotton stalk	3.37
Rice straw	0.61
Maize straw	7.95
Total	11.93

Table 5. 8: Proposed system from agriculture residue

Based on agricultural residues in all counties in Texas, biomass power plants can provide up to 11.93 TWh of electricity per year. The annual power generation between one county and another in Texas ranges from 600.49 GWh to 330 MWh. There are 26 counties with sufficient agricultural resources to provide more than 100 GWh of electricity. There are 86 counties that have obtained sufficient resources from agricultural resources to provide electricity for more than 10 GWh and less than 100 GWh. As shown in Figure 5.25.



County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Sherman	600.49	San Patricio	104.24	Grayson	48.39	Randall	34.81	Knox	15.73	Gillespie	5.4	Reagan	3.63	Kinney	1.77	Red River	0.33
Hartley	555.46	Hockley	103	Bailey	47.58	Jefferson	33.47	Mitchell	15.73	Kendall	5.4	San Saba	3.63	LaSalle	1.77	Rusk	0.33
Hansford	396.13	Medina	91.55	Castro	47.58	LIMESTONE	32.97	Nolan	15.73	Kerr	5.4	Schleicher	3.63	Live Oak	1.77	Smith	0.33
Moore	368.42	VICTORIA	83.68	Cochran	47.58	Collin	32.88	Runnels	15.73	Kimble	5.4	Somervell	3.63	Maverick	1.77	Titus	0.33
Wharton	364.38	MILAM	83.54	Crosby	47.58	Wilson	28.92	Stonewall	15.73	Llano	5.4	Sterling	3.63	McMullen	1.77	Upshur	0.33
Ochiltree	271.72	Matagorda	83.41	Dawson	47.58	Tom Green	26.35	Taylor	15.73	Mason	5.4	Upton	3.63	Starr	1.77	Van Zandt	0.33
Carson	257.86	Swisher	82.22	Gaines	47.58	Caldwell	25.6	Hunt	15.14	Real	5.4	Brewster	2.92	Webb	1.77	Wood	0.33
Williamson	256.17	Bee	81.2	Hale	47.58	Bexar	25.32	AUSTIN	14.46	Sutton	5.4	Culberson	2.92	Zapata	1.77		
Hill	236.82	Brazoria	76.2	Lubbock	47.58	FAYETTE	24.8	Childress	13.75	Val Verde	5.4	El Paso	2.92	Zavala	1.77		
Lamb	231.01	Lynn	76.12	Parmer	47.58	Armstrong	22.06	Cottle	13.75	Delta	4.39	Hudspeth	2.92	LEE	1.11		
Bell	209.97	Briscoe	69.64	Terry	47.58	Dallam	22.06	Foard	13.75	Dallas	4.06	Jeff Davis	2.92	Anderson	0.33		
Deaf Smith	200.78	Uvalde	68.05	Yoakum	47.58	Hemphill	22.06	Hardeman	13.75	Denton	4.06	Pecos	2.92	Bowie	0.33		
Hidalgo	200.71	Lamar	67.8	NAVARRO	47.52	Lipscomb	22.06	Motley	13.75	Falls	4.06	Presidio	2.92	Camp	0.33		
Jackson	199.12	Scurry	63.31	Fannin	45.9	Oldham	22.06	Wichita	13.75	Coke	3.63	Reeves	2.92	Cass	0.33		
Nueces	198.4	Guadalupe	62.73	Brooks	44.9	Potter	22.06	Wilbarger	13.75	Concho	3.63	Terrell	2.92	Cherokee	0.33		
Hutchinson	160.61	Willacy	62.16	Jim Wells	44.9	Roberts	22.06	Cooke	12.93	Crockett	3.63	Atascosa	1.77	Franklin	0.33		
Floyd	159.8	Borden	61.33	Kenedy	44.9	Coleman	20.63	Bosque	7.69	Erath	3.63	Blanco	1.77	Gregg	0.33		
Colorado	152.27	Dickens	61.33	Travis	37.96	Gonzales	18.4	Coryell	7.69	Hood	3.63	Dewitt	1.77	Harrison	0.33		
McLennan	149.1	Garza	61.33	JOHNSON	37.68	BURLESON	17.18	Hamilton	7.69	Irion	3.63	Dimmit	1.77	Henderson	0.33		
Cameron	140.3	Kent	61.33	Chambers	35.86	Hays	17.04	Comanche	7.51	Lampasas	3.63	Duval	1.77	Hopkins	0.33		
Ellis	114.07	King	61.33	Collingsworth	35.81	Baylor	15.73	Bandera	5.4	McCulloch	3.63	Frio	1.77	Marion	0.33		
Aransas	104.24	Motley	61.33	Donley	35.81	Fisher	15.73	Burnet	5.4	Menard	3.63	Goliad	1.77	Morris	0.33		
Kleberg	104.24	Gray	59.19	Hall	35.81	Haskell	15.73	Comal	5.4	Mills	3.63	Jim Hogg	1.77	Panola	0.33		
Refugio	104.24	CALHOUN	53.76	Wheele	35.81	Jones	15.73	Edwards	5.4	Palo Pinto	3.63	Karnes	1.77	Rains	0.33		

Figure 5. 25: Annual energy from Biomass generation based on agriculture residue

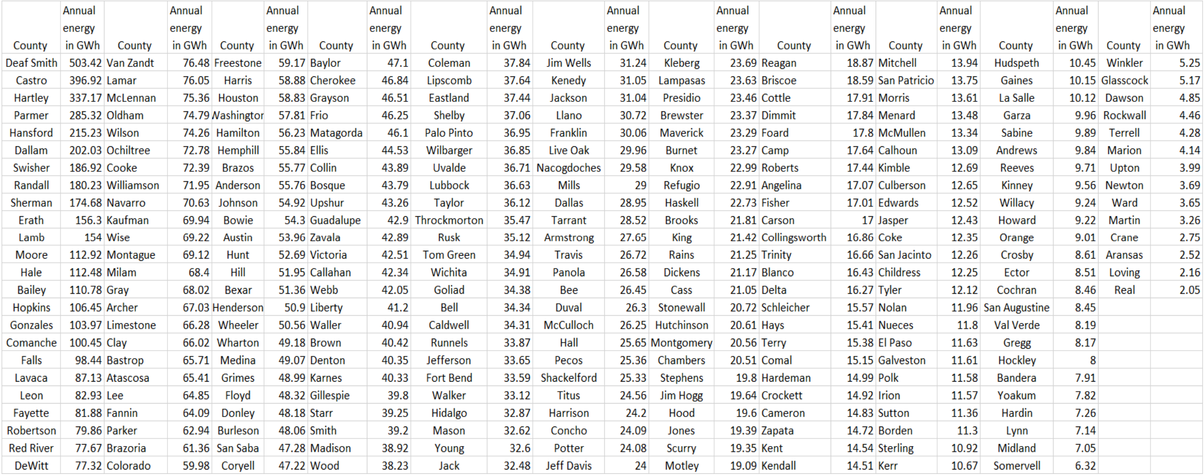
5.6 Results

Biomass power plants in Texas can provide up to 39.536 TWh of electricity from four sources each year from livestock, wastewater, municipal solid waste, and agricultural residues. The previous four resources are used in two technologies; direct combustion and anaerobic digestion. Wastewater and livestock are classified in anaerobic digestion technology. The other two resources: municipal solid waste and agricultural residues are used in the direct combustion technology. The results from all resources are shown in Table 5.9.

SCENARIO	Annual Energy
Livestock	10.687 TWh
Wastewater	241.145 GWh
MSW	16.705 TWh
Agriculture residue	11.93 TWh
Total	39.563 TWh

Table 5. 9: Annual energy from Biomass energy in Texas

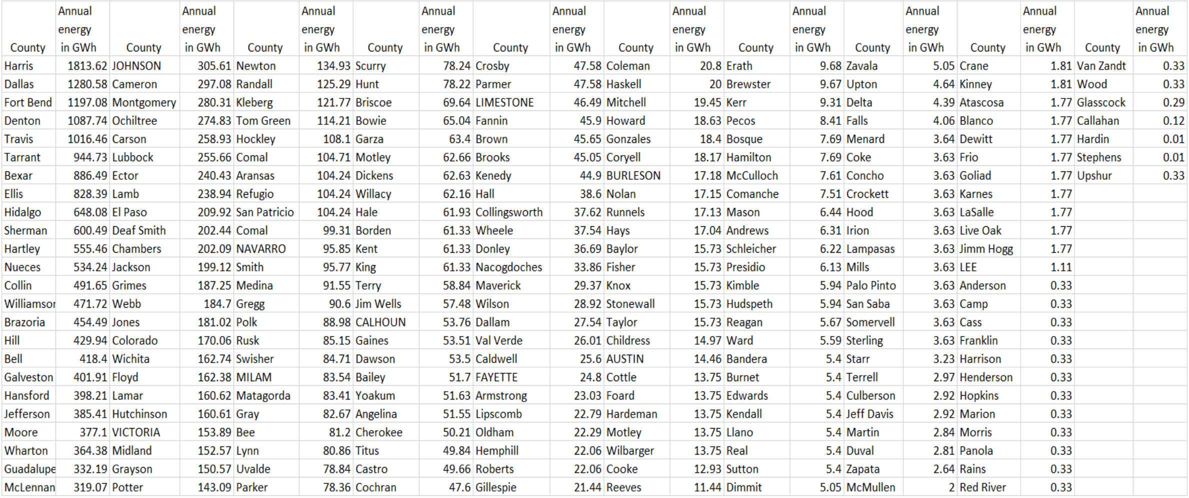
Biomass power plants in Texas can provide up to 10.921 TWh of electricity from anaerobic digester technology. The annual energy generation varies from 503 GWh to 2 GWh. There are 17 counties in Texas that have enough resources to power up more than 100 GWh based on an anaerobic digester. However, there are 202 counties that have enough resources based on direct combustion to power more than 10 GWh and less than 100 GWh. There are only 35 counties in Texas that could power less than 10 GWh. As shown in Figure 5.26



County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh
Deaf Smith	503.42	Van Zandt	76.48	Freestone	59.17	Baylor	47.1	Coleman	37.84	Jim Wells	31.24	Kleberg	23.69	Reagan	18.87	Mitchell	13.94	Hudspeth	10.45	Winkler	5.25
Castro	396.92	Lamar	76.05	Harris	58.88	Cherokee	46.84	Lipscomb	37.64	Kenedy	31.05	Lampasas	23.63	Briscoe	18.59	San Patricio	13.75	Gaines	10.15	Glasscock	5.17
Hartley	337.17	McLennan	75.36	Houston	58.83	Grayson	46.51	Eastland	37.44	Jackson	31.04	Presidio	23.46	Cottle	17.91	Morris	13.61	La Salle	10.12	Dawson	4.85
Parmer	285.32	Oldham	74.79	Washington	57.81	Frio	46.25	Shelby	37.06	Llano	30.72	Brewster	23.37	Dimmit	17.84	Menard	13.48	Garza	9.96	Rockwall	4.46
Hansford	215.23	Wilson	74.26	Hamilton	56.23	Matagorda	46.1	Palo Pinto	36.95	Franklin	30.06	Maverick	23.29	Foard	17.8	McMullen	13.34	Sabine	9.89	Terrell	4.28
Dallam	202.03	Ochiltree	72.78	Hemphill	55.84	Ellis	44.53	Wilbarger	36.85	Live Oak	29.96	Burnet	23.27	Camp	17.64	Calhoun	13.09	Andrews	9.84	Marion	4.14
Swisher	186.92	Cooke	72.39	Brazos	55.77	Collin	43.89	Uvalde	36.71	Nacogdoches	29.58	Knox	22.99	Roberts	17.44	Kimble	12.69	Reeves	9.71	Upton	3.99
Randall	180.23	Williamson	71.95	Anderson	55.76	Bosque	43.79	Lubbock	36.63	Mills	29	Refugio	22.91	Angelina	17.07	Culberson	12.65	Kinney	9.56	Newton	3.69
Sherman	174.68	Navarro	70.63	Johnson	54.92	Upshur	43.26	Taylor	36.12	Dallas	28.95	Haskell	22.73	Fisher	17.01	Edwards	12.52	Willacy	9.24	Ward	3.65
Erath	156.3	Kaufman	69.94	Bowie	54.3	Guadalupe	42.9	Throckmorton	35.47	Tarrant	28.52	Brooks	21.81	Carson	17	Jasper	12.43	Howard	9.22	Martin	3.26
Lamb	154	Wise	69.22	Austin	53.96	Zavala	42.89	Rusk	35.12	Armstrong	27.65	King	21.42	Collingsworth	16.86	Coke	12.35	Orange	9.01	Crane	2.75
Moore	112.92	Montague	69.12	Hunt	52.69	Victoria	42.51	Tom Green	34.94	Travis	26.72	Rains	21.25	Trinity	16.66	San Jacinto	12.26	Crosby	8.61	Aransas	2.52
Hale	112.48	Milam	68.4	Hill	51.95	Callahan	42.34	Wichita	34.91	Panola	26.58	Dickens	21.17	Blanco	16.43	Childress	12.25	Ector	8.51	Loving	2.16
Bailey	110.78	Gray	68.02	Bexar	51.36	Webb	42.05	Goliad	34.38	Bee	26.45	Cass	21.05	Delta	16.27	Tyler	12.12	Cochran	8.46	Real	2.05
Hopkins	106.45	Archer	67.03	Henderson	50.9	Liberty	41.2	Bell	34.34	Duval	26.3	Stonewall	20.72	Schleicher	15.57	Nolan	11.96	San Augustine	8.45		
Gonzales	103.97	Limestone	66.28	Wheeler	50.56	Waller	40.94	Caldwell	34.31	McCulloch	26.25	Hutchinson	20.61	Hays	15.41	Nueces	11.8	Val Verde	8.19		
Comanche	100.45	Clay	66.02	Wharton	49.18	Brown	40.42	Runnels	33.87	Hall	25.65	Montgomery	20.56	Terry	15.38	El Paso	11.63	Gregg	8.17		
Falls	98.44	Bastrop	65.71	Medina	49.07	Denton	40.35	Jefferson	33.65	Pecos	25.36	Chambers	20.51	Comal	15.15	Galveston	11.61	Hockley	8		
Lavaca	87.13	Atascosa	65.41	Grimes	48.99	Karnes	40.33	Fort Bend	33.59	Shackelford	25.33	Stephens	19.8	Hardeman	14.99	Polk	11.58	Bandera	7.91		
Leon	82.93	Lee	64.85	Floyd	48.32	Gillespie	39.8	Walker	33.12	Titus	24.56	Jim Hogg	19.64	Crockett	14.92	Irion	11.57	Yoakum	7.82		
Fayette	81.88	Fannin	64.09	Donley	48.18	Starr	39.25	Hidalgo	32.87	Harrison	24.2	Hood	19.6	Cameron	14.83	Sutton	11.36	Hardin	7.26		
Robertson	79.86	Parker	62.94	Burleson	48.06	Smith	39.2	Mason	32.62	Concho	24.09	Jones	19.39	Zapata	14.72	Borden	11.3	Lynn	7.14		
Red River	77.67	Brazoria	61.36	San Saba	47.28	Madison	38.92	Young	32.6	Potter	24.08	Scurry	19.35	Kent	14.54	Sterling	10.92	Midland	7.05		
DeWitt	77.32	Colorado	59.98	Coryell	47.22	Wood	38.23	Jack	32.48	Jeff Davis	24	Motley	19.09	Kendall	14.51	Kerr	10.67	Somervell	6.32		

Figure 5. 26: Annual energy from Biomass resources based on aerobic digester

Biomass power plants in Texas can provide up to 28.63 TWh of electricity from direct combustion technology. The annual energy generation varies from 1,813 GWh to 330 MWh. There are five counties in Texas that have enough resources to power up more than 1 TWh based on direct combustion. However, there are 52 counties that have enough resources based on direct combustion to power more than 100 GWh and less than 1,000 GWh. There are 87 counties in Texas that could power more than 10 MWh and less than 100 GWh. As shown in Figure 5.27.



County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh	County	Annual energy in GWh
Harris	1813.62	JOHNSON	305.61	Newton	134.93	Scurry	78.24	Crosby	47.58	Coleman	20.8	Erath	9.68	Zavala	5.05	Crane	1.81	Van Zandt	0.33
Dallas	1280.58	Cameron	297.08	Randall	125.29	Hunt	78.22	Parmer	47.58	Haskell	20	Brewster	9.67	Upton	4.64	Kinney	1.81	Wood	0.33
Fort Bend	1197.08	Montgomery	280.31	Kleberg	121.77	Briscoe	69.64	LIMESTONE	46.49	Mitchell	19.45	Kerr	9.31	Delta	4.39	Atascosa	1.77	Glasscock	0.29
Denton	1087.74	Ochiltree	274.83	Tom Green	114.21	Bowie	65.04	Fannin	45.9	Howard	18.63	Pecos	8.41	Falls	4.06	Blanco	1.77	Callahan	0.12
Travis	1016.46	Carson	258.93	Hockley	108.1	Garza	63.4	Brown	45.65	Gonzales	18.4	Bosque	7.69	Menard	3.64	Dewitt	1.77	Hardin	0.01
Tarrant	944.73	Lubbock	255.66	Comal	104.71	Motley	62.66	Brooks	45.05	Coryell	18.17	Hamilton	7.69	Coke	3.63	Frio	1.77	Stephens	0.01
Bexar	886.49	Ector	240.43	Aransas	104.24	Dickens	62.63	Kenedy	44.9	BURLESON	17.18	McCulloch	7.61	Concho	3.63	Goliad	1.77	Upshur	0.33
Ellis	828.39	Lamb	238.94	Refugio	104.24	Willacy	62.16	Hall	38.6	Nolan	17.15	Comanche	7.51	Crockett	3.63	Karnes	1.77		
Hidalgo	648.08	El Paso	209.92	San Patricio	104.24	Hale	61.93	Collingsworth	37.62	Runnels	17.13	Mason	6.44	Hood	3.63	LaSalle	1.77		
Sherman	600.49	Deaf Smith	202.44	Comal	99.31	Borden	61.33	Wheele	37.54	Hays	17.04	Andrews	6.31	Irion	3.63	Live Oak	1.77		
Hartley	555.46	Chambers	202.09	NAVARRO	95.85	Kent	61.33	Donley	36.69	Baylor	15.73	Schleicher	6.22	Lampasas	3.63	Jimm Hogg	1.77		
Nueces	534.24	Jackson	199.12	Smith	95.77	King	61.33	Nacogdoches	33.86	Fisher	15.73	Presidio	6.13	Mills	3.63	LEE	1.11		
Collin	491.65	Grimes	187.25	Medina	91.55	Terry	58.84	Maverick	29.37	Knox	15.73	Kimble	5.94	Palo Pinto	3.63	Anderson	0.33		
Williamsor	471.72	Webb	184.7	Gregg	90.6	Jim Wells	57.48	Wilson	28.92	Stonewall	15.73	Hudspeth	5.94	San Saba	3.63	Camp	0.33		
Brazoria	454.49	Jones	181.02	Polk	88.98	CALHOUN	53.76	Dallam	27.54	Taylor	15.73	Reagan	5.67	Somervell	3.63	Cass	0.33		
Hill	429.94	Colorado	170.06	Rusk	85.15	Gaines	53.51	Val Verde	26.01	Childress	14.97	Ward	5.59	Sterling	3.63	Franklin	0.33		
Bell	418.4	Wichita	162.74	Swisher	84.71	Dawson	53.5	Caldwell	25.6	AUSTIN	14.46	Bandera	5.4	Starr	3.23	Harrison	0.33		
Galveston	401.91	Floyd	162.38	MILAM	83.54	Bailey	51.7	FAYETTE	24.8	Cottle	13.75	Burnet	5.4	Terrell	2.97	Henderson	0.33		
Hansford	398.21	Lamar	160.62	Matagorda	83.41	Yoakum	51.63	Armstrong	23.03	Foard	13.75	Edwards	5.4	Culberson	2.92	Hopkins	0.33		
Jefferson	385.41	Hutchinson	160.61	Gray	82.67	Angelina	51.55	Lipscomb	22.79	Hardeman	13.75	Kendall	5.4	Jeff Davis	2.92	Marion	0.33		
Moore	377.1	VICTORIA	153.89	Bee	81.2	Cherokee	50.21	Oldham	22.29	Motley	13.75	Llano	5.4	Martin	2.84	Morris	0.33		
Wharton	364.38	Midland	152.57	Lynn	80.86	Titus	49.84	Hemphill	22.06	Wilbarger	13.75	Real	5.4	Duval	2.81	Panola	0.33		
Guadalupe	332.19	Grayson	150.57	Uvalde	78.84	Castro	49.66	Roberts	22.06	Cooke	12.93	Sutton	5.4	Zapata	2.64	Rains	0.33		
McLennan	319.07	Potter	143.09	Parker	78.36	Cochran	47.6	Gillespie	21.44	Reeves	11.44	Dimmit	5.05	McMullen	2	Red River	0.33		

Figure 5. 27: Annual energy from Biomass resources based on direct combustion

In the two technologies of direct combustion and anaerobic digester, Texas can use up to 39.56 TWh of biomass energy from 254 counties to generate electricity every year. The annual energy generation varies from one county to another in the range of 1,872 to 2.16 GWh. As shown in Figure 5.28.

County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Harris	1872.5	McLennan	394.43	Grayson	197.08	Hockley	116.1	Cooke	85.32	Brooks	66.86	Brazos	55.77	Wood	38.56	Nolan	29.11	Crockett	18.55	Ward	9.24
Dallas	1309.5	Lamb	392.94	Victoria	196.4	Uvalde	115.55	Donley	84.87	Calhoun	66.85	Collingsworth	54.48	Eastland	37.44	Hardeman	28.74	Blanco	18.2	Orange	9.01
Fort Bend	1230.7	Guadalupe	375.09	Hutchinson	181.22	Comal	114.46	Dickens	83.8	Clay	66.02	Maverick	52.66	Shelby	37.06	Burnet	28.67	Camp	17.97	Upton	8.63
Denton	1128.1	Johnson	360.53	Hale	174.41	Limestone	112.77	Leon	82.93	Lee	65.96	Taylor	51.85	Stonewall	36.45	Howard	27.85	Edwards	17.92	San Augustine	8.45
Travis	1043.2	Ochiltree	347.61	Potter	167.17	Fannin	109.99	King	82.75	Bastrop	65.71	Bosque	51.48	Goliad	36.15	Concho	27.72	Zapata	17.36	Real	7.45
Tarrant	973.25	Parmer	332.9	Navarro	166.48	Comanche	107.96	Robertson	79.86	Coryell	65.39	Henderson	51.23	Llano	36.12	Lampasas	27.26	Menard	17.12	Hardin	7.27
Bexar	937.85	Cameron	311.91	Erath	165.98	Bee	107.65	DeWitt	79.09	Burleson	65.24	Runnels	51	Throckmorton	35.47	Childress	27.22	Sutton	16.76	Terrell	7.25
Hartley	892.63	Randall	305.52	Bailey	162.48	Hopkins	106.78	Red River	78	Hall	64.25	San Saba	50.91	Val Verde	34.2	Jeff Davis	26.92	Trinity	16.66	Martin	6.1
Ellis	872.92	Montgomery	300.87	Midland	159.62	Aransas	106.76	Hemphill	77.9	Hamilton	63.92	Armstrong	50.68	McCulloch	33.86	Panola	26.91	Hudspeth	16.39	Glasscock	5.46
Sherman	775.17	Lubbock	292.29	Milam	151.94	Fayette	106.68	Van Zandt	76.81	Gaines	63.66	Wilbarger	50.6	Pecos	33.77	Shackelford	25.33	Andrews	16.15	Winkler	5.25
Deaf Smith	705.86	Carson	275.93	Gray	150.69	Wilson	103.18	Kenedy	75.95	Nacogdoches	63.44	Frio	48.02	Mitchell	33.39	Reagan	24.54	Coke	15.98	Crane	4.56
Hidalgo	680.95	Swisher	271.63	Tom Green	149.15	Falls	102.5	Kent	75.87	Baylor	62.83	Zavala	47.94	Walker	33.12	Harrison	24.53	Culberson	15.57	Marion	4.47
Hansford	613.44	Ector	248.94	Kleberg	145.46	Polk	100.56	Titus	74.4	Gillespie	61.24	Upshur	43.59	Brewster	33.04	Hood	23.23	McMullen	15.34	Rockwall	4.46
Nueces	546.04	Lamar	236.67	Parker	141.3	Gregg	98.77	Terry	74.22	Lipscomb	60.43	Haskell	42.73	Fisher	32.74	Dimmit	22.89	Irion	15.2	Loving	2.16
Williamson	543.67	Grimes	236.24	Medina	140.62	Scurry	97.59	Garza	73.36	Caldwell	59.91	Starr	42.48	Mills	32.63	Schleicher	21.79	Sterling	14.55		
Collin	535.54	Jackson	230.16	Newton	138.62	Oldham	97.08	Borden	72.63	Yoakum	59.45	Callahan	42.46	Young	32.6	Rains	21.58	Morris	13.94		
Brazoria	515.85	Colorado	230.04	Smith	134.97	Cherokee	97.05	Willacy	71.4	Freestone	59.17	Karnes	42.1	Jack	32.48	Cass	21.38	Bandera	13.31		
Moore	490.02	Dallam	229.57	Hunt	130.91	Motley	95.5	Kaufman	69.94	Houston	58.83	Liberty	41.2	Hays	32.45	Jim Hogg	21.34	Jasper	12.43		
Hill	481.89	Webb	226.75	Matagorda	129.51	Jim Wells	88.72	Wise	69.22	Coleman	58.64	Waller	40.94	Live Oak	31.73	Reeves	21.15	San Jacinto	12.26		
Bell	452.74	Chambers	222.6	Refugio	127.15	Briscoe	88.23	Montague	69.12	Dawson	58.35	Palo Pinto	40.58	Cottle	31.66	Delta	20.66	Tyler	12.12		
Castro	446.58	El Paso	221.55	Gonzales	122.37	Wheeler	88.1	Angelina	68.62	Washington	57.81	Roberts	39.5	Foard	31.55	Kerr	19.98	La Salle	11.89		
Jefferson	419.06	Floyd	210.7	Rusk	120.27	Lynn	88	Austin	68.42	Crosby	56.19	Mason	39.06	Franklin	30.39	Kendall	19.91	Kinney	11.37		
Wharton	413.56	Jones	200.41	Bowie	119.34	Lavaca	87.13	Atascosa	67.18	Anderson	56.09	Madison	38.92	Presidio	29.59	Stephens	19.81	Somervell	9.95		
Galveston	413.52	Wichita	197.65	San Patricio	117.99	Brown	86.07	Archer	67.03	Cochran	56.06	Knox	38.72	Duval	29.11	Kimble	18.63	Sabine	9.89		

Figure 5. 28: Annual energy from Biomass resources in Texas by counties

Based on this electrical proposal model in Texas from Biomass energy resources, Counties in Texas could be classified into four main groups: The first one is the richest one and each county has enough resources to power up more than 500 GWh per year and there are 17 counties in this group. The second group has 68 counties and could be considered as moderate due to its resources of biomass energy, and each county in this group could power more than 100 GWh yearly. The third group has 153 counties and it is poor due to its resources of biomass energy and each county in this group could power more than 10 GWh yearly. The last group is the smallest one and it has only 16 counties with very limited resources and it does not exceed 10 GWh from each county per year. This classification is shown in Figure 5.29.

Based on this electrical proposal model in Texas from Biomass energy resources, Counties in Texas could be classified into four main groups: The first one is the richest one and each county has enough resources to power up more than 500 GWh per year and there are 17 counties in this group. The second group has 68 counties and could be considered as moderate due to its resources of biomass energy, and each county in this group could power more than 100 GWh yearly. The third group has 153 counties and it is poor due to its resources of biomass energy and each county in this group could power more than 10 GWh yearly. The last group is the smallest one and it has only 16 counties with very limited resources and it does not exceed 10 GWh from each county per year. This classification is shown in Figure 5.29.

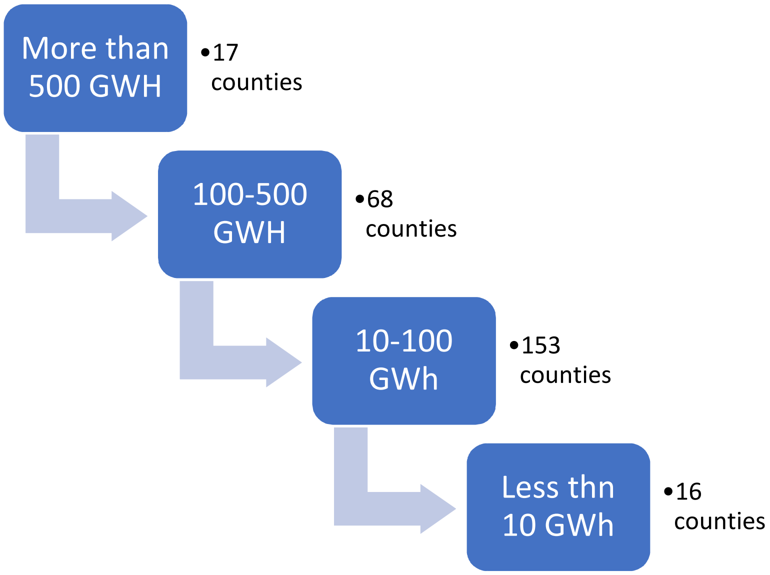


Figure 5. 29: Biomass power plant classifications in Texas

CHAPTER VI

WIND ENERGY

6.1 Wind Energy

The movement of the gases particles is called the wind movement and it has energy. It is used since the old days for agriculture applications in windmills and in water systems. There are no specific rules for wind movement to describe in detail the movement during the day But there are some general rules or phenomena:

1-Sea and land breeze

The earth's surface has land and water and during the daytime, the air temperature on the land is higher, and due to that the air is lighter, so it rises and moves while the wind on the water is cooler and denser, so it falls. As shown in Figure 6.1 'Sea and Land Breezes, n.d', at night, movement occurs in the opposite way.

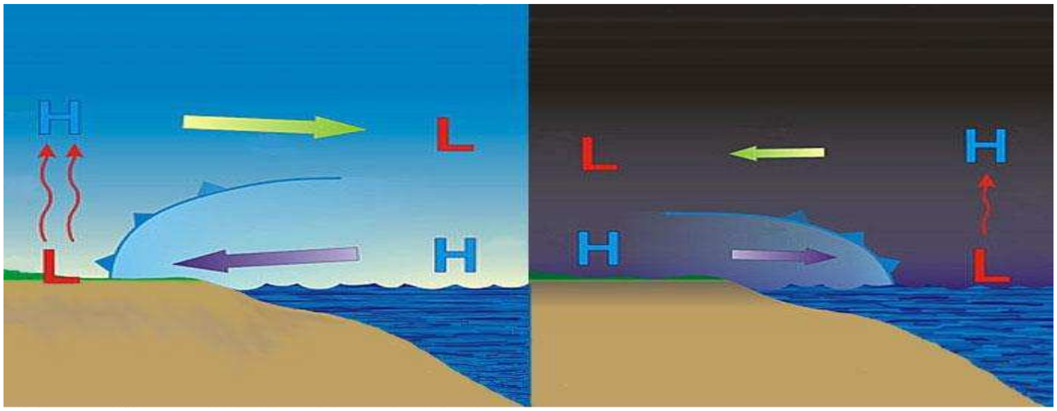


Figure 6. 1: Sea and land breeze

2- Mountain and valley breeze

The movement of the wind from the valley to the mountain during the daytime while in the night reverses from the mountain to the valley, as shown in Figure 6.2 'Britannica,2020'.

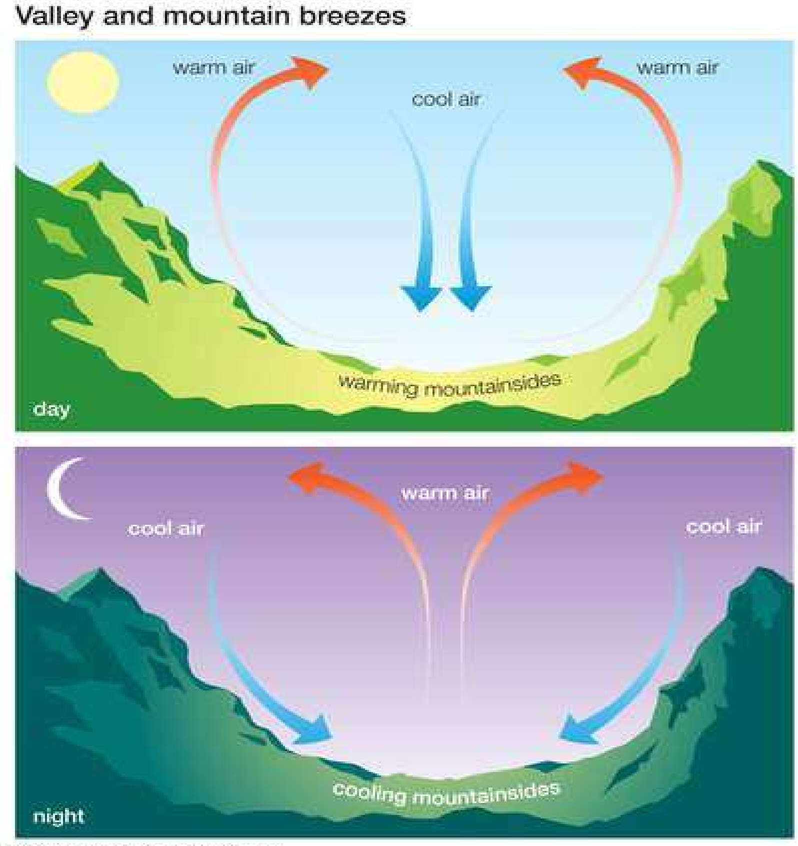


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Figure 6. 2: Mountain and valley breeze

3- Rotate the earth around the sun

Based on the earth spins on the sun, there are two separate parts on the earth one is hotter than the other depending on the season. Therefore, the wind flows from the hot area to the cold one based on the three cell model which is clear in Figure 6.3 ‘Atmospheric circulation, n.d’. The idea simply depends on the movement of the wind from the hot place (equator) to the other part of the land. The three-cell model splits the earth into two parts and each part into three parts They are Hadley, mid-latitude, and polar models.

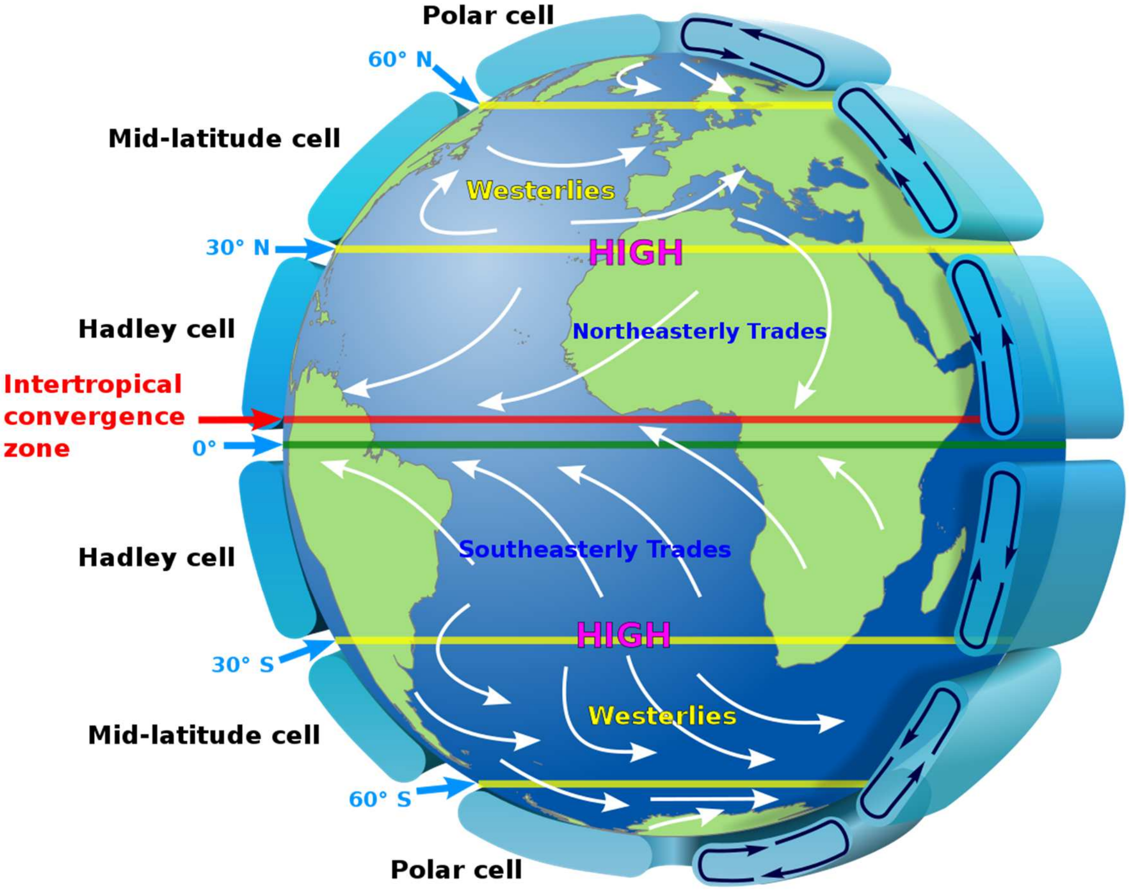


Figure 6. 3: Three cell model

6.2 Physical Law Of Wind Energy

The available energy in the wind comes in the form of kinetic energy. As shown in Equation 6.1, the work done by wind energy is the product of force and displacement.

$E = F * S$….6.1

Where:

E: work done in Joule

F: force in Newton

S: displacement in meter

The force that hit the wind turbine can be determined by the second law of motion of Newton, which is, in this case, the product of the mass of air, and the acceleration of wind as shown in Equation 6.2

$F = m * a$…….6.2

Where:

M: mass of the air in Kg

a: acceleration in m^2/s

Power can be defined as the energy rate per unit time, as shown in Equation 6.3. Air mass is calculated from the product of air density and volume, as shown in Equation 6.4

P=$\frac{dE}{dt}$=$\frac{dm}{dt} * s * a$…………..6.3

Where:

P: power in Watt

T: time in s

S: displacement in m

$m = \rho * V$……..6.4

ρ: air density in kg/m^3

V: volume in m^3

The relationship between acceleration and displacement is obtained by using the second motion formula which discovered by Newton in Equation 6.5. By assuming that the initial speed is zero and then substituting it into Equation 6.5, the acceleration speed can be calculated by Equation 6.6.

$v^2 = u^2 + 2as$ … … … 6.5

Where:

v: velocity in m/s.

u: initial speed in m/s

By assuming the initial speed is zero and substitute it in Equation 6.5

a=$\frac{v^2}{2s}$ …………..6.6

By substituting Equation 6.5 into Equation 6.6, the power can be obtained in the form of speed and mass as shown in Equation 6.7.

P= $\frac{dm}{dt} * \frac{v^2}{2}$…….6.7

By substituting Equation 6.4 into Equation 6.7, the power can be obtained in the form of speed and volume as shown in Equation 6.8.

$$P=\frac{d\rho * V}{dt} * \frac{v^2}{2} \ldots\ldots 6.8$$

The volume can be determined by the product of area and displacement, or it can be replaced by the value in Equation 6.9. Power can be obtained by a combination of area and speed as shown in Equation 6.10.

$$V = A * S \ldots\ldots 6.9$$

Where;

A: Area in m^2

$$P=\frac{d\rho * A * S}{dt} * \frac{v^2}{2} \ldots\ldots 6.10$$

The change of displacement per unit time is velocity, so it is replaced by Equation 6.10. The power of wind energy can be determined according to the cubic velocity of wind, area, and air density, as shown in Equation 6.11‘Masters,2013’.

$$P = \frac{1}{2} * \rho * A * v^3 \ldots\ldots 6.11$$

6.3 Wind Turbine Types

According to energy extraction, wind technology can be divided into four categories: machines based on rotary lift, machines based on rotary drag, machines based on flying lift, and machines using flow-induced vibration. Machines based on lifting and towing are the most popular main wind technology concepts, such as horizontal and vertical wind turbines, The flow induced vibration and flying left technologies are less efficient compared to lift and drag technology, as well, it is only applicable for the small size.

In general, wind turbines have two types: horizontal and vertical wind turbines as shown in Figure 6.4 ‘South et al,1983’. The horizontal wind turbine can be the first blade, two blades, three blades, and multiple blades. There are several types of vertical wind turbines, such as Savonius , Spiral, and Darrieus.

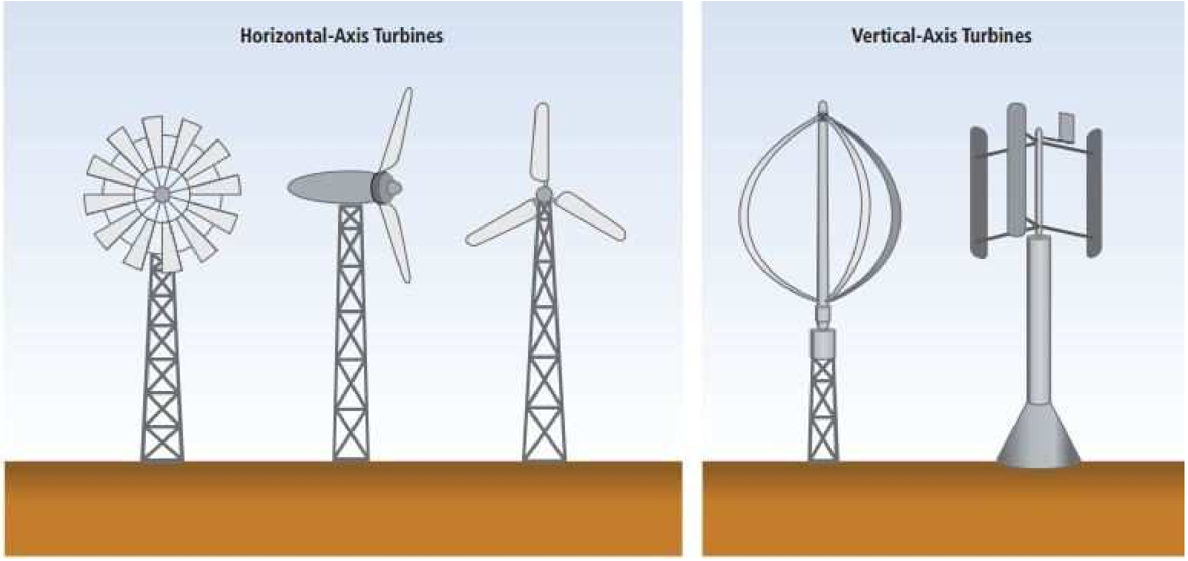


Figure 6. 4: Wind turbine types

In a vertical wind turbine, components such as gearboxes and generators are located in the basement, while in a horizontal wind turbine, the components should be located on the top of the tower, as shown in Figure 6.5 ‘Horizontal/Vertical Axis Machines, n.d’. Horizontal wind turbines are more efficient, compact in design, beautiful in scenery, and friendly to birds. Vertical Turbines are cheaper than horizontal turbines because they use half the materials of horizontal fans, but they are inefficient and very dangerous to bird migration.

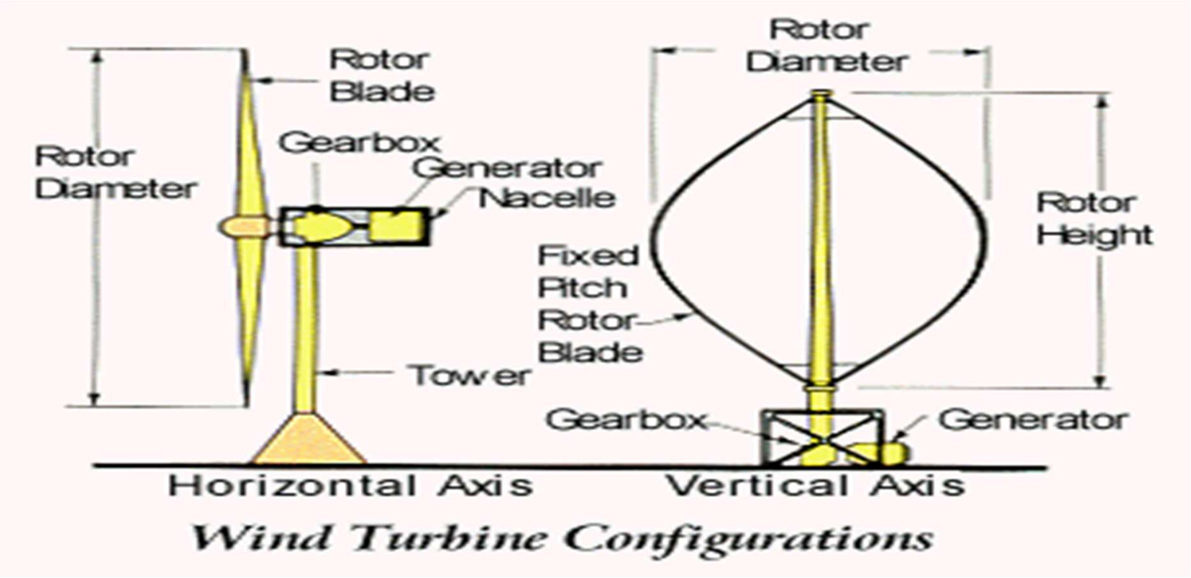


Figure 6. 5: Horizontal vs Vertical wind turbine

6.4 Wind Turbine Components

Wind turbines have many main components, such as towers, rotors, gearboxes, generators, and nacelles, as shown in Figure 6.6 ‘Masters,2013’.

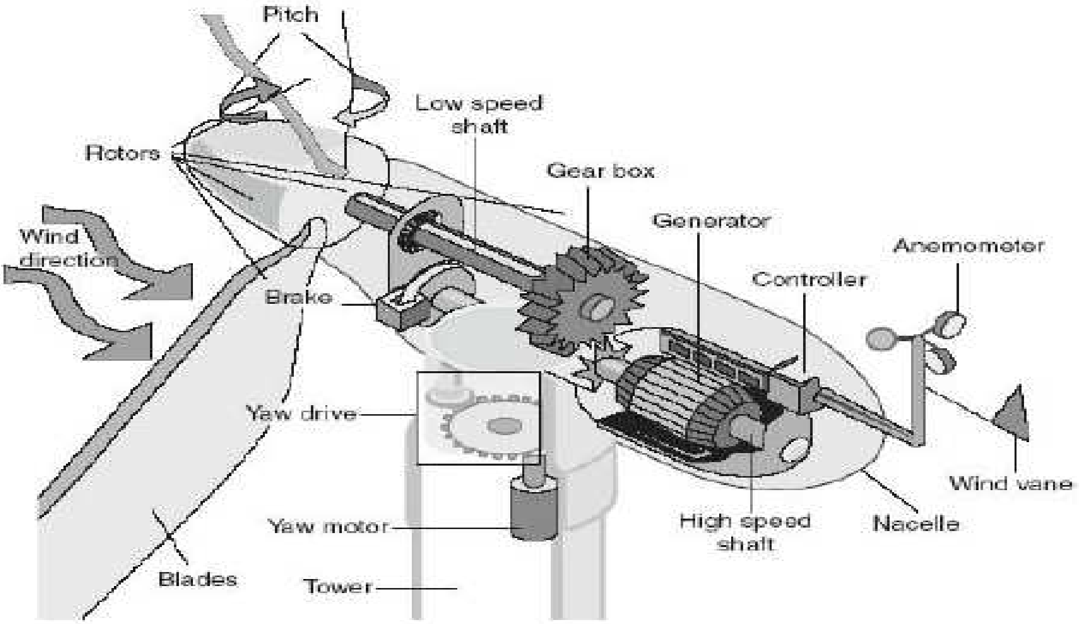
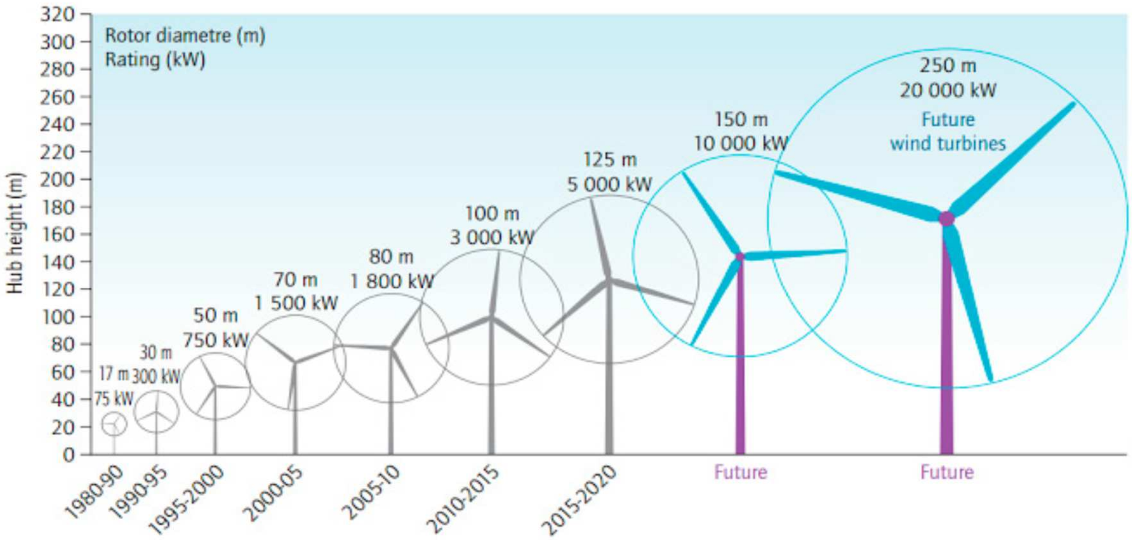


Figure 6. 6: Wind turbine components

6.4.1 Tower

The tower is the part that holds all of the wind turbine components. The height of the wind turbine tower is correlated to the wind speed. The higher, the higher the cost. Wind turbine tower tall is directly proportionate to the wind speed, thus a higher tower means higher wind speed which causes more generation 'Stiebler,2008'.

As the technology of wind turbines grows, the tower must get taller. The growth in wind turbine height is the core of improving wind turbine technology, hence higher height required special design for the towers in order to handle the weight of the wind turbine, and the higher wind speed. Figure 6.7 'IEA. Technology Roadmap –Wind Energy,2013' illustrates the growth in the wind turbine height from 1980 until now. The height of the wind turbine in 1980 was 17 m with only 75 kW power capacity, whereas the wind turbine in the current technology reaches up to 150 m with 10 MW capacity. In addition, scientists predict that wind turbine technology will reach 250 m it will reach 20 MW in the next few years.



Source: adapted from EWEA, 2009.

Figure 6. 7: Wind turbine height growth

The tower of the wind turbine can be categorized based on the structure into the main four types as shown in Figure 6.8 ‘Basic Construction of Wind Turbine, 2020’; The first type is the tubular tower, its best features are easy to install, friendly to birds, and be considered good looking. The second type is the lattice tower. The best advantage is that because its shape requires less materials, the manufacturing cost is lower. Their drawbacks are the high maintenance and their impact on the birds. The third type so-called is the Guyed tower which is fit for the small wind turbine and it is low-cost due to its small size. The last type is called the Hybrid tower, it is a mixture of the tubular and lattice types and it is easy for installation.

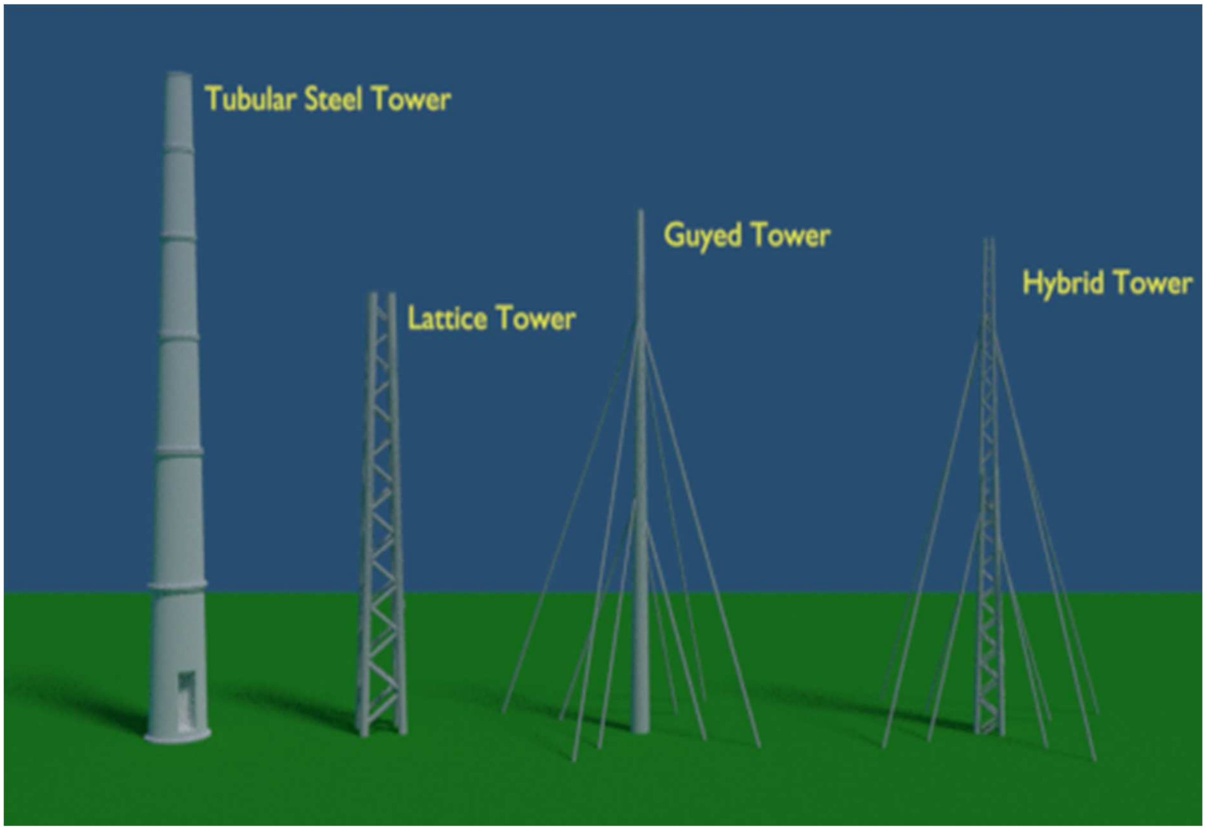


Figure 6. 8: Wind turbine towers types

6.4.2 Rotor

The rotor is the only part facing the wind. It converts wind energy into mechanical energy. The rotor has main components such as blades, hub, shaft, and bearing. Usually, it is made of carbon material to increase the roughness of the rotor to withstand the wind and reduce weight.

6.4.3 Gear Box

The gearbox is the most important part of the wind turbine. It is usually connected between two terminals, the low-speed shaft and the high-speed shaft, the first is connected to the rotor side and the second is connected to the generator side. The gearbox is used to increase the rotational speed from the low shaft that is around 50 rpm to a higher speed shaft connected to an electric generator, which around 1500 rpm and the common ratio of the gearbox is 1:100 ‘Stiebler,2008’.

In some technologies, this is a so-called direct drive wind turbine, where the wind turbine does not have a gearbox The generator rotates at the same speed as the rotor. As shown in Figure 6.9 ‘Friedrich and Lukas,2017’, the weight of the direct drive wind turbine is lighter than the weight of an ordinary wind turbine with a gearbox. And it is more compact, therefore, due to its light weight, we can achieve tall towers. Although a wind turbine without a gearbox is more expensive than a wind turbine with a gearbox, it is more efficient.

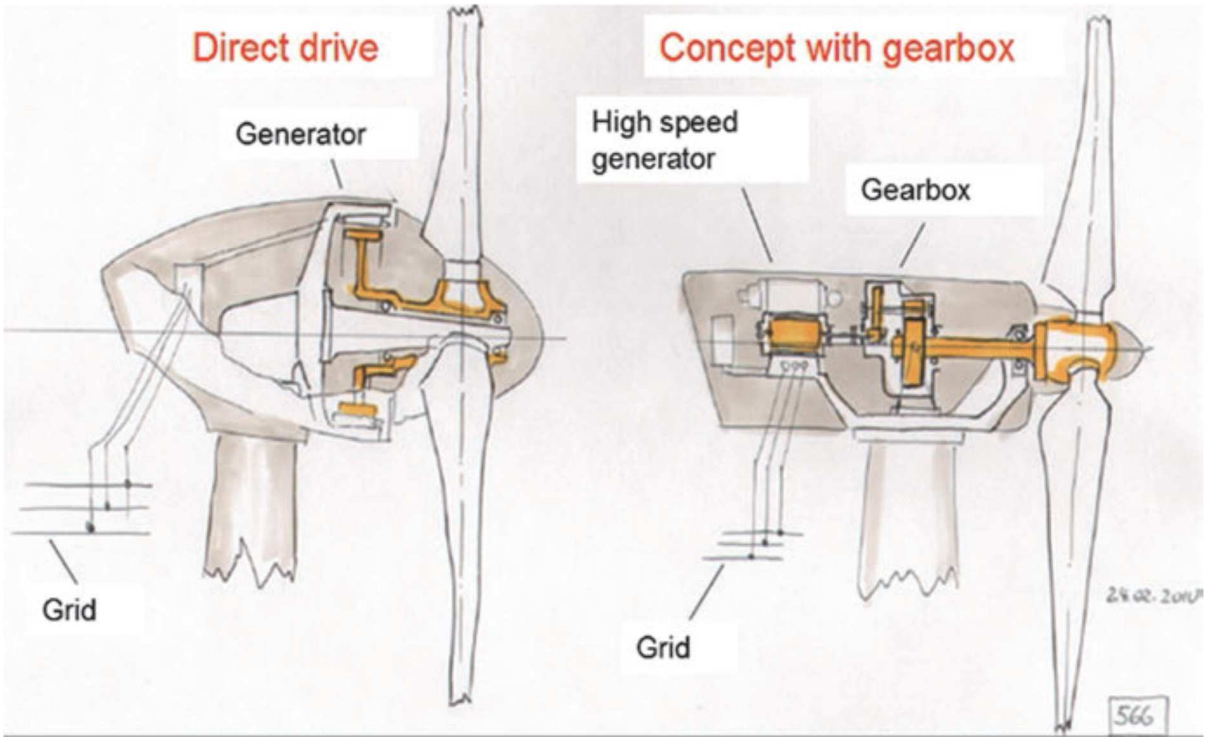


Figure 6. 9: Gearbox wind turbine vs Direct drive wind turbine

6.4.4 Generator

Generally, a wind turbine system has three types of wind turbine generators: DC generators, AC synchronous generators, and AC asynchronous generators. In principle, all previous types can run at fixed or variable speeds. Therefore, all wind turbine generators operate at variable speeds to reduce the stress on the rotor blades due to wind speed fluctuations. More than that, the variable speed generator improves the aerodynamics and torque efficiency of the wind turbine. Doubly-fed induction generators are one of the best ways to allow wind turbines to rotate at variable speeds. The rotor motor is connected to two power sources. The stator is connected with the electrical grid, hence, it has a fixed frequency, thus the rotor part can turn at the optimal speed of the wind turbine and achieve the maximum energy ‘Wildi,2006’. Figure 6.10 ‘Wildi, 2006’shows the components of a doubly-fed induction generator.

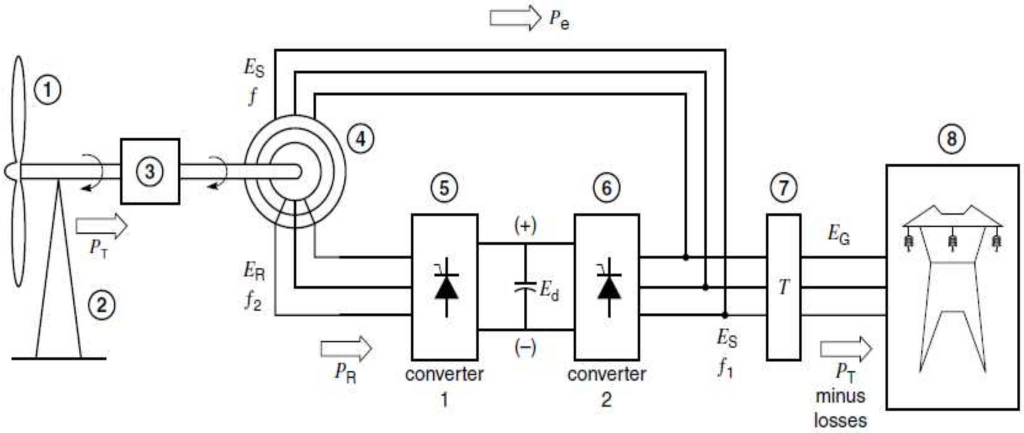


Figure 6. 10: Doubly Fed induction generator

[1: rotor 2: Tower 3: Gear box 4: Generator 5: converter AC-DC 6: converter DC-AC 7: Power transformer 8: Electrical grid]

6.4.5 Nacelle

The nacelle is the cradle of the wind turbine, except for the rotor and tower, all components include gearbox, generator, yaw mechanism and safety brake. It has a yaw mechanism that can point the rotor in the direction of wind speed to achieve higher efficiency. When the wind speed is higher than the cut-off speed and the generator branch line fails, the safety brake will be used to stop the turbine.

6.5 Wind Turbine Generation

The energy of the wind turbine indicates how much energy the wind turbine can extract from the available energy in the wind, which is determined by Equation 6.11.

$P = \frac{1}{2} * \rho * A * v^3$ …..6.11

To determine the wind turbine energy, the simple model theory has been used by 'Masters,2013', which is the following: The extracted wind energy at the wind turbine is the difference between the kinetic energy before and after the rotor. Which rely on the difference between the Upwind and Downwind velocity as shown in Figure 6.11'Masters,2013'.

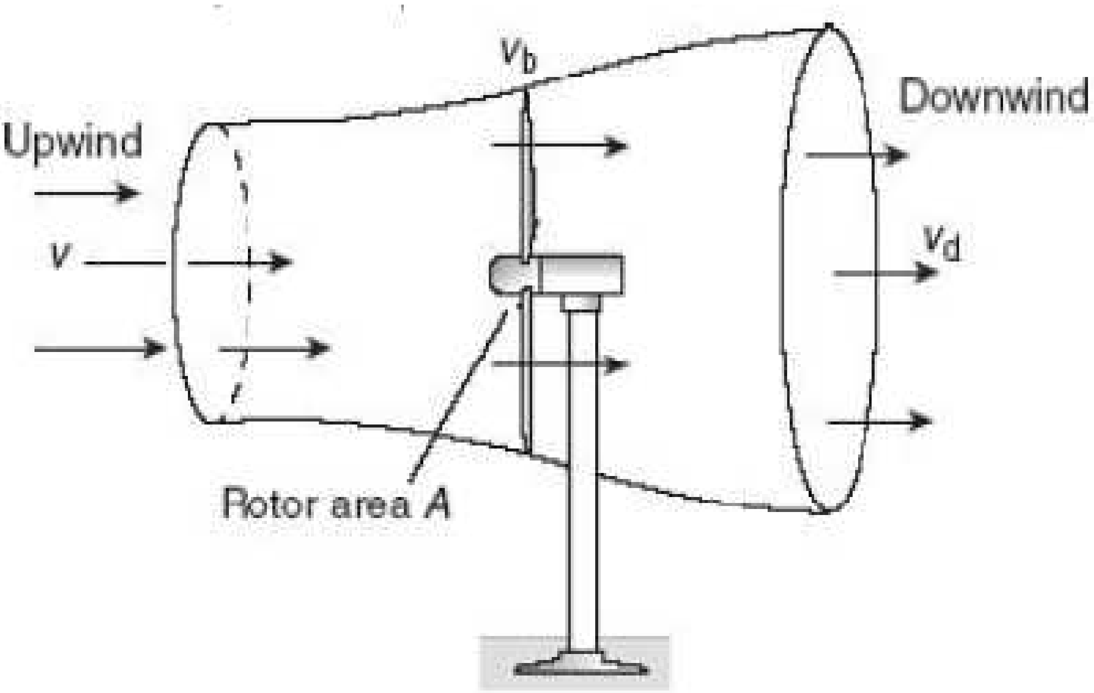


Figure 6. 11: Simple model theory for wind turbine

Where:

V_{Upwind} : Velocity before the rotor

$V_{Downwind}$: Velocity after the rotor

V_b : Velocity at the rotor

E_b: Energy extracted at the rotor

P_b: Power extracted at the rotor

$E_b = \frac{1}{2} * m * (v_{Upwind}^2 - v_{Downwind}^2)$ …..6.12 'Masters,2013'

As shown in Equation 6.3, power is the energy rate per unit of time. By replacing Equation 6.3 with Equation 6.12, the power extracted from the rotor can be realized by Equation 6.13‘Masters,2013’.

$P_b = \frac{1}{2} * \frac{dm}{dt} * (v_{Upwind}^2 - v_{Downwind}^2)$ …….6.13

Air mass is calculated from the product of air density and volume, as shown in Equation 6.4, In addition, the change of the displacement per unit of time is the velocity. From all of that, Equation 6.13 can be written in a new form as shown in Equation 6.14 ‘Masters,2013’.

$P_b = \frac{1}{2} * \rho * \mathrm{A} * v_b * (v_{Upwind}^2 - v_{Downwind}^2)$ …..6.14

By assuming the velocity at the rotor (vb) is the average velocity of Upwind and Downwind, Equation 6.14 ‘Masters,2013’ can be written as the following:

$P_b = \frac{1}{2} * \rho * \mathrm{A} * (\frac{v_{Upwind}+v_{Downwind}}{2}) * (v_{Upwind}^2 - v_{Downwind}^2)$ …..6.14

To simplify the calculations, the ratio of the Upwind velocity and Downwind velocity equals to ƛ. By using that to rearrange Equation 6.14.

$P_b = \frac{1}{2} * \rho * \mathrm{A} * (\frac{v_{Upwind}+ƛ*v_{Upwind}}{2})* * (v_{Upwind}^2 - ƛ * v_{Upwind}^2)$ ….6.15‘Masters,2013’

$P_b = \frac{1}{2} * \rho * \mathrm{A} * v_{Upwind}^3 * [\frac{1}{2}(1 + ƛ)(1 - ƛ^2)]$ ………6.16 ‘Masters,2013’

$P_b = Power\ in\ the\ wind * Fraction\ Extracetd$……….6.17 ‘Masters,2013’

The fraction extracted is known as the rotor efficiency (C_p) in the wind turbine technology.

$P_b = \frac{1}{2} * \rho * \mathrm{A} * v_{Upwind}^3 * C_p$ ……………..6.18 ‘Masters,2013’

The rotor efficiency could be determined using Equation 6.19 'Masters,2013', and it depends on the velocity before and after the wind turbine representing the factor ƛ

$C_p = \frac{1}{2}[(1+ƛ)(1-ƛ^2)]$…..6.19

From Equation 6.19, the maximum efficiency could be achieved for the rotor efficiency, by taking the derivative of Equation 6.19 with respect to ƛ and set it to zero 'Masters,2013', as the following:

$$\frac{dC_p}{dƛ} = \frac{1}{2} * [(1+ƛ) * (-2ƛ) + (1-ƛ^2)]$$

$$\frac{dC_p}{dƛ} = \frac{1}{2} * [(1+ƛ) * (-2ƛ) + (1-ƛ)(1+ƛ)]$$

$$\frac{dC_p}{dƛ} = \frac{1}{2} * [(1+ƛ)(-2ƛ + 1 - ƛ)]$$

$$\frac{dC_p}{dƛ} = \frac{1}{2} * [(1+ƛ)(1-3ƛ)] = 0$$

At ƛ=1/3 or-1, -1 is not an applicable value, so it is neglectable.

From the previous calculations, the maximum value of the rotor efficiency is achieved at ƛ=1/3. Therefore, by substituting the value in the formula into the Equation 6.19, the maximum rotor efficiency is 16/27 (0.5925), which is known by the Betz coefficient. There is usually an important term related to rotor efficiency, called the tip speed ratio, which represents the ratio of the wind speed to the wind speed inside the rotor.

Figure 6.12 'Hau,2013' shows the rotor efficiency of several wind turbine technologies, as shown in the figure, the maximum efficiency can be achieved under the Betz limit. In terms of tip speed ratio, the three-blade horizontal wind turbine technology has the highest rotor efficiency among various wind turbine technologies.

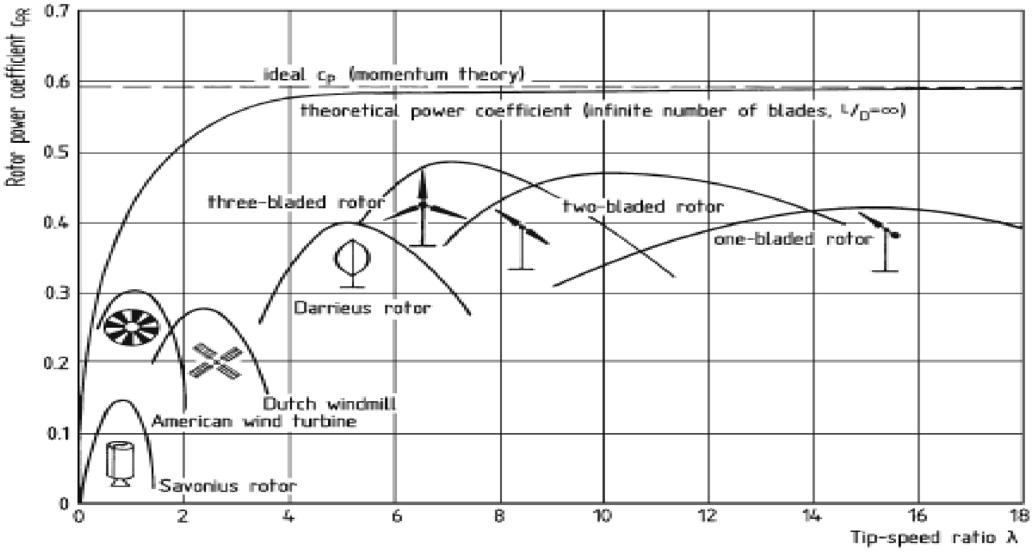


Figure 6. 12: Rotor efficiency vs wind turbine types

As shown in Equation 6.18, wind power depends on the rotor efficiency, air density, area, and wind speed. Air density depends on many factors: temperature, pressure, and altitude.

$$P_b = \frac{1}{2} * \rho * A * v_{Upwind}^{3} * C_p \text{ ……………..6.18}$$

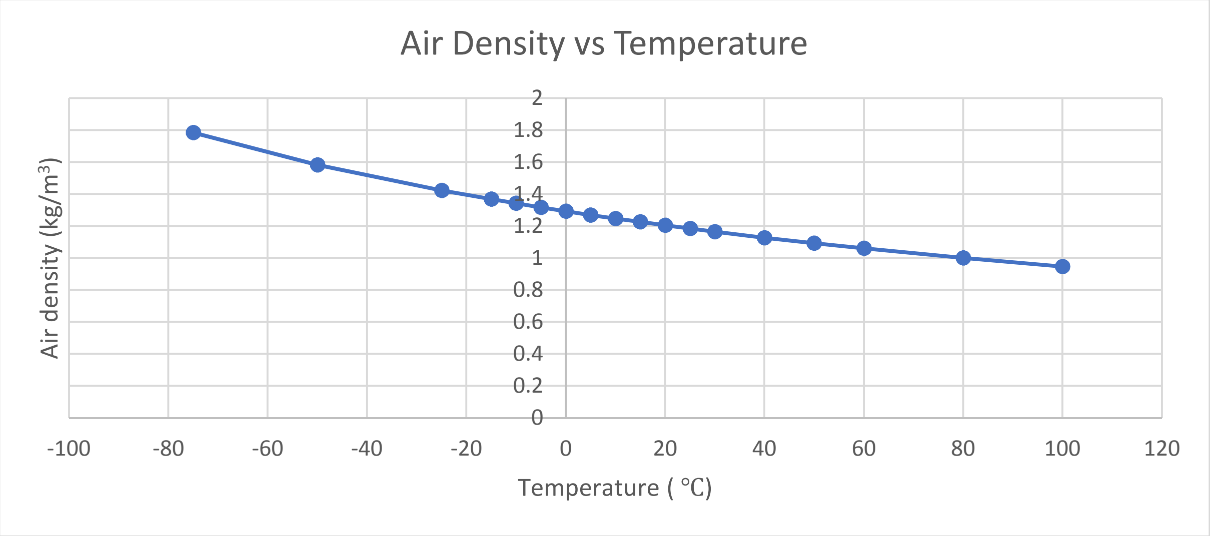


Figure 6. 13: Air density vs Temperature

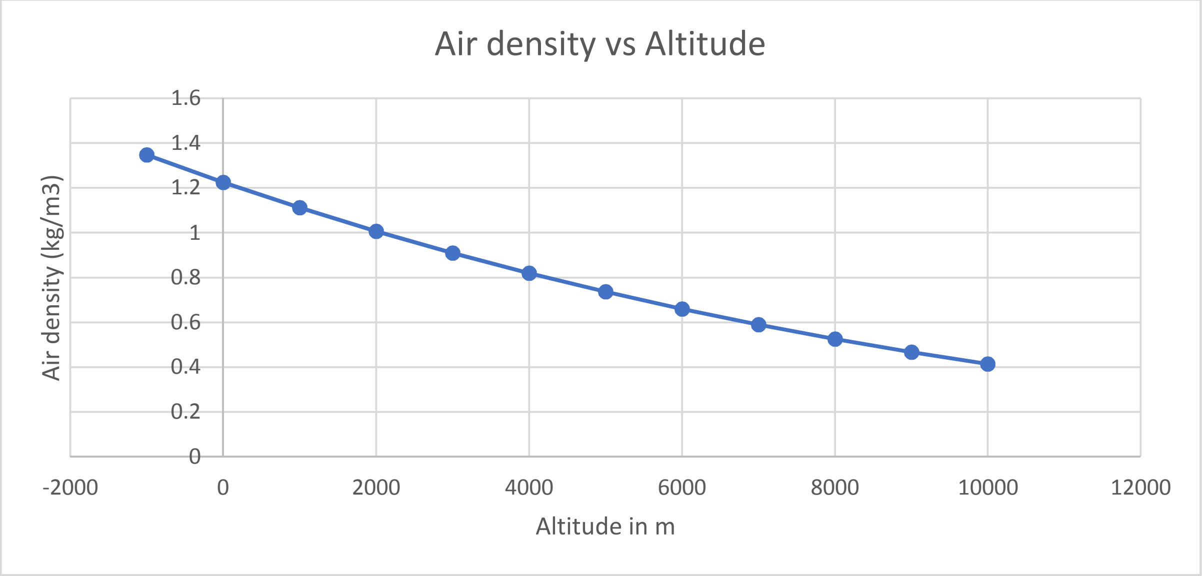


Figure 6. 14: Air density vs Altitude

Figures 6.13 & 6.14 ‘Engineering ToolBox, 2003’ shows that temperature and altitude are inversely proportional to air density. However, the change rate in the value is not quite enough to achieve more power generation in wind power, the highest value of air density is around 1.2 and the lowest value is 0.8 in the normal condition as shown in the previous Figures.

According to the latest technology of wind turbines, the area produced by the rotor is the area of a circle, depending on the length of the blades, GE’s Haliade-X 12 MW has the highest length of blades of a wind turbine up to 107 m ‘Kellner,2019’, So the area depends on the technology of the wind turbine. In summary, wind speed is the most important factor in determining the power of a wind turbine because it varies between regions and also appears as cubic power in Equation 6.18.

6.6 Wind Speed

Like all types of renewable energy, wind energy is an non-dispatchable resource, but as the wind spreads, it becomes more complicated due to sudden changes in wind speed during the hours, days, and months. In solar energy, the sun's movement changes in an hour, and thus the solar radiation changes, and for water energy, it happened in days while in the wind as mentioned above it changes suddenly and immediately.

Unfortunately, there are not mathematical equations to describe and predict the wind speed, so that we must find another way to predict the wind energy available at a certain site, Figure 6.15 'Wind Speed Summary for 2021,2021' shows how wind speed could vary from one hour to another on the same day or from one day to another, and definitely from one year to another. Some trends may be noticed, for example, the wind speed in the morning and evening is higher than the wind speed in the noon and afternoon, but the overall movement is still blurred, and there is no trend that can be explained or predicted.

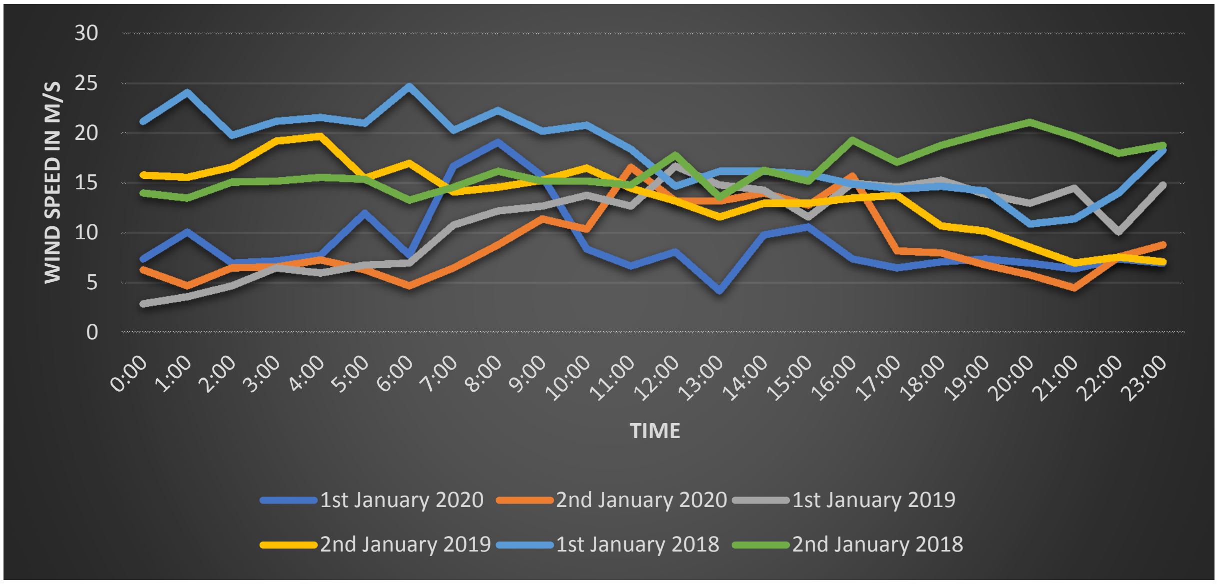


Figure 6. 15: Wind speed on Edinburg Texas for some days in 2018,2019&2020

To predict the wind energy available at a certain site, the statistics data for wind speed is the way using some statistics functions, in most physics phenomena the normal distribution (

Gauss distribution) is used while in the wind it is not fit for wind data so Weibull distribution used for wind energy.

6.6.1 Weibull Distribution Function

The Weibull distribution function is a probability distribution function defined as shown in Equation 6.20 ‘Oyedepo,2012’.

F(v)= $(\frac{K}{C})(\frac{V}{C})^{K-1} \exp\left[-\left(\frac{V}{C}\right)^{k}\right]$…………6.20 ‘Oyedepo,2012’

Where:

F(v) : the probability of the wind speed (unit less)

V: the wind speed (m/s), $V \geq 0$

K: shape parameter (unit less) , $K>1$

C: scale parameter (m/s) , $C >0$

When the scale parameter is equal to 2 and the shape parameter is equal to 1, it is called the Rayleigh distribution function, which is a special case of the Weibull distribution function ‘Glen ,2014’.

6.6.2 Wind Speed Measurement

There are two instruments that can be used to measure wind speed. Cup and sonic anemometer. Wind speed is usually measured at a certain altitude It is smaller than the height of the wind turbine hub, so Equation 6.21‘Effect of Wind Shear Coefficient for the Vertical Extrapolation of Wind Speed Data and its Impact on the Viability of Wind Energy Project,2015’ must be used to convert the wind speed result to the required height which is known as Hellmann’s power law.

$$\frac{V}{V0} = (\frac{H}{H0})^{\alpha} \text{……………}6.21$$

V: wind speed at required point

V0: wind speed measure by anemometer.

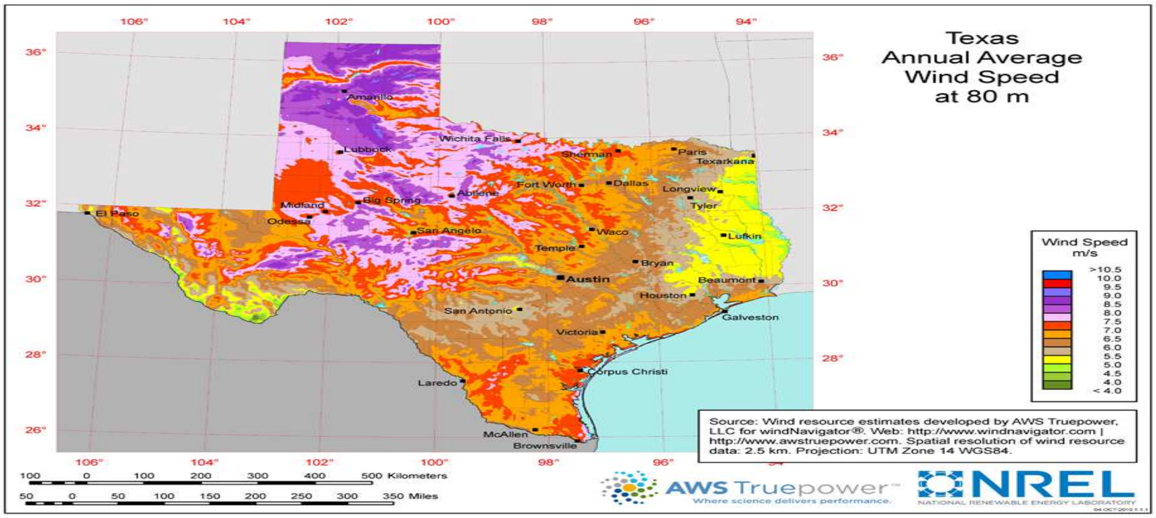
H: elevation at required point

H0: elevation at measured point

α: friction factor or Hellmann’s exponents

6.7 Wind Speed In Texas

The wind speed in Texas varies from county to county. According to NREL data, the wind speed at 80 meters in Texas varies from 4.5 m/s to 10.5 m/s, as shown in Figure 6.16 ‘Texas 80-Meter Wind Resource Map,2021’.



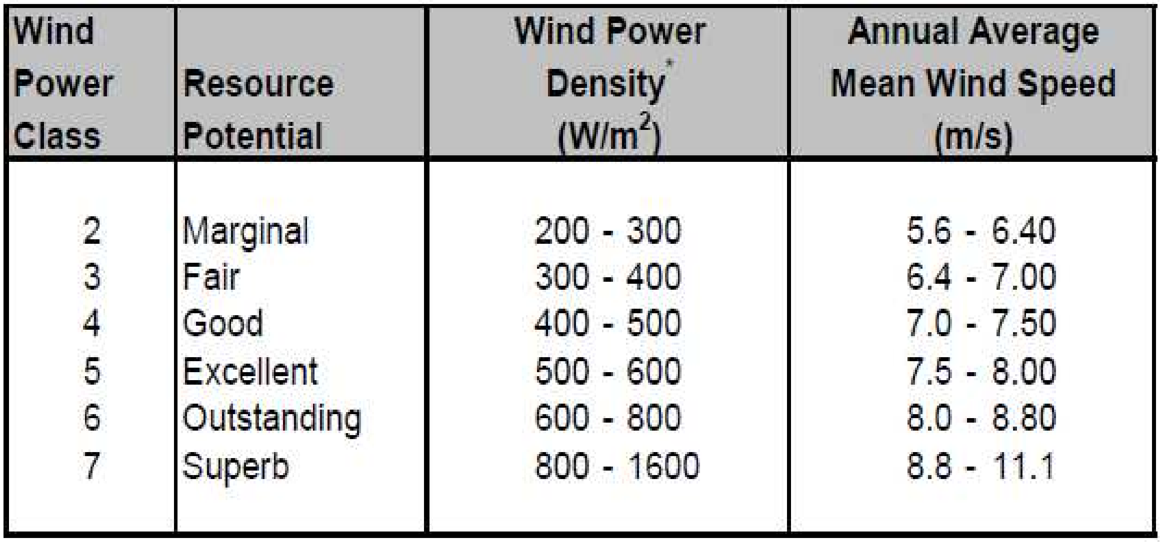
Texas Annual Average Wind Speed at 80 m

Source: Wind resource estimates developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: UTM Zone 14 WGS84.

Figure 6. 16: Wind speed in Texas

6.7.1 Power Classification Based On Wind Speed

According to the average wind speed, wind energy can be classified into 6 categories (2, 3, 4, 5, 6, & 7). These categories can be classified as potential resources as marginal, fair, good, excellent, outstanding, and superb. , As shown in Figure 6.17 ‘Banks et al,2008’.



Wind Power Class	Resource Potential	Wind Power Density* (W/m^2)	Annual Average Mean Wind Speed (m/s)
2	Marginal	200 - 300	5.6 - 6.40
3	Fair	300 - 400	6.4 - 7.00
4	Good	400 - 500	7.0 - 7.50
5	Excellent	500 - 600	7.5 - 8.00
6	Outstanding	600 - 800	8.0 - 8.80
7	Superb	800 - 1600	8.8 - 11.1

Figure 6. 17: Wind speed classification at 50 m height

There are four counties in Texas that can be categorized under the Superb potential classification of wind energy potential resources. In addition, there are 9 counties that can be defined as outstanding potential resources, and 10 counties can be put under excellent potential resources classification. 49 counties could be classified as good potential resources and 99 counties could be considered under the fair potential resource category due to wind energy. In addition, Texas has 62 counties with normal wind speeds, which can be classified as marginal. Only 21 counties in Texas are not classified due to their low average wind speed therefore, they are not good resources for wind turbines, as shown in Table 6.1.

Superb	Outstanding	Excellent	Good	Fair	Marginal
Coke, Nolan ,Tom Green, and Mitchell	El Paso, Sterling, Schleicher Taylor ,Runnels ,Menard Concho, Sutton Howard	Jones, Red River, Matagorda Wichita, Scurry, Clay Fisher, Irion, Archer Stonewall	Mason, Mcculloch, Bowie, Kent, Morris, Callahan, Gillespie, Shackelford, Franklin, Hartley, Edwards, Titus Kenedy, Borden, Bailey, Kimble, Coleman, Glasscock, Kendall, Delta, Willacy, Real, Kerr, Eastland, Hopkins, Cherokee, Montague, Lamar, Gregg, Limestone Llano, Wood, Cass, Jack, Dallam, Upshur, Bell, Brooks, Nacogdoches, Moore, Cooke, Bandera, Mclennan, Haskell, Knox, Throckmorton, Palo Pinto, Brown, Wise	Gray, Rusk, Falls, Camp, Marion, Blanco, Hood, Cochran, Harrison, Erath, Madison, Smith Williamson, Yoakum, Aransas, Baylor, Sherman, Crockett, Ochiltree, Wilbarger, Milam, Hutchinson, Panola, Somervell, Coryell, Reagan, King, Dawson, Shelby, Parmer, Martin, Comanche, Roberts, Midland, Stephens, Leon, San Saba, Anderson, Cameron, Hudspeth, Culberson, Hansford, Freestone, Brazoria, Parker, Hardeman, Foard, Lampasas, Burnet, Young, Tarrant, Donley, Sabine, Lee, Crosby, Bosque, Grayson, Robertson, Brazos, Hockley, Navarro, Rains, Oldham, Lubbock, Dickens, Kinney, Mcmullen, Burleson, Atascosa, Houston, Bexar, Uvalde, Garza, Hall, Hamilton, Cottle, Denton, Frio, Collingsworth, Motley, Medina, Heill, Hays, Hill, Childress, Ellis, Carson, San Augustine, Wheeler, Briscoe, Val Verde, Mills, Chambers, Potter, Lamb, Zavala Comal, Armstrong, Deaf Smith,	Guadalupe, Henderson, Floyd, Wilson, Washington, Lynn, Lipscomb, Kleberg, Jim Hogg, Caldwell, Dimmit, Collin, Maverick, Refugio, Fannin, Kaufman, Duval, Swisher, Johnson, Travis, Angelina, Hidalgo, Hale, Wharton, Van Zandt, Jackson, Dallas, Fayette, Hunt, Gonzales, Trinity, Bastrop, Live Oak, Grimes, Upton, Randall, Lavaca, De Witt, Terry, Rockwall, Calhoun, Karnes, Walker, La Salle, Jim Wells, Victoria, Tyler, Bee, Colorado, Castro, Austin, Waller, Starr, Gaines, Reeves, San Jacinto, Terrell, Jasper, Jeff Davis, Polk, Loving, Crane,

Table 6. 1: Texas counties based on the wind power classification

6.7.2 Power Curve Of Wind Turbine

In this work, the Enercon E-126 7.580 wind turbine model was used. The main parameters that describe the power curve of the wind turbine are: cut in speed which is 3 m/s in this model and it represents the initial speed that wind turbines start to generate. Cut out wind speed which is 34 m/s in this model It represents the maximum speed at which the wind turbine can work. The last important parameter is the rated speed which is 16.5 m/s and it is the speed where the wind turbine generates its rated power, which is 7.58MW.

The power curve of Enercon E-126 7.580 is illustrated in Figure 6.18 'Enercon E-126 7.580'. As shown in the Figure, when the wind speed is between 7-11 m/s, the power coefficient reaches 47-48%. On the other hand, the rated power reached when the wind speed is greater than 16 m/s is 7.58 MW.

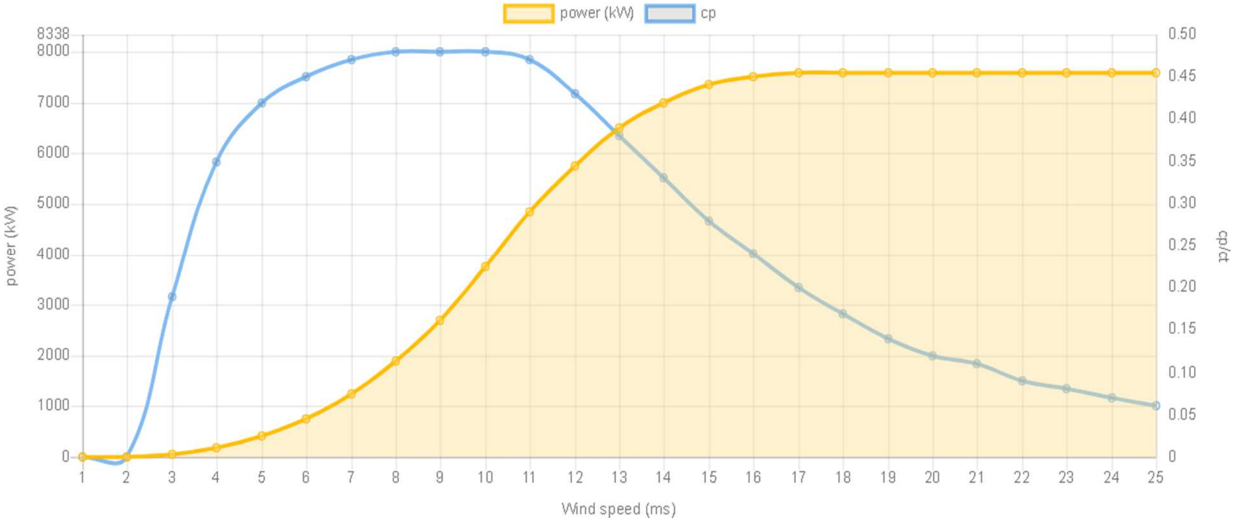


Figure 6. 18: Power curve of Enercon E-126 7.580

6.8 Hypothetical Wind Energy Model

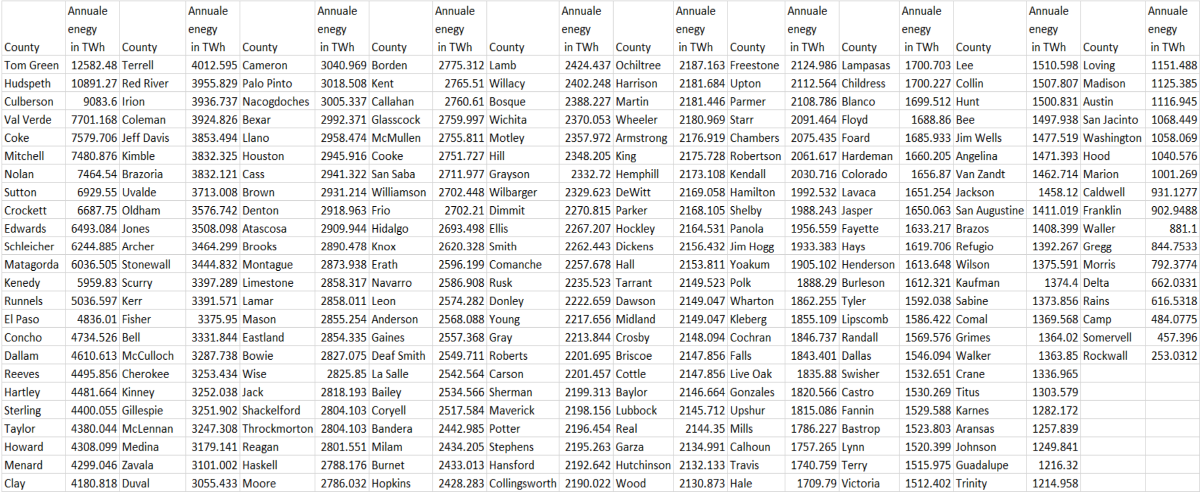
As known, wind turbines are an infinite resource, it is a renewable resource therefore, the land area of Texas is 695,662 Km^2, and all the land can be used to install wind turbines on it to generate electricity. Although of the ability to produce electricity from a wind turbine at any county in Texas, the generation varies from one county to another based on the wind speed.

The electricity generation from wind energy relies on the surface land and the wind speed. Texas counties could be classified into 7 main groups based on the wind speed. So based on these groups. Each group has a different range of power per m^2 based on the wind speed. Depending on the classification chows in Table 6.1 and the power range shown in Figure 6.17, Texas could power through the wind technology from 512.7 to 698.5 PWh annually on a 30% capacity factor. The annual energy from wind turbine based on this hypothetical model varies from 12.6 PW to 253 TWh in 254 counties as shown in Figure 6.19, the calculations are as the following:

$$p\ @\ Tom\ Green = avg(power\ range) * area * capacity\ factor * 8760$$

$$p\ @\ Tom\ Green = avg(800{,}1600) * 3989.8 * 10^6 * 0.30 * 8760$$

$$p\ @\ Tom\ Green = 12{,}582.48\ TWh$$



County	Annuale enegy in TWh	County	Annuale enegy in TWh	County	Annuale enegy in TWh	County	Annuale enegy in TWh	County	Annuale enegy in TWh	County	Annuale enegy in TWh	County	Annuale enegy in TWh	County	Annuale enegy in TWh	County	Annuale enegy in TWh	County	Annuale enegy in TWh
Tom Green	12582.48	Terrell	4012.595	Cameron	3040.969	Borden	2775.312	Lamb	2424.437	Ochiltree	2187.163	Freestone	2124.986	Lampasas	1700.703	Lee	1510.598	Loving	1151.488
Hudspeth	10891.27	Red River	3955.829	Palo Pinto	3018.508	Kent	2765.51	Willacy	2402.248	Harrison	2181.684	Upton	2112.564	Childress	1700.227	Collin	1507.807	Madison	1125.385
Culberson	9083.6	Irion	3936.737	Nacogdoches	3005.337	Callahan	2760.61	Bosque	2388.227	Martin	2181.446	Parmer	2108.786	Blanco	1699.512	Hunt	1500.831	Austin	1116.945
Val Verde	7701.168	Coleman	3924.826	Bexar	2992.371	Glasscock	2759.997	Wichita	2370.053	Wheeler	2180.969	Starr	2091.464	Floyd	1688.86	Bee	1497.938	San Jacinto	1068.449
Coke	7579.706	Jeff Davis	3853.494	Llano	2958.474	McMullen	2755.811	Motley	2357.972	Armstrong	2176.919	Chambers	2075.435	Foard	1685.933	Jim Wells	1477.519	Washington	1058.069
Mitchell	7480.876	Kimble	3832.325	Houston	2945.916	Cooke	2751.727	Hill	2348.205	King	2175.728	Robertson	2061.617	Hardeman	1660.205	Angelina	1471.393	Hood	1040.576
Nolan	7464.54	Brazoria	3832.121	Cass	2941.322	San Saba	2711.977	Grayson	2332.72	Hemphill	2173.108	Kendall	2030.716	Colorado	1656.87	Van Zandt	1462.714	Marion	1001.269
Sutton	6929.55	Uvalde	3713.008	Brown	2931.214	Williamson	2702.448	Wilbarger	2329.623	DeWitt	2169.058	Hamilton	1992.532	Lavaca	1651.254	Jackson	1458.12	Caldwell	931.1277
Crockett	6687.75	Oldham	3576.742	Denton	2918.963	Frio	2702.21	Dimmit	2270.815	Parker	2168.105	Shelby	1988.243	Jasper	1650.063	San Augustine	1411.019	Franklin	902.9488
Edwards	6493.084	Jones	3508.098	Atascosa	2909.944	Hidalgo	2693.498	Ellis	2267.207	Hockley	2164.531	Panola	1956.559	Fayette	1633.217	Brazos	1408.399	Waller	881.1
Schleicher	6244.885	Archer	3464.299	Brooks	2890.478	Knox	2620.328	Smith	2262.443	Dickens	2156.432	Jim Hogg	1933.383	Hays	1619.706	Refugio	1392.267	Gregg	844.7533
Matagorda	6036.505	Stonewall	3444.832	Montague	2873.938	Erath	2596.199	Comanche	2257.678	Hall	2153.811	Yoakum	1905.102	Henderson	1613.648	Wilson	1375.591	Morris	792.3774
Kenedy	5959.83	Scurry	3397.289	Limestone	2858.317	Navarro	2586.908	Rusk	2235.523	Tarrant	2149.523	Polk	1888.29	Burleson	1612.321	Kaufman	1374.4	Delta	662.0331
Runnels	5036.597	Kerr	3391.571	Lamar	2858.011	Leon	2574.282	Donley	2222.659	Dawson	2149.047	Wharton	1862.255	Tyler	1592.038	Sabine	1373.856	Rains	616.5318
El Paso	4836.01	Fisher	3375.95	Mason	2855.254	Anderson	2568.088	Young	2217.656	Midland	2149.047	Kleberg	1855.109	Lipscomb	1586.422	Comal	1369.568	Camp	484.0775
Concho	4734.526	Bell	3331.844	Eastland	2854.335	Gaines	2557.368	Gray	2213.844	Crosby	2148.094	Cochran	1846.737	Randall	1569.576	Grimes	1364.02	Somervell	457.396
Dallam	4610.613	McCulloch	3287.738	Bowie	2827.075	Deaf Smith	2549.711	Roberts	2201.695	Briscoe	2147.856	Falls	1843.401	Dallas	1546.094	Walker	1363.85	Rockwall	253.0312
Reeves	4495.856	Cherokee	3253.434	Wise	2825.85	La Salle	2542.564	Carson	2201.457	Cottle	2147.856	Live Oak	1835.88	Swisher	1532.651	Crane	1336.965		
Hartley	4481.664	Kinney	3252.038	Jack	2818.193	Bailey	2534.566	Sherman	2199.313	Baylor	2146.664	Gonzales	1820.566	Castro	1530.269	Titus	1303.579		
Sterling	4400.055	Gillespie	3251.902	Shackelford	2804.103	Coryell	2517.584	Maverick	2198.156	Lubbock	2145.712	Upshur	1815.086	Fannin	1529.588	Karnes	1282.172		
Taylor	4380.044	McLennan	3247.308	Throckmorton	2804.103	Bandera	2442.985	Potter	2196.454	Real	2144.35	Mills	1786.227	Bastrop	1523.803	Aransas	1257.839		
Howard	4308.099	Medina	3179.141	Reagan	2801.551	Milam	2434.205	Stephens	2195.263	Garza	2134.991	Calhoun	1757.265	Lynn	1520.399	Johnson	1249.841		
Menard	4299.046	Zavala	3101.002	Haskell	2788.176	Burnet	2433.013	Hansford	2192.642	Hutchinson	2132.133	Travis	1740.759	Terry	1515.975	Guadalupe	1216.32		
Clay	4180.818	Duval	3055.433	Moore	2786.032	Hopkins	2428.283	Collingsworth	2190.022	Wood	2130.873	Hale	1709.79	Victoria	1512.402	Trinity	1214.958		

Figure 6. 19: Hypothetical model of wind energy in the state of Texas

However, the previous model is not practical because it depends on all land in the state of Texas, which is not applicable to apply. Based on ‘Brain Post: Map of Where NOBODY Lives in the USA | 47% of the USA is Uninhabited,2014’. around 47 % of the land in the US is unhabituated by people. Therefore, in order to obtain more realistic results, a factor of 0.47 is included in the results. Based on this, Texas can provide up to 328.3 PWh, and that represents the maximum electrical energy could be obtained from the wind energy , which is still enough to power the entire United States.

6.9 Electrical Proposal System Based On Rotor Efficiency

In Texas, wind energy resources are unlimited, which is different from the other resources mentioned in the previous chapters. Biomass, Geothermal, and hydroelectric energy are limited resources due to different factors such as water storage, earth's temperature and agriculture residue etc.., while Wind turbine depends on area and wind speed, both are applicable everywhere and available, In this proposed system, wind farms are installed in each county of

Texas with the same capacity to show changes in energy production based on the geographic location of Texas.

In this proposal system, there are many scenarios based on the capacity installed of wind turbines from one to another. In all cases, there are some general rules and assumptions, as follows:

1- The Enercon E-126 7.580 wind turbine model is used in all scenarios.

2- The rated power of the wind turbine model is 7.58 MW

3- The height of the hub of the wind turbine model is 135 meters

4- The rotor diameter of the wind turbine model is 127 meters, so the swept area is 12,668 m^2

5- The rotor efficiency of the wind turbine model is 48%

6- The air density of all counties in Texas is 1.2

7- Wind speed in Texas's counties is taken from NREL as an average at all counties at the height of 80 meters

8- The power generation of wind turbine is calculated by the hub's wind speed.

9- Friction coefficient is 0.15 for all wind farms

The flow chart of the proposal system is shown in the Figure 6.20, which based on the previous assumptions and Equations 6.18 & 6.21.

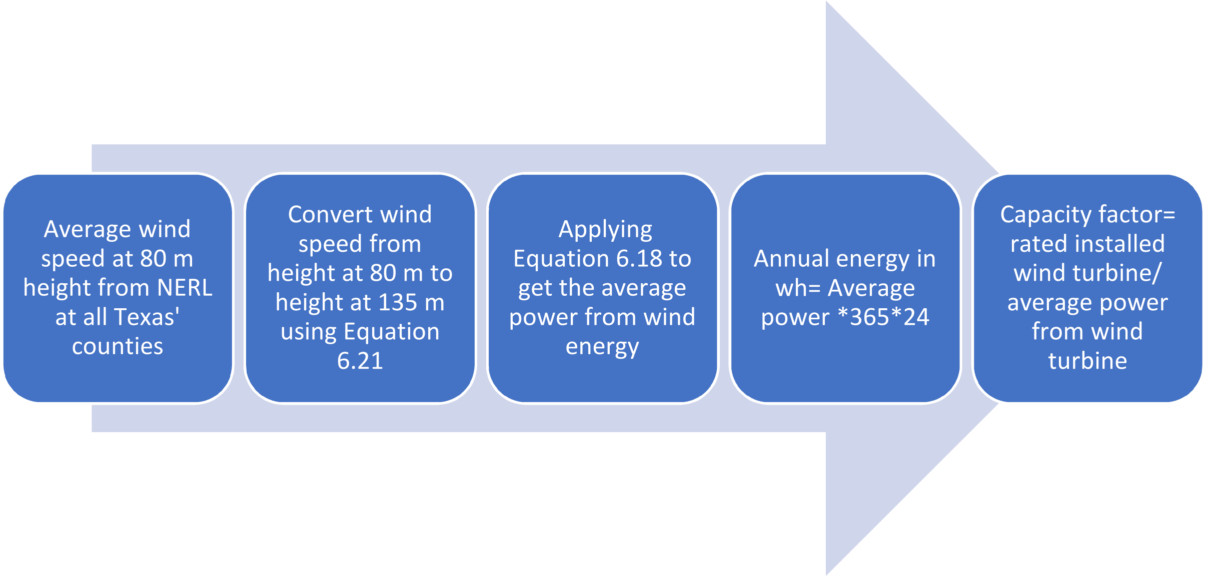


Figure 6. 20: Flow-chart design of the proposal system

In this electrical proposal system, there are three schemes based on capacity. The first plan is almost 183% of the current installed capacity, the second plan is about 100% of the current installed capacity in Texas, and the last plan is 125% of the current installed capacity. The method in the scenario depends on the wind speed and the county-level classification of potential resources, as shown in Table 6.1. Figure 6.21 illustrates the details and differences between all options.

Scenario #1

Proposal :Install 30 wind turbine (7.58 MW) at every county in texas, total of 57 GW which is 237% of the current installed in Texas.

Scenario #2

Proposal :Install 25 GW wind turbines which is almost 100% of the current installed in Texas

Approach1

Proporal :Install 13 wind turbines (7.58 MW) at every county

Approach2

Proposal :Install 26 wind turbines (7.58 MW) in 127 counties which has the higest wind speed in Texas

Approach3

Proposal :Install 52 wind turbines (7.58 MW) in 64 counties which has the higest wind speed in Texas

Approach4

Proposal :Install 104 wind turbines (7.58 MW) in 32 counties which has the higest wind speed in Texas

Approach5

Proposal :Install 208 wind turbines (7.58 MW) in 16 counties which has the higest wind speed in Texas

Scenario #3

Proposal :Install 31 GW wind turbines which is 125% of the current capacity installed wind turbine in Texas based on the wind speed classificatins

Approach 1

Proposal :Install 57 wind turbines in 72 counties which are classified on as superb, outstanding,

Excellent, and good potential resource

Approach 2

Proposal :Install 178 wind turbines in 23 counties which are classified on as superb,

outstanding, and Excellent potential resources

Figure 6. 21 :Scenarios and approaches techniques in the electrical proposal system

6.9.1 Scenario #1

In this scenario #1, 30 Enercon E-126 7.580 wind turbines were installed in every county in Texas. In order to understand the generational differences between different countries. By applying the flow-chart design shown in Figure 6.20 and the previous 9 rules to 30 wind turbines in each county in Texas, the result is shown in Figure 6.22.

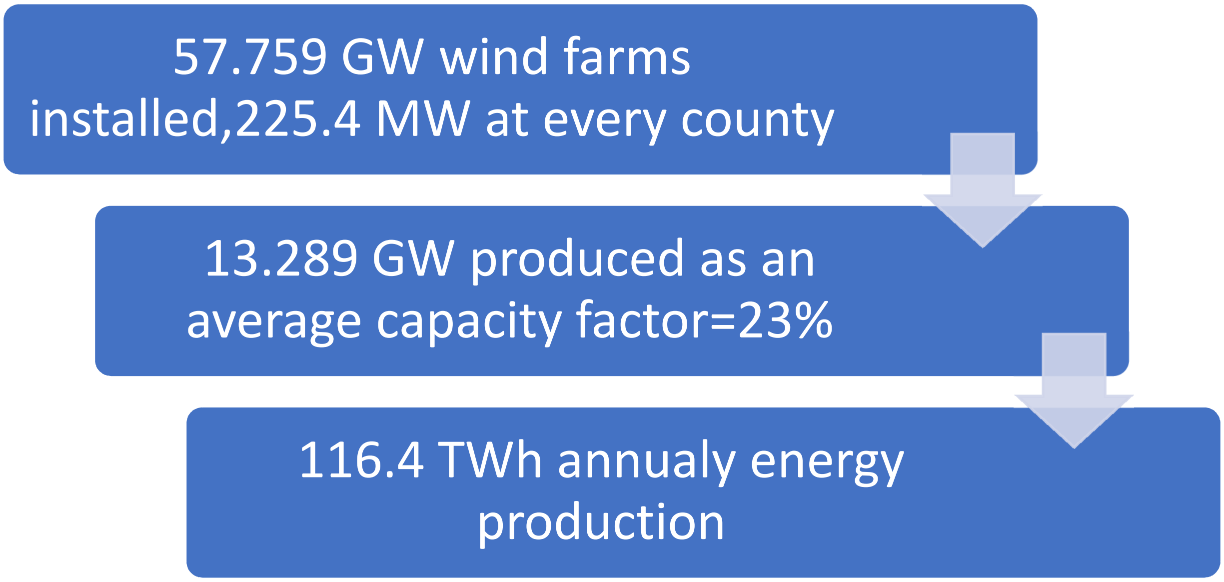


Figure 6. 22: Scenario#1 results

In this scenario, it is recommended to install 30 wind turbines of the Enercon E-126 7.580 wind turbine model in 254 counties with a total capacity of 57.759 GW. By using the design flow chart shown in Figure 6.20 and 9 general assumptions, this method can achieve 13.289 GW of power, a capacity factor of up to 23%, and annual energy consumption of about 116.41 TWh.

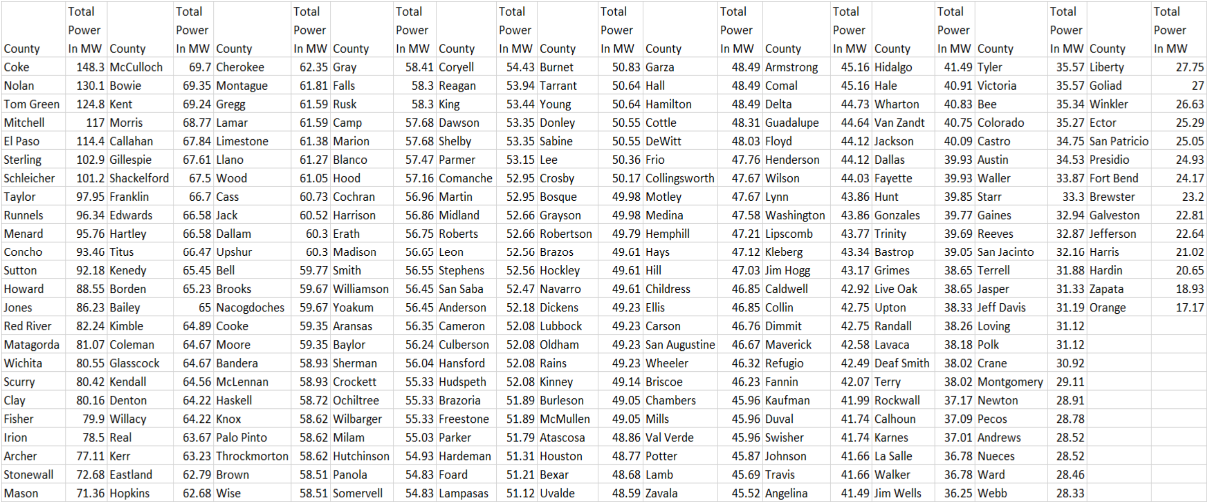
The variation in generation from one county to another is shown in Figure 6.23 from 1.3 to .15 TWh, Counties such as Coke could generate up to 148.3 MW with capacity factor up to

66%, on the other hand there are some counties such as Orange with only electric generation from wind with 17.1 MW and capacity factor around 7.5%. There are seven counties in Texas with potential resources ranging from wind energy to power generation over 100 megawatts. Texas has 120 counties with enough resources to power more than 50 MW and less than 100 MW. 129 counties in Texas can generate more than 10 MW of electricity and less than 50 MW due to limited wind energy resources. By applying Flow chart as shown in Figure 6.20, the average generation power in Coke county as the following:

$$\text{Average Power in Coke County} = \frac{1}{2} * \rho * A * V^3 * C_p * \text{Number of Wind Turbines}$$

$$\text{Average Power in Coke County} = \frac{1}{2} * 1.2 * 12668 * 11.06^3 * .48 * 30$$

$$\text{Average Power in Coke County} = 148.3119 \text{ MW} \approx 148.31 \text{ MW}$$



County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW
Coke	148.3	McCulloch	69.7	Cherokee	62.35	Gray	58.41	Coryell	54.43	Burnet	50.83	Garza	48.49	Armstrong	45.16	Hidalgo	41.49	Tyler	35.57	Liberty	27.75
Nolan	130.1	Bowie	69.35	Montague	61.81	Falls	58.3	Reagan	53.94	Tarrant	50.64	Hall	48.49	Comal	45.16	Hale	40.91	Victoria	35.57	Goliad	27
Tom Green	124.8	Kent	69.24	Gregg	61.59	Rusk	58.3	King	53.44	Young	50.64	Hamilton	48.49	Delta	44.73	Wharton	40.83	Bee	35.34	Winkler	26.63
Mitchell	117	Morris	68.77	Lamar	61.59	Camp	57.68	Dawson	53.35	Donley	50.55	Cottle	48.31	Guadalupe	44.64	Van Zandt	40.75	Colorado	35.27	Ector	25.29
El Paso	114.4	Callahan	67.84	Limestone	61.38	Marion	57.68	Shelby	53.35	Sabine	50.55	DeWitt	48.03	Floyd	44.12	Jackson	40.09	Castro	34.75	San Patricio	25.05
Sterling	102.9	Gillespie	67.61	Llano	61.27	Blanco	57.47	Parmer	53.15	Lee	50.36	Frio	47.76	Henderson	44.12	Dallas	39.93	Austin	34.53	Presidio	24.93
Schleicher	101.2	Shackelford	67.5	Wood	61.05	Hood	57.16	Comanche	52.95	Crosby	50.17	Collingsworth	47.67	Wilson	44.03	Fayette	39.93	Waller	33.87	Fort Bend	24.17
Taylor	97.95	Franklin	66.7	Cass	60.73	Cochran	56.96	Martin	52.95	Bosque	49.98	Motley	47.67	Lynn	43.86	Hunt	39.85	Starr	33.3	Brewster	23.2
Runnels	96.34	Edwards	66.58	Jack	60.52	Harrison	56.86	Midland	52.66	Grayson	49.98	Medina	47.58	Washington	43.86	Gonzales	39.77	Gaines	32.94	Galveston	22.81
Menard	95.76	Hartley	66.58	Dallam	60.3	Erath	56.75	Roberts	52.66	Robertson	49.79	Hemphill	47.21	Lipscomb	43.77	Trinity	39.69	Reeves	32.87	Jefferson	22.64
Concho	93.46	Titus	66.47	Upshur	60.3	Madison	56.65	Leon	52.56	Brazos	49.61	Hays	47.12	Kleberg	43.34	Bastrop	39.05	San Jacinto	32.16	Harris	21.02
Sutton	92.18	Kenedy	65.45	Bell	59.77	Smith	56.55	Stephens	52.56	Hockley	49.61	Hill	47.03	Jim Hogg	43.17	Grimes	38.65	Terrell	31.88	Hardin	20.65
Howard	88.55	Borden	65.23	Brooks	59.67	Williamson	56.45	San Saba	52.47	Navarro	49.61	Childress	46.85	Caldwell	42.92	Live Oak	38.65	Jasper	31.33	Zapata	18.93
Jones	86.23	Bailey	65	Nacogdoches	59.67	Yoakum	56.45	Anderson	52.18	Dickens	49.23	Ellis	46.85	Collin	42.75	Upton	38.33	Jeff Davis	31.19	Orange	17.17
Red River	82.24	Kimble	64.89	Cooke	59.35	Aransas	56.35	Cameron	52.08	Lubbock	49.23	Carson	46.76	Dimmit	42.75	Randall	38.26	Loving	31.12		
Matagorda	81.07	Coleman	64.67	Moore	59.35	Baylor	56.24	Culberson	52.08	Oldham	49.23	San Augustine	46.67	Maverick	42.58	Lavaca	38.18	Polk	31.12		
Wichita	80.55	Glasscock	64.67	Bandera	58.93	Sherman	56.04	Hansford	52.08	Rains	49.23	Wheeler	46.32	Refugio	42.49	Deaf Smith	38.02	Crane	30.92		
Scurry	80.42	Kendall	64.56	McLennan	58.93	Crockett	55.33	Hudspeth	52.08	Kinney	49.14	Briscoe	46.23	Fannin	42.07	Terry	38.02	Montgomery	29.11		
Clay	80.16	Denton	64.22	Haskell	58.72	Ochiltree	55.33	Brazoria	51.89	Burleson	49.05	Chambers	45.96	Kaufman	41.99	Rockwall	37.17	Newton	28.91		
Fisher	79.9	Willacy	64.22	Knox	58.62	Wilbarger	55.33	Freestone	51.89	McMullen	49.05	Mills	45.96	Duval	41.74	Calhoun	37.09	Pecos	28.78		
Irion	78.5	Real	63.67	Palo Pinto	58.62	Milam	55.03	Parker	51.79	Atascosa	48.86	Val Verde	45.96	Swisher	41.74	Karnes	37.01	Andrews	28.52		
Archer	77.11	Kerr	63.23	Throckmorton	58.62	Hutchinson	54.93	Hardeman	51.31	Houston	48.77	Potter	45.87	Johnson	41.66	La Salle	36.78	Nueces	28.52		
Stonewall	72.68	Eastland	62.79	Brown	58.51	Panola	54.83	Foard	51.21	Bexar	48.68	Lamb	45.69	Travis	41.66	Walker	36.78	Ward	28.46		
Mason	71.36	Hopkins	62.68	Wise	58.51	Somervell	54.83	Lampasas	51.12	Uvalde	48.59	Zavala	45.52	Angelina	41.49	Jim Wells	36.25	Webb	28.33		

Figure 6. 23: Scenario #1 results by counties

6.9.2 Scenario #2

The current wind turbine capacity installed in Texas is about 24.2 GW ‘Texas ranks first in U.S.-installed wind capacity and number of turbines,2019’. Therefore, in this case, the recommended wind turbine capacity is 25 GW, which is almost 100% of the existing capacity in Texas.

In this scenario, sorting for all Texas counties based on their average wind speed. In approach #1, all counties are included in the calculation range. In approach #2, taking the first 127 counties on the list that has the highest average wind speed. In approach #3, taking the first 64 counties on the list that has the highest average wind speed. In approach #2, taking the first 32 counties on the list that has the highest average wind speed. In approach #2, taking the first 16 counties on the list that has the highest average wind speed.

Therefore, the purpose of this solution is to explain how the distribution of wind turbines in different counties will produce different power generation values, and how to obtain more energy by installing fewer wind turbines in many ways.

6.9.2.1 Approach #1

In the first Approach in this scenario, it is recommended to install 13 wind turbines of the Enercon E-126 7.580 wind turbine model in 254 counties with a total capacity of 25.029 GW. By using the design flow chart design shown in Figure 6.20 and 9 general assumptions, this method can reach a power of 5.78 GW, a capacity factor of up to 23.13%, and an annual energy of about 50.448 TWh.

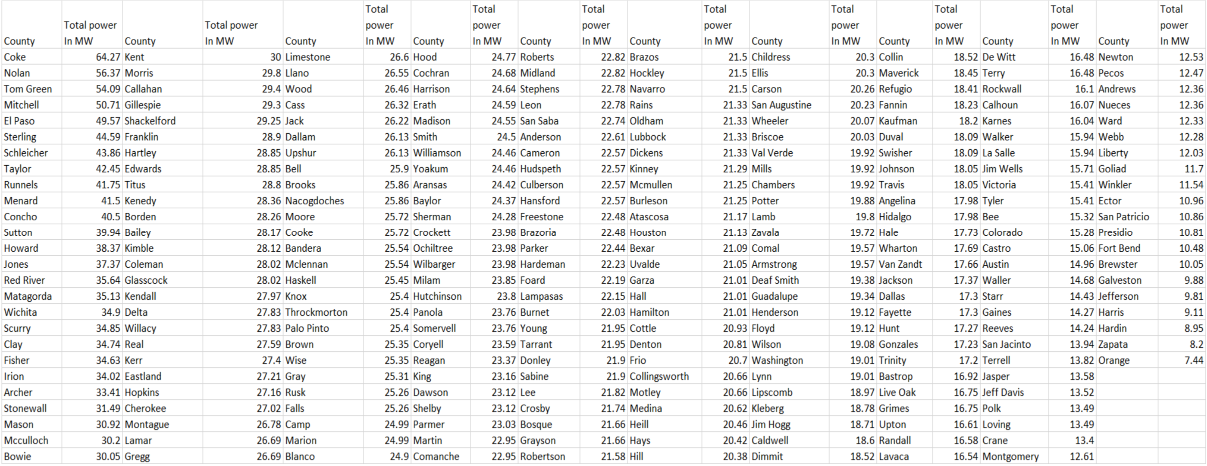
The power generation capacity of this method varies from 64.26 MW to 7.43 MW. There are four counties in Texas with potential resources ranging from wind energy to power generation over 50 MW. Texas has 244 counties with enough resources to power more than 10 MW and less than 50 MW. Only 6 counties in Texas cannot provide more than 5 MW of electricity and less than 10 MW due to limited wind energy resources. All previous results are shown in Figure 6.24. In Coke County, the maximum value is 64.26 MW, the capacity factor is 65.2%, In Orange County, the minimum value is 7.43, and the capacity factor is 7.5%

By applying Flow chart as shown in Figure 6.20, the average generation power in Coke county as the following:

$$\text{Average Power in Coke County} = \frac{1}{2} * \rho * A * V^3 * C_p * \text{Number of Wind Turbines}$$

$$\text{Average Power in Coke County} = \frac{1}{2} * 1.2 * 12668 * 11.06^3 * .48 * 13$$

$$\text{Average Power in Coke County} = 64.26666 \text{ MW} \approx 64.27 \text{ MW}$$



County	Total power In MW	County	Total power In MW	County	Total power In MW	County	Total power In MW	County	Total power In MW	County	Total power In MW	County	Total power In MW	County	Total power In MW	County	Total power In MW	County	Total power In MW
Coke	64.27	Kent	30	Limestone	26.6	Hood	24.77	Roberts	22.82	Brazos	21.5	Childress	20.3	Collin	18.52	De Witt	16.48	Newton	12.53
Nolan	56.37	Morris	29.8	Llano	26.55	Cochran	24.68	Midland	22.82	Hockley	21.5	Ellis	20.3	Maverick	18.45	Terry	16.48	Pecos	12.47
Tom Green	54.09	Callahan	29.4	Wood	26.46	Harrison	24.64	Stephens	22.78	Navarro	21.5	Carson	20.26	Refugio	18.41	Rockwall	16.1	Andrews	12.36
Mitchell	50.71	Gillespie	29.3	Cass	26.32	Erath	24.59	Leon	22.78	Rains	21.33	San Augustine	20.23	Fannin	18.23	Calhoun	16.07	Nueces	12.36
El Paso	49.57	Shackelford	29.25	Jack	26.22	Madison	24.55	San Saba	22.74	Oldham	21.33	Wheeler	20.07	Kaufman	18.2	Karnes	16.04	Ward	12.33
Sterling	44.59	Franklin	28.9	Dallam	26.13	Smith	24.5	Anderson	22.61	Lubbock	21.33	Briscoe	20.03	Duval	18.09	Walker	15.94	Webb	12.28
Schleicher	43.86	Hartley	28.85	Upshur	26.13	Williamson	24.46	Cameron	22.57	Dickens	21.33	Val Verde	19.92	Swisher	18.09	La Salle	15.94	Liberty	12.03
Taylor	42.45	Edwards	28.85	Bell	25.9	Yoakum	24.46	Hudspeth	22.57	Kinney	21.29	Mills	19.92	Johnson	18.05	Jim Wells	15.71	Goliad	11.7
Runnels	41.75	Titus	28.8	Brooks	25.86	Aransas	24.42	Culberson	22.57	Mcmullen	21.25	Chambers	19.92	Travis	18.05	Victoria	15.41	Winkler	11.54
Menard	41.5	Kenedy	28.36	Nacogdoches	25.86	Baylor	24.37	Hansford	22.57	Burleson	21.25	Potter	19.88	Angelina	17.98	Tyler	15.41	Ector	10.96
Concho	40.5	Borden	28.26	Moore	25.72	Sherman	24.28	Freestone	22.48	Atascosa	21.17	Lamb	19.8	Hidalgo	17.98	Bee	15.32	San Patricio	10.86
Sutton	39.94	Bailey	28.17	Cooke	25.72	Crockett	23.98	Brazoria	22.48	Houston	21.13	Zavala	19.72	Hale	17.73	Colorado	15.28	Presidio	10.81
Howard	38.37	Kimble	28.12	Bandera	25.54	Ochiltree	23.98	Parker	22.44	Bexar	21.09	Comal	19.57	Wharton	17.69	Castro	15.06	Fort Bend	10.48
Jones	37.37	Coleman	28.02	Mclennan	25.54	Wilbarger	23.98	Hardeman	22.23	Uvalde	21.05	Armstrong	19.57	Van Zandt	17.66	Austin	14.96	Brewster	10.05
Red River	35.64	Glasscock	28.02	Haskell	25.45	Milam	23.85	Foard	22.19	Garza	21.01	Deaf Smith	19.38	Jackson	17.37	Waller	14.68	Galveston	9.88
Matagorda	35.13	Kendall	27.97	Knox	25.4	Hutchinson	23.8	Lampasas	22.15	Hall	21.01	Guadalupe	19.34	Dallas	17.3	Starr	14.43	Jefferson	9.81
Wichita	34.9	Delta	27.83	Throckmorton	25.4	Panola	23.76	Burnet	22.03	Hamilton	21.01	Henderson	19.12	Fayette	17.3	Gaines	14.27	Harris	9.11
Scurry	34.85	Willacy	27.83	Palo Pinto	25.4	Somervell	23.76	Young	21.95	Cottle	20.93	Floyd	19.12	Hunt	17.27	Reeves	14.24	Hardin	8.95
Clay	34.74	Real	27.59	Brown	25.35	Coryell	23.59	Tarrant	21.95	Denton	20.81	Wilson	19.08	Gonzales	17.23	San Jacinto	13.94	Zapata	8.2
Fisher	34.63	Kerr	27.4	Wise	25.35	Reagan	23.37	Donley	21.9	Frio	20.7	Washington	19.01	Trinity	17.2	Terrell	13.82	Orange	7.44
Irion	34.02	Eastland	27.21	Gray	25.31	King	23.16	Sabine	21.9	Collingsworth	20.66	Lynn	19.01	Bastrop	16.92	Jasper	13.58		
Archer	33.41	Hopkins	27.16	Rusk	25.26	Dawson	23.12	Lee	21.82	Motley	20.66	Lipscomb	18.97	Live Oak	16.75	Jeff Davis	13.52		
Stonewall	31.49	Cherokee	27.02	Falls	25.26	Shelby	23.12	Crosby	21.74	Medina	20.62	Kleberg	18.78	Grimes	16.75	Polk	13.49		
Mason	30.92	Montague	26.78	Camp	24.99	Parmer	23.03	Bosque	21.66	Heill	20.46	Jim Hogg	18.71	Upton	16.61	Loving	13.49		
Mcculloch	30.2	Lamar	26.69	Marion	24.99	Martin	22.95	Grayson	21.66	Hays	20.42	Caldwell	18.6	Randall	16.58	Crane	13.4		
Bowie	30.05	Gregg	26.69	Blanco	24.9	Comanche	22.95	Robertson	21.58	Hill	20.38	Dimmit	18.52	Lavaca	16.54	Montgomery	12.61		

Figure 6. 24: Approach#1 scenario#2 results by counties

6.9.2.2 Approach #2

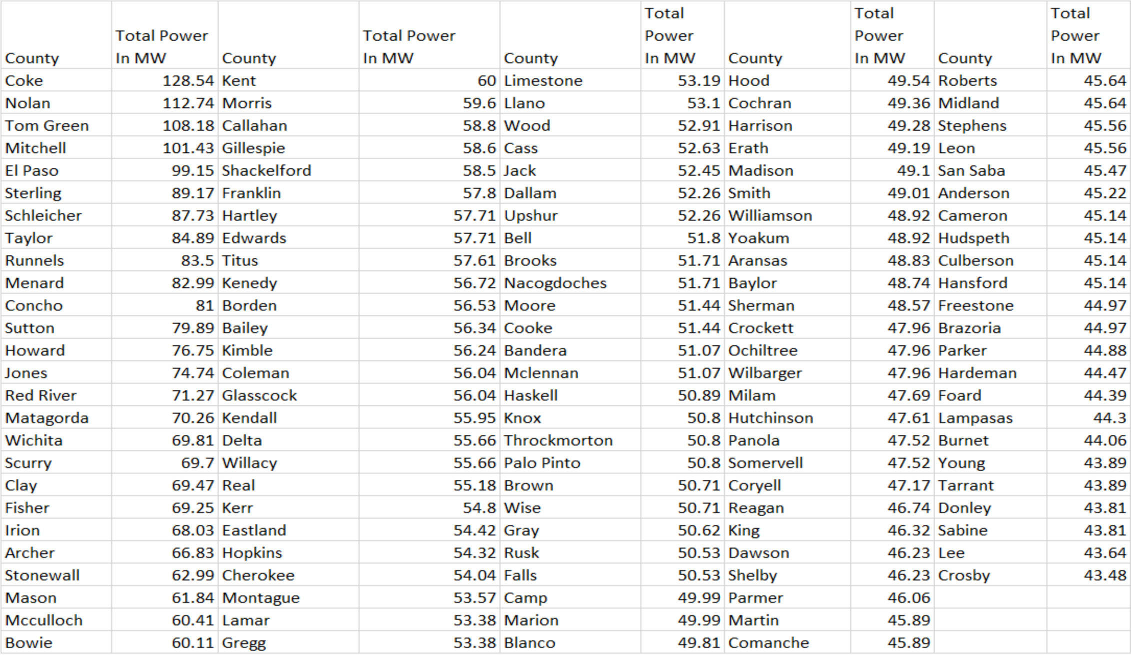
In the second method, in this case, it is recommended to install 26 wind turbines of the Enercon E-126 7.580 wind turbine model in 127 counties with a total capacity of 25.029 GW. By using the design flow chart design shown in Figure 6.20 and 9 general assumptions, this method can reach a power of 7.162 GW, a capacity factor of up to 28.61%, and annual energy of about 62.746 TWh.

The power generation capacity of this method varies from 128.53 MW to 43.48 MW. There are four counties in Texas with potential resources ranging from wind energy to power generation over 100 MW. Texas has 71 counties with enough resources to power more than 50 MW and less than 100 MW. Only 52 counties in Texas cannot provide more than 40 MW of electricity and less than 50 megawatts due to limited wind energy resources. All previous results are shown in Figure 6.25. In Coke County, the maximum value is 128.53 MW, the capacity factor is 65.2%, in Crosby County, the minimum value is 43.48 MW, and the capacity factor is 22.06%.By applying Flow chart as shown in Figure 6.19, the average generation power in Coke county as the following:

$$\text{Average Power in Coke County} = \frac{1}{2} * \rho * A * V^3 * C_p * \text{Number of Wind Turbines}$$

$$\text{Average Power in Coke County} = \frac{1}{2} * 1.2 * 12668 * 11.06^3 * .48 * 26$$

$$\text{Average Power in Coke County} = 128.5332 \text{ MW} \approx 128.54 \text{ MW}$$



County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW
Coke	128.54	Kent	60	Limestone	53.19	Hood	49.54	Roberts	45.64
Nolan	112.74	Morris	59.6	Llano	53.1	Cochran	49.36	Midland	45.64
Tom Green	108.18	Callahan	58.8	Wood	52.91	Harrison	49.28	Stephens	45.56
Mitchell	101.43	Gillespie	58.6	Cass	52.63	Erath	49.19	Leon	45.56
El Paso	99.15	Shackelford	58.5	Jack	52.45	Madison	49.1	San Saba	45.47
Sterling	89.17	Franklin	57.8	Dallam	52.26	Smith	49.01	Anderson	45.22
Schleicher	87.73	Hartley	57.71	Upshur	52.26	Williamson	48.92	Cameron	45.14
Taylor	84.89	Edwards	57.71	Bell	51.8	Yoakum	48.92	Hudspeth	45.14
Runnels	83.5	Titus	57.61	Brooks	51.71	Aransas	48.83	Culberson	45.14
Menard	82.99	Kenedy	56.72	Nacogdoches	51.71	Baylor	48.74	Hansford	45.14
Concho	81	Borden	56.53	Moore	51.44	Sherman	48.57	Freestone	44.97
Sutton	79.89	Bailey	56.34	Cooke	51.44	Crockett	47.96	Brazoria	44.97
Howard	76.75	Kimble	56.24	Bandera	51.07	Ochiltree	47.96	Parker	44.88
Jones	74.74	Coleman	56.04	Mclennan	51.07	Wilbarger	47.96	Hardeman	44.47
Red River	71.27	Glasscock	56.04	Haskell	50.89	Milam	47.69	Foard	44.39
Matagorda	70.26	Kendall	55.95	Knox	50.8	Hutchinson	47.61	Lampasas	44.3
Wichita	69.81	Delta	55.66	Throckmorton	50.8	Panola	47.52	Burnet	44.06
Scurry	69.7	Willacy	55.66	Palo Pinto	50.8	Somervell	47.52	Young	43.89
Clay	69.47	Real	55.18	Brown	50.71	Coryell	47.17	Tarrant	43.89
Fisher	69.25	Kerr	54.8	Wise	50.71	Reagan	46.74	Donley	43.81
Irion	68.03	Eastland	54.42	Gray	50.62	King	46.32	Sabine	43.81
Archer	66.83	Hopkins	54.32	Rusk	50.53	Dawson	46.23	Lee	43.64
Stonewall	62.99	Cherokee	54.04	Falls	50.53	Shelby	46.23	Crosby	43.48
Mason	61.84	Montague	53.57	Camp	49.99	Parmer	46.06		
Mcculloch	60.41	Lamar	53.38	Marion	49.99	Martin	45.89		
Bowie	60.11	Gregg	53.38	Blanco	49.81	Comanche	45.89		

Figure 6. 25: Approach#2 scenario#2 results by counties

6.9.2.3 Approach #3

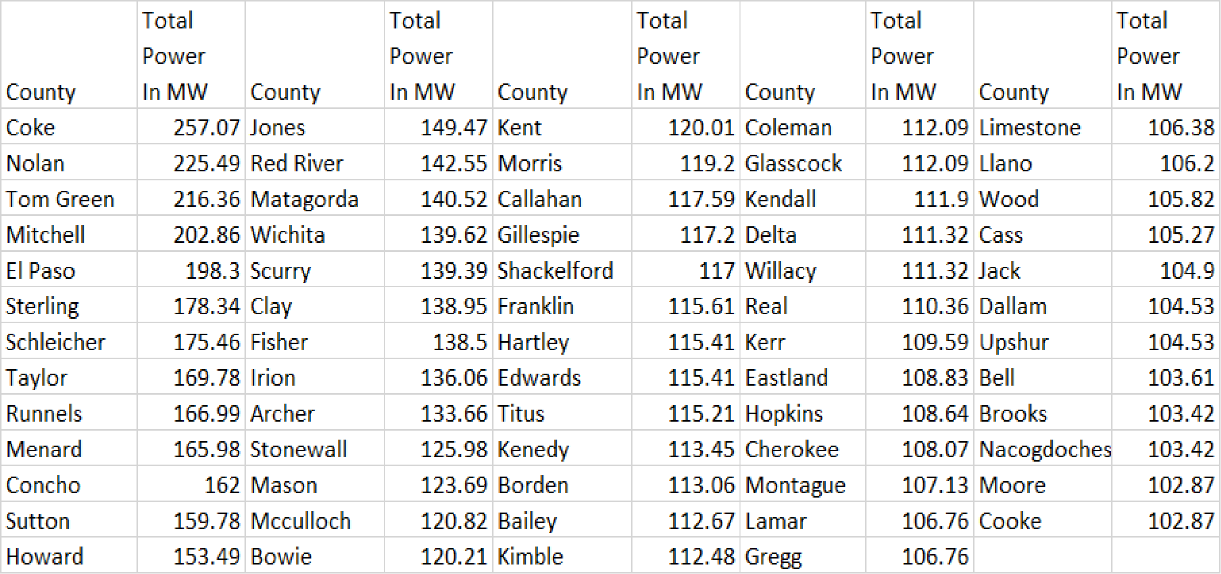
In the third approach, in this case, it is recommended to install 52 wind turbines of the Enercon E-126 7.580 wind turbine model in 64 counties with a total capacity of 25.226 GW. By using the design flow chart design shown in Figure 6.20 and 9 general assumptions, this method can reach a power of 8.364 GW, a capacity factor of up to 33.156%, and annual energy of about 73.271 TWh.

The power generation capacity of this method varies from 257.07 MW to 102.87 MW. In this approach, all of the 64 counties have potential resources to power more than 100 MW from wind energy resources. In Coke County, the maximum value is 254.07 MW, the capacity factor is 64.45%, In Cooke and Moore Counties, the minimum value is 102.87 MW, and the capacity factor is 26.09%. All previous results are shown in Figure 6.26.By applying Flow chart as shown in Figure 6.20, the average generation power in Coke county as the following:

Average Power in Coke County = $\frac{1}{2}$ *ρ*A*V^3*C_p * Number of Wind Turbines

Average Power in Coke County = $\frac{1}{2}$ *1.2*12668*11.06^3*.48 *52

Average Power in Coke County =257.074 MW ≈257.07 MW



County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW	County	Total Power In MW
Coke	257.07	Jones	149.47	Kent	120.01	Coleman	112.09	Limestone	106.38
Nolan	225.49	Red River	142.55	Morris	119.2	Glasscock	112.09	Llano	106.2
Tom Green	216.36	Matagorda	140.52	Callahan	117.59	Kendall	111.9	Wood	105.82
Mitchell	202.86	Wichita	139.62	Gillespie	117.2	Delta	111.32	Cass	105.27
El Paso	198.3	Scurry	139.39	Shackelford	117	Willacy	111.32	Jack	104.9
Sterling	178.34	Clay	138.95	Franklin	115.61	Real	110.36	Dallam	104.53
Schleicher	175.46	Fisher	138.5	Hartley	115.41	Kerr	109.59	Upshur	104.53
Taylor	169.78	Irion	136.06	Edwards	115.41	Eastland	108.83	Bell	103.61
Runnels	166.99	Archer	133.66	Titus	115.21	Hopkins	108.64	Brooks	103.42
Menard	165.98	Stonewall	125.98	Kenedy	113.45	Cherokee	108.07	Nacogdoches	103.42
Concho	162	Mason	123.69	Borden	113.06	Montague	107.13	Moore	102.87
Sutton	159.78	Mcculloch	120.82	Bailey	112.67	Lamar	106.76	Cooke	102.87
Howard	153.49	Bowie	120.21	Kimble	112.48	Gregg	106.76		

Figure 6. 26: Approach#3 scenario#2 results by counties

6.9.2.4 Approach #4

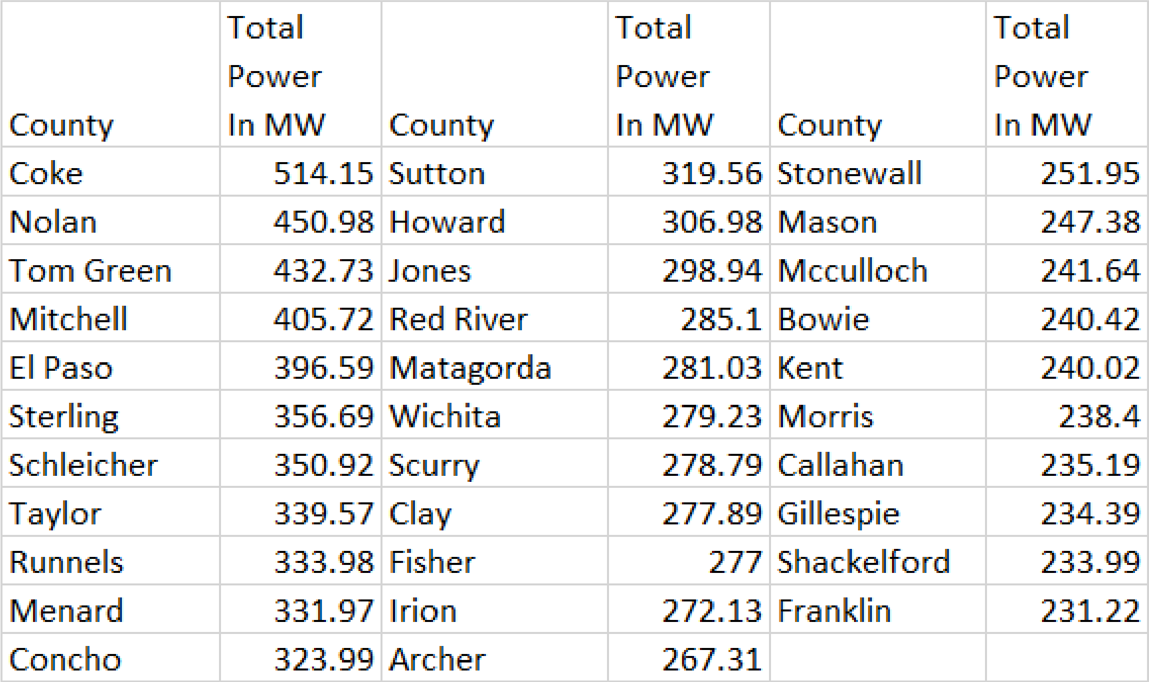
In the fourth approach, in this case, it is recommended to install 104 wind turbines of the Enercon E-126 7.580 wind turbine model in 32 counties with a total capacity of 25.226 GW. By using the design flow chart design shown in Figure 6.20 and 9 general assumptions, this method can reach a power of 9.775 GW, a capacity factor of up to 38.74%, and annual energy of about 85.636 TWh.

The power generation capacity of this method varies from 514.14 MW to 231.21 MW. In this approach, all of the 32 counties have potential resources to power more than 200 MW from wind energy resources. In Coke County, the maximum value is 514.14 MW, the capacity factor is 65.21%, In Franklin County, the minimum value is 231.21 MW, and the capacity factor is 28.5%. All previous results are shown in Figure 6.27. By applying Flow chart as shown in Figure 6.20, the average generation power in Coke county as the following:

$$\text{Average Power in Coke County} = \frac{1}{2} * \rho * A * V^3 * C_p * \text{Number of Wind Turbines}$$

$$\text{Average Power in Coke County} = \frac{1}{2} * 1.2 * 12668 * 11.06^3 * .48 * 104$$

$$\text{Average Power in Coke County} = 514.148 \text{ MW} \approx 514.15 \text{ MW}$$



County	Total Power In MW	County	Total Power In MW	County	Total Power In MW
Coke	514.15	Sutton	319.56	Stonewall	251.95
Nolan	450.98	Howard	306.98	Mason	247.38
Tom Green	432.73	Jones	298.94	Mcculloch	241.64
Mitchell	405.72	Red River	285.1	Bowie	240.42
El Paso	396.59	Matagorda	281.03	Kent	240.02
Sterling	356.69	Wichita	279.23	Morris	238.4
Schleicher	350.92	Scurry	278.79	Callahan	235.19
Taylor	339.57	Clay	277.89	Gillespie	234.39
Runnels	333.98	Fisher	277	Shackelford	233.99
Menard	331.97	Irion	272.13	Franklin	231.22
Concho	323.99	Archer	267.31		

Figure 6. 27: Approach#4 scenario#2 results by counties

6.9.2.5 Approach #5

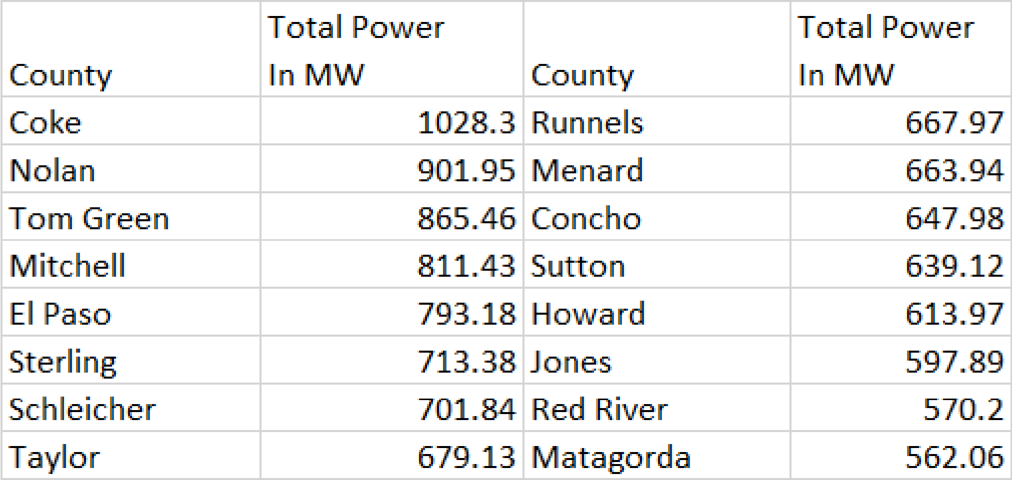
In the fifth approach, in this case, it is recommended to install 208 wind turbines of the Enercon E-126 7.580 wind turbine model in 16 counties with a total capacity of 25.226 GW. By using the design flow chart design shown in Figure 6.20 and 9 general assumptions, this method can reach a power of 11.457 GW, a capacity factor of up to 45.41%, and annual energy of about 100.37 TWh.

The power generation capacity of this method varies from 1,028.29 MW to 562.06 MW. In this approach, all of the 16 counties have potential resources to power more than 500MW from wind energy resources. In Coke County, the maximum value is 1028.29 MW, the capacity factor is 65.21%, In Matagorda County, the minimum value is 562.06 MW, and the capacity factor is 35.64%. All previous results are shown in Figure 6.28. By applying Flow chart as shown in Figure 6.20, the average generation power in Coke county as the following:

$$\text{Average Power in Coke County} = \frac{1}{2} * \rho * A * V^3 * C_p * \text{Number of Wind Turbines}$$

$$\text{Average Power in Coke County} = \frac{1}{2} * 1.2 * 12668 * 11.06^3 * .48 * 208$$

$$\text{Average Power in Coke County} = 1{,}028.295978 \text{ MW} \approx 1{,}028.30 \text{ MW}$$



County	Total Power In MW	County	Total Power In MW
Coke	1028.3	Runnels	667.97
Nolan	901.95	Menard	663.94
Tom Green	865.46	Concho	647.98
Mitchell	811.43	Sutton	639.12
El Paso	793.18	Howard	613.97
Sterling	713.38	Jones	597.89
Schleicher	701.84	Red River	570.2
Taylor	679.13	Matagorda	562.06

Figure 6. 28: Approach#5 scenario#2 results by counties

6.9.3 Scenario #3

In this scenario, 31 GW of the wind turbine is proposed to install in Texas which is 125% of the capacity of the installed wind turbine but with different distribution based on two approaches, all of them are based on the power classification due to wind energy resources potential in Texas's counties that show in Table 6.1. The first approach is to recommend installing wind turbines in counties classified as superb, outstanding, Excellent, and good counties. The second approach is only for superb, outstanding, and excellent counties.

6.9.3.1 Approach #1

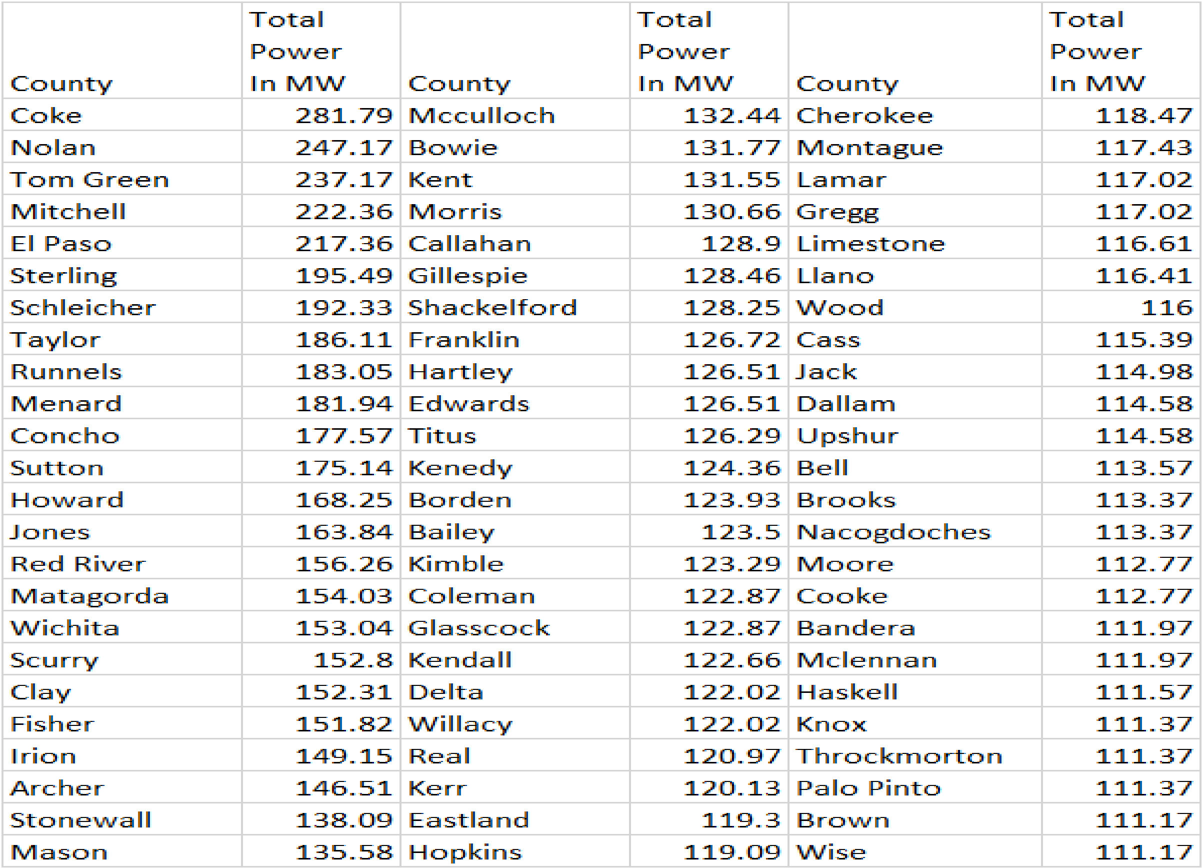
In the first method, in this case, it is recommended to install 57 wind turbines of the Enercon E-126 7.580 wind turbine model in 72 counties with a total capacity of 31.108 GW. These 72 counties are all classified as superb, outstanding, Excellent, and good potential resources for wind energy. By using the flow chart design shown in Figure 6.20 and 9 general assumptions, this method can achieve 10.060 GW of power, a capacity factor of up to 32.33%, and annual energy consumption of about 88.129 TWh.

The power generation capacity of this method varies from 281.79 MW to 111.17 MW. In this approach, all of the 72 counties have potential resources to power more than 100 MW from wind energy resources. In Coke County, the maximum value is 281.79 MW, the capacity factor is 65.22%, In Wise County, the minimum value is 111.17 MW, and the capacity factor is 25.73%. All previous results are shown in Figure 6.29. By applying Flow chart as shown in Figure 6.20, the average generation power in Coke county as the following:

Average Power in Coke County = $\frac{1}{2}*\rho*A*V^3*C_p$ * Number of Wind Turbines

Average Power in Coke County = $\frac{1}{2}*1.2*12668*11.06^3*.48*57$

Average Power in Coke County =281.7926478 MW ≈281.79 MW



County	Total Power In MW	County	Total Power In MW	County	Total Power In MW
Coke	281.79	Mcculloch	132.44	Cherokee	118.47
Nolan	247.17	Bowie	131.77	Montague	117.43
Tom Green	237.17	Kent	131.55	Lamar	117.02
Mitchell	222.36	Morris	130.66	Gregg	117.02
El Paso	217.36	Callahan	128.9	Limestone	116.61
Sterling	195.49	Gillespie	128.46	Llano	116.41
Schleicher	192.33	Shackelford	128.25	Wood	116
Taylor	186.11	Franklin	126.72	Cass	115.39
Runnels	183.05	Hartley	126.51	Jack	114.98
Menard	181.94	Edwards	126.51	Dallam	114.58
Concho	177.57	Titus	126.29	Upshur	114.58
Sutton	175.14	Kenedy	124.36	Bell	113.57
Howard	168.25	Borden	123.93	Brooks	113.37
Jones	163.84	Bailey	123.5	Nacogdoches	113.37
Red River	156.26	Kimble	123.29	Moore	112.77
Matagorda	154.03	Coleman	122.87	Cooke	112.77
Wichita	153.04	Glasscock	122.87	Bandera	111.97
Scurry	152.8	Kendall	122.66	Mclennan	111.97
Clay	152.31	Delta	122.02	Haskell	111.57
Fisher	151.82	Willacy	122.02	Knox	111.37
Irion	149.15	Real	120.97	Throckmorton	111.37
Archer	146.51	Kerr	120.13	Palo Pinto	111.37
Stonewall	138.09	Eastland	119.3	Brown	111.17
Mason	135.58	Hopkins	119.09	Wise	111.17

Figure 6. 29: Approach#1 scenario#3 results by counties

6.9.3.2 Approach #2

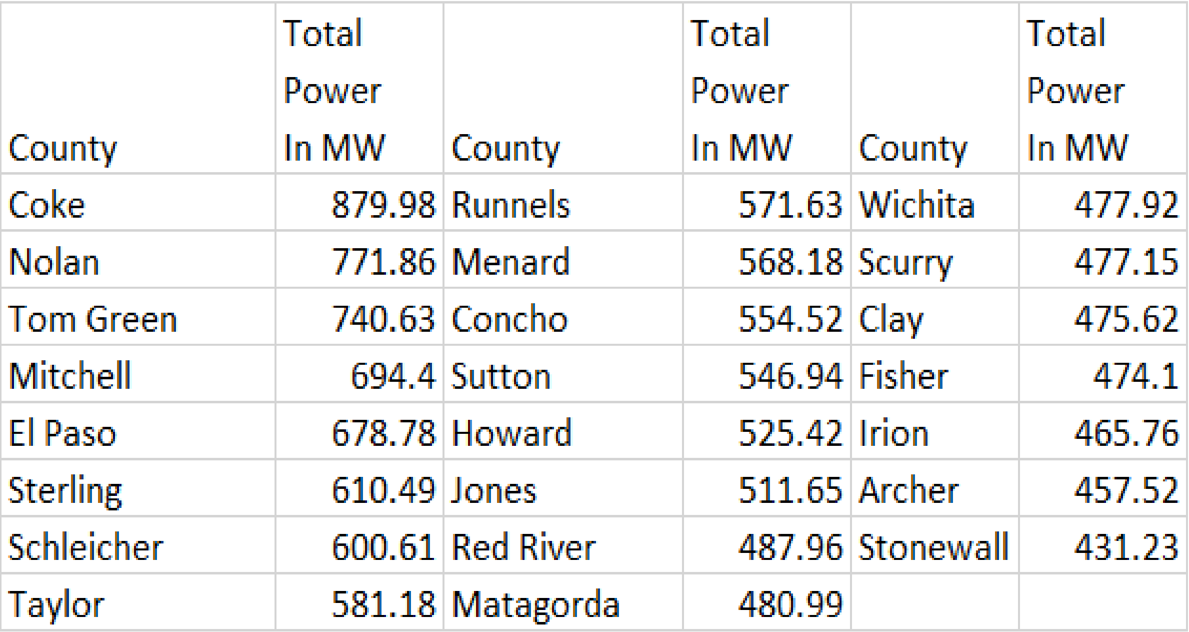
In the second method, in this scenario, it is recommended to install 178 wind turbines of the Enercon E-126 7.580 wind turbine model in 23 counties with a total capacity of 31.032 GW. These 23 counties are all classified as superb, outstanding, and Excellent potential resources for wind energy. By using the design flow chart design shown in Figure 6.20 and 9 general assumptions, this method can achieve 13.064 GW of power, a capacity factor of up to 42.09%, and annual energy consumption of about 114.445 TWh.

The power generation capacity of this method varies from 879.98 MW to 431.22 MW. In this approach, all of the 23 counties have potential resources to power more than 400 Mw from wind energy resources. In Coke County, the maximum value is 879.98 MW, the capacity factor is 65.22%, In Stonewall County, the minimum value is 431.22 MW, and the capacity factor is 31.96%. All previous results are shown in Figure 6.30. By applying Flow chart as shown in Figure 6.20, the average generation power in Coke county as the following:

$$\text{Average Power in Coke County} = \frac{1}{2} * \rho * A * V^3 * C_p * \text{Number of Wind Turbines}$$

$$\text{Average Power in Coke County} = \frac{1}{2} * 1.2 * 12668 * 11.06^3 * .48 * 178$$

$$\text{Average Power in Coke County} = 879.9840 \text{ MW} \approx 879.98 \text{ MW}$$



County	Total Power In MW	County	Total Power In MW	County	Total Power In MW
Coke	879.98	Runnels	571.63	Wichita	477.92
Nolan	771.86	Menard	568.18	Scurry	477.15
Tom Green	740.63	Concho	554.52	Clay	475.62
Mitchell	694.4	Sutton	546.94	Fisher	474.1
El Paso	678.78	Howard	525.42	Irion	465.76
Sterling	610.49	Jones	511.65	Archer	457.52
Schleicher	600.61	Red River	487.96	Stonewall	431.23
Taylor	581.18	Matagorda	480.99		

Figure 6. 30: Approach#2 scenario#3 results by counties

6.10 Electrical Proposal System Based On Rayleigh Distribution Function

In the previous power proposal system, the calculation of the energy production of the wind turbine depends on the rotor efficiency of the wind turbine model and the available energy in the wind. However, assuming that the efficiency of a wind turbine is constant around 48%, and when the wind speed is between 5-16 m/s, its efficiency varies from 44-48%. Hence, the results are more optimistic. There is another way to determine the energy produced by a wind turbine based on the Rayleigh distribution function and capacity factor. This method has been addressed in ‘Masters,2013’as shown in Equations 6.22 &6.23 ‘Masters,2013’.

$CF = 0.087V_{avg} - \frac{P_r}{D^2}$ ……..6.22

Where:

CF: Capacity factor

V_{avg}: Average wind speed in m/s

P_r : Rated power of the wind turbine in kW

D: the diameter of the rotor in m

$E_A = 8760 * P_r * CF$……6.23

Where:

E_A : Annual Energy in kWh

In this electrical proposal system based on the Rayleigh distribution function, The method is three simple steps, first bring the average wind speed from NERL, and the second step is to convert the wind speed from height at 80 m to the height of the rotor, which is 135 m. The first two steps are exactly the same in the electrical advice system based on rotor efficiency. The last step depends on the capacity factor and the Rayleigh distribution function. Figure 6.31 shows the flow chart of the electrical proposal system based on the Rayleigh distribution function.

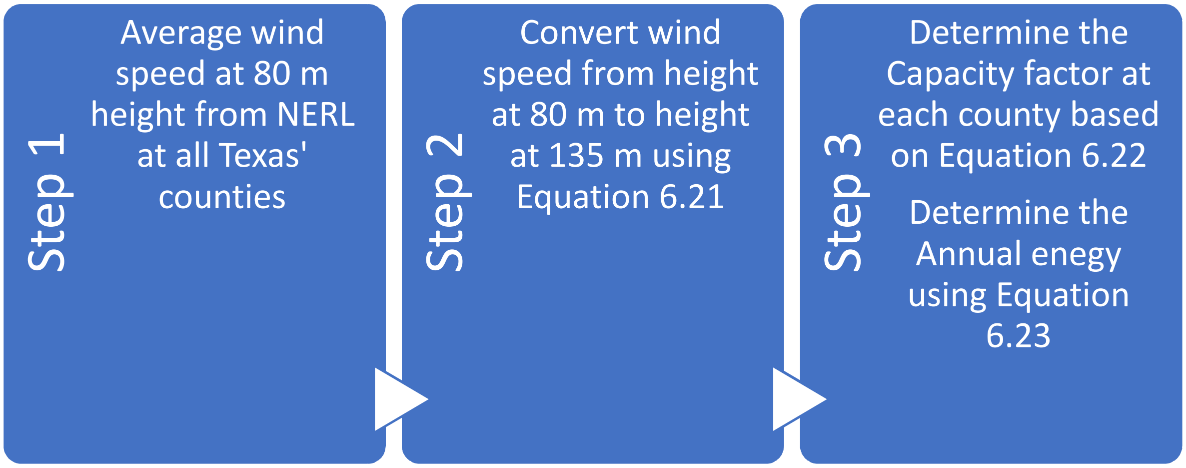


Figure 6. 31: Flowchart of the New electrical proposal system based on Rayleigh Function

In this electrical proposal system based on the Rayleigh distribution function, all cases based on the rotor efficiency in Section 6.8 are discussed in this section based on the Rayleigh distribution function. Finally, a comparison table is provided to show the differences between the two systems.

6.10.1 Scenario 1

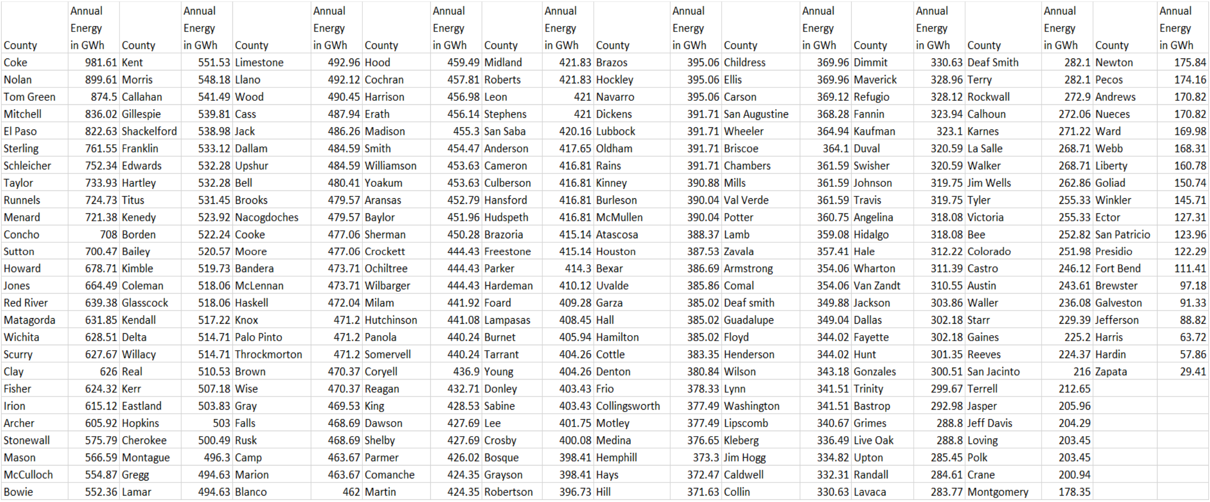
In this scenario #1, 30 Enercon E-126 7.580 wind turbines were installed in every county in Texas. By applying Flow chart as shown in Figure 6.31, the Annual Energy generation in Coke county as the following:

$$\text{Annual Energy in Coke County} = 8{,}760 * 7{,}580 * CF * \text{Number of Wind Turbines}$$

$$\text{Annual Energy in Coke County} = 8{,}760 * 7{,}580 * ((.087 * 11.065) - (\frac{7{,}580}{127^2}))*30$$

$$\text{Annual Energy in Coke County} = 981.4583923\text{ GWh} \approx 981.61\text{ GWh}$$

Figure 6.32 shows the change in power generation from one county to another, from 29.41 to 981.61 GWh and in total 102.05 TWh. There are 49 counties in Texas with enough resources to supply electricity above 500 GWh and below 981.61 GWh. In this case, the power generation of 198 counties in Texas may exceed 100 GWh, up to 500 GWh. Figure 6.32 illustrates all the results of this scenario 1.



County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Coke	981.61	Kent	551.53	Limestone	492.96	Hood	459.49	Midland	421.83	Brazos	395.06	Childress	369.96	Dimmit	330.63	Deaf Smith	282.1	Newton	175.84
Nolan	899.61	Morris	548.18	Llano	492.12	Cochran	457.81	Roberts	421.83	Hockley	395.06	Ellis	369.96	Maverick	328.96	Terry	282.1	Pecos	174.16
Tom Green	874.5	Callahan	541.49	Wood	490.45	Harrison	456.98	Leon	421	Navarro	395.06	Carson	369.12	Refugio	328.12	Rockwall	272.9	Andrews	170.82
Mitchell	836.02	Gillespie	539.81	Cass	487.94	Erath	456.14	Stephens	421	Dickens	391.71	San Augustine	368.28	Fannin	323.94	Calhoun	272.06	Nueces	170.82
El Paso	822.63	Shackelford	538.98	Jack	486.26	Madison	455.3	San Saba	420.16	Lubbock	391.71	Wheeler	364.94	Kaufman	323.1	Karnes	271.22	Ward	169.98
Sterling	761.55	Franklin	533.12	Dallam	484.59	Smith	454.47	Anderson	417.65	Oldham	391.71	Briscoe	364.1	Duval	320.59	La Salle	268.71	Webb	168.31
Schleicher	752.34	Edwards	532.28	Upshur	484.59	Williamson	453.63	Cameron	416.81	Rains	391.71	Chambers	361.59	Swisher	320.59	Walker	268.71	Liberty	160.78
Taylor	733.93	Hartley	532.28	Bell	480.41	Yoakum	453.63	Culberson	416.81	Kinney	390.88	Mills	361.59	Johnson	319.75	Jim Wells	262.86	Goliad	150.74
Runnels	724.73	Titus	531.45	Brooks	479.57	Aransas	452.79	Hansford	416.81	Burleson	390.04	Val Verde	361.59	Travis	319.75	Tyler	255.33	Winkler	145.71
Menard	721.38	Kenedy	523.92	Nacogdoches	479.57	Baylor	451.96	Hudspeth	416.81	McMullen	390.04	Potter	360.75	Angelina	318.08	Victoria	255.33	Ector	127.31
Concho	708	Borden	522.24	Cooke	477.06	Sherman	450.28	Brazoria	415.14	Atascosa	388.37	Lamb	359.08	Hidalgo	318.08	Bee	252.82	San Patricio	123.96
Sutton	700.47	Bailey	520.57	Moore	477.06	Crockett	444.43	Freestone	415.14	Houston	387.53	Zavala	357.41	Hale	312.22	Colorado	251.98	Presidio	122.29
Howard	678.71	Kimble	519.73	Bandera	473.71	Ochiltree	444.43	Parker	414.3	Bexar	386.69	Armstrong	354.06	Wharton	311.39	Castro	246.12	Fort Bend	111.41
Jones	664.49	Coleman	518.06	McLennan	473.71	Wilbarger	444.43	Hardeman	410.12	Uvalde	385.86	Comal	354.06	Van Zandt	310.55	Austin	243.61	Brewster	97.18
Red River	639.38	Glasscock	518.06	Haskell	472.04	Milam	441.92	Foard	409.28	Garza	385.02	Deaf smith	349.88	Jackson	303.86	Waller	236.08	Galveston	91.33
Matagorda	631.85	Kendall	517.22	Knox	471.2	Hutchinson	441.08	Lampasas	408.45	Hall	385.02	Guadalupe	349.04	Dallas	302.18	Starr	229.39	Jefferson	88.82
Wichita	628.51	Delta	514.71	Palo Pinto	471.2	Panola	440.24	Burnet	405.94	Hamilton	385.02	Floyd	344.02	Fayette	302.18	Gaines	225.2	Harris	63.72
Scurry	627.67	Willacy	514.71	Throckmorton	471.2	Somervell	440.24	Tarrant	404.26	Cottle	383.35	Henderson	344.02	Hunt	301.35	Reeves	224.37	Hardin	57.86
Clay	626	Real	510.53	Brown	470.37	Coryell	436.9	Young	404.26	Denton	380.84	Wilson	343.18	Gonzales	300.51	San Jacinto	216	Zapata	29.41
Fisher	624.32	Kerr	507.18	Wise	470.37	Reagan	432.71	Donley	403.43	Frio	378.33	Lynn	341.51	Trinity	299.67	Terrell	212.65		
Irion	615.12	Eastland	503.83	Gray	469.53	King	428.53	Sabine	403.43	Collingsworth	377.49	Washington	341.51	Bastrop	292.98	Jasper	205.96		
Archer	605.92	Hopkins	503	Falls	468.69	Dawson	427.69	Lee	401.75	Motley	377.49	Lipscomb	340.67	Grimes	288.8	Jeff Davis	204.29		
Stonewall	575.79	Cherokee	500.49	Rusk	468.69	Shelby	427.69	Crosby	400.08	Medina	376.65	Kleberg	336.49	Live Oak	288.8	Loving	203.45		
Mason	566.59	Montague	496.3	Camp	463.67	Parmer	426.02	Bosque	398.41	Hemphill	373.3	Jim Hogg	334.82	Upton	285.45	Polk	203.45		
McCulloch	554.87	Gregg	494.63	Marion	463.67	Comanche	424.35	Grayson	398.41	Hays	372.47	Caldwell	332.31	Randall	284.61	Crane	200.94		
Bowie	552.36	Lamar	494.63	Blanco	462	Martin	424.35	Robertson	396.73	Hill	371.63	Collin	330.63	Lavaca	283.77	Montgomery	178.35		

Figure 6. 32: Results of scenario 1 based on Rayleigh Function electrical proposal

6.10.2 Scenario 2

The current wind turbine capacity installed in Texas is about 24.2 GW 'Texas ranks first in U.S.-installed wind capacity and number of turbines,2019'. Therefore, in this case, the recommended wind turbine capacity is 25 GW, which is almost the rated capacity of the installed wind turbine in Texas.

In this scenario, sorting for all Texas counties based on their average wind speed. In approach #1, all counties are included in the calculation range. In approach #2, taking the first 127 counties on the list that has the highest average wind speed. In approach #3, taking the first 64 counties on the list that has the highest average wind speed. In Approach #2, taking the first

32 counties on the list that has the highest average wind speed. In approach #2, taking the first 16 counties on the list that has the highest average wind speed.

Therefore, the purpose of this solution is to explain how the distribution of wind turbines in different counties will produce different power generation values, and how to obtain more energy by installing fewer wind turbines in many ways.

6.10.2.1 Approach 1

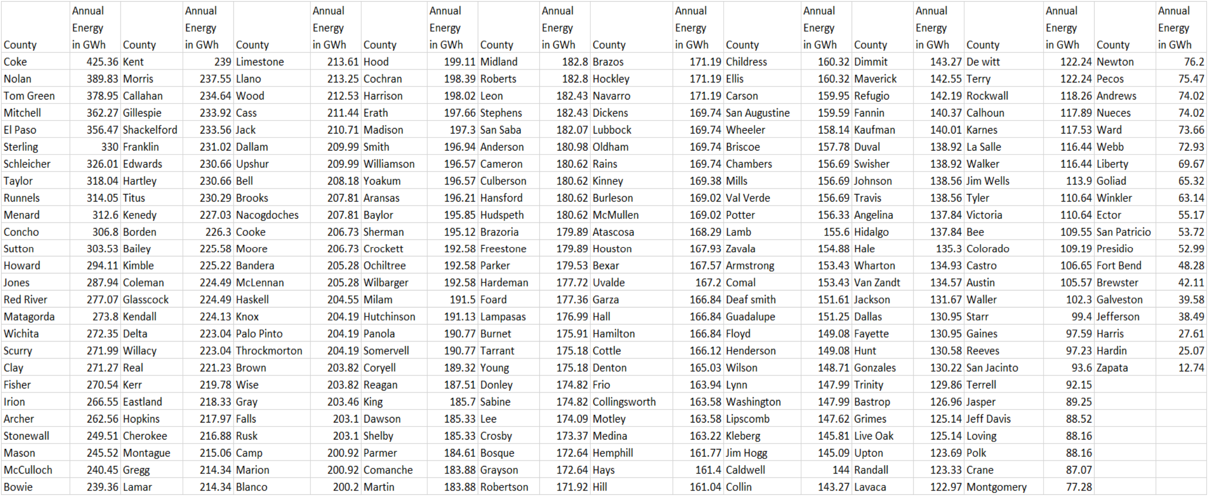
In the first Approach in this scenario, it is recommended to install 13 wind turbines of the Enercon E-126 7.580 wind turbine model in 253 counties with a total capacity of 24.930 GW. By applying Flow chart as shown in Figure 6.31, the Annual Energy generation in Coke county as the following:

Annual Energy in Coke County = $8{,}760 * 7{,}580 * CF*$ Number of Wind Turbines

Annual Energy in Coke County = $8{,}760 * 7{,}580 * ((.087 * 11.065) - (\frac{7{,}580}{127^2}))*13$

Annual Energy in Coke County =425.298 GWh ≈425.36 GWh

Figure 6.33 shows the change in power generation from one county to another, from 12.74 to 425.36 GWh and in total 44.22 TWh. There are 223 counties in Texas with enough resources to supply electricity above 100 GWh and below 425.36 GWh. In this case, the power generation of 30 counties in Texas may exceed 12.74 GWh, up to 100 GWh. Figure 6.33 illustrates all the results of this scenario.



County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Coke	425.36	Kent	239	Limestone	213.61	Hood	199.11	Midland	182.8	Brazos	171.19	Childress	160.32	Dimmit	143.27	De witt	122.24	Newton	76.2
Nolan	389.83	Morris	237.55	Llano	213.25	Cochran	198.39	Roberts	182.8	Hockley	171.19	Ellis	160.32	Maverick	142.55	Terry	122.24	Pecos	75.47
Tom Green	378.95	Callahan	234.64	Wood	212.53	Harrison	198.02	Leon	182.43	Navarro	171.19	Carson	159.95	Refugio	142.19	Rockwall	118.26	Andrews	74.02
Mitchell	362.27	Gillespie	233.92	Cass	211.44	Erath	197.66	Stephens	182.43	Dickens	169.74	San Augustine	159.59	Fannin	140.37	Calhoun	117.89	Nueces	74.02
El Paso	356.47	Shackelford	233.56	Jack	210.71	Madison	197.3	San Saba	182.07	Lubbock	169.74	Wheeler	158.14	Kaufman	140.01	Karnes	117.53	Ward	73.66
Sterling	330	Franklin	231.02	Dallam	209.99	Smith	196.94	Anderson	180.98	Oldham	169.74	Briscoe	157.78	Duval	138.92	La Salle	116.44	Webb	72.93
Schleicher	326.01	Edwards	230.66	Upshur	209.99	Williamson	196.57	Cameron	180.62	Rains	169.74	Chambers	156.69	Swisher	138.92	Walker	116.44	Liberty	69.67
Taylor	318.04	Hartley	230.66	Bell	208.18	Yoakum	196.57	Culberson	180.62	Kinney	169.38	Mills	156.69	Johnson	138.56	Jim Wells	113.9	Goliad	65.32
Runnels	314.05	Titus	230.29	Brooks	207.81	Aransas	196.21	Hansford	180.62	Burleson	169.02	Val Verde	156.69	Travis	138.56	Tyler	110.64	Winkler	63.14
Menard	312.6	Kenedy	227.03	Nacogdoches	207.81	Baylor	195.85	Hudspeth	180.62	McMullen	169.02	Potter	156.33	Angelina	137.84	Victoria	110.64	Ector	55.17
Concho	306.8	Borden	226.3	Cooke	206.73	Sherman	195.12	Brazoria	179.89	Atascosa	168.29	Lamb	155.6	Hidalgo	137.84	Bee	109.55	San Patricio	53.72
Sutton	303.53	Bailey	225.58	Moore	206.73	Crockett	192.58	Freestone	179.89	Houston	167.93	Zavala	154.88	Hale	135.3	Colorado	109.19	Presidio	52.99
Howard	294.11	Kimble	225.22	Bandera	205.28	Ochiltree	192.58	Parker	179.53	Bexar	167.57	Armstrong	153.43	Wharton	134.93	Castro	106.65	Fort Bend	48.28
Jones	287.94	Coleman	224.49	McLennan	205.28	Wilbarger	192.58	Hardeman	177.72	Uvalde	167.2	Comal	153.43	Van Zandt	134.57	Austin	105.57	Brewster	42.11
Red River	277.07	Glasscock	224.49	Haskell	204.55	Milam	191.5	Foard	177.36	Garza	166.84	Deaf smith	151.61	Jackson	131.67	Waller	102.3	Galveston	39.58
Matagorda	273.8	Kendall	224.13	Knox	204.19	Hutchinson	191.13	Lampasas	176.99	Hall	166.84	Guadalupe	151.25	Dallas	130.95	Starr	99.4	Jefferson	38.49
Wichita	272.35	Delta	223.04	Palo Pinto	204.19	Panola	190.77	Burnet	175.91	Hamilton	166.84	Floyd	149.08	Fayette	130.95	Gaines	97.59	Harris	27.61
Scurry	271.99	Willacy	223.04	Throckmorton	204.19	Somervell	190.77	Tarrant	175.18	Cottle	166.12	Henderson	149.08	Hunt	130.58	Reeves	97.23	Hardin	25.07
Clay	271.27	Real	221.23	Brown	203.82	Coryell	189.32	Young	175.18	Denton	165.03	Wilson	148.71	Gonzales	130.22	San Jacinto	93.6	Zapata	12.74
Fisher	270.54	Kerr	219.78	Wise	203.82	Reagan	187.51	Donley	174.82	Frio	163.94	Lynn	147.99	Trinity	129.86	Terrell	92.15		
Irion	266.55	Eastland	218.33	Gray	203.46	King	185.7	Sabine	174.82	Collingsworth	163.58	Washington	147.99	Bastrop	126.96	Jasper	89.25		
Archer	262.56	Hopkins	217.97	Falls	203.1	Dawson	185.33	Lee	174.09	Motley	163.58	Lipscomb	147.62	Grimes	125.14	Jeff Davis	88.52		
Stonewall	249.51	Cherokee	216.88	Rusk	203.1	Shelby	185.33	Crosby	173.37	Medina	163.22	Kleberg	145.81	Live Oak	125.14	Loving	88.16		
Mason	245.52	Montague	215.06	Camp	200.92	Parmer	184.61	Bosque	172.64	Hemphill	161.77	Jim Hogg	145.09	Upton	123.69	Polk	88.16		
McCulloch	240.45	Gregg	214.34	Marion	200.92	Comanche	183.88	Grayson	172.64	Hays	161.4	Caldwell	144	Randall	123.33	Crane	87.07		
Bowie	239.36	Lamar	214.34	Blanco	200.2	Martin	183.88	Robertson	171.92	Hill	161.04	Collin	143.27	Lavaca	122.97	Montgomery	77.28		

Figure 6. 33: Results of scenario 2 Approach 1 based on Rayleigh Function

6.10.2.2 Approach 2

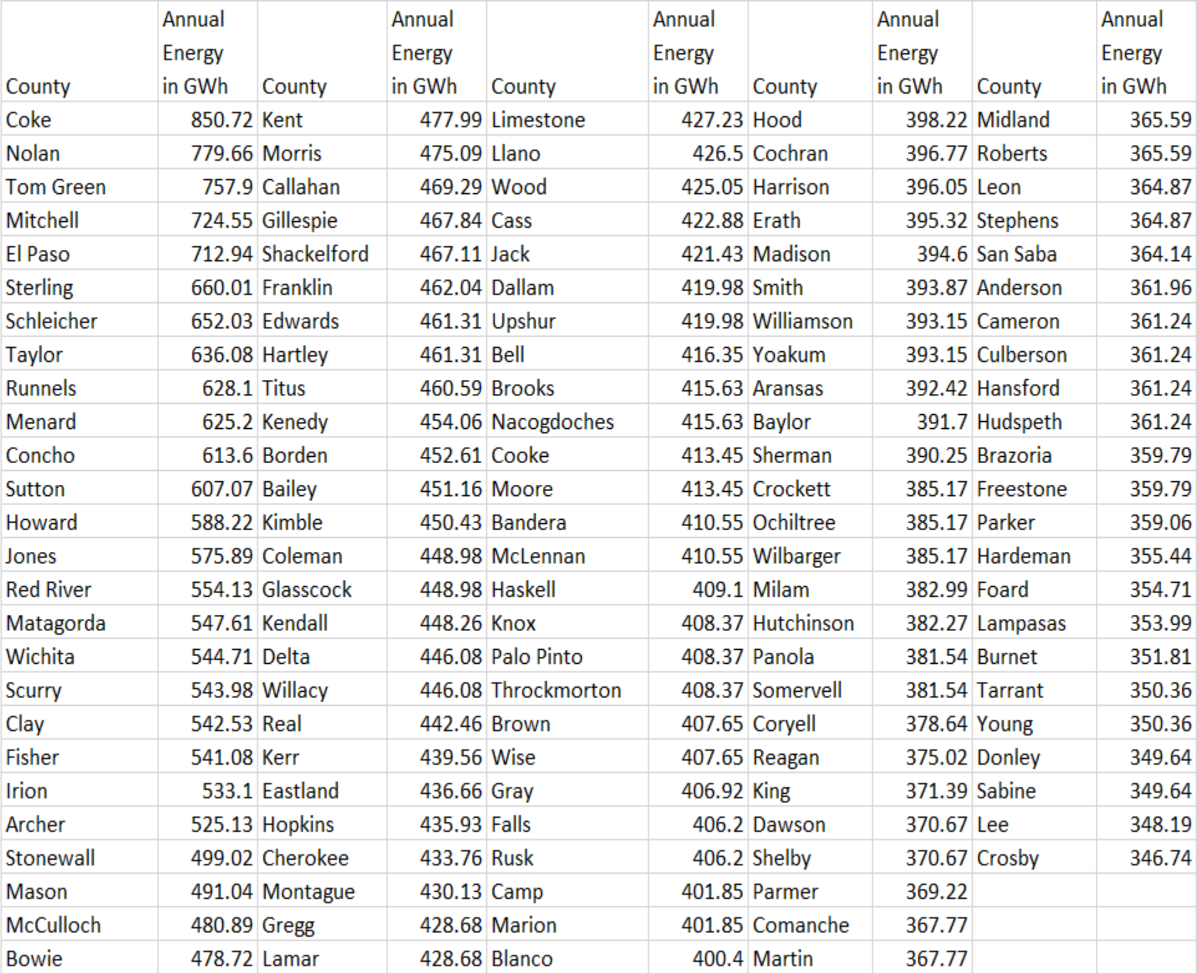
In the second method, in this case, it is recommended to install 26 wind turbines of the Enercon E-126 7.580 wind turbine model in 127 counties with a total capacity of 25.029 GW. By applying Flow chart as shown in Figure 6.31, the Annual Energy generation in Coke county as the following:

$$\text{Annual Energy in Coke County} = 8{,}760 * 7{,}580 * CF * \text{Number of Wind Turbines}$$

$$\text{Annual Energy in Coke County} = 8{,}760 * 7{,}580 * ((.087 * 11.065) - (\frac{7{,}580}{127^2}))*26$$

Annual Energy in Coke County =850.5972 GWh ≈850.72 GWh

Figure 6.34 shows the change in power generation from one county to another, from 346.74 to 850.72 GWh and in total 56.36 TWh. There are 22 counties in Texas with enough resources to supply electricity above 500 GWh and below 850.72 GWh. In this case, the power generation of 105 counties in Texas may exceed 346.74 GWh, up to 500 GWh. Figure 6.34 illustrates all the results of this scenario.



County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Coke	850.72	Kent	477.99	Limestone	427.23	Hood	398.22	Midland	365.59
Nolan	779.66	Morris	475.09	Llano	426.5	Cochran	396.77	Roberts	365.59
Tom Green	757.9	Callahan	469.29	Wood	425.05	Harrison	396.05	Leon	364.87
Mitchell	724.55	Gillespie	467.84	Cass	422.88	Erath	395.32	Stephens	364.87
El Paso	712.94	Shackelford	467.11	Jack	421.43	Madison	394.6	San Saba	364.14
Sterling	660.01	Franklin	462.04	Dallam	419.98	Smith	393.87	Anderson	361.96
Schleicher	652.03	Edwards	461.31	Upshur	419.98	Williamson	393.15	Cameron	361.24
Taylor	636.08	Hartley	461.31	Bell	416.35	Yoakum	393.15	Culberson	361.24
Runnels	628.1	Titus	460.59	Brooks	415.63	Aransas	392.42	Hansford	361.24
Menard	625.2	Kenedy	454.06	Nacogdoches	415.63	Baylor	391.7	Hudspeth	361.24
Concho	613.6	Borden	452.61	Cooke	413.45	Sherman	390.25	Brazoria	359.79
Sutton	607.07	Bailey	451.16	Moore	413.45	Crockett	385.17	Freestone	359.79
Howard	588.22	Kimble	450.43	Bandera	410.55	Ochiltree	385.17	Parker	359.06
Jones	575.89	Coleman	448.98	McLennan	410.55	Wilbarger	385.17	Hardeman	355.44
Red River	554.13	Glasscock	448.98	Haskell	409.1	Milam	382.99	Foard	354.71
Matagorda	547.61	Kendall	448.26	Knox	408.37	Hutchinson	382.27	Lampasas	353.99
Wichita	544.71	Delta	446.08	Palo Pinto	408.37	Panola	381.54	Burnet	351.81
Scurry	543.98	Willacy	446.08	Throckmorton	408.37	Somervell	381.54	Tarrant	350.36
Clay	542.53	Real	442.46	Brown	407.65	Coryell	378.64	Young	350.36
Fisher	541.08	Kerr	439.56	Wise	407.65	Reagan	375.02	Donley	349.64
Irion	533.1	Eastland	436.66	Gray	406.92	King	371.39	Sabine	349.64
Archer	525.13	Hopkins	435.93	Falls	406.2	Dawson	370.67	Lee	348.19
Stonewall	499.02	Cherokee	433.76	Rusk	406.2	Shelby	370.67	Crosby	346.74
Mason	491.04	Montague	430.13	Camp	401.85	Parmer	369.22		
McCulloch	480.89	Gregg	428.68	Marion	401.85	Comanche	367.77		
Bowie	478.72	Lamar	428.68	Blanco	400.4	Martin	367.77		

Figure 6. 34: Results of scenario 2 Approach 2 based on Rayleigh Function

6.10.2.3 Approach 3

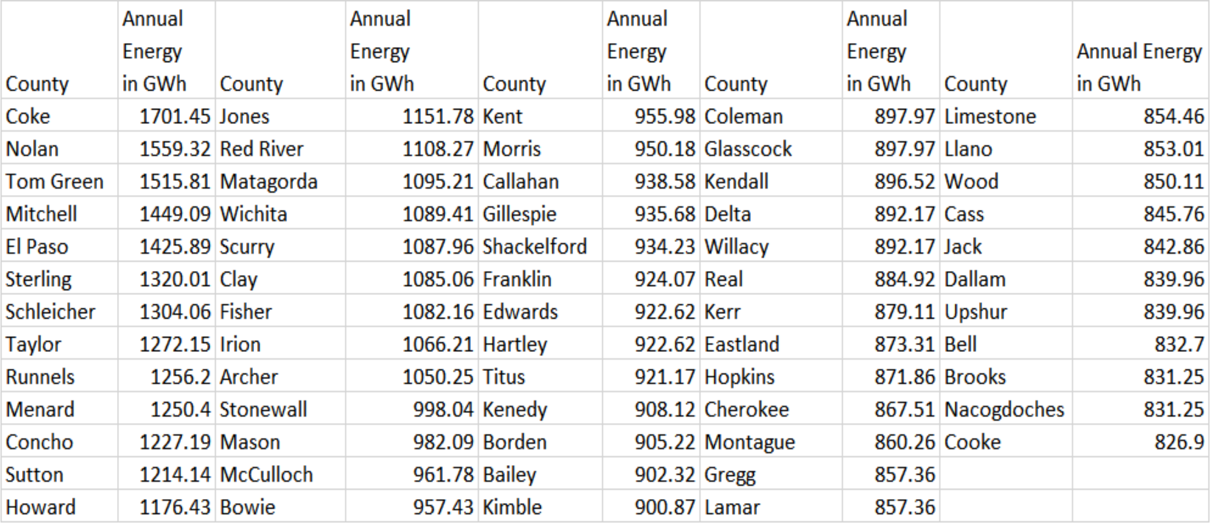
In the third approach, in this case, it is recommended to install 52 wind turbines of the Enercon E-126 7.580 wind turbine model in 64 counties with a total capacity of 25.226 GW. By applying Flow chart as shown in Figure 6.31, the Annual Energy generation in Coke county as the following:

$$\text{Annual Energy in Coke County} = 8{,}760 * 7{,}580 * CF * \text{Number of Wind Turbines}$$

$$\text{Annual Energy in Coke County} = 8{,}760 * 7{,}580 * ((.087 * 11.065) - (\frac{7{,}580}{127^2}))*52$$

Annual Energy in Coke County =1,701.194 GWh ≈1,701.45 GWh

Figure 6.35 shows the change in power generation from one county to another, from 826.9 to 1,701.45 GWh and in total 64.91 TWh. There are 22 counties in Texas with enough resources to supply electricity above 1,000 GWh and below 1,701.45 GWh. In this case, the power generation of 42 counties in Texas may exceed 826.9 GWh, up to 1,000 GWh. Figure 6.35 illustrates all the results of this scenario.



County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Coke	1701.45	Jones	1151.78	Kent	955.98	Coleman	897.97	Limestone	854.46
Nolan	1559.32	Red River	1108.27	Morris	950.18	Glasscock	897.97	Llano	853.01
Tom Green	1515.81	Matagorda	1095.21	Callahan	938.58	Kendall	896.52	Wood	850.11
Mitchell	1449.09	Wichita	1089.41	Gillespie	935.68	Delta	892.17	Cass	845.76
El Paso	1425.89	Scurry	1087.96	Shackelford	934.23	Willacy	892.17	Jack	842.86
Sterling	1320.01	Clay	1085.06	Franklin	924.07	Real	884.92	Dallam	839.96
Schleicher	1304.06	Fisher	1082.16	Edwards	922.62	Kerr	879.11	Upshur	839.96
Taylor	1272.15	Irion	1066.21	Hartley	922.62	Eastland	873.31	Bell	832.7
Runnels	1256.2	Archer	1050.25	Titus	921.17	Hopkins	871.86	Brooks	831.25
Menard	1250.4	Stonewall	998.04	Kenedy	908.12	Cherokee	867.51	Nacogdoches	831.25
Concho	1227.19	Mason	982.09	Borden	905.22	Montague	860.26	Cooke	826.9
Sutton	1214.14	McCulloch	961.78	Bailey	902.32	Gregg	857.36		
Howard	1176.43	Bowie	957.43	Kimble	900.87	Lamar	857.36		

Figure 6. 35: Results of scenario 2approach 3 based on Rayleigh Function

6.10.2.4 Approach 4

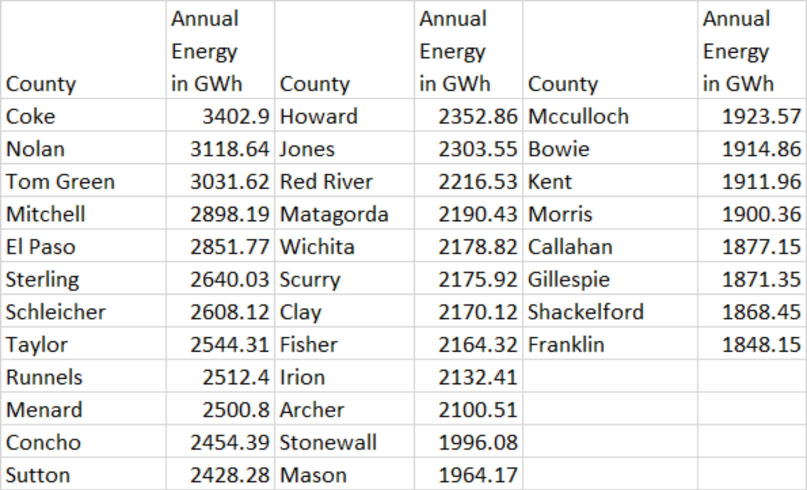
In the fourth approach, in this case, it is recommended to install 104 wind turbines of the Enercon E-126 7.580 wind turbine model in 32 counties with a total capacity of 25.226 GW.By applying Flow chart as shown in Figure 6.31, the Annual Energy generation in Coke county as the following:

Annual Energy in Coke County = $8{,}760 * 7{,}580 * CF*$ Number of Wind Turbines

Annual Energy in Coke County = $8{,}760 * 7{,}580 * ((.087 * 11.065) - (\frac{7{,}580}{127^2}))*104$

Annual Energy in Coke County =3,402.389 GWh ≈3,402.9 GWh

Figure 6.36 shows the change in power generation from one county to another, from 1,848.5 to 3,402.9 GWh and in total 74.05 TWh. There are10 counties in Texas with enough resources to supply electricity above 2,500 GWh and below 3,402.9 GWh. In this case, the power generation of 22 counties in Texas may exceed 1,848.5 GWh, up to 2,500 GWh. Figure 6.36 illustrates all the results of this scenario.



County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Coke	3402.9	Howard	2352.86	Mcculloch	1923.57
Nolan	3118.64	Jones	2303.55	Bowie	1914.86
Tom Green	3031.62	Red River	2216.53	Kent	1911.96
Mitchell	2898.19	Matagorda	2190.43	Morris	1900.36
El Paso	2851.77	Wichita	2178.82	Callahan	1877.15
Sterling	2640.03	Scurry	2175.92	Gillespie	1871.35
Schleicher	2608.12	Clay	2170.12	Shackelford	1868.45
Taylor	2544.31	Fisher	2164.32	Franklin	1848.15
Runnels	2512.4	Irion	2132.41		
Menard	2500.8	Archer	2100.51		
Concho	2454.39	Stonewall	1996.08		
Sutton	2428.28	Mason	1964.17		

Figure 6. 36: Results of scenario 2approach 4 based on Rayleigh Function

6.10.2.5 Approach 5

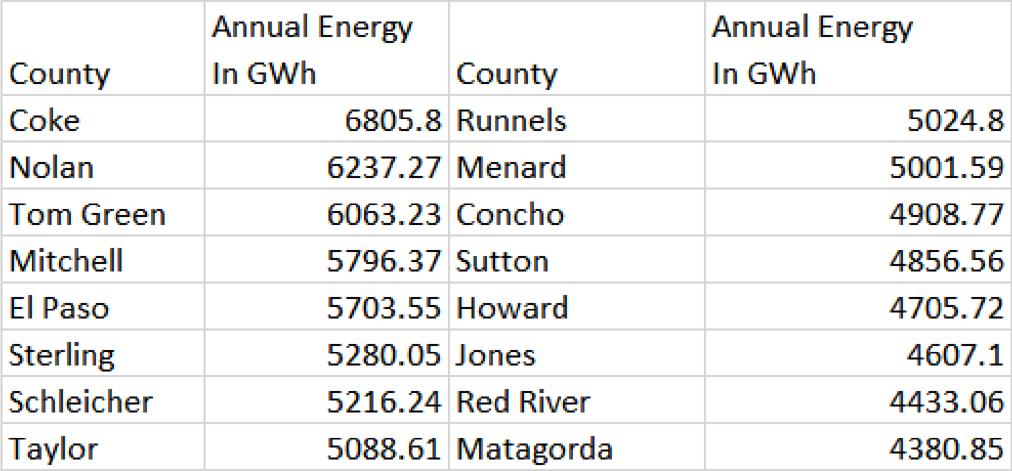
In the fifth approach, in this case, it is recommended to install 208 wind turbines of the Enercon E-126 7.580 wind turbine model in 16 counties with a total capacity of 25.226 GW. By applying Flow chart as shown in Figure 6.31, the Annual Energy generation in Coke county as the following:

Annual Energy in Coke County = $8{,}760 * 7{,}580 * CF*$ Number of Wind Turbines

Annual Energy in Coke County = $8{,}760 * 7{,}580 * ((.087 * 11.065) - (\frac{7{,}580}{127^2}))*208$

Annual Energy in Coke County =6,804.7781 GWh ≈6,805.8 GWh

Figure 6.37 shows the change in power generation from one county to another, from 4,380.85 to 6,805.8 GWh and in total 84.11 TWh. There are10 counties in Texas with enough resources to supply electricity above 5,000 GWh and below 6,805.8 GWh. In this case, the power generation of 6 counties in Texas may exceed 4,380.85 GWh, up to 5,000 GWh. Figure 6.37 illustrates all the results of this scenario.



County	Annual Energy In GWh	County	Annual Energy In GWh
Coke	6805.8	Runnels	5024.8
Nolan	6237.27	Menard	5001.59
Tom Green	6063.23	Concho	4908.77
Mitchell	5796.37	Sutton	4856.56
El Paso	5703.55	Howard	4705.72
Sterling	5280.05	Jones	4607.1
Schleicher	5216.24	Red River	4433.06
Taylor	5088.61	Matagorda	4380.85

Figure 6. 37: Results of scenario 2approach 5 based on Rayleigh Function

6.10.3 Scenario 3

In this scenario, 31 GW of the wind turbine is proposed to install in Texas which already has that installed wind turbine but with different distribution based on two approaches, all of them are based on the power classification due to wind energy resources potential in Texas's counties that show in table 6.1. The first approach is to recommend installing wind turbines in counties classified as superb, outstanding, Excellent, and good counties. The approach method is only for superb, outstanding, and excellent counties.

6.10.3.1 Approach 1

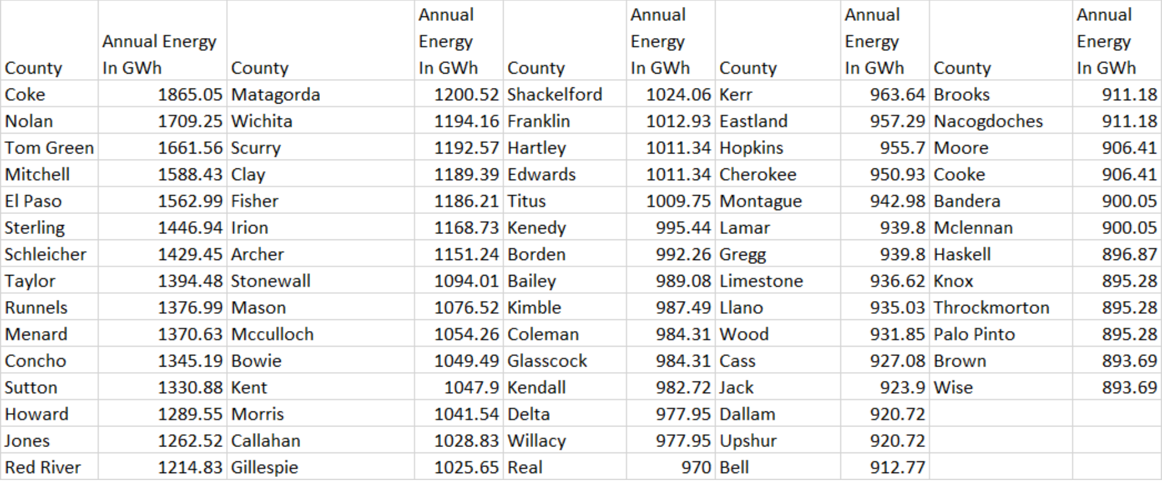
In the first method, in this case, it is recommended to install 57 wind turbines of the Enercon E-126 7.580 wind turbine model in 72 counties with a total capacity of 31.108 GW. These 72 counties are all classified as superb, outstanding, Excellent, and good potential resources for wind energy. By applying Flow chart as shown in Figure 6.31, the Annual Energy generation in Coke county as the following:

$$\text{Annual Energy in Coke County} = 8{,}760 * 7{,}580 * CF * \text{Number of Wind Turbines}$$

$$\text{Annual Energy in Coke County} = 8{,}760 * 7{,}580 * ((.087 * 11.065) - (\frac{7{,}580}{127^2}))*57$$

Annual Energy in Coke County =1,864.770 GWh ≈1,865.05 GWh

Figure 6.38 shows the change in power generation from one county to another, from 893.69 to 1,865.08 GWh and in total 78.32 TWh. There are 35 counties in Texas with enough resources to supply electricity above 1,000 GWh and below 1,865.08 GWh. In this case, the power generation of 37 counties in Texas may exceed 893.69 GWh, up to 1,865.69 GWh. Figure 6.38 illustrates all the results of this scenario.



County	Annual Energy In GWh	County	Annual Energy In GWh	County	Annual Energy In GWh	County	Annual Energy In GWh	County	Annual Energy In GWh
Coke	1865.05	Matagorda	1200.52	Shackelford	1024.06	Kerr	963.64	Brooks	911.18
Nolan	1709.25	Wichita	1194.16	Franklin	1012.93	Eastland	957.29	Nacogdoches	911.18
Tom Green	1661.56	Scurry	1192.57	Hartley	1011.34	Hopkins	955.7	Moore	906.41
Mitchell	1588.43	Clay	1189.39	Edwards	1011.34	Cherokee	950.93	Cooke	906.41
El Paso	1562.99	Fisher	1186.21	Titus	1009.75	Montague	942.98	Bandera	900.05
Sterling	1446.94	Irion	1168.73	Kenedy	995.44	Lamar	939.8	Mclennan	900.05
Schleicher	1429.45	Archer	1151.24	Borden	992.26	Gregg	939.8	Haskell	896.87
Taylor	1394.48	Stonewall	1094.01	Bailey	989.08	Limestone	936.62	Knox	895.28
Runnels	1376.99	Mason	1076.52	Kimble	987.49	Llano	935.03	Throckmorton	895.28
Menard	1370.63	Mcculloch	1054.26	Coleman	984.31	Wood	931.85	Palo Pinto	895.28
Concho	1345.19	Bowie	1049.49	Glasscock	984.31	Cass	927.08	Brown	893.69
Sutton	1330.88	Kent	1047.9	Kendall	982.72	Jack	923.9	Wise	893.69
Howard	1289.55	Morris	1041.54	Delta	977.95	Dallam	920.72		
Jones	1262.52	Callahan	1028.83	Willacy	977.95	Upshur	920.72		
Red River	1214.83	Gillespie	1025.65	Real	970	Bell	912.77		

Figure 6. 38: Results of scenario 3 Approach 1 based on Rayleigh Function

6.10.3.2 Approach 2

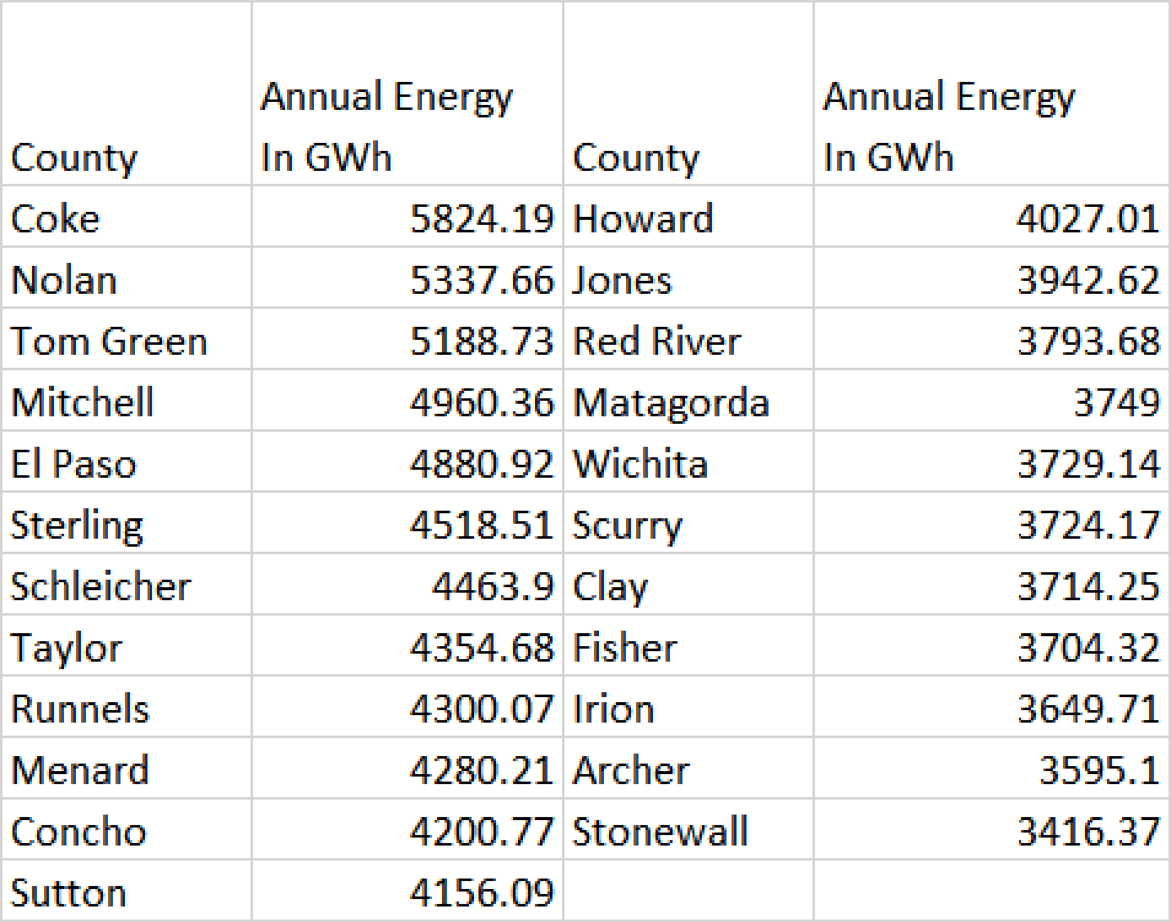
In the second method, in this scenario, it is recommended to install 178 wind turbines of the Enercon E-126 7.580 wind turbine model in 23 counties with a total capacity of 31.032 GW. These 23 counties are all classified as superb, outstanding, and Excellent potential resources for wind energy. By applying Flow chart as shown in Figure 6.31, the Annual Energy generation in Coke county as the following:

Annual Energy in Coke County = $8{,}760 * 7{,}580 * CF*$ Number of Wind Turbines

Annual Energy in Coke County = $8{,}760 * 7{,}580 * ((.087 * 11.065) - (\frac{7{,}580}{127^2}))*178$

Annual Energy in Coke County =5,823.319 GWh ≈5,824.19 GWh

Figure 6.39 shows the change in power generation from one county to another, from 3,416.37 to 5,824.19 GWh and in total 97.51 TWh. There are13 counties in Texas with enough resources to supply electricity above 4,000 GWh and below 5,824.19 GWh. In this case, the power generation of 10 counties in Texas may exceed 3,416.37 GWh, up to 4,000 GWh. Figure 6.39 illustrates all the results of this scenario.



County	Annual Energy In GWh	County	Annual Energy In GWh
Coke	5824.19	Howard	4027.01
Nolan	5337.66	Jones	3942.62
Tom Green	5188.73	Red River	3793.68
Mitchell	4960.36	Matagorda	3749
El Paso	4880.92	Wichita	3729.14
Sterling	4518.51	Scurry	3724.17
Schleicher	4463.9	Clay	3714.25
Taylor	4354.68	Fisher	3704.32
Runnels	4300.07	Irion	3649.71
Menard	4280.21	Archer	3595.1
Concho	4200.77	Stonewall	3416.37
Sutton	4156.09		

Figure 6. 39: Results of scenario 3 Approach 2 based on Rayleigh Function

6.11 Results

As mentioned at the beginning, the electrical proposal system based on rotor efficiency (System 1) is more optimistic in terms of energy generation compare with the electrical proposal system based on the Rayleigh distribution function (system 2). Therefore, the energy generated from the first system is higher than the second system. However, in all cases, the change in energy will not exceed 20%. As shown in Table 6.2, in most cases, the electrical suggestion system based on the Rayleigh distribution function will generate in average 87.26% of the expected energy from the electrical suggestion system based on the rotor efficiency.

	Expected Annual energy in TWh in Electrical proposal system based on rotor efficiency (system 1)	Expected Annual energy in TWh in Electrical proposal system based on Rayleigh function (system2)	Ratio between Expected Annual Energy of system 2 to Expected Annual Energy system 1
Scenario #1	116.4	102.05	87.67%
Scenario#2 approach #1	50.448	44.22	87.65%
Scenario#2 approach #2	62.746	56.36	89.82%
Scenario#2 approach #3	73.27	64.91	88.59%
Scenario#2 approach #4	85.636	74.05	86.47%
Scenario#2 approach #5	100.37	84.11	83.799%
Scenario#3 approach #1	88.129	78.32	88.86%
Scenario#3 approach #2	114.445	97.51	85.20%

Table 6. 2: Comparison between electrical proposal system based on system 1& 2

According to 'Wind Energy in Texas, 2020', the current capacity factor in Texas is approximately 32%. and it could reach up to 45.4% in scenario#2 approach#5 based on system 1 and 38.4% based on system 2, as noticed increasing of capacity factor is directly proportionally with increases in the wind farm size which could reach to 1.576 GW, which could approximately need the area around 127.5 Km^2 'How much land does a wind farm require?,(n.d)' fortunately, Texas has enough area for such big wind farms .From all of that, the distribution of the wind turbine among Texas could power more electricity if they redistribute only on the top counties based on the wind speed, which shows the impact of the wind speed on the power generation from the wind turbine. All results from different scenarios are shown in Table 6.3.

	Installed wind turbine in GW	Capacity factor (System 1)	Capacity factor (System 2)	Wind farm size
Wind Turbine installed in Texas	24	32%		varies
Scenario #1	57.759	23	20.2%	227.4 Mw
Scenario#2 approach #1	25.029	23.13%,	20.2	98.54 Mw
Scenario#2 approach #2	25.029	28.61%	25.7	197.08 Mw
Scenario#2 approach #3	25.226	33.156%	29.3%	394.16 Mw
Scenario#2 approach #4	25.226	38.74%	33.5%	788.32 Mw
Scenario#2 approach #5	25.226	45.41%	38.4%	1,576.64 Mw
Scenario#3 approach #1	31.108	32.33%	28.7 %	432.06 Mw
Scenario#3 approach #2	31.032	42.09%	36.1%	1,349.24 Mw

Table 6. 3: Comparison between system 1&2 regarding the capacity factor

Figure 6.30 illustrates the differences in size between all previous scenario from both systems and current situation compare with the hypothetical model of wind energy in the state of Texas.

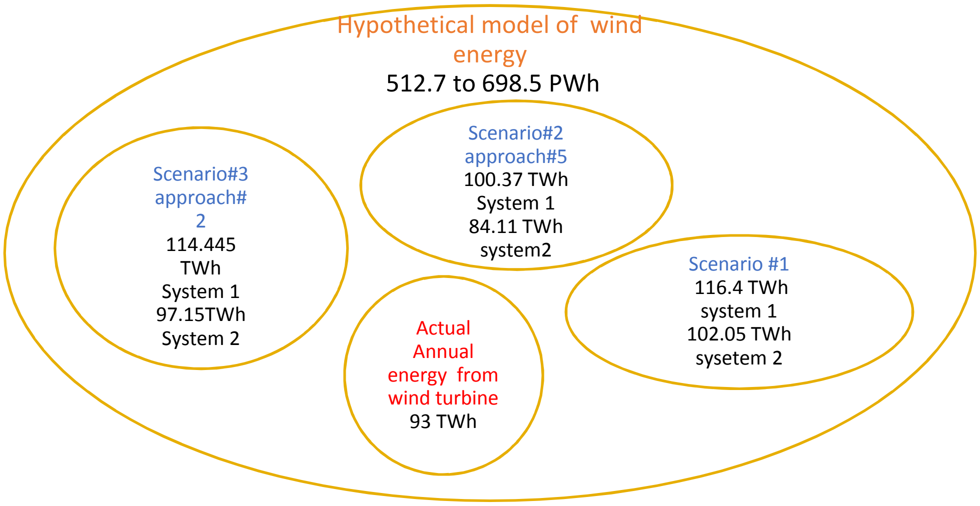


Figure 6. 40: Maximum results from the electrical proposed system

6.12 Transmission Grid and Wind Power

Wind Energy faces some challenges in order to use more in the power industry, according to ‘ Chen,2013’ there are 5 main issues of wind power as the following: First, wind energy is unpredictable It is not a constant source and it could be lost at any moment. Second, power generation fluctuates and is unstable, mainly depending on wind speed. Third, it is not dispatchable resources and not controllable at all. Fourth, the need for special control devices in the results of the fluctuation in frequency and dynamic effect of the wind power, in addition to the reactive power. Finally, the location of the wind turbine is usually in remote areas thus, a need for a new electrical grid in order to transmit the power generation to clients. Based on the previous features of wind power, there is an urge to install a new electric transmission line or at least upgrade the electrical grid to handle the extra power from wind energy. There are some additional plans like increasing the voltage level of the power grid by adding higher voltage transformer and especial electrical conductors ‘Chen, 2013’. However, there are some other challenges with wind power such as noise and negative impact on the wildlife especially birds ‘Advantages and Challenges of Wind Energy, n.d’.

CHAPTER VII

SOLAR ENERGY

7.1 Solar Energy

Solar energy is the available energy in the heat and solar radiation. Solar energy can be converted into electrical energy in two ways: photovoltaic systems (PV) and concentrated solar energy (CSP). Photovoltaic systems rely on solar radiation based on the photoelectric effect to generate electricity. The CSP system relies on the heat generated by the sun incident on the earth and converted into electricity.

Solar energy is available everywhere and in a large amount. The amount of solar energy incident on the earth is several times the electricity demand on the earth. Based on the world Energy assessment in 2000, the annual incident energy from Solar energy in the north of America was between 181.1 to 7,410 Exajoules ‘Energy and the challenge of sustainability,2000’ while the annual consumption of electricity in the USA in 2019 was 37.1 Exajoules ‘U.S. energy facts explained,2020’, thus the incident energy of the sun in North America is larger than whole electricity consumption in the USA from 4.6 to 189.5 times.

Solar energy could be considered as one of the fewest main forms of energy or in other words called primary energy. Solar energy is responsible for many other forms of renewable energy such as wind, biomass, hydroelectric and geothermal energy. The differences in temperature cause the wind speed, so the sun is responsible indirectly for the wind energy. The cycle of water from condensation and vaporization happens due to the effect of the sun. Part of the heat energy preserved inside the earth comes from the incident energy from the sun. All plants need the sun in its cycle of life due to the important roles played in Photosynthesis, thus the biomass energy depends directly on the sun in its production. Solar power plants can be centralized or decentralized. Contrasted with other types of renewable energy, this fact is one of the best features of solar energy. Even conventional power plants such as fossil and nuclear power are centralized power plants, and most of the other renewable power plants especially hydroelectric power plants and geothermal power plants are always installed in large-capacity centralized forms. Even to make matters worse, biomass energy and wind power plants may appear in a decentralized form, but they are not economically efficient. Solar power plants, especially photovoltaic power plants, are economically dispersed or concentrated. This function supports the concept of smart grid and helps to transform the grid from a traditional concept to a microgrid concept.

Due to the simple fact that solar energy is a clean energy source, it is neither a greenhouse gas nor from the sun, nor from the power generation process of PV and CSP systems. It is renewable because the sun is everywhere. This makes solar energy an independent energy source. Solar radiation and temperature fluctuations are one of the worst features of solar energy other than the sun that is not available for 24 hours a day, all of which become non-dispatchable resources.

7.2 What Is Light

Light can be described as electromagnetic waves and particles called photons. The particle's definition has been noticed based on the photoelectric effect discovered by Heinrich Hertz The photoelectric effect is related to the ability of blue and ultraviolet light to remove charge from charged objects, while other colors of light (such as redness) cannot do this. Einstein explained this in a popular paper published in 1922.

In Einstein's explanation, light consists of particles called photons and it has a certain amount of energy. In order to eject electrons from the material, the photon should have an energy equal to or greater than the electron energy called a threshold, otherwise, the electrons will not be ejected. As shown in Figure 7.1 ‘Shaik, n.d’.

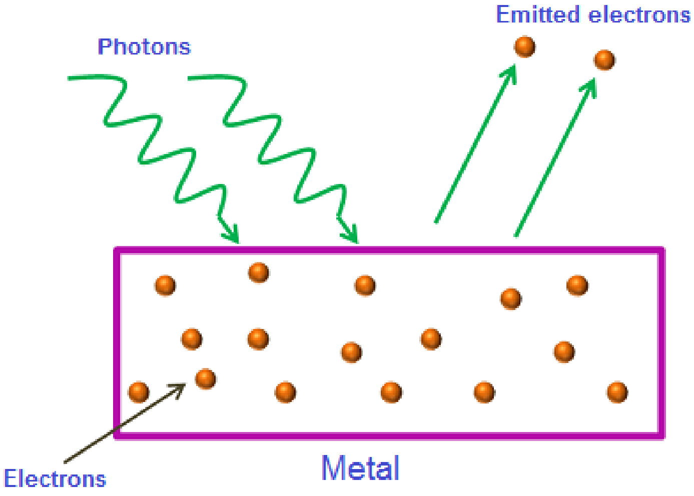


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Figure 7. 1: Photoelectric effect explanation

Light is an electromagnetic wave, and it is an electromagnetic wave that transmits energy in space. The wavelength of light can be determined by Equation 7.1.

$C = \lambda * v$ 7.1

Where:

C: Speed of light in m/s

ƛ: Wavelength in m

V: Frequency in Hz

Planck's law is used to determine the energy of the wavelength at a specific frequency as shown in Equation 7.2

$E = h * v$…….7.2

Where:

E: energy in Joule

h: Planck’s constant equals 6.626x10-34 J.s

The electromagnetic wave of the light has a variety of ranges of frequencies and for each frequency, it has a specific wavelength as shown in Figure 7.2 ‘The Electromagnetic spectrum,2020’, hence specific energy based on Planck's law. The electromagnetic spectrum varies from a few Herts in radio waves to ten septillions (10^{25}) Herts in Gamma-ray. The wavelength of visible light varies between 400-700 mm, as shown in Figure 7.2.

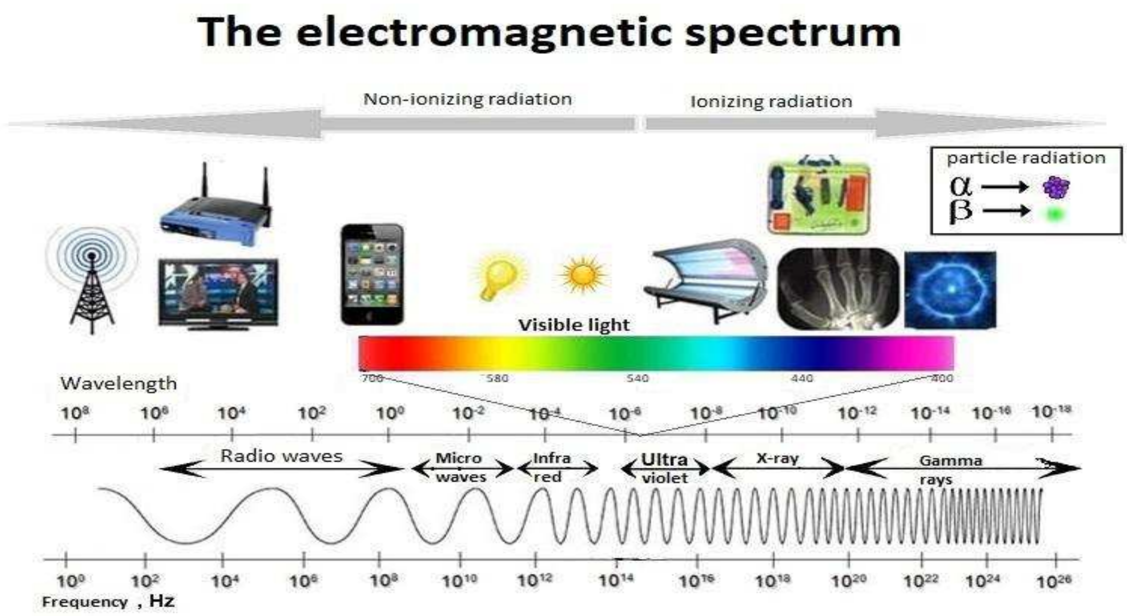


Figure 7. 2: The electromagnetic spectrum

7.3 The Spectrum Of The Sun

A blackbody radiator is an object that absorbs all electromagnetic waves of all wavelengths and does not reflect electromagnetic waves. The electromagnetic spectrum of the black body can be defines using Planck's law as shown in Equation 7.3.

$$B(V,T) = \frac{2hV^3}{c^2}\frac{1}{e^{\frac{hV}{K_BT}}-1} \text{ ....7.3}$$

Where:

B: Spectral radiance of the body in W/m2

h: Planck's constant equals 6.626x10-34 J.s

V: Frequency in Hertz

T: Absolute temperature in kelvin

KB: Boltzmann constant equals 1.380649 *10-23 J.K-1

As shown in Figure 7.3 'Ling et al, 2016', the spectrum radiance depends on the absolute temperature, as the temperature increase, the radiance will increase and the peak of the spectrum will be shifted to the left side of the curve, in other word it will occur at the low wavelength.

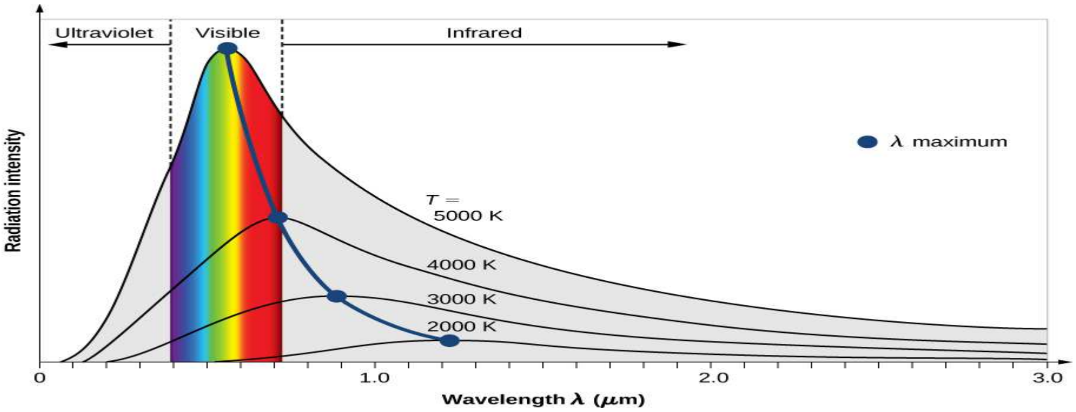


Figure 7. 3: Black body spectrum

The sun is considered a blackbody radiator, not a perfect blackbody. According to NASA, the surface temperature of the sun is close to 6000K 'sun, n.d'. As shown in Figure 7.4 'Sunlight and the Human Eye, n.d', the solar spectrum on the sun has the peak value of irradiance in the visible light and especially in the blue color. 5% of the solar spectrum is under the ultraviolet wavelength, and 45% of it under the infrared and 50% in the visible light 'Zayat et al, 2007'.

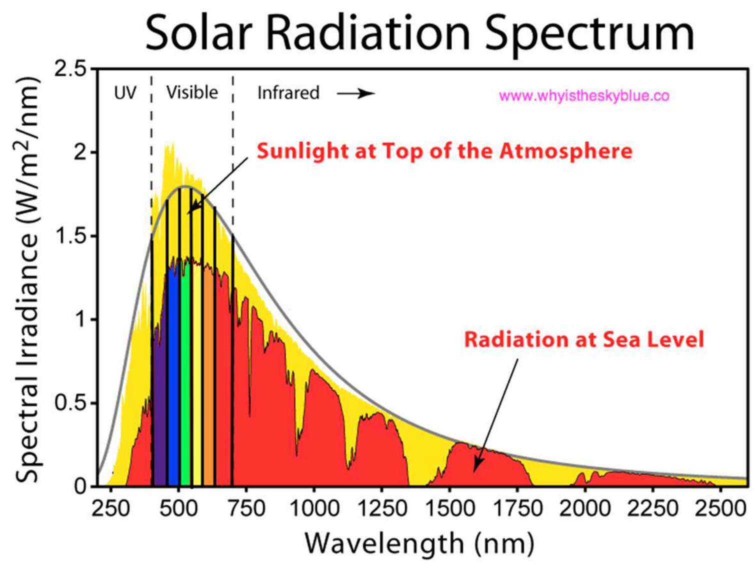


Figure 7. 4: Solar spectrum on the earth

7.4 Solar Radiation

When traveling in the atmosphere, part of the solar radiation is lost due to the scattering and absorption of another molecule in the atmosphere. The ozone layer absorbs ultraviolet light. Water, oxygen and carbon dioxide absorb infrared rays. Figure 7.5 ‘Cleveland et al, 2013’ illustrates the difference between the solar spectrum on the surface of the atmosphere and the surface of the earth. It is also known as the Extraterrestrial and terrestrial solar spectrum.

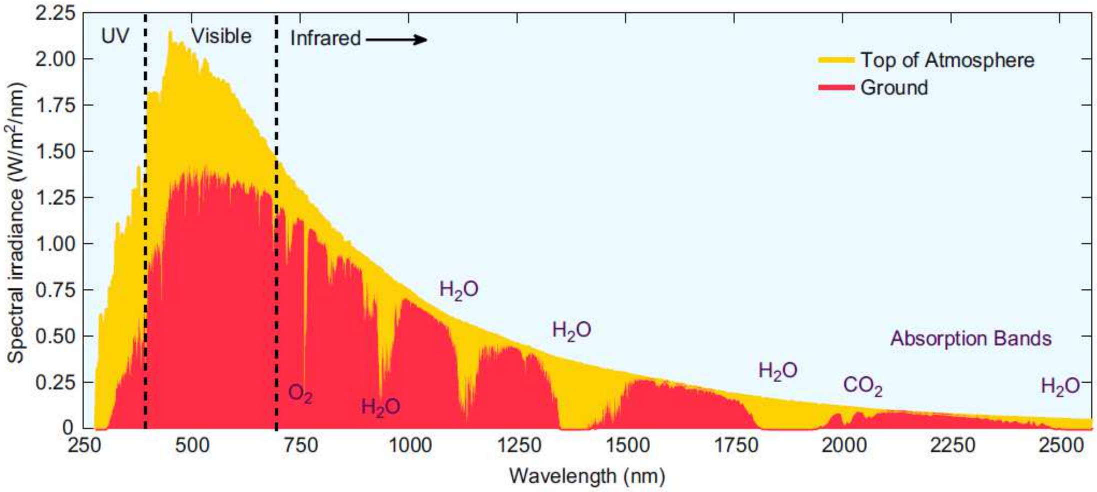


Figure 7. 5: Solar spectrum on atmosphere and earth

Due to reflections from clouds, atmosphere, and the surface of the earth, some of the solar radiation reaching the earth may be lost. Absorption from clouds and atmosphere is another cause of loss. As shown in Figure 7.6 ‘The role of Clouds,2004’, almost 49% of solar radiation is lost in the process of flowing to the earth's surface, and only 51% of solar radiation is absorbed by the earth.

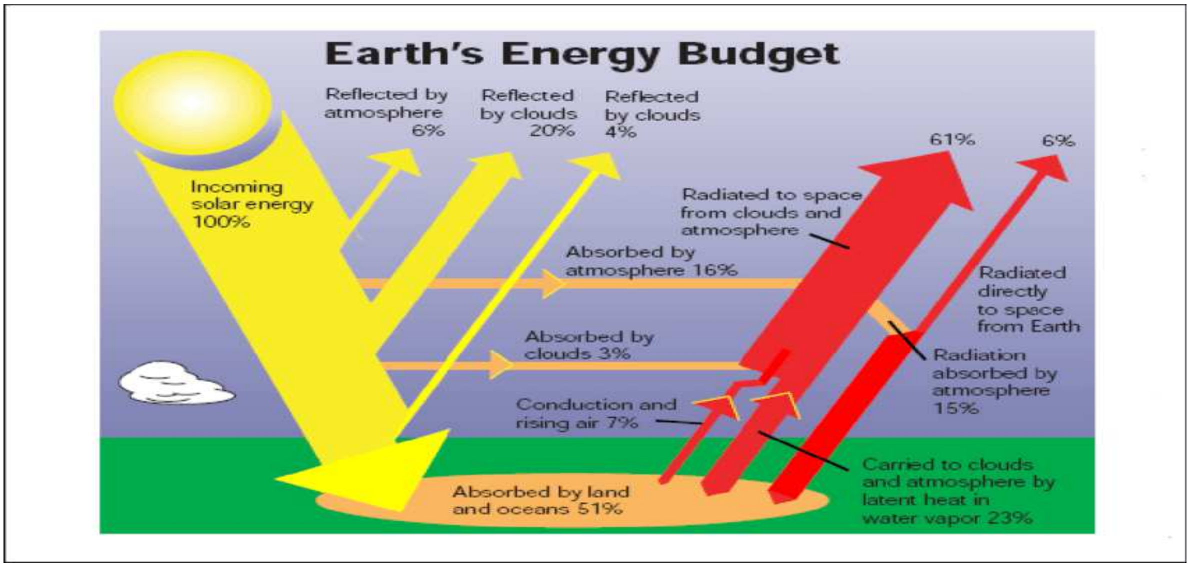


Figure 7. 6: Losses in solar radiation

7.5 Solar Radiation Types

Solar radiation based on loss at a specific point can be divided into many types; for example, direct solar radiation hits a specific point, while diffuse solar radiation is another type, which comes from scattering objects. The reflected solar radiation comes from the earth itself or any other particles that hit the sun and radiate directly to a specific point. As shown in Figure 7.7 ‘Gueymard,2012’.

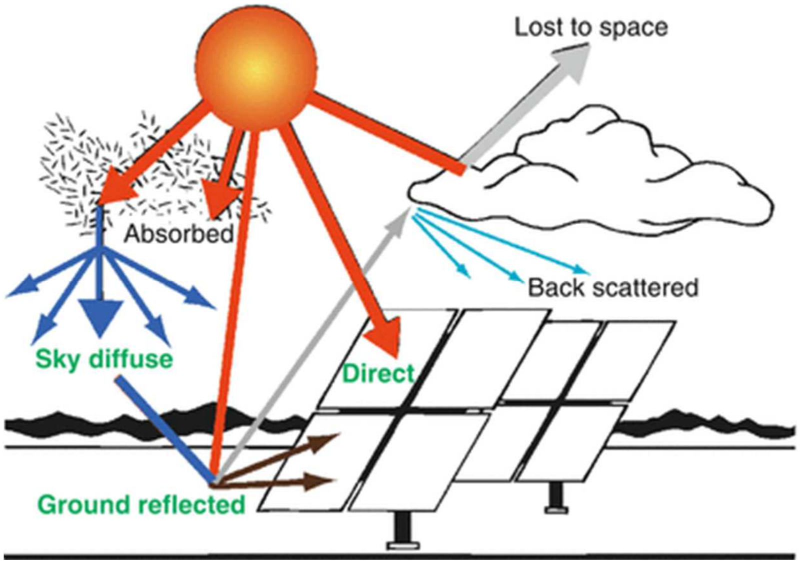


Figure 7. 7: Solar radiation types

As shown in Figure 7.7, the solar radiation changes from one point in the earth to another based on many factors such as the move of the sun in the sky, the time of the day, the day of the season, the season of the year, the altitude of the site, the environment of the site, and the buildings beside the site, etc.…

The Global horizontal radiation is the sum of direct radiation (Gb, called beam radiation) and scattered radiation, as shown in Equation 7.4. The plane of the array is the sum of direct, diffuse, and reflected radiation, as shown in Equation 7.5. Direct radiation is equal to the multiplication between the direct normal radiation (Gb, n), and the cosine of the angle between its vertical line and the line of the sun at a specific point (ϴZ). As shown in Figure 7.8 'Brownson,2014' which illustrates direct normal radiation and direct radiation.

$$\text{Global rorizontal radiation (GHR)} = \text{Direct radiation} + \text{Diffuse radiation} \ldots\ldots 7.4$$

$$\text{Plane of the array} = \text{Direct radiation} + \text{Diffuse radaition} + \text{Reflected radiation} \ldots 7.5$$

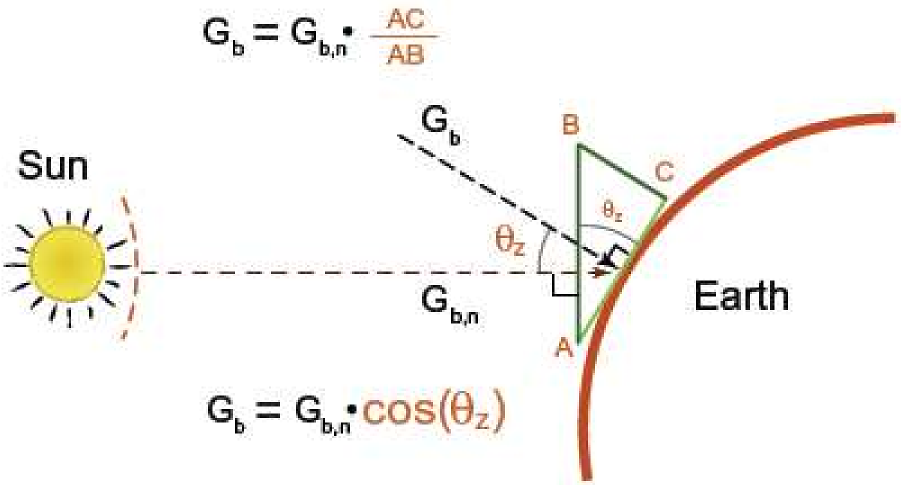


Figure 7. 8: Solar radiation at specific point

Figure 7.9 ‘Ramos and Andreas,2011’ illustrates the data of different types of solar radiation in Edinburg Texas on the 1st of March 2020, Global Horizontal radiation varies from 0 to 970 W/m^2 from 7 in the morning to 6 in the evening, and the peak is 970 at the noon. The range of direct radiation is 0 to 300 W/m^2, with a peak at 11 o'clock in the morning. The diffuse radiation is almost negligible, while the normal direct radiation varies between 0-820 W/m^2 and the peak at 4 in the afternoon.

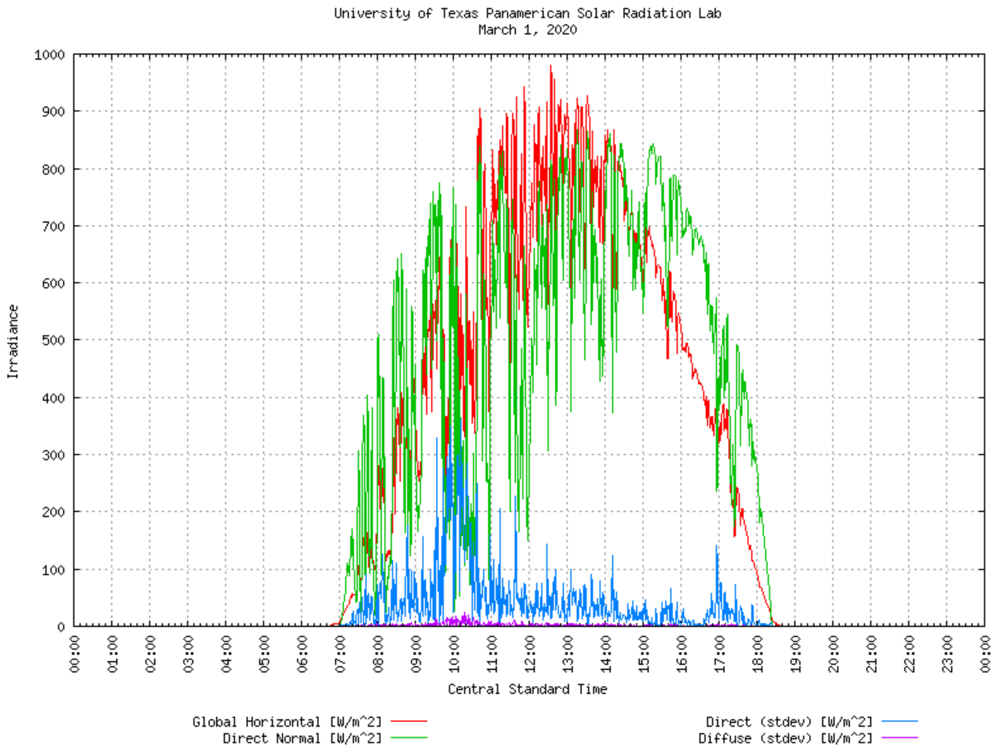


Figure 7. 9: Solar radiation types in Edinburg, Tx

7.6 Photo-Voltaic Principle

The sunlight hits the Photovoltaic cell then it transmits into the absorber layer. Light excites the charge carrier in the semiconductor material due to its energy. This excitation generates free carriers (holes and electrons). The electron moves to the n-type layer and the hole moves to the p-type layer. In the end, the pair once again formed a connection. In short, the principle of charge generated by photovoltaic cells is to excite the charge, then separate, and finally collect. As shown in Figure 7.10 ‘Sarkar and Rahman,2018’.

Most PV Cells share the same composition, and the P-layer is a positive semiconductor material rich in positive charge holes. The N-layer is a negative semiconductor material rich in negatively charged electrons. The depletion layer separated between the P-layer, and the n-layer prevents free charge from moving from one layer to the other. The front contact usually has an anti-reflective coating layer and a grade layer to reduce the loss of the coating and protect it from moisture and black metals. The bottom layer is a conductive layer, with connection caps and bypass diodes in the junction box. The electric symbol of the PV cell looks like the diode electric symbol with two arrows in the top to refer to the sunlight. As shown in Figure 7.10.

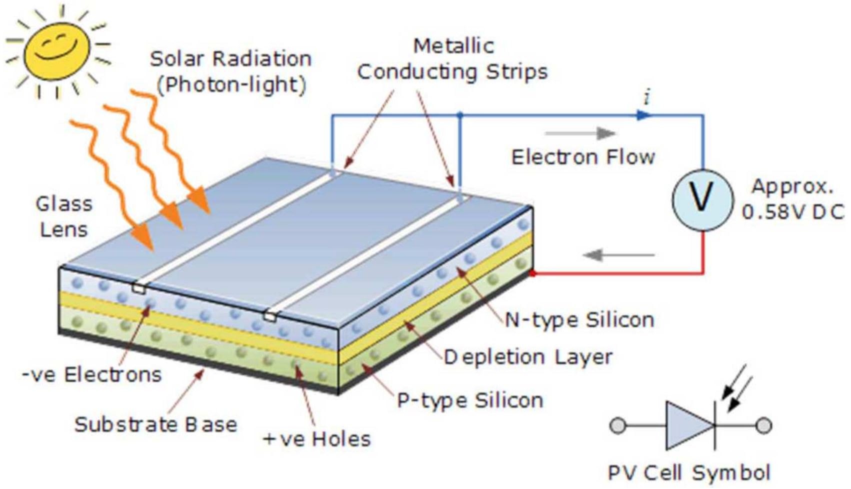


Figure 7. 10: PV cell principle of work and components

7.7 PV Cells Types

Historically, PV cells are divided into three categories. The first generation is based on pure material such crystalline silicon, thus the performance of PV cells from the first generation is stable and high efficiency. On the other hand, it is too expensive due to the difficult process of manufacturing and using the bulk of pure material. The second generation is based on less material compared with the first generation, so it has less pure material. Due to that it is less expensive and cheap as well due to simplicity in the manufacturing process. However, the efficiency is less than the first generation and the performance is less stable. The third generation attempts to solve the Shockley-Quisel limit, which is the maximum theoretical efficiency of a single P-N junction of a solar cell ‘Singh et all,2015’.Hence, it is expected to be cheaper and with high efficiency.

PV cells can be classified based on the semiconductor material. The crystalline silicone material used in the first generation of technology. Thin film material which is used in the second-generation technology. It is believed that the material used in thin film solar cells may be amorphous silicon, which is another method of □-□ semiconductor material, such as cadmium telluride (CdTe), which is the largest market in thin film technology. One of the best technology among the thin film solar cells is the Copper indium gallium selenide (CIGS) which has a good rate of energy conversion efficiency and it is considered as the highest among all thin film solar cell types. Plastic solar cell is also known as the organic cell is a thin film cell. Photovoltaic cells such as dye-sensitized starting from the third-generation solar cells. The dye-sensitized depends on the photoelectrochemical process. Multi junction solar cells based on □-□ elements on the periodic chemical table are the most efficient solar cell and they are in the third generation as well. Figure 7.11‘Durganjali et al ,2020’ illustrates the different types of solar cells between different generations.

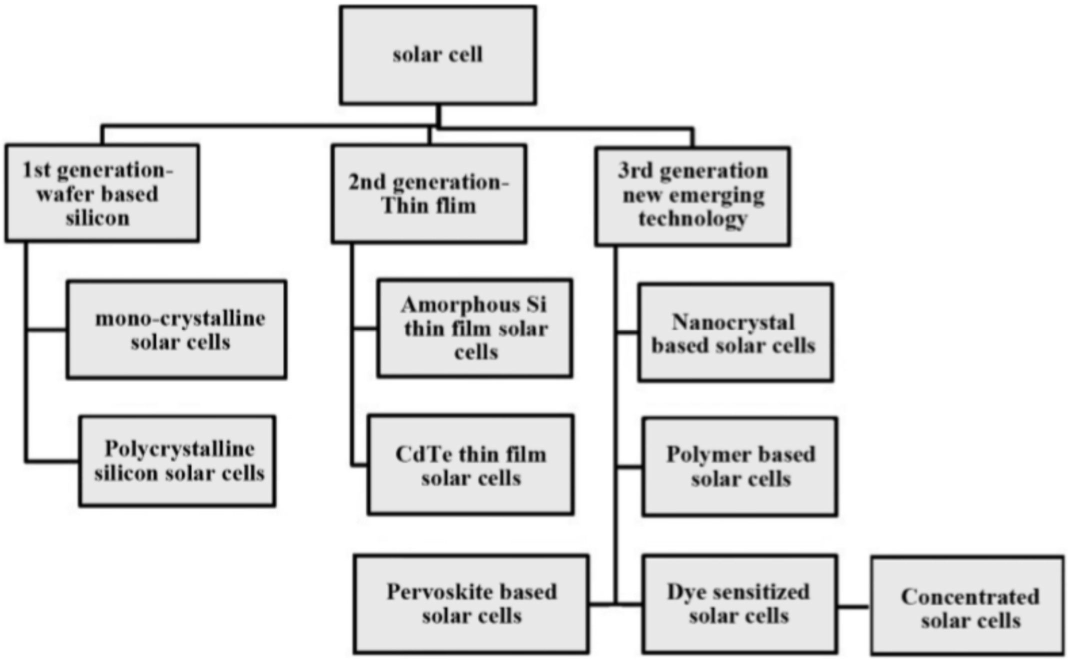


Figure 7. 11: Solar cell generations

7.8 Electrical PV System

Electric photovoltaic systems have many components, such as photovoltaic arrays, inverters, batteries, charge controllers, and DC and AC cables.

7.8.1 PV Array

The array is a combination of photovoltaic modules, and photovoltaic modules have many photovoltaic cells according to the manufacturing situation, and a photovoltaic module can contain up to 72 cells. The photovoltaic array is the core of the photovoltaic electrical system and the source of its direct current power generation. Figure 7.12 'EL-Shimy et al,2018' illustrates the differences between the solar cell, module, and array in the size.

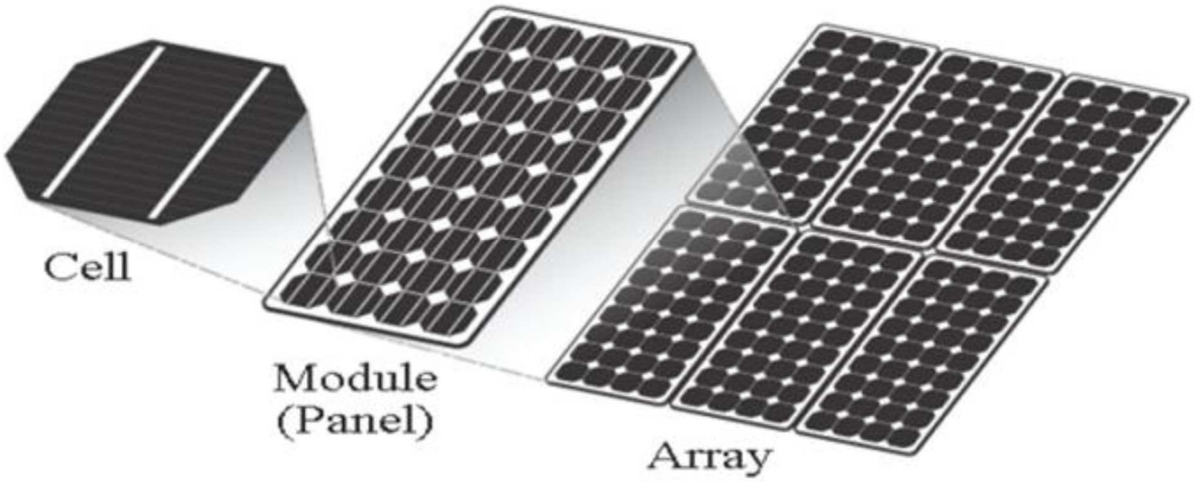


Figure 7. 12: Solar Cell, Module, and array

7.8.2 Solar Power Inverter

The solar power inverter is the part that is responsible for convert the DC current to AC current. The solar power inverters have many types based on the size of the PV electrical systems; Central type solar power inverter, which is used for large projects and usually its size is in several kW or in MW, it is good for the project with less area and cheaper but however, it is less reliable. String solar Inverters, with power ranging from several kilowatts to several tens kilowatts, are more expensive than previous models and require a larger area but it has good performance and general reliability for the whole system. A micro inverter is the best option for small PV systems, and it is expensive and has higher reliability as well And it is connected to only one PV module, so its size ranges from a few watts to hundreds of watts.

7.8.3 Charge Controller

The charge controller is the main component of the photovoltaic system that is not connected to the grid. The main task of the charge controller is to control the charging and discharging of the battery according to the capacity of the battery and the power generated from one side of the PV array. It is usually connected to the four sides of the photovoltaic array, battery pack DC electrical load , and power inverter. as shown in Figure 7.13.

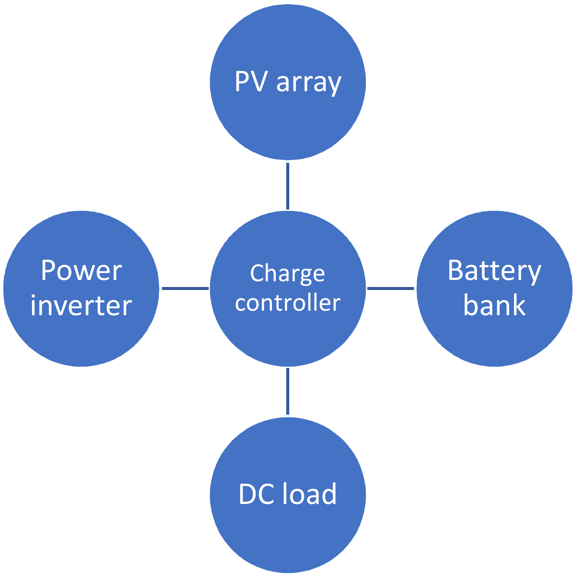


Figure 7. 13: Charge controller connections

7.8.4 Battery Bank

The battery is the storage part of the photovoltaic system. It is used to store the excess energy from the power generation part when the load is minimum, and to use when the peak load is at the maximum and the PV cell does not generate electricity, especially at night there is no production because there is no sun. The battery should be a deep cycle battery to discharge most of its power at peak load. Lead-acid batteries are the most popular type in solar projects.

7.8.5 Cables

Cables in PV electrical systems have two types of cables, the first one is the DC cables which are connected between the PV modules, between the PV modules and the inverter, between the PV modules and the charge controller, and finally between the charge controller and the Battery. In large-scale projects, AC cables are connected between the AC load and the inverter and between the solar inverter and the power transformer.

Photovoltaic electrical systems may have other components, such as circuit breakers, fixed circuit breakers, and fuse protection devices. Protection relays, such as overcurrent, ground fault, overvoltage and undervoltage protection. There may be power conversion in large projects. Correspondingly, it has the structure of a photovoltaic device, which can fix all photovoltaic modules at a desired angle and withstand wind speed and gusts.

7.9. PV Systems Types

According to the connection between the photovoltaic system and the grid, it can be classified as: grid PV system, independent (off-grid PV system). Grid-connected systems are usually very simple, without battery packs and charge controllers. Connect with the grid and rely on it. However, there are some systems called on-grid ties with battery bank, this system has a battery bank and it is connected with grid as well and it is a good option for the electric grid which has the higher electric tariff at the peak time so for that the battery bank used to shift the generation from the maximum to the minimum time. The off-grid system is more complicated than the grid-connected system. It should have a battery and charging control functions, and should be used in remote areas or where there is no grid available. Figure 7.14 illustrates all the previous systems.

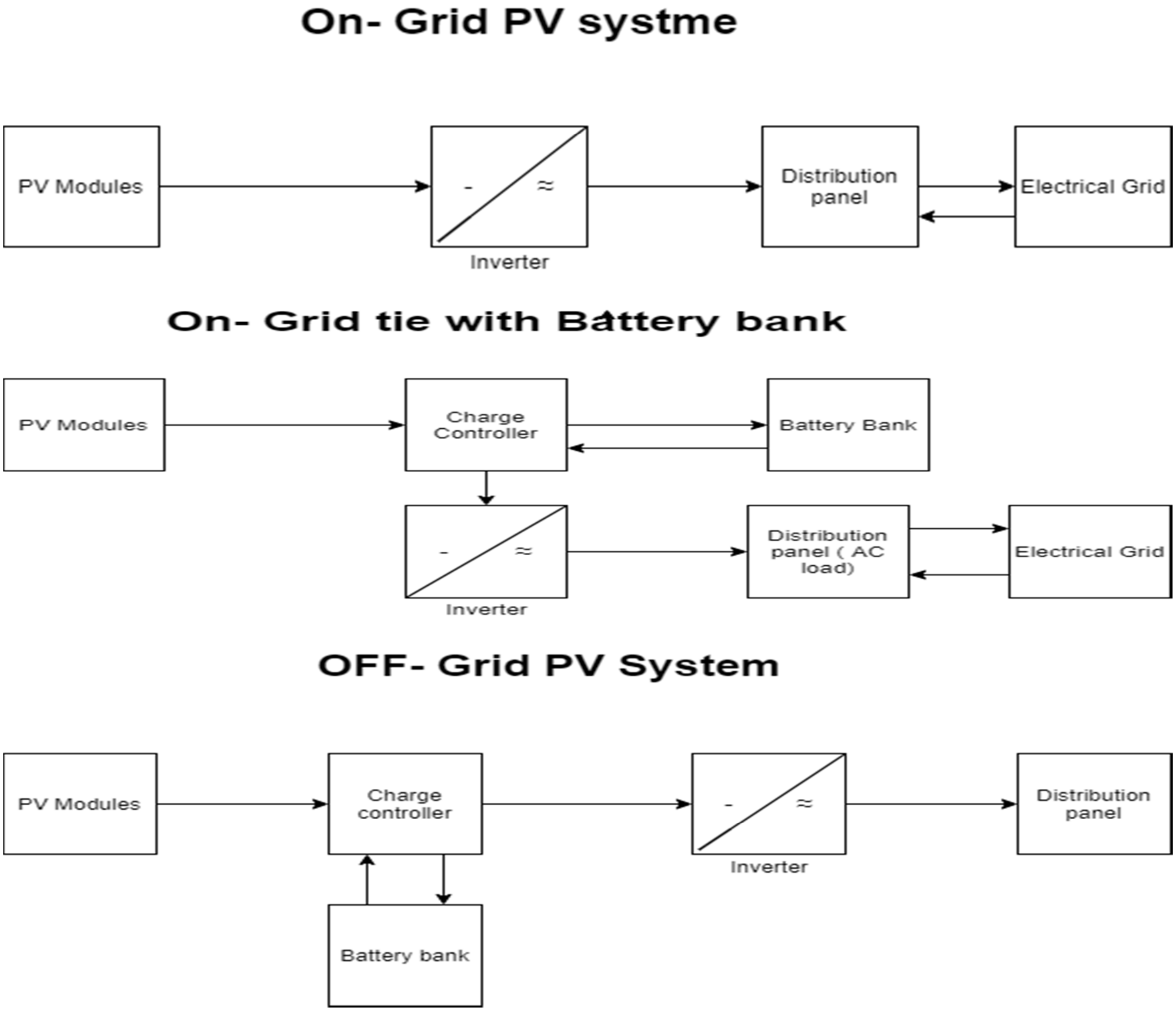


Figure 7. 14: PV systems types

Owing to its installation method, photovoltaic systems can be divided into fixed systems and tracking systems. Generally, because the tracking system makes the PV module always point to the sun and follow its movement, the tracking system has better performance and generates more electricity, but in comparison, the system is expensive in contrast with the fixed PV, and it requires more maintenance due to the motors' machines. The tracking system can be a single-axis or dual-axis tracker.

Contrasted with stationary photovoltaic systems, single-axis tracker systems can achieve 17-22% more energy ‘McWilliams et al, 2016’ ,while the dual-axis tracker system could achieve 30 % more energy compared to the fixed PV system ‘Zaghba et al,2019’.

7.10 Efficiencies

Owing to NERL, the solar cell efficiency reached 47.1% in 2020, which is determined by the multi-junction solar cell type and it is exactly called four junctions not concentrated. Figure 7.15 ‘Best Research-Cell Efficiency Chart,2020’ illustrates the efficiency between different types of solar cells and as shown the multijunction cells and the emerging PV are on the top of the list and they belong to the third generation of PV cells, following by the crystalline silicon and thin-film, which belong to the first and second generation respectively. However, with the exception of the perovskite/silicon tandem, most crystalline silicon and thin film types are more effective than the emerging PV.

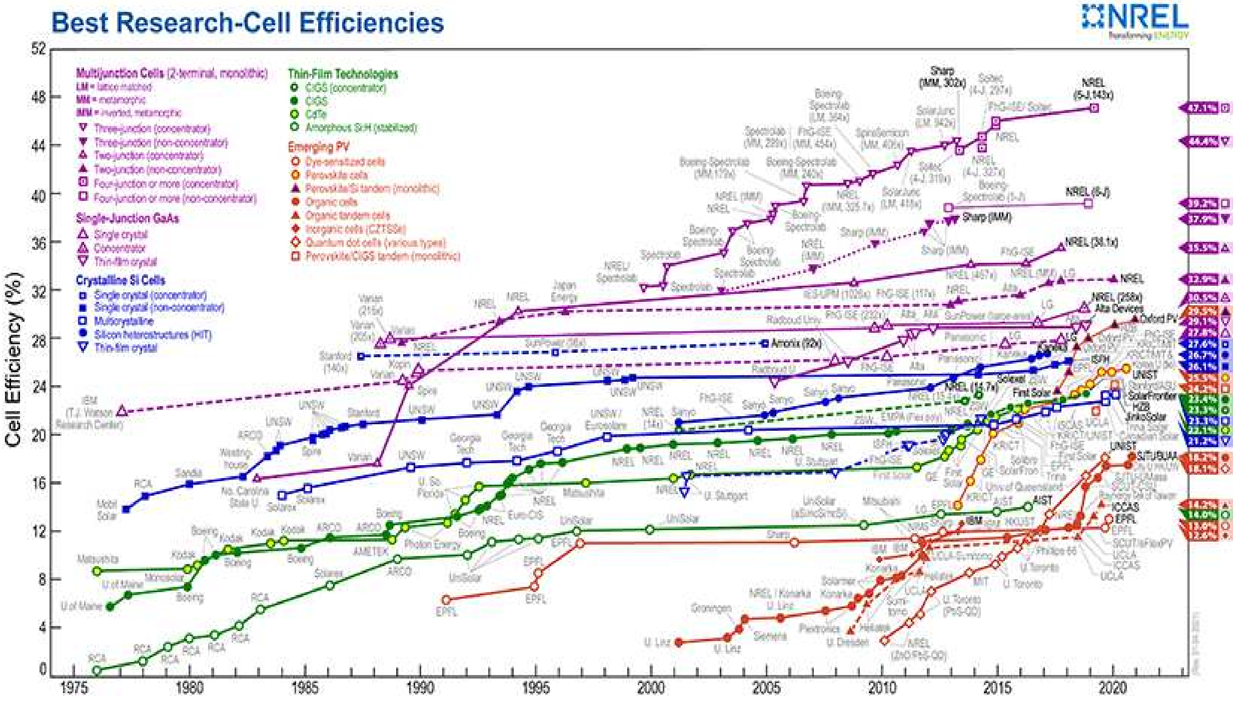


Figure 7. 15: Solar cell efficiency

Although that, the efficiency of the PV modules is less than the solar cell efficiency, due to two main reasons, the spaces between cells that form the module and the losses in the connection between the cells in the same module. By 2020, due to NERL, the energy conversion rate of photovoltaic modules has reached 40.6%, which is an achievement of UNSW. For solar cells, modules that rely on multi-junction technology have the highest efficiency, followed by crystalline silicon, and then thin films, as shown in Figure 7.16 ‘Champion Photovoltaic Module Efficiency Chart,2020’. In spite of that, the highest solar module which is commercially available has an efficiency of up to 22.8 % and it belongs to the Sun Power company it is based on the first generation of products that rely on crystalline silicon.

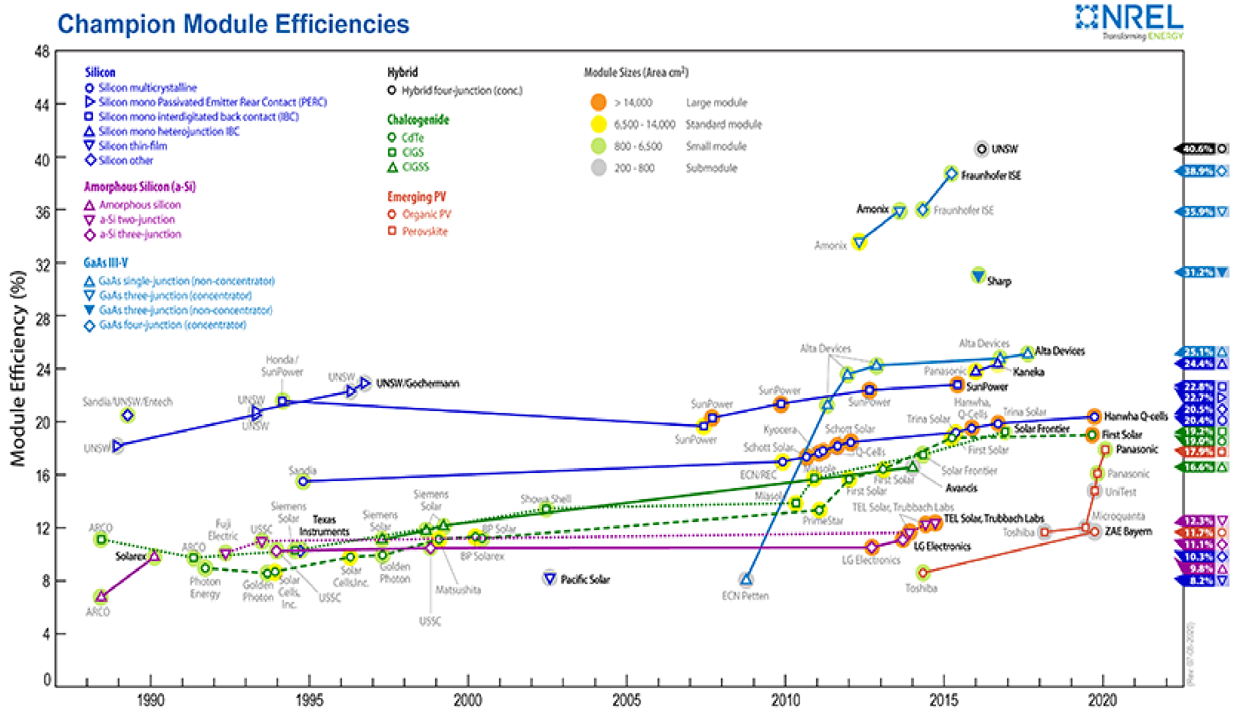


Figure 7. 16: PV modules efficiency

7.11 Power Generation in PV Modules

Power generation from PV modules depends on the area of the module, the energy conversion efficiency based on the technology used, and finally at the solar irradiation as shown in Equation 7.6 ‘Abuelrub and Singh,2017’.

$$P_{PV} = GHI * A * \eta \ldots\ldots.7.6$$

Where:

P_{PV}: power generation in PV modules in Watt

A: Area of the PV module in m^2

GHI: Global horizontal irradiance in W/m^2

η: efficiency of the PV module

Total solar farm power output could be determined using Equations 7.7 &7.8 ‘Abuelrub and Singh,2017’

$P_{SF} = U * S_S \ldots\ldots 7.7$

$U = \frac{GHI}{GHI(STC)} \ldots\ldots 7.8$

Where:

P_{SF}: Power output of solar farm in W.

U: Utilization factor

GHI(STC): Global horizontal irradiance at standard test condition which equals to 1000w/m^2

The total solar radiation value changes as shown in Figure 7.9, so the power output of the PV module will fluctuate accordingly. In order to avoid the difficulty of using the Global horizontal radiation to determine the output power of the photovoltaic power plant, another concept is used, called the Peak Sun Hours, and it is based on ‘Cleveland and Morris,2014’ It is the equivalent number of hours per day when solar radiation is equal to 1000 w/m^2.Figure 7.17 ‘How many peak sun hours do solar panels need?, 2021’ illustrates how to determine the peak solar hour at a specific location by accumulating all solar radiation during the day and then dividing it by 1000 (this is solar radiation under standard test conditions).

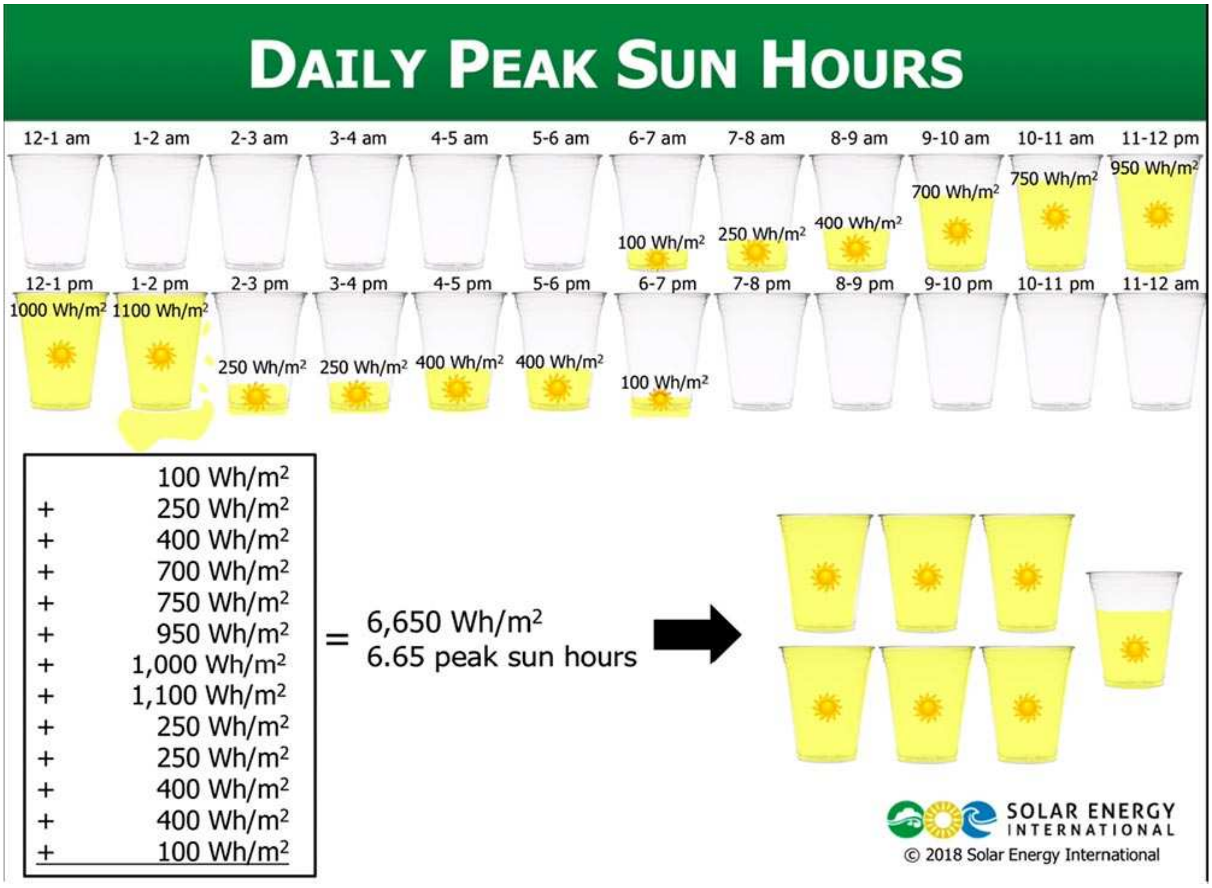


Figure 7. 17: Peak Sun Hours concept

So, based on that Equation 7.6 could be written in the form of the Peak Sun Hours as shown in Equation 7.9, to determine the annual energy from PV module.

$E_A = PSH * A * \eta * 365 \ldots .7.9$

Where:

E_A: Annual energy in WH

PSH: Peak Sun hours

Equation 7.9 can be written according to the rated power of the photovoltaic panel installation capacity, so that the annual energy of the solar farm can be determined more conveniently, as shown below:

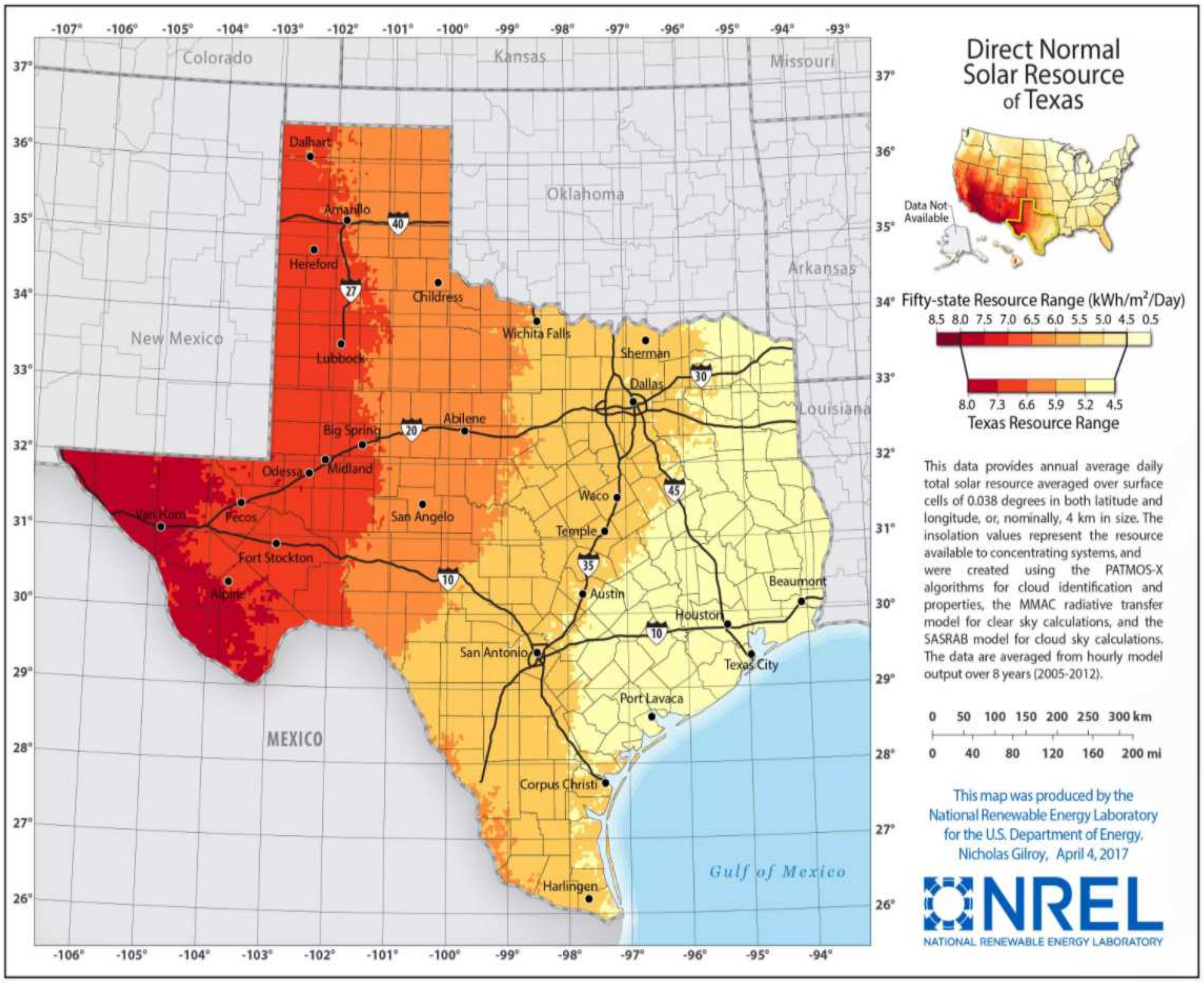
$E_A = PSH * P_r * 365$……7.10

Where:

P_r: Rated power of the Installed capacity of Solar Farm in W.

7.12 Solar Radiation In Texas

The solar radiation resources in The US vary from 0.5 to .5 kWh /day/m2 as average while in Texas varies from 4.5 to 8 kWh/day/m2. This fact makes Texas a good potential resource for photovoltaic systems. Peak sun hours vary from 7.3 to 8 kWh/day/m2 in the highest western region of Texas in cities such as Van Horn. Peak Sun Hours vary from 6.6-7.3 kWh/day/m2 in the eastern northern part of Texas such as Lubbock. The middle eastern part of Texas has an average that varies from 5.9-6.6 kWh/day/m2 of Peak Sun Hours. In the middle eastern part, there are Peak Sun Hours vary from 5.2 –5.9 kWh/day/m2. The eastern part of Texas is the lowest part due to the number of Peak Sun hours which vary from 4.5-5.2 kWh/day/m2.As shown in Figure 7.18 ‘Gilroy,2017’. However, the previous results are for the direct normal irradiance which could be more optimistic in the calculation for the solar energy but due to the ability to use the tracking system in PV plants, so using the Direct normal irradiance instead of Global horizontal radiation will give more accurate results. Hence, in this work, assuming that the value of the peak solar hour is equal to the direct normal irradiance, it will represent the maximum value of the peak solar hour.



This data provides annual average daily total solar resource averaged over surface cells of 0.038 degrees in both latitude and longitude, or, nominally, 4 km in size. The insolation values represent the resource available to concentrating systems, and were created using the PATMOS-X algorithms for cloud identification and properties, the MMAC radiative transfer model for clear sky calculations, and the SASRAB model for cloud sky calculations. The data are averaged from hourly model output over 8 years (2005-2012).

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy. Nicholas Gilroy, April 4, 2017

Figure 7.18: Solar radiation (Peak Sun Hours) in Texas

7.13 Hypothetical PV Model

The maximum electrical energy can be obtained based on PV in the state of Texas depends on the total area available in Texas and the average solar radiation, by using the Sun Power PV, which has an efficiency of up to 22.8 %, In this case, the electrical PV system determines the maximum potential energy that can be achieved based on area, solar radiation, and current technology by installing PV modules all over square meter in Texas. Figure 7.19 shows the flowchart of this scenario.

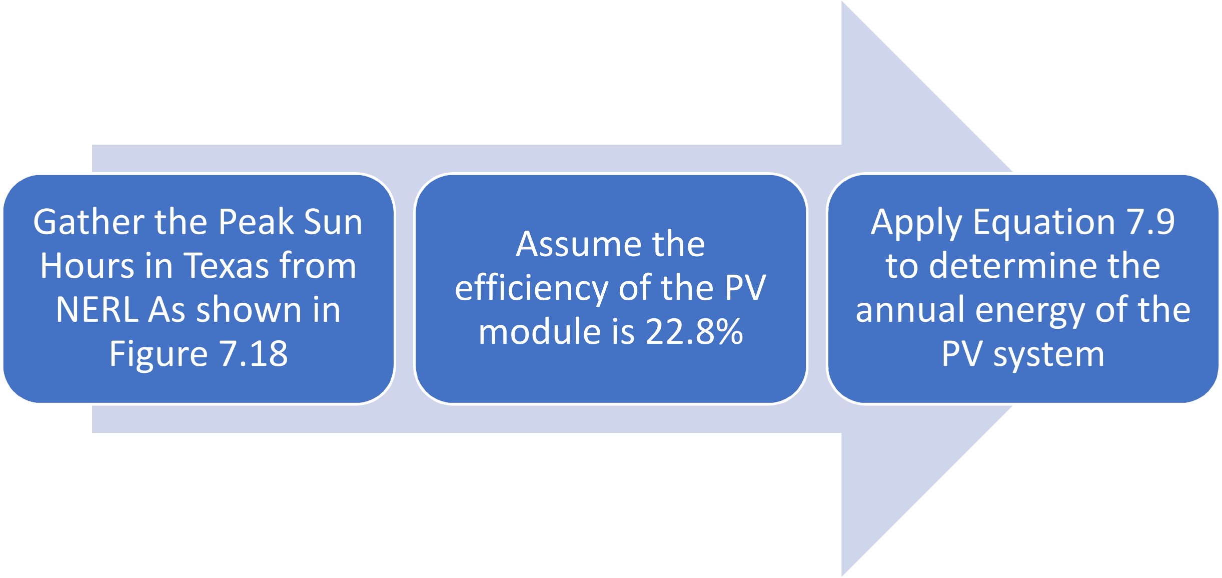


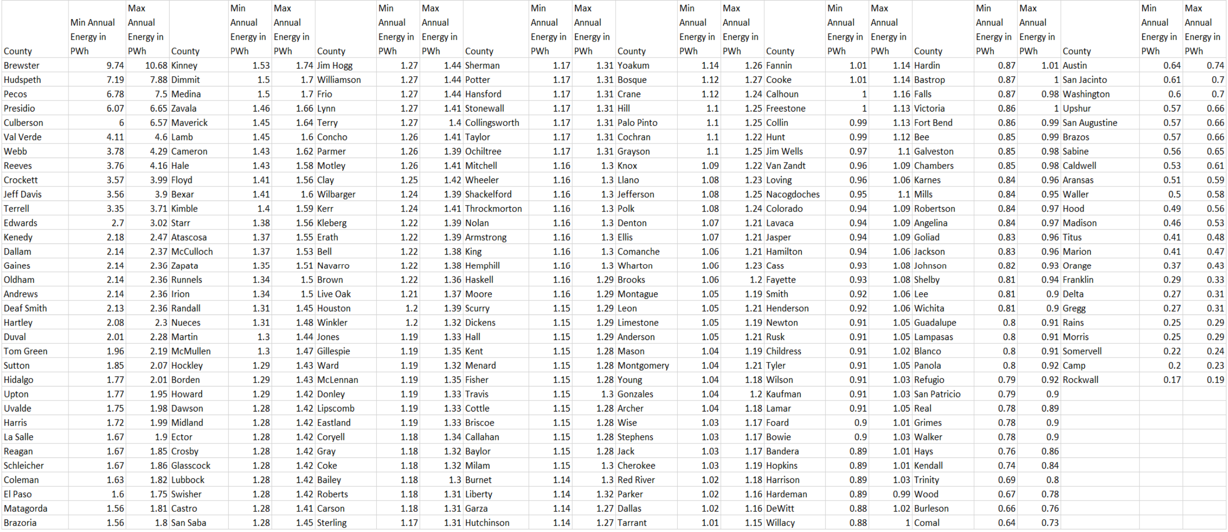
Figure 7. 18: Flowchart of design PV system

In this hypothetical model for solar energy in Texas, Annual energy from PV technology depends on the area, solar irradiance, and the current PV technology. Therefore, the annual energy available in Texas is between 324.74 PWh to 365.26 PWh that comes from the Texas area and the current technology from PV in 2020. The energy available from PV technology by counties varies from 10.68 PWh in Brewster to 0.19 PWh in Rockwall. As shown in Figure 7.20, 5 counties have sufficient resources to generate more than 5 PWh. 197 counties have sufficient resources based on photovoltaic technology to produce more than 1 PWh per year. According to this situation, 52 counties have less than 1 PWh of power generation. As shown in Figure 7.20.By applying Flow chart as shown in Figure 7.19, the maximum annual generation energy in Brewster as the following:

Max Annual Energy = Area of Brewster county *η* Max Peak Sun Hours *365

Max Annual Energy = 16038.057*10^6*22.8%*8KWh*365

Max Annual Energy = 10.6774 PWh ≈ 10.68 PWh



County	Min Annual Energy in PWh	Max Annual Energy in PWh	County	Min Annual Energy in PWh	Max Annual Energy in PWh	County	Min Annual Energy in PWh	Max Annual Energy in PWh	County	Min Annual Energy in PWh	Max Annual Energy in PWh	County	Min Annual Energy in PWh	Max Annual Energy in PWh	County	Min Annual Energy in PWh	Max Annual Energy in PWh	County	Min Annual Energy in PWh	Max Annual Energy in PWh	County	Min Annual Energy in PWh	Max Annual Energy in PWh
Brewster	9.74	10.68	Kinney	1.53	1.74	Jim Hogg	1.27	1.44	Sherman	1.17	1.31	Yoakum	1.14	1.26	Fannin	1.01	1.14	Hardin	0.87	1.01	Austin	0.64	0.74
Hudspeth	7.19	7.88	Dimmit	1.5	1.7	Williamson	1.27	1.44	Potter	1.17	1.31	Bosque	1.12	1.27	Cooke	1.01	1.14	Bastrop	0.87	1	San Jacinto	0.61	0.7
Pecos	6.78	7.5	Medina	1.5	1.7	Frio	1.27	1.44	Hansford	1.17	1.31	Crane	1.12	1.24	Calhoun	1	1.16	Falls	0.87	0.98	Washington	0.6	0.7
Presidio	6.07	6.65	Zavala	1.46	1.66	Lynn	1.27	1.41	Stonewall	1.17	1.31	Hill	1.1	1.25	Freestone	1	1.13	Victoria	0.86	1	Upshur	0.57	0.66
Culberson	6	6.57	Maverick	1.45	1.64	Terry	1.27	1.4	Collingsworth	1.17	1.31	Palo Pinto	1.1	1.25	Collin	0.99	1.13	Fort Bend	0.86	0.99	San Augustine	0.57	0.66
Val Verde	4.11	4.6	Lamb	1.45	1.6	Concho	1.26	1.41	Taylor	1.17	1.31	Cochran	1.1	1.22	Hunt	0.99	1.12	Bee	0.85	0.99	Brazos	0.57	0.66
Webb	3.78	4.29	Cameron	1.43	1.62	Parmer	1.26	1.39	Ochiltree	1.17	1.31	Grayson	1.1	1.25	Jim Wells	0.97	1.1	Galveston	0.85	0.98	Sabine	0.56	0.65
Reeves	3.76	4.16	Hale	1.43	1.58	Motley	1.26	1.41	Mitchell	1.16	1.3	Knox	1.09	1.22	Van Zandt	0.96	1.09	Chambers	0.85	0.98	Caldwell	0.53	0.61
Crockett	3.57	3.99	Floyd	1.41	1.56	Clay	1.25	1.42	Wheeler	1.16	1.3	Llano	1.08	1.23	Loving	0.96	1.06	Karnes	0.84	0.96	Aransas	0.51	0.59
Jeff Davis	3.56	3.9	Bexar	1.41	1.6	Wilbarger	1.24	1.39	Shackelford	1.16	1.3	Jefferson	1.08	1.25	Nacogdoches	0.95	1.1	Mills	0.84	0.95	Waller	0.5	0.58
Terrell	3.35	3.71	Kimble	1.4	1.59	Kerr	1.24	1.41	Throckmorton	1.16	1.3	Polk	1.08	1.24	Colorado	0.94	1.09	Robertson	0.84	0.97	Hood	0.49	0.56
Edwards	2.7	3.02	Starr	1.38	1.56	Kleberg	1.22	1.39	Nolan	1.16	1.3	Denton	1.07	1.21	Lavaca	0.94	1.09	Angelina	0.84	0.97	Madison	0.46	0.53
Kenedy	2.18	2.47	Atascosa	1.37	1.55	Erath	1.22	1.39	Armstrong	1.16	1.3	Ellis	1.07	1.21	Jasper	0.94	1.09	Goliad	0.83	0.96	Titus	0.41	0.48
Dallam	2.14	2.37	McCulloch	1.37	1.53	Bell	1.22	1.38	King	1.16	1.3	Comanche	1.06	1.21	Hamilton	0.94	1.06	Jackson	0.83	0.96	Marion	0.41	0.47
Gaines	2.14	2.36	Zapata	1.35	1.51	Navarro	1.22	1.38	Hemphill	1.16	1.3	Wharton	1.06	1.23	Cass	0.93	1.08	Johnson	0.82	0.93	Orange	0.37	0.43
Oldham	2.14	2.36	Runnels	1.34	1.5	Brown	1.22	1.36	Haskell	1.16	1.29	Brooks	1.06	1.2	Fayette	0.93	1.08	Shelby	0.81	0.94	Franklin	0.29	0.33
Andrews	2.14	2.36	Irion	1.34	1.5	Live Oak	1.21	1.37	Moore	1.16	1.29	Montague	1.05	1.19	Smith	0.92	1.06	Lee	0.81	0.9	Delta	0.27	0.31
Deaf Smith	2.13	2.36	Randall	1.31	1.45	Houston	1.2	1.39	Scurry	1.15	1.29	Leon	1.05	1.21	Henderson	0.92	1.06	Wichita	0.81	0.9	Gregg	0.27	0.31
Hartley	2.08	2.3	Nueces	1.31	1.48	Winkler	1.2	1.32	Dickens	1.15	1.29	Limestone	1.05	1.19	Newton	0.91	1.05	Guadalupe	0.8	0.91	Rains	0.25	0.29
Duval	2.01	2.28	Martin	1.3	1.44	Jones	1.19	1.33	Hall	1.15	1.29	Anderson	1.05	1.21	Rusk	0.91	1.05	Lampasas	0.8	0.91	Morris	0.25	0.29
Tom Green	1.96	2.19	McMullen	1.3	1.47	Gillespie	1.19	1.35	Kent	1.15	1.28	Mason	1.04	1.19	Childress	0.91	1.02	Blanco	0.8	0.91	Somervell	0.22	0.24
Sutton	1.85	2.07	Hockley	1.29	1.43	Ward	1.19	1.32	Menard	1.15	1.28	Montgomery	1.04	1.21	Tyler	0.91	1.05	Panola	0.8	0.92	Camp	0.2	0.23
Hidalgo	1.77	2.01	Borden	1.29	1.43	McLennan	1.19	1.35	Fisher	1.15	1.28	Young	1.04	1.18	Wilson	0.91	1.03	Refugio	0.79	0.92	Rockwall	0.17	0.19
Upton	1.77	1.95	Howard	1.29	1.42	Donley	1.19	1.33	Travis	1.15	1.3	Gonzales	1.04	1.2	Kaufman	0.91	1.03	San Patricio	0.79	0.9			
Uvalde	1.75	1.98	Dawson	1.28	1.42	Lipscomb	1.19	1.33	Cottle	1.15	1.28	Archer	1.04	1.18	Lamar	0.91	1.05	Real	0.78	0.89			
Harris	1.72	1.99	Midland	1.28	1.42	Eastland	1.19	1.33	Briscoe	1.15	1.28	Wise	1.03	1.17	Foard	0.9	1.01	Grimes	0.78	0.9			
La Salle	1.67	1.9	Ector	1.28	1.42	Coryell	1.18	1.34	Callahan	1.15	1.28	Stephens	1.03	1.17	Bowie	0.9	1.03	Walker	0.78	0.9			
Reagan	1.67	1.85	Crosby	1.28	1.42	Gray	1.18	1.32	Baylor	1.15	1.28	Jack	1.03	1.17	Bandera	0.89	1.01	Hays	0.76	0.86			
Schleicher	1.67	1.86	Glasscock	1.28	1.42	Coke	1.18	1.32	Milam	1.15	1.3	Cherokee	1.03	1.19	Hopkins	0.89	1.01	Kendall	0.74	0.84			
Coleman	1.63	1.82	Lubbock	1.28	1.42	Bailey	1.18	1.3	Burnet	1.14	1.3	Red River	1.02	1.18	Harrison	0.89	1.03	Trinity	0.69	0.8			
El Paso	1.6	1.75	Swisher	1.28	1.42	Roberts	1.18	1.31	Liberty	1.14	1.32	Parker	1.02	1.16	Hardeman	0.89	0.99	Wood	0.67	0.78			
Matagorda	1.56	1.81	Castro	1.28	1.41	Carson	1.18	1.31	Garza	1.14	1.27	Dallas	1.02	1.16	DeWitt	0.88	1.02	Burleson	0.66	0.76			
Brazoria	1.56	1.8	San Saba	1.28	1.45	Sterling	1.17	1.31	Hutchinson	1.14	1.27	Tarrant	1.01	1.15	Willacy	0.88	1	Comal	0.64	0.73			

Figure 7. 19: Hypothetical model of PV in Texas

However, the previous results is not practical because it depends on all land in the state of Texas, which is not applicable to apply. Based on 'Brain Post,2021' around 47 % of the land in the US is unhabituated by people. Therefore, in order to obtain more realistic results, a factor of 0.47 is included in the results. Based on this, Texas can provide up to 152.62 to 171.67 PWh which is still enough to power the entire United States.

7.14 Electrical Proposal System

In this system , the PV technology-based proposal system has five main approaches. This system imitates the current installed capacity of PV modules in Texas and distributes them in a variety of ways to achieve better results. In this scenario , it is used to show changes in power generation due to the different allocation of photovoltaic panels in Texas. The rated capacity of this Scenario is 6.7 GW, which is the 90 % of the rated capacity of PV installed in Texas up to 2020‘Texas Solar ,2020’. The Peak Sun Hours in Texas varies from 4.5-8, based on that it could classify Texas counties into five categories as shown in Table 7.1.

Class	Peak Sun Hours (Max Direct Normal irradiance)	Number of Counties
1	7.3-8	6
2	6.6-7.3	37
3	5.9-6.6	59
4	5.2-5.9	83
5	4.5-5.2	69

Table 7. 1: Peak Sun Hours based on counties classification

In this scenario, there are 5 approaches based on the classification in Table 7.1. Approach 1 depends on all counties in Texas. Approach 2 depends only on counties in the first four classes. Approach3 depends only on counties in the first three classes. Approach 4 depends only on the first two classes. Approach 5 is only for counties in class 1.In this scenario, to determine the annual energy, Equation 7.10 is used as the following:

Annual Energy=(Rated PV panels)* Peak Sun Hours *365

Maximum Annual Energy= (Rated PV panels)* Maximum Peak Sun Hours *365

Minimum Annual Energy= (Rated PV panels)* Minimum Peak Sun Hours *365

7.14.1 Approach 1

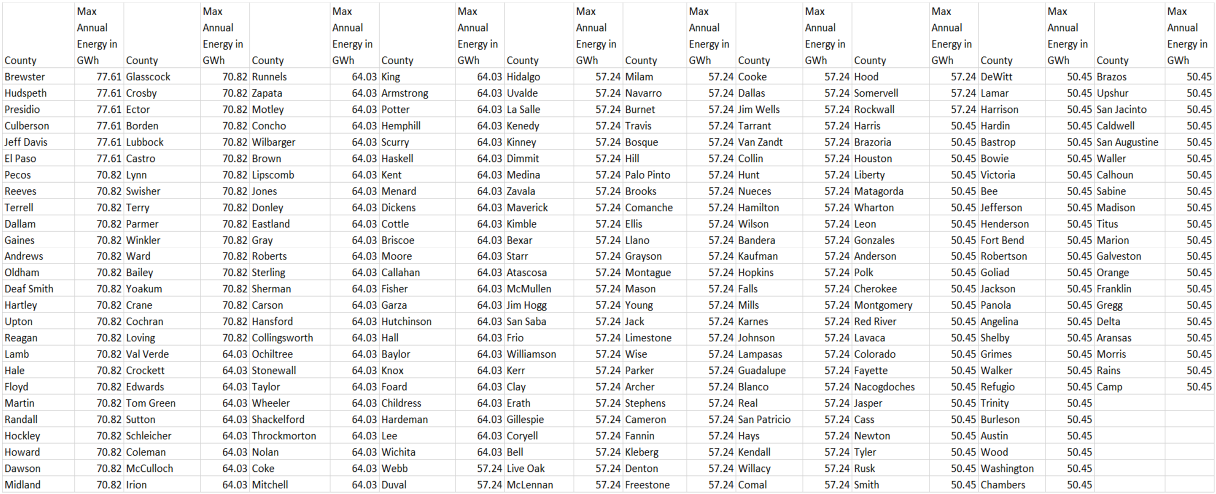
In this approach, 6.7 GW of PV panels is distributed equally among all counties, hence, 26.58 MW of PV panels are proposed to install in 254 counties in Texas. This approach generates between 13.37 to 15.1 TWh yearly. Counties that rely on class 1 will produce up to 77.61 GWh annually. Counties Class 2 counties produce 70.82 GWh. Counties in class 3 have enough resources to power up to 64.03 GWh. Level 4 counties may generate up to 57.24 GWh. In the end, category 5 only has enough resources to power up 50.45 GWh. As shown in Figure

7.21.By applying Equation 7.10, the maximum annual generation energy in Brewster as the following:

Max Annual Energy = Installed rated PV * Max Peak Sun Hours *365

Max Annual Energy = 26.58 MW *8 *365

Max Annual Energy = 77.6136 GWh ≈ 77.61 GWh



County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh
Brewster	77.61	Glasscock	70.82	Runnels	64.03	King	64.03	Hidalgo	57.24	Milam	57.24	Cooke	57.24	Hood	57.24	DeWitt	50.45	Brazos	50.45
Hudspeth	77.61	Crosby	70.82	Zapata	64.03	Armstrong	64.03	Uvalde	57.24	Navarro	57.24	Dallas	57.24	Somervell	57.24	Lamar	50.45	Upshur	50.45
Presidio	77.61	Ector	70.82	Motley	64.03	Potter	64.03	La Salle	57.24	Burnet	57.24	Jim Wells	57.24	Rockwall	57.24	Harrison	50.45	San Jacinto	50.45
Culberson	77.61	Borden	70.82	Concho	64.03	Hemphill	64.03	Kenedy	57.24	Travis	57.24	Tarrant	57.24	Harris	50.45	Hardin	50.45	Caldwell	50.45
Jeff Davis	77.61	Lubbock	70.82	Wilbarger	64.03	Scurry	64.03	Kinney	57.24	Bosque	57.24	Van Zandt	57.24	Brazoria	50.45	Bastrop	50.45	San Augustine	50.45
El Paso	77.61	Castro	70.82	Brown	64.03	Haskell	64.03	Dimmit	57.24	Hill	57.24	Collin	57.24	Houston	50.45	Bowie	50.45	Waller	50.45
Pecos	70.82	Lynn	70.82	Lipscomb	64.03	Kent	64.03	Medina	57.24	Palo Pinto	57.24	Hunt	57.24	Liberty	50.45	Victoria	50.45	Calhoun	50.45
Reeves	70.82	Swisher	70.82	Jones	64.03	Menard	64.03	Zavala	57.24	Brooks	57.24	Nueces	57.24	Matagorda	50.45	Bee	50.45	Sabine	50.45
Terrell	70.82	Terry	70.82	Donley	64.03	Dickens	64.03	Maverick	57.24	Comanche	57.24	Hamilton	57.24	Wharton	50.45	Jefferson	50.45	Madison	50.45
Dallam	70.82	Parmer	70.82	Eastland	64.03	Cottle	64.03	Kimble	57.24	Ellis	57.24	Wilson	57.24	Leon	50.45	Henderson	50.45	Titus	50.45
Gaines	70.82	Winkler	70.82	Gray	64.03	Briscoe	64.03	Bexar	57.24	Llano	57.24	Bandera	57.24	Gonzales	50.45	Fort Bend	50.45	Marion	50.45
Andrews	70.82	Ward	70.82	Roberts	64.03	Moore	64.03	Starr	57.24	Grayson	57.24	Kaufman	57.24	Anderson	50.45	Robertson	50.45	Galveston	50.45
Oldham	70.82	Bailey	70.82	Sterling	64.03	Callahan	64.03	Atascosa	57.24	Montague	57.24	Hopkins	57.24	Polk	50.45	Goliad	50.45	Orange	50.45
Deaf Smith	70.82	Yoakum	70.82	Sherman	64.03	Fisher	64.03	McMullen	57.24	Mason	57.24	Falls	57.24	Cherokee	50.45	Jackson	50.45	Franklin	50.45
Hartley	70.82	Crane	70.82	Carson	64.03	Garza	64.03	Jim Hogg	57.24	Young	57.24	Mills	57.24	Montgomery	50.45	Panola	50.45	Gregg	50.45
Upton	70.82	Cochran	70.82	Hansford	64.03	Hutchinson	64.03	San Saba	57.24	Jack	57.24	Karnes	57.24	Red River	50.45	Angelina	50.45	Delta	50.45
Reagan	70.82	Loving	70.82	Collingsworth	64.03	Hall	64.03	Frio	57.24	Limestone	57.24	Johnson	57.24	Lavaca	50.45	Shelby	50.45	Aransas	50.45
Lamb	70.82	Val Verde	64.03	Ochiltree	64.03	Baylor	64.03	Williamson	57.24	Wise	57.24	Lampasas	57.24	Colorado	50.45	Grimes	50.45	Morris	50.45
Hale	70.82	Crockett	64.03	Stonewall	64.03	Knox	64.03	Kerr	57.24	Parker	57.24	Guadalupe	57.24	Fayette	50.45	Walker	50.45	Rains	50.45
Floyd	70.82	Edwards	64.03	Taylor	64.03	Foard	64.03	Clay	57.24	Archer	57.24	Blanco	57.24	Nacogdoches	50.45	Refugio	50.45	Camp	50.45
Martin	70.82	Tom Green	64.03	Wheeler	64.03	Childress	64.03	Erath	57.24	Stephens	57.24	Real	57.24	Jasper	50.45	Trinity	50.45		
Randall	70.82	Sutton	64.03	Shackelford	64.03	Hardeman	64.03	Gillespie	57.24	Cameron	57.24	San Patricio	57.24	Cass	50.45	Burleson	50.45		
Hockley	70.82	Schleicher	64.03	Throckmorton	64.03	Lee	64.03	Coryell	57.24	Fannin	57.24	Hays	57.24	Newton	50.45	Austin	50.45		
Howard	70.82	Coleman	64.03	Nolan	64.03	Wichita	64.03	Bell	57.24	Kleberg	57.24	Kendall	57.24	Tyler	50.45	Wood	50.45		
Dawson	70.82	McCulloch	64.03	Coke	64.03	Webb	57.24	Live Oak	57.24	Denton	57.24	Willacy	57.24	Rusk	50.45	Washington	50.45		
Midland	70.82	Irion	64.03	Mitchell	64.03	Duval	57.24	McLennan	57.24	Freestone	57.24	Comal	57.24	Smith	50.45	Chambers	50.45		

Figure 7. 20: Approach 1 results in 254 counties

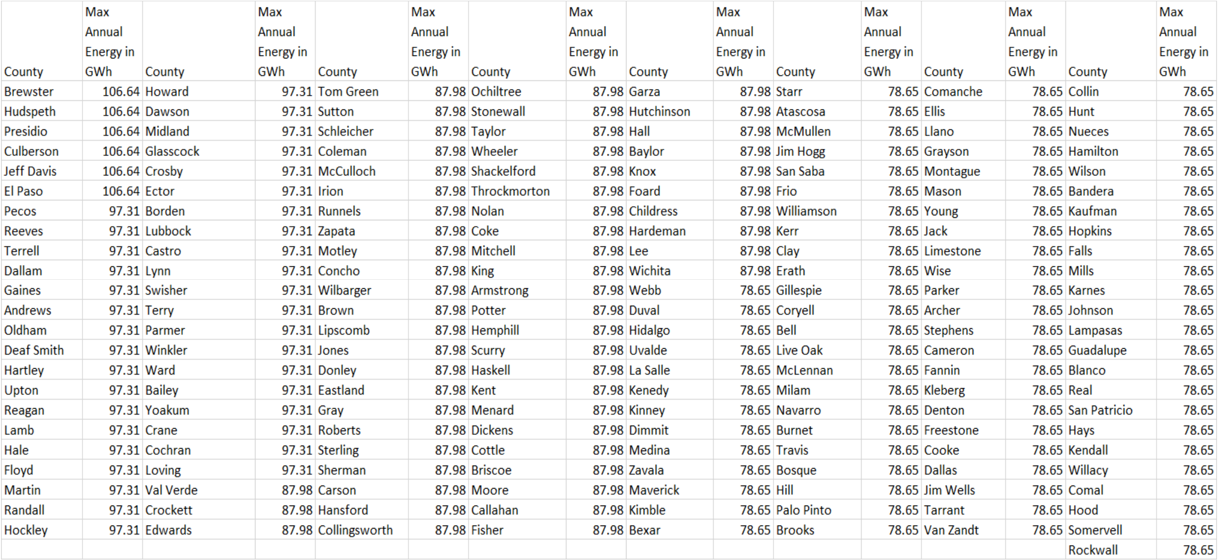
7.14.2 Approach 2

In this approach, 6.7 GW of PV panels is distributed equally among all counties from classes 1 to 4 excepting class 5, hence, 36.52 MW of PV panels are proposed to install in 185 counties in Texas. This approach generates between 14.23 to 15.95 TWh yearly. Counties that rely on Category 1 will generate 106.63 GWh per year. The power generation of the second category counties is 97.30 GWh. Counties in class 3 have enough resources to power up to 87.97 GWh. Level 4 counties may generate up to 78.65 GWh. As shown in Figure 7.22. By applying Equation 7.10, the maximum annual generation energy in Brewster as the following:

Max Annual Energy = Installed rated PV * Max Peak Sun Hours *365

Max Annual Energy = 36.52 MW *8 *365

Max Annual Energy = 106.6384 GWh ≈ 106.64 GW



County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh
Brewster	106.64	Howard	97.31	Tom Green	87.98	Ochiltree	87.98	Garza	87.98	Starr	78.65	Comanche	78.65	Collin	78.65
Hudspeth	106.64	Dawson	97.31	Sutton	87.98	Stonewall	87.98	Hutchinson	87.98	Atascosa	78.65	Ellis	78.65	Hunt	78.65
Presidio	106.64	Midland	97.31	Schleicher	87.98	Taylor	87.98	Hall	87.98	McMullen	78.65	Llano	78.65	Nueces	78.65
Culberson	106.64	Glasscock	97.31	Coleman	87.98	Wheeler	87.98	Baylor	87.98	Jim Hogg	78.65	Grayson	78.65	Hamilton	78.65
Jeff Davis	106.64	Crosby	97.31	McCulloch	87.98	Shackelford	87.98	Knox	87.98	San Saba	78.65	Montague	78.65	Wilson	78.65
El Paso	106.64	Ector	97.31	Irion	87.98	Throckmorton	87.98	Foard	87.98	Frio	78.65	Mason	78.65	Bandera	78.65
Pecos	97.31	Borden	97.31	Runnels	87.98	Nolan	87.98	Childress	87.98	Williamson	78.65	Young	78.65	Kaufman	78.65
Reeves	97.31	Lubbock	97.31	Zapata	87.98	Coke	87.98	Hardeman	87.98	Kerr	78.65	Jack	78.65	Hopkins	78.65
Terrell	97.31	Castro	97.31	Motley	87.98	Mitchell	87.98	Lee	87.98	Clay	78.65	Limestone	78.65	Falls	78.65
Dallam	97.31	Lynn	97.31	Concho	87.98	King	87.98	Wichita	87.98	Erath	78.65	Wise	78.65	Mills	78.65
Gaines	97.31	Swisher	97.31	Wilbarger	87.98	Armstrong	87.98	Webb	78.65	Gillespie	78.65	Parker	78.65	Karnes	78.65
Andrews	97.31	Terry	97.31	Brown	87.98	Potter	87.98	Duval	78.65	Coryell	78.65	Archer	78.65	Johnson	78.65
Oldham	97.31	Parmer	97.31	Lipscomb	87.98	Hemphill	87.98	Hidalgo	78.65	Bell	78.65	Stephens	78.65	Lampasas	78.65
Deaf Smith	97.31	Winkler	97.31	Jones	87.98	Scurry	87.98	Uvalde	78.65	Live Oak	78.65	Cameron	78.65	Guadalupe	78.65
Hartley	97.31	Ward	97.31	Donley	87.98	Haskell	87.98	La Salle	78.65	McLennan	78.65	Fannin	78.65	Blanco	78.65
Upton	97.31	Bailey	97.31	Eastland	87.98	Kent	87.98	Kenedy	78.65	Milam	78.65	Kleberg	78.65	Real	78.65
Reagan	97.31	Yoakum	97.31	Gray	87.98	Menard	87.98	Kinney	78.65	Navarro	78.65	Denton	78.65	San Patricio	78.65
Lamb	97.31	Crane	97.31	Roberts	87.98	Dickens	87.98	Dimmit	78.65	Burnet	78.65	Freestone	78.65	Hays	78.65
Hale	97.31	Cochran	97.31	Sterling	87.98	Cottle	87.98	Medina	78.65	Travis	78.65	Cooke	78.65	Kendall	78.65
Floyd	97.31	Loving	97.31	Sherman	87.98	Briscoe	87.98	Zavala	78.65	Bosque	78.65	Dallas	78.65	Willacy	78.65
Martin	97.31	Val Verde	87.98	Carson	87.98	Moore	87.98	Maverick	78.65	Hill	78.65	Jim Wells	78.65	Comal	78.65
Randall	97.31	Crockett	87.98	Hansford	87.98	Callahan	87.98	Kimble	78.65	Palo Pinto	78.65	Tarrant	78.65	Hood	78.65
Hockley	97.31	Edwards	87.98	Collingsworth	87.98	Fisher	87.98	Bexar	78.65	Brooks	78.65	Van Zandt	78.65	Somervell	78.65
														Rockwall	78.65

Figure 7. 21: Approach 2 results in 185 counties

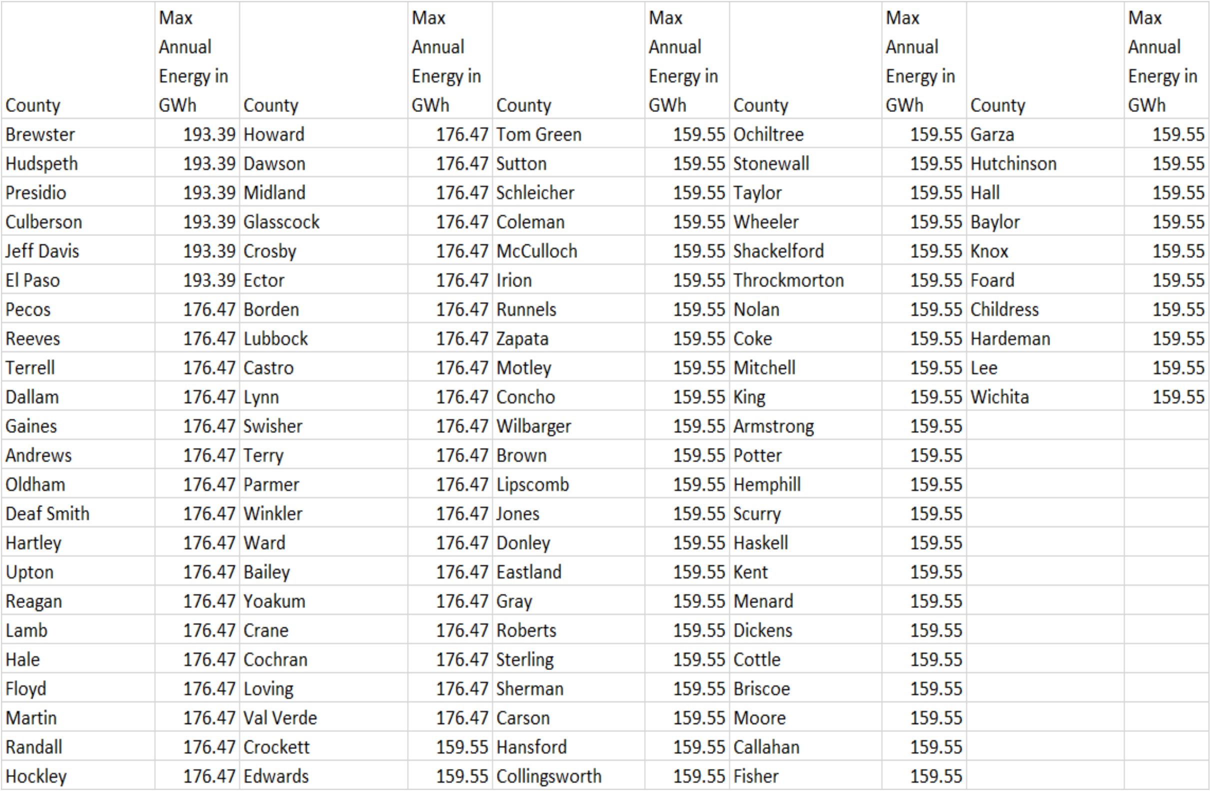
7.14.3 Approach 3

In this approach, 6.7 GW of PV panels is distributed equally among all counties from classes 1 to 3 exception classes 4 &5, hence, 66.23 MW of PV panels are proposed to install in 102 counties in Texas. This method produces 15.37 to 17.1 TWh per year. Counties that rely on Category 1 will generate 193.39 GWh per year. The electricity generation in the second category counties is 176.47 GWh. Counties in class 3 have enough resources to power up to 159.55 GWh. As shown in Figure 7.23 .By applying Equation 7.10, the maximum annual generation energy in Brewster as the following:

Max Annual Energy = Installed rated PV * Max Peak Sun Hours *365

Max Annual Energy = 66.23 MW *8 *365

Max Annual Energy = 193.3916 GWh ≈ 193.39 GWh



County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh
Brewster	193.39	Howard	176.47	Tom Green	159.55	Ochiltree	159.55	Garza	159.55
Hudspeth	193.39	Dawson	176.47	Sutton	159.55	Stonewall	159.55	Hutchinson	159.55
Presidio	193.39	Midland	176.47	Schleicher	159.55	Taylor	159.55	Hall	159.55
Culberson	193.39	Glasscock	176.47	Coleman	159.55	Wheeler	159.55	Baylor	159.55
Jeff Davis	193.39	Crosby	176.47	McCulloch	159.55	Shackelford	159.55	Knox	159.55
El Paso	193.39	Ector	176.47	Irion	159.55	Throckmorton	159.55	Foard	159.55
Pecos	176.47	Borden	176.47	Runnels	159.55	Nolan	159.55	Childress	159.55
Reeves	176.47	Lubbock	176.47	Zapata	159.55	Coke	159.55	Hardeman	159.55
Terrell	176.47	Castro	176.47	Motley	159.55	Mitchell	159.55	Lee	159.55
Dallam	176.47	Lynn	176.47	Concho	159.55	King	159.55	Wichita	159.55
Gaines	176.47	Swisher	176.47	Wilbarger	159.55	Armstrong	159.55		
Andrews	176.47	Terry	176.47	Brown	159.55	Potter	159.55		
Oldham	176.47	Parmer	176.47	Lipscomb	159.55	Hemphill	159.55		
Deaf Smith	176.47	Winkler	176.47	Jones	159.55	Scurry	159.55		
Hartley	176.47	Ward	176.47	Donley	159.55	Haskell	159.55		
Upton	176.47	Bailey	176.47	Eastland	159.55	Kent	159.55		
Reagan	176.47	Yoakum	176.47	Gray	159.55	Menard	159.55		
Lamb	176.47	Crane	176.47	Roberts	159.55	Dickens	159.55		
Hale	176.47	Cochran	176.47	Sterling	159.55	Cottle	159.55		
Floyd	176.47	Loving	176.47	Sherman	159.55	Briscoe	159.55		
Martin	176.47	Val Verde	176.47	Carson	159.55	Moore	159.55		
Randall	176.47	Crockett	159.55	Hansford	159.55	Callahan	159.55		
Hockley	176.47	Edwards	159.55	Collingsworth	159.55	Fisher	159.55		

Figure 7. 22: Approach 3 results in 102 counties

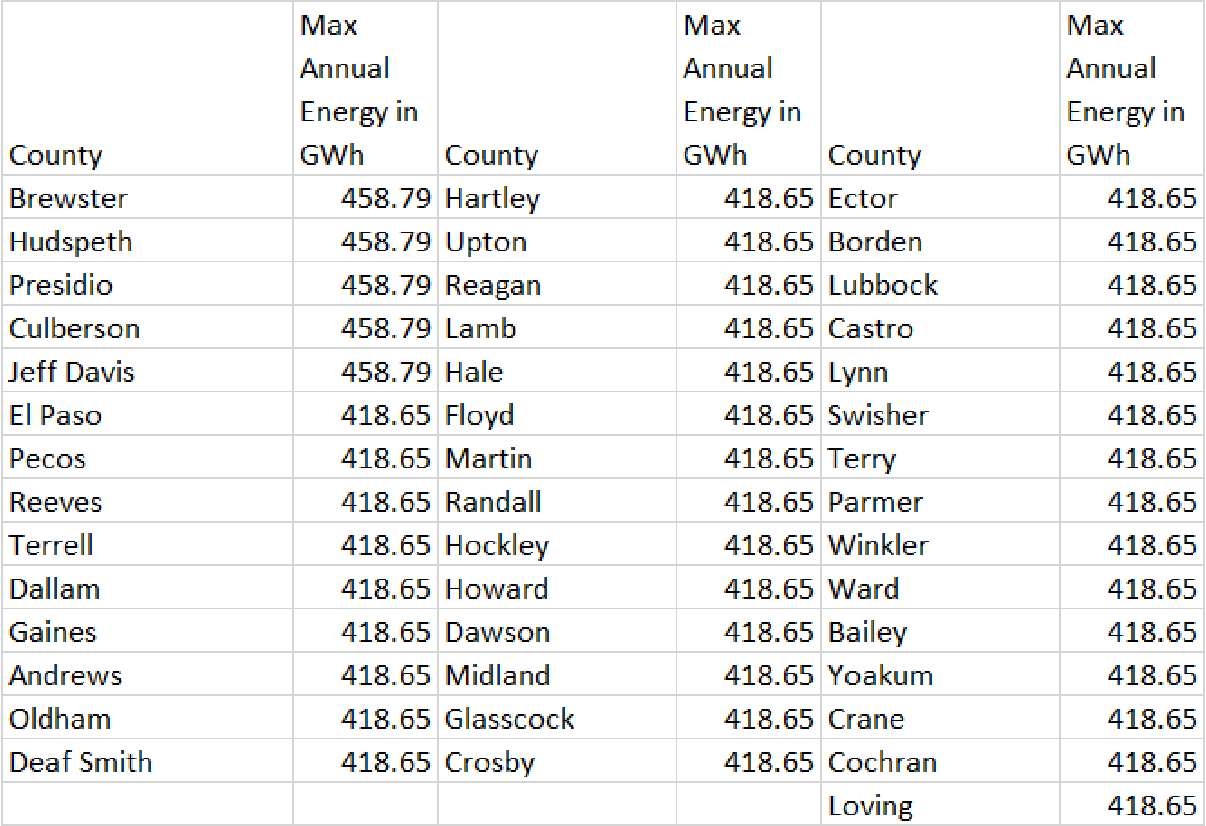
7.14.4 Approach 4

In this approach, 6.7 GW of PV panels is distributed equally among counties only from classes 1 & 2, hence, 157.12 MW of PV panels are proposed to install in 43 counties in Texas. This method produces 16.51 to 18.24 TWh per year. Counties that rely on Category 1 will generate 458.8 GWh per year. The electricity generation in the second category counties is 418.64 GWh. As shown in Figure 7.24. By applying Equation 7.10, the maximum annual generation energy in Brewster as the following:

Max Annual Energy = Installed rated PV * Max Peak Sun Hours *365

Max Annual Energy = 157.12 MW *8 *365

Max Annual Energy = 458.7904 GWh ≈ 458.79 GWh



County	Max Annual Energy in GWh	County	Max Annual Energy in GWh	County	Max Annual Energy in GWh
Brewster	458.79	Hartley	418.65	Ector	418.65
Hudspeth	458.79	Upton	418.65	Borden	418.65
Presidio	458.79	Reagan	418.65	Lubbock	418.65
Culberson	458.79	Lamb	418.65	Castro	418.65
Jeff Davis	458.79	Hale	418.65	Lynn	418.65
El Paso	418.65	Floyd	418.65	Swisher	418.65
Pecos	418.65	Martin	418.65	Terry	418.65
Reeves	418.65	Randall	418.65	Parmer	418.65
Terrell	418.65	Hockley	418.65	Winkler	418.65
Dallam	418.65	Howard	418.65	Ward	418.65
Gaines	418.65	Dawson	418.65	Bailey	418.65
Andrews	418.65	Midland	418.65	Yoakum	418.65
Oldham	418.65	Glasscock	418.65	Crane	418.65
Deaf Smith	418.65	Crosby	418.65	Cochran	418.65
				Loving	418.65

Figure 7. 23: Approach 4 results in 43

7.14.5 Approach 5

In this way, 6.7 GW of photovoltaic panels are evenly distributed in the first category of the 6 counties. Hence, it is proposed to install 1,126 MW of photovoltaic panels in every county in class 1. This method produces 18 to 19.72 TWh per year. Counties in Category 1 will provide individually up to 3.287 TWh of electricity annually. As shown in Table 7.2.By applying Equation 7.10, the maximum annual generation energy in Brewster as the following:

Max Annual Energy = Installed rated PV * Max Peak Sun Hours *365

Max Annual Energy = 1,126 MW *8 *365

Max Annual Energy = 3,287 TWh ≈ 3.29 TWh

County	Max Annual Energy in TWh
Brewster	3.29
Hudspeth	3.29
Presidio	3.29
Culberson	3.29
Jeff Davis	3.29
El Paso	3.29

Table 7. 2: Approach 5 results in 6 counties

As shown in all methods. The energy produced by a photovoltaic system may vary depending on the distribution of photovoltaic panels from one location to another. Compared with approach 1, approach 5 can obtain 134% more energy. As shown in Table 7.3.

Approach	Minimum Annual energy in TWh	Maximum Annual energy in TWh	Average Annual energy in TWh	Number of Counties	Rated PV system per County in MW
1	13.37	15.09	14.23	254	26.58
2	14.23	15.95	15.09	185	36.52
3	15.37	17.10	16.235	102	66.23
4	16.51	18.24	17.75	43	157.12
5	18	19.72	18.86	6	1,126

Table 7. 3: Results from all approaches in the electrical proposal system

7.15 Results

Texas generates electricity around 866 GWh annually from PV technology ‘Solar energy generation by state,2021' which means Texas is used only 0.266% of what is available from the sun in Texas due to PV technology with respect to the hypothetical model. Obviously, the power generation of all approaches in the proposed electrical system exceeds 13 TWh, which is more than 15 times the power generation of Texas. This is due to the new technology and the distribution of photovoltaic panels. Figure 7.25 illustrates all the results from the hypothetical model and the electrical proposal system.

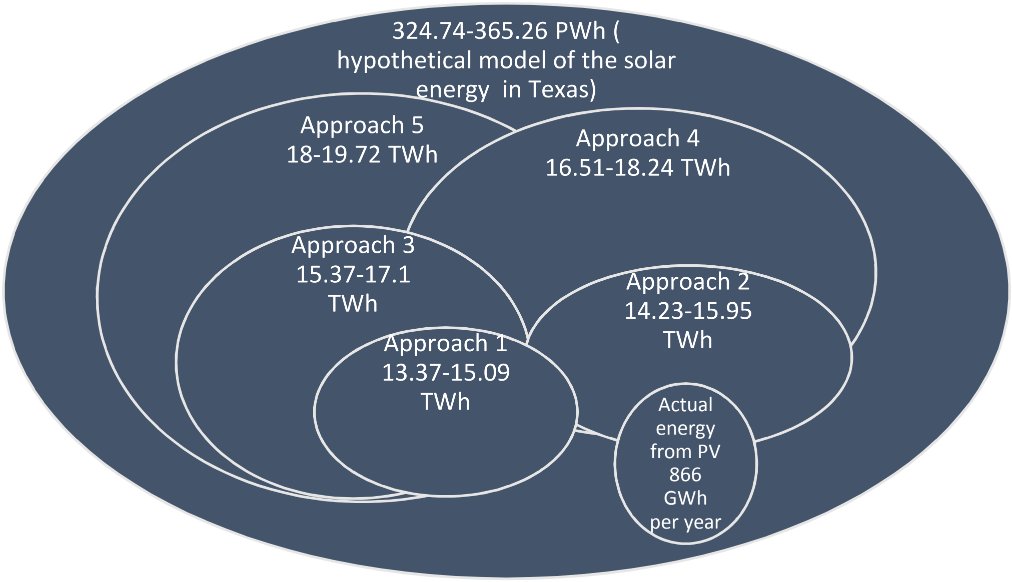


Figure 7. 24: Comparison between hypothetical model and proposal system

CHAPTER VIII

CONCENTRATED SOLAR POWER

8.1 Concentrated Solar Power

Concentrated solar power (CSP) is another way to convert sun energy into electricity. Thermal energy is converted into mechanical energy used by thermal engines and then converted into electrical energy. The electricity generated by CSP is in the form of alternating current, which comes from a generator, while in a photovoltaic system, it is generated in the form of DC and then converted to AC form by an inverter.

The principle of work of the CSP plants is to collect the thermal energy from the sunlight using solar collectors such as mirrors and lenses, that this thermal energy is used to heat a fluid, which uses to drive a steam turbine connected with an electric generator to produce electricity. The CSP plant shares most parts with the thermal power plant. Although the source for PV systems and CSP systems have the same source of energy which is the sun. However, all components are different between the two systems and the principle of work as well. In contrast, the steam turbines and generators of the CSP plant and the fossil plant are the same. Hence, CSP is closer to the traditional power plant more than the PV systems. One of the best advantages of the CSP between renewable resources is considered as a dispatchable resource ‘IEA,2010’. This advantage comes from the ability of the energy storage system to be added to the CSP system. This storage system is different from traditional storage systems, which rely on thermal energy. Figure 8.1‘Praveen et al,2018’ illustrates the working principle and components of the CSP system.

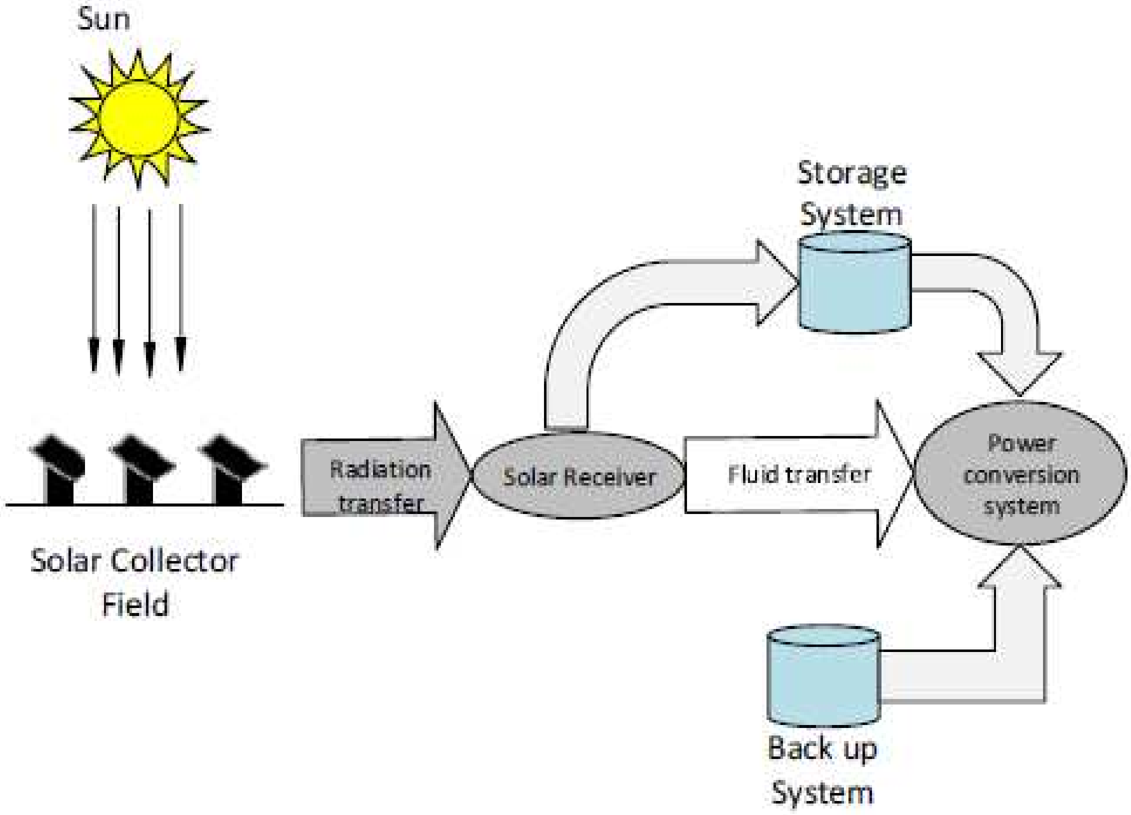


Figure 8. 1: The principle of CSP plants

The operating principle of a CSP plant depends on three levels, namely thermal energy, mechanical energy and electrical energy, as shown in Figure 8.2 ‘Soomro et al,2019’. As mentioned earlier, the last two steps are similar to any other traditional power plants, such as natural gas, so they can be installed anywhere. However, the decision is made by the heat collected by the sunlight through the collector at the receiver. CSP plants are very attractive for all areas where the direct normal radiation is good. Most countries in the world have enough radiation to produce 1.6 MWh/m^2, if the latitude lesser than 45 North ‘Mehta et al,2014’ Texas latitude varies from 26 to above 36 North, thus, it has enough resources from the solar radiation, and it has great potential resources for CSP plants.

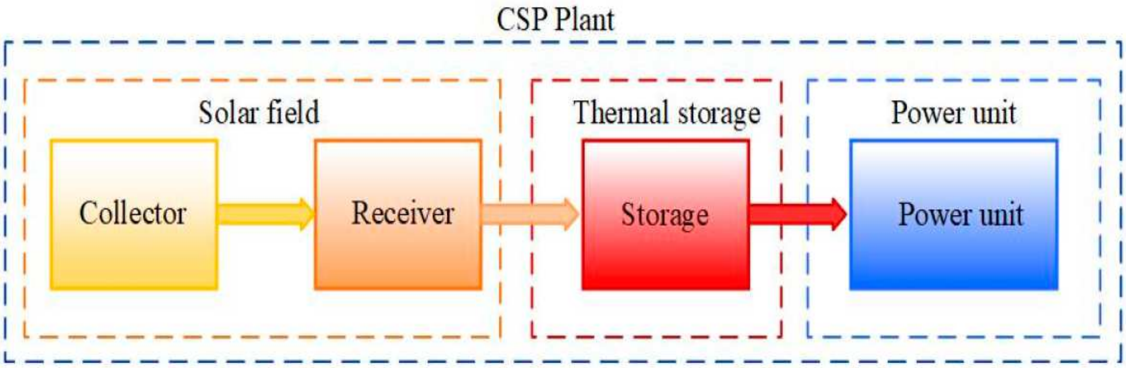


Figure 8. 2: CSP plants operating principle

8.2 Concentrated Solar Power Technologies

Based on the type of receiver, Concentrated solar power technology can be considered, which can be divided into two types: point and line receivers. Point receivers depend on collecting all solar radiation in a single point receiver, such as towers (CRS) and parabolic Dishes. In the same sense, the line receiver relies on the focus of the solar radiation line receiver of the type such as linear Fresnel reflectors and parabolic troughs. Moreover, the type of receiver could be classified into fixed or mobile receivers. Linear Fresnel reflectors and towers are fixed receivers where the parts of the receiver of the system is stationary. On the other hand, parabolic Dishes and parabolic troughs are movable receivers and move with the collective devices

‘IEA,2010’. Figure 8.3 ‘Mehta et al,2014’ illustrates the CSP technology based on the receiver type.

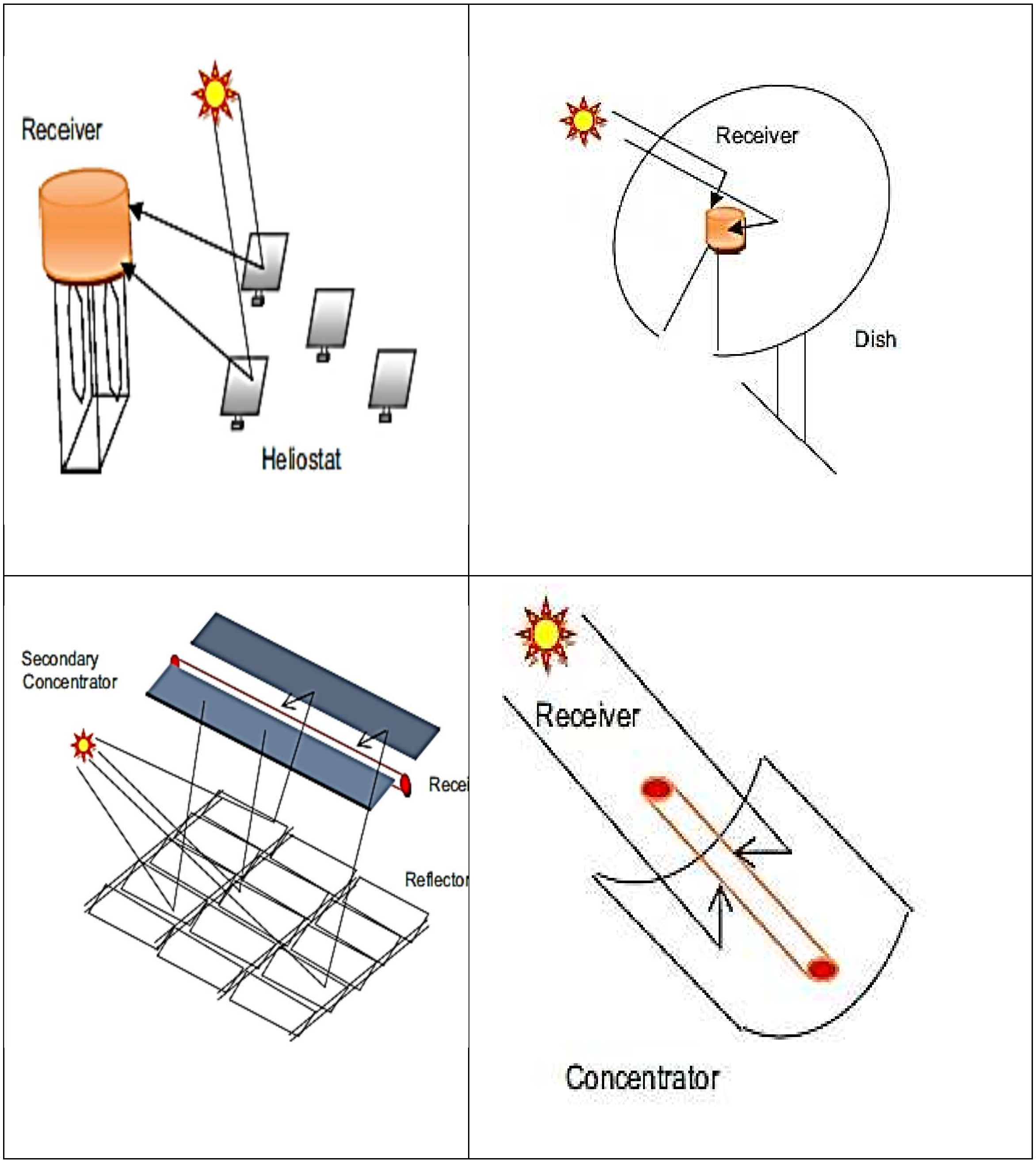


Figure 8. 3: CSP Technologies point and line receivers

8.2.1 Parabolic Trough System

The parabolic trough (PT) power plants are the most popular commercial CSP plants 'Kassem et al,2017'. The PT system consists of a parabolic collector with a pipe receiver in the middle of the collector. As shown in Figure 8.4'Soomro et al,2019', the hot fluid in the tube is connected to the steam generator through a heat exchanger, which is used to rotate the steam turbine connected to the generator. Owing to the linear shape of the receivers tube in PT systems, the single tracker suffices for this system t to follow the sun rays from the east to the west, and no need for another axis to track it from south to north 'Kassem et al,2017'.Therefore, the cost of a single tracker system will be lower than that of a dual tracker system, so the PT system will be cheaper than a CSP system with a dual-axis tracker.

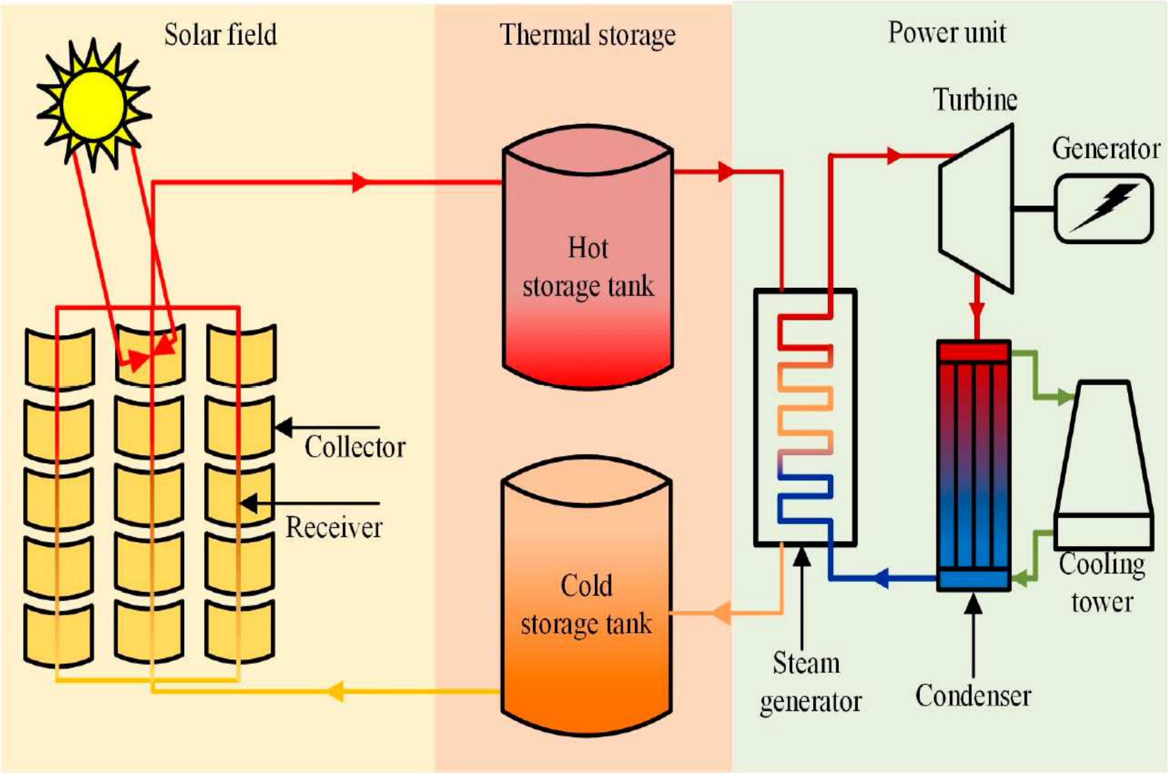


Figure 8. 4: Parabolic trough power plant scheme

8.2.2 Solar Tower System

The solar tower is also known as a central receiver system ‘Soomro et al,2019’. The solar tower system consists of a fixed-point receiver, a collector called a heliostat, and a tower designed to reach a specific height of the focal point receiver, as shown in Figure 8.5 ‘Soomro et al,2019’. The point receiver system requires a dual tracking system to track the sun's rays. Contrasted with the CSP system single tracker, the dual track system of the solar tower requires a lot of land and a lot of cost. The heliostats focus all sun rays in the point receiver where the heat thermal fluid then moves toward to steam generator, which drives the turbine connected to the electric generator to produce electricity. The solar Tower systems have efficiency from 20-35 % ‘Soomro et al,2019’.

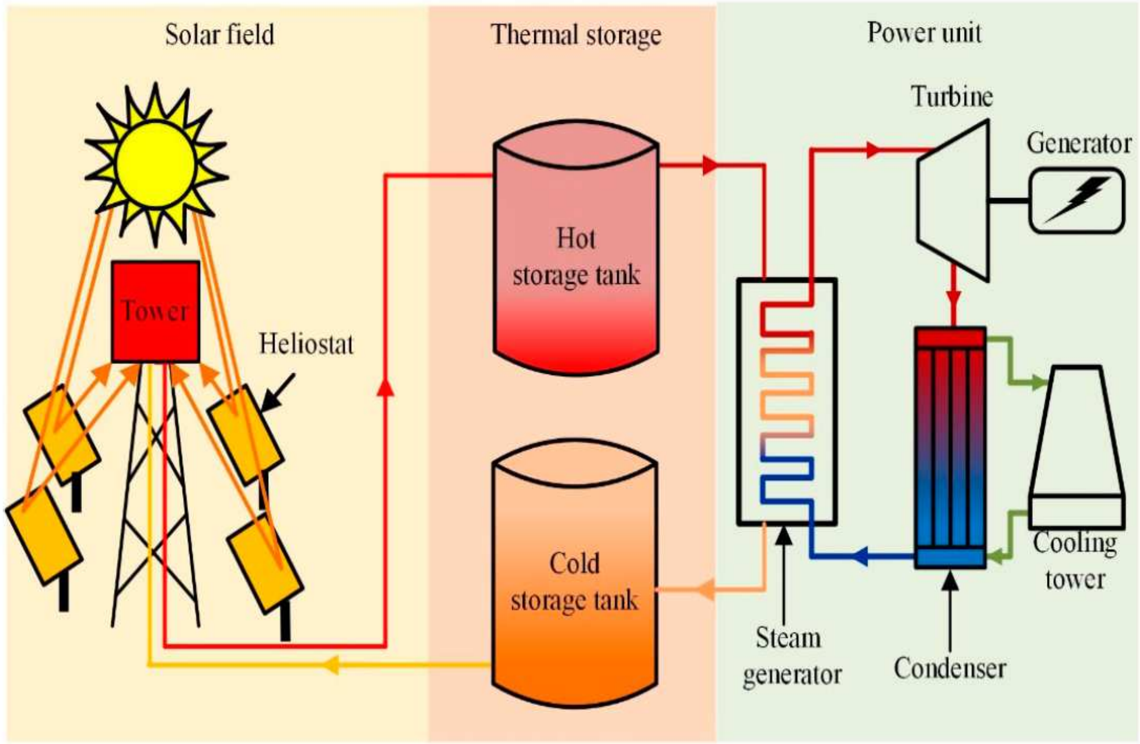


Figure 8. 5: Solar Power Tower plant scheme

8.2.3 Linear Fresnel Reflector

A linear Fresnel reflector system depends on the linear focusing receiver. Linear Fresnel reflector consists of a flat or curved mirror as collectors for sun rays ‘Soomro et al,2019’.The absorber tube, which is the linear receiver is not connected with the mirrors as shown in Figure 8.6‘Soomro et al,2019’. Therefore, this fact requires less material and therefore requires less capital cost. The linear Fresnel reflector depends on the linear receiver technology, thus, it is a single-axis tracker system in that it requires less area. The rest components of the system related to the thermal storage and the power block are the same as all CSP technologies. The heat thermal fluid absorbs the thermal energy from the absorber tube then, it is connected with a heat exchanger to move the energy into the steam turbine to drive the steam turbine, which connected with the electric generator. One of the greatest advantages of the linear Fresnel mirror system is its simplest design curved mirror. However, the biggest disadvantage of this technology is the lowest efficiency in converting solar energy into electrical energy ‘IEA,2010’.

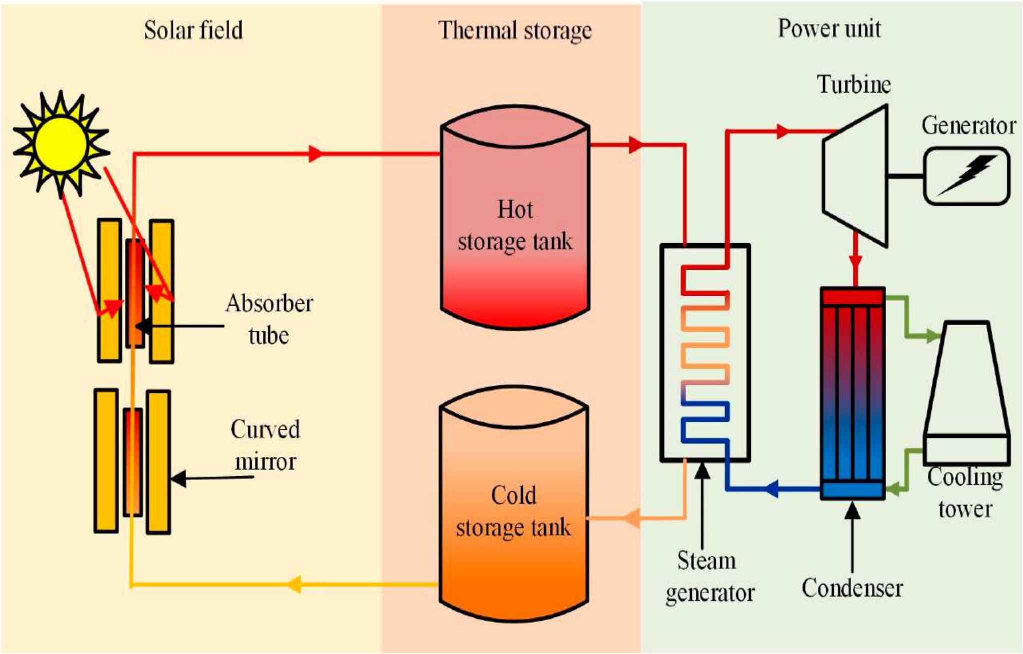


Figure 8. 6: Linear Fresnel Reflector plants scheme

8.2.4 Parabolic Dish System

The parabolic dish technology depends on the point receiver, so it is a two-track system of the collector part, which is a Dish reflector, as shown in Figure 8.7 ‘Soomro et al,2019’. The working principle of the parabolic Dish is to focus the sunlight from the parabolic reflector to the focal point of the receiver system. In contrast to the other CSP technologies, The Parabolic dish does not have a heat thermal fluid and power block. Hence, the dish parabolic has a steam turbine and does not need a cold-water cycle, thus, it is compact. Parabolic Dish plant has a higher efficiency of conversion the sun energy into electricity among all CSP technologies ‘IEA,2010’.However, the size of the Parabolic dish plants varies from several watts to tens KW ‘IEA,2010’. Parabolic dish systems are so expensive and that is why are not popular commercially ‘Soomro et al,2019’.

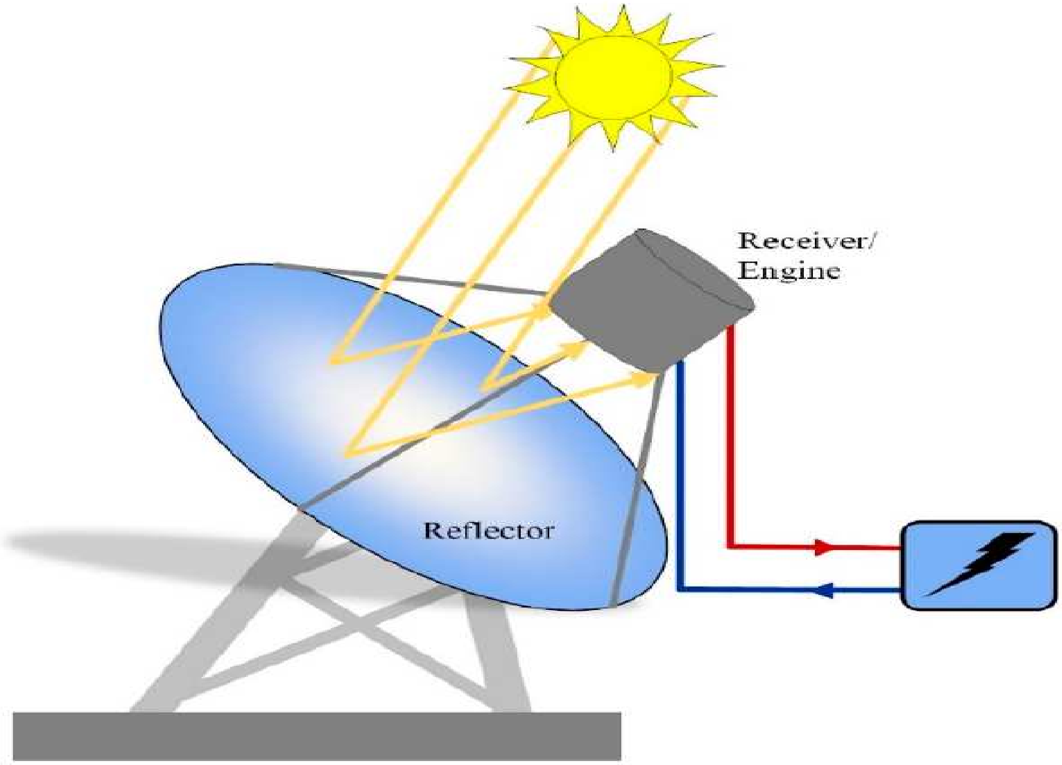


Figure 8. 7: Parabolic Dish plants scheme

In summation, there are four popular technologies for CSP. Among other technologies, parabolic technology has the lowest capital cost. The solar tower technology has the highest capacity factor, which can reach 78%. The paraboloid temperature can reach up to 1,000°C. The Linear Fresnel reflector system has the lowest capacity factor and the operating temperature as well. However, compared with other technologies, less area is required per megawatt. The parabolic trough system has good characteristics in different aspects due to its good capacity factor, price, and required land and that is why it is the dominant technology in the market as mentioned before. Table 6.1 'Soomro et al,2019'& 'Mehta et al,2014' &' Ong et al 2013' shows the comparison between different technologies of CSP.

	Parabolic trough	Solar tower	Linear Fresnel reflector	Parabolic dish
Plant capacity in MW	30-300	100-200	1-100	5-25
Capacity factor	23-56 %	20-78%	20-25%	24-25%
Operating temperature range in □	20-400	300-565	50-300	100-1000
Capital cost $/kW	3972	>4000	--	12,578
Capital cost $/m2	424	476	234	-
Capacity weighted average land use MW/m^2	38,450	40,468	19,020	40,468

Table 8. 1: Comparison between CSP technologies

8.3 Thermal Storage System

The storage system is preferably attached with renewable energy resources or in general with all non-dispatchable resources. The purpose of adding a storage system to a CSP system may be to meet power demand, even if the CSP does not generate electricity after sunset This may be to avoid losing energy from the CSP during solar peak hours. In some cities with normal direct radiation, the CSP system tends to produce more power than its rated power, so the heat absorbed will be greater than the processing capacity of the turbine. However, instead of defocusing some of the reflectors using the storage system will be an efficient way to avoid wasting energy ‘IEA,2010’.

The strategy of the heat storage system connected to the CSP system is to store the excess heat in molten salt or synthetic oil. In order to use this heat storage when the demand is greater than the generation side due to the bad weather conditions or the absence of the sun. Figure 8.8 ‘IEA,2010’ illustrates the components of the thermal storage system with the CSP. The valve controls the amount of the heat thermal fluid which will go to the power cycle and the storage cycle based on the demand and generation status. The storage has two tanks one for the hot and the other for cold molten salt. The valve has three directions; one from the solar mirrors to the heat exchanger, which connected with the molten salt. The second one from the heat exchanger of the molten salt with the power cycle. And the last one is between the solar cycle and the power cycle.

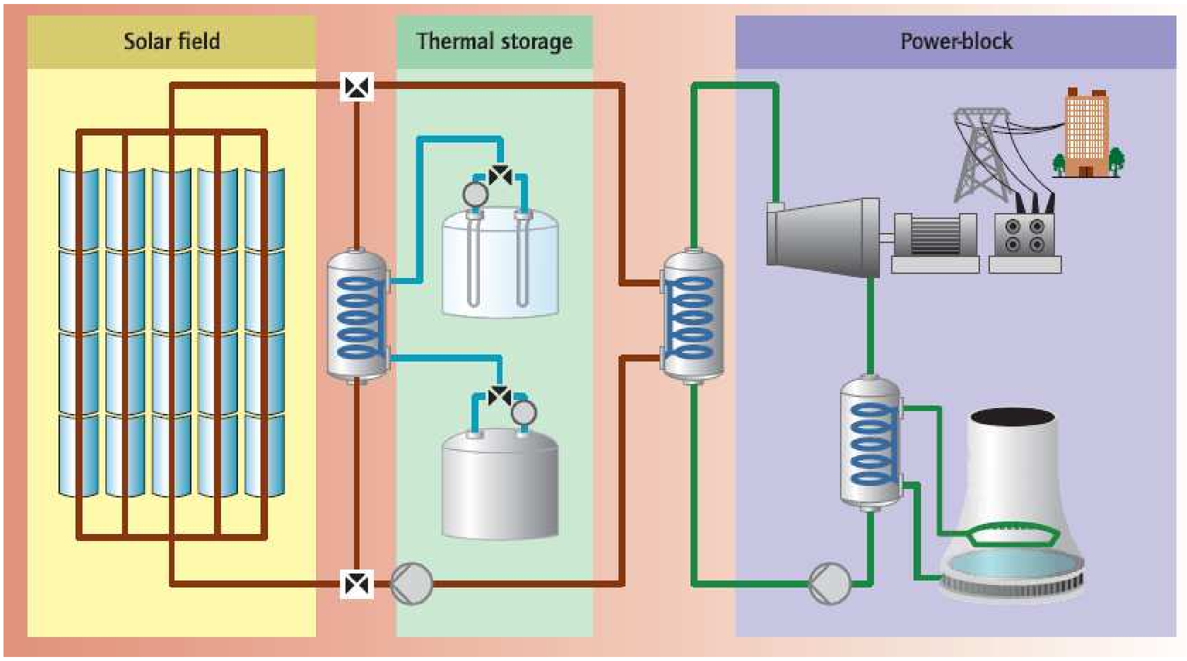
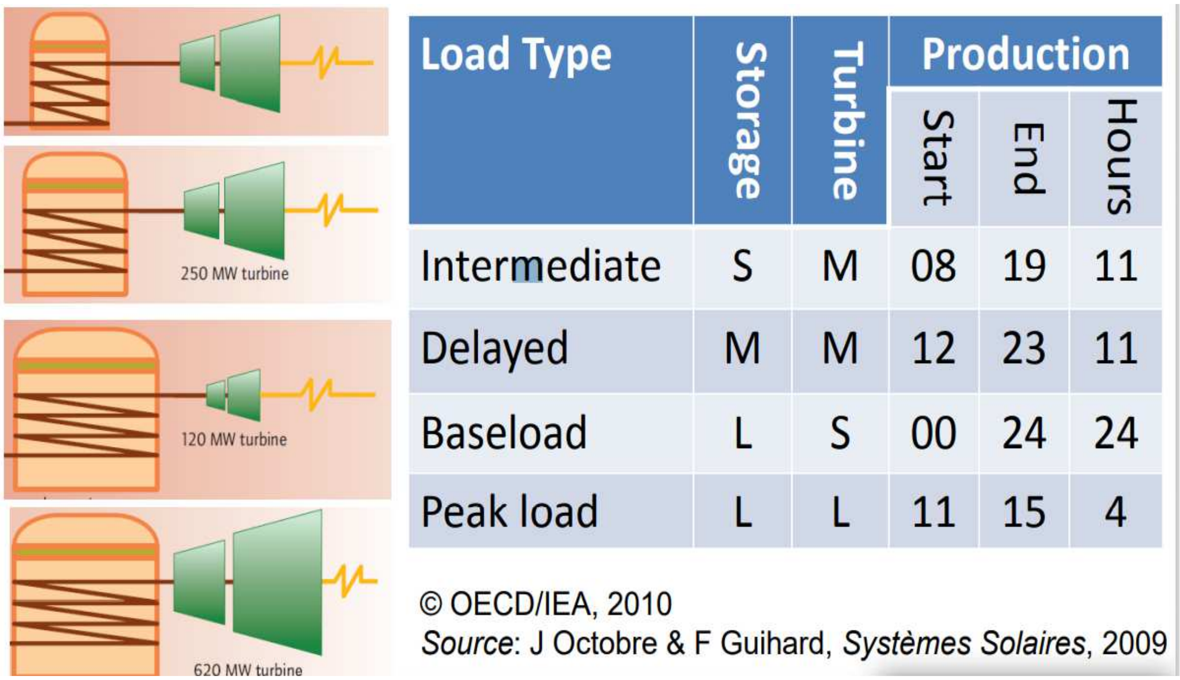


Figure 8. 8: Thermal storage system in CSP plant

The thermal storage sizes could be small, medium, and large. Each storage size is used for different purposes. CSP plants usually come with smaller storage capacity to meet the needs of the CSP system during operation (availability of the sun) and avoid wasting energy. Therefore, it is called an intermediate load system. The medium storage size is a good way to delay the electricity generation from the CSP plant from the non-peak load time to the peak load time which usually after sunset. Therefore, it is called a delayed intermediate system. A very large storage system is used to meet the needs of the demand all-time in 24 hours, however, to achieve that small turbine is needed to avoid oversize in the system. Thus, it is known as a based load system because it meets the demand at all-time. In contrast to the previous type. If a large storage system is provided with a large turbine then that systems are used to feed the demand at the peak load time only for few hours a day by store all thermal energy during the day and use all of it in short periods, hence a large turbine capacity is needed and it is known as peak load system. Figure 8.9 ‘Ross, 2012’ illustrates all previous types.



Load Type	Storage	Turbine	Production		
			Start	End	Hours
Intermediate	S	M	08	19	11
Delayed	M	M	12	23	11
Baseload	L	S	00	24	24
Peak load	L	L	11	15	4

© OECD/IEA, 2010
Source: J Octobre & F Guihard, *Systèmes Solaires*, 2009

Figure 8. 9: Thermal storage system types

Molten salts have a lot of merits such as a higher temperature, suitable for long thermal storage systems, increase reliability in the systems ‘Kassem et al,2017’. However, it needs a two-fluid cycle and boiler in the power cycle ‘Kassem et al,2017’. On the other hand, synthetic oil which is the second option of the thermal storage system has some advantages as well such as is the most mature, high thermal stable, and high melting points and used as heat transfer fluid in commercial projects ‘Kassem et al,2017’. However, it has a lower temperature than the salt and it is more expensive ‘Kassem et al,2017’.

8.4 Efficiency Of Concentrated Solar Power Plants

The CSP system has three main modules, namely solar, mechanical and electrical. Consequently, the process in each block will affect the gross output of the CSP system and the total efficiency as well. Due to the efficiency of the optics that cannot absorb all solar radiation, and due to the efficiency of the receiver that collects all the sunlight, the solar block will suffer losses. The turbine in the mechanical part also has efficiency, which determines the ratio of energy converted from thermal energy to mechanical energy. Finally, the efficiency of the generator is the last process and is usually the most efficient.

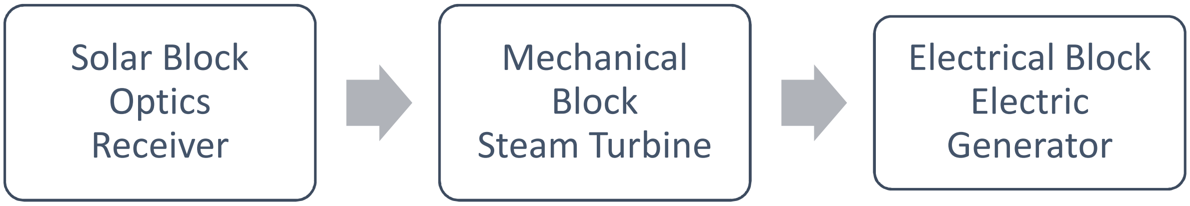


Figure 8. 10: Main Blocks in CSP systems

As shown in Figure 8.10, the total efficiency of CSP systems depends in the three main blocks and their efficiency as well as shown in Equation 8.1' Concentrated Solar power, n.d'.

$$\eta_{CSP} = \eta_{Optics} * \eta_{Receiver} * \eta_{Mechanical} * \eta_{Generatr} \ldots\ldots 8.1$$

Where:

η_{CSP} : The total efficiency of the CSP system (varies based on the technology)

η_{optics} : The efficiency of the optics

η_{Receiver} : The efficiency of the receiver

$\eta_{\mathrm{Mechanical}}$: The efficiency of the steam turbine

$\eta_{\mathrm{Generator}}$: The efficiency of the electric generator

The optics efficiency of collectors in CSP is the fraction of solar energy incident on the glass of the collector, which is concentrated in the receiver to heat the fluid as shown in Equation 8.2 ‘Lopez-Martin and Valenzuela,2018’.

$\eta_{Optics} = \frac{Q_{sun}}{Q_{useful}}$ ………8.2

Where:

Q_{sun} : the solar flux in the glass cover in W

Q_{useful}: heat collected by the system in W

The efficiency of the receiver is the product of the glass transmittance with the absorptance of the absorber tube as shown in Equation 8.3 ‘Lopez-Martin and Valenzuela,2018’.

$\eta_{Receiver} = \alpha * \tau$ ……8.3

Where:

τ: is the transmittance of the glass cover (Dimensionless)

α: is the absorptance of the absorber tube (Dimensionless)

$\eta_{Mechanical}$ can be determined according to Carnot's law to depend on the mechanical efficiency of the steam turbine, as shown in Equation 8.4.

$\eta_{Carnot} = 1 - \frac{T_L}{T_H}$….8.4

Where:

η_{Carnot} : Carnot’s efficiency

T_L: Lower operation temperature in Kelvin

$T_{H:}$ Upper operation temperature in Kelvin

For the thermodynamic solar system, the efficiency depends on the absorption part of the solar energy and the conversion from solar into thermal, the absorption efficiency shows in Equation 8.5 ‘Steinfeld and Palumbo,2001’.

$$\eta_{absorption} = 1 - (\frac{\sigma T^4}{IC}) \text{ ……8.5}$$

Where:

σ: the Stefan-Boltzmann constant

T: is the nominal cavity receiver temperature in Kelvin

I: The incoming solar power in W

C: mean flux concentration ratio (Dimensionless)

Hence, the maximum overall efficiency can be achieved for thermodynamic solar system is the product of the absorption efficiency and the Carnot efficiency as shown in Equation 8.6 ‘Steinfeld and Palumbo,2001’.

$$\eta_{max} = 1 - \left(\frac{\sigma T^4}{IC}\right) * 1 - \frac{T_L}{T_H}\text{…. 8.6 6 ‘Steinfeld and Palumbo,2001’}$$

Figure 8.11 ‘Steinfeld and Palumbo,2001’ illustrates the maximum efficiency for thermodynamic solar system at different operation temperature.

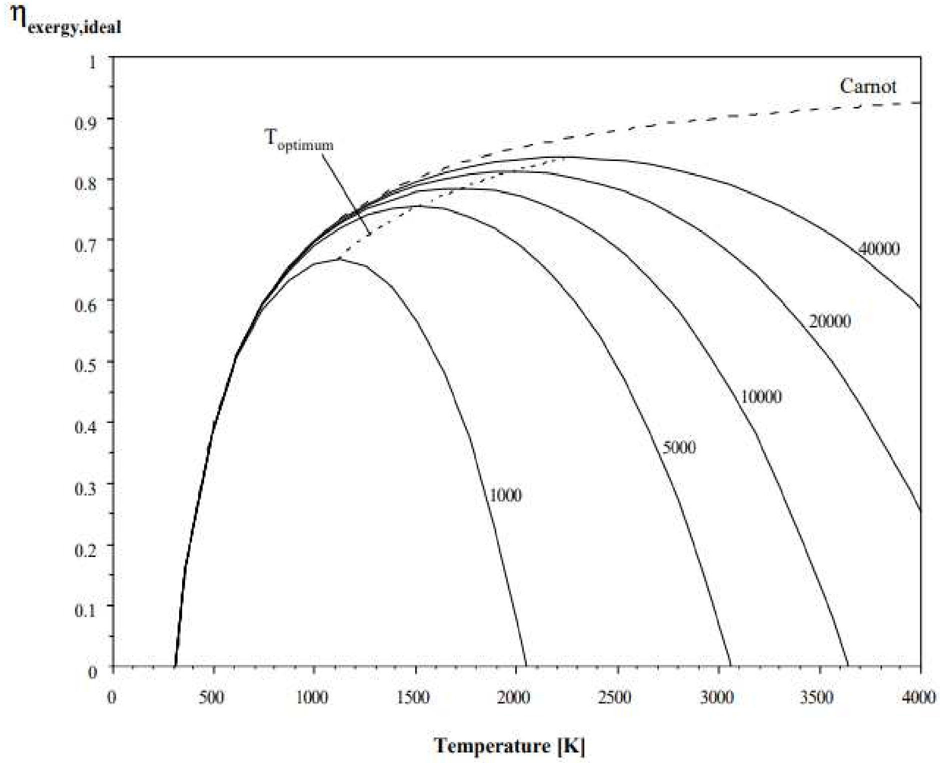


Figure 8. 11: Maximum efficiency for thermodynamic solar systems

However, the CSP system has a generator and also has efficiency, and the overall efficiency of the CSP system should be increased. The CSP system has 4 main technologies, each of which has a different efficiency range, as shown in Table 8.2. ‘Soomro et al,2019’ and ‘Ong et al 2013’.

	Parabolic trough	Solar tower	Linear Fresnel reflector	Parabolic dish
Annual net efficiency (solar to electric)	15%	25-35%	8-10%	25-30%
Direct Area acres/MW	6.2	8.9	2.0	2.8
Total Area acres/MW	9.5	10	4.7	10

Table 8. 2: Efficiency and area of CSP technologies

8.5 Direct Normal Radiation In Texas

As mentioned above, CSP systems rely on direct normal irradiation (DNI). The range of the DNI varies from 4.5 - 8 kWh/m^2/day, while the DNI range in the United States is 0.5-8 kWh/m^2/day. Therefore, Texas is a good potential source of CSP plants, as shown in Figure 8.12 'Gilroy,2017'.

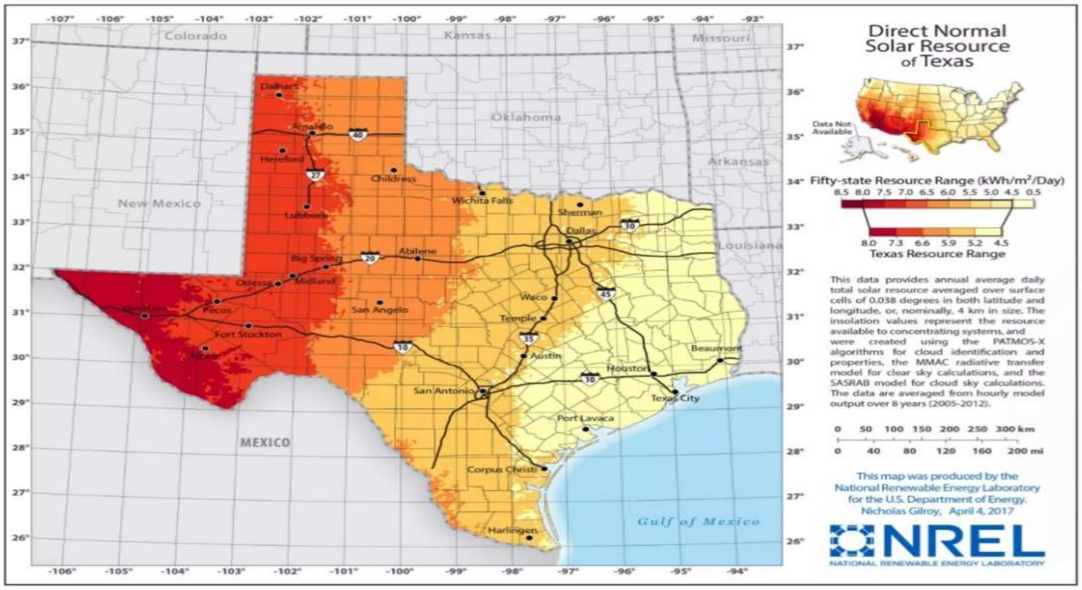


Figure 8. 12: Direct Normal Irradiation of Texas

Regarding the DNI, Texas counties could be classified into five main classes. The first-class has the lowest DNI, which varies from 4.5 to 5.2 kWh/m^2 /day, there are 69 counties in this class. The second class has DNI from 5.2 to 5.9 kWh/m^2/day, there are 83 counties in Texas in this class. The third class has DNI from 5.9 to 6.6 kWh/m^2/day, there are 59 counties in Texas in this class. In the fourth class, the DNI varies from 6.6-7.3 kWh/m^2/day and there are 37 counties in Texas in this class. In the fifth, the DNI varies from 7.3-8 kWh/m^2/day, there are 6 counties in Texas in this class. As shown in Table 8.3.

	Class 1	Class 2	Class 3	Class 4	Class 5
DNI in kWh/m^2/day	4.5-5.2	5.2-5.9	5.9-6.6	6.6-7.3	7.3-8
Number of Counties	69	83	59	37	6

Table 8. 3: Texas counties classification based on DNI

The Edinburg campus of the University of Texas at Rio Grande Valley is equipped with radiometer sensors to determine the type of solar radiation data. The types and ranges of radiometers are shown in Table 8.4. Figure 8.13 shows the solar radiation data on February 4, 2021.

Solar Radiation Types	Radiometer Types	Radiometer Wavelength (nm)
Direct Normal Irradiation	CHP-1	200-4000
Global Horizontal Irradiation	CMP-11	285-2800
Diffuse Horizontal Irradiation	CMP-11	285-2800
Far Infra-Red Radiation	CRG-3	4500-4200

Table 8. 4: Radiometers types and wavelength range

As shown in Figure 8.13 'Ramos and Andreas,2011', the direct normal irradiation (green line) is greater than the global horizontal radiation (red- line) and that is the case when the weather is sunny and not cloudy, however, if there is a lot of clouds and dust the diffuse radiation will be high.

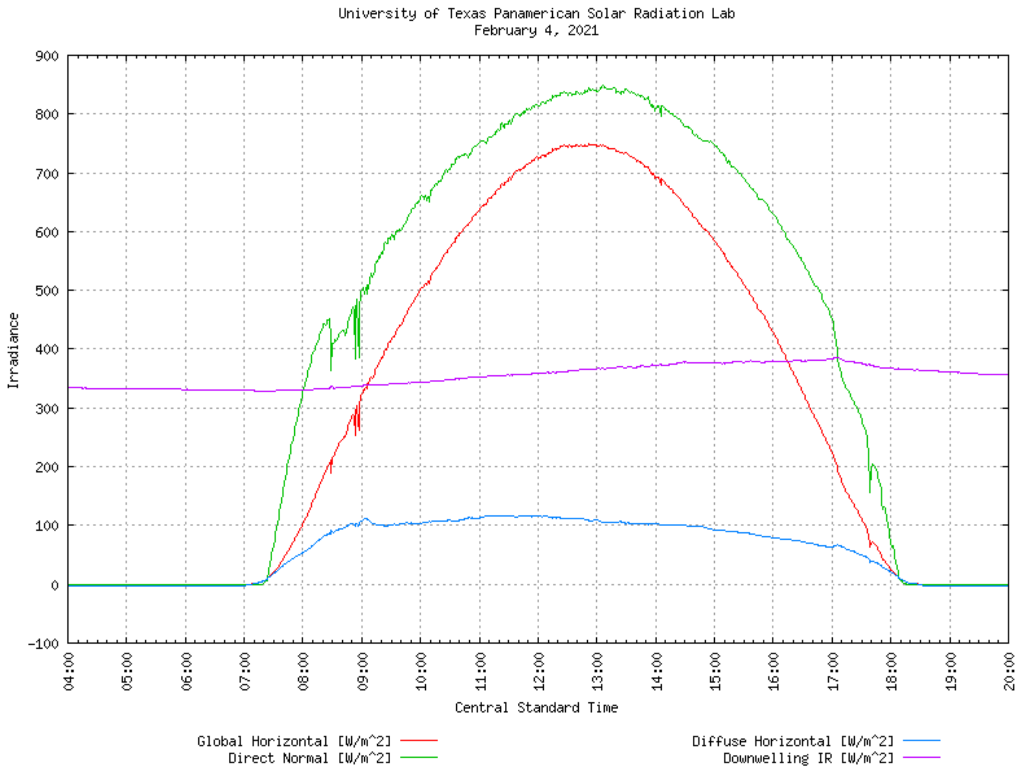


Figure 8. 13: DNI in Edinburg, Tx

8.6 Hypothetical CSP System

In this model, the maximum electrical energy that can be generated from the CSP system is calculated, For the state of Texas. CSP technology can be used to convert solar energy into electrical energy. In theory, all incident energy on the earth can be converted into electrical energy based on technical efficiency, site area and DNI (as shown in Equation 8.7). Therefore, CSP has 4 main technologies, so the model shows the maximum electrical energy of all counties in Texas for these 4 technologies.

$$E_A = \eta_{Average} * DNI * ratio * A * 365 \ldots\ldots 8.7$$

Where:

E_A: Annual energy in kWh

$\eta_{Average}$: Average efficiency of the CSP technology

DNI: Direct Normal solar irradiation in kWh/ m^2/ day

A: The area in m^2

Ratio: the ratio between the direct solar area in CSP plant (thermal part) to Total area of the CSP plant

8.6.1 Parabolic Trough System

By using parabolic trough technology to install a CSP plant per square meter in Texas, the method is to take the ratio of direct solar land to the total land required in Table 8.2 and apply Equation 8.7. as the following:

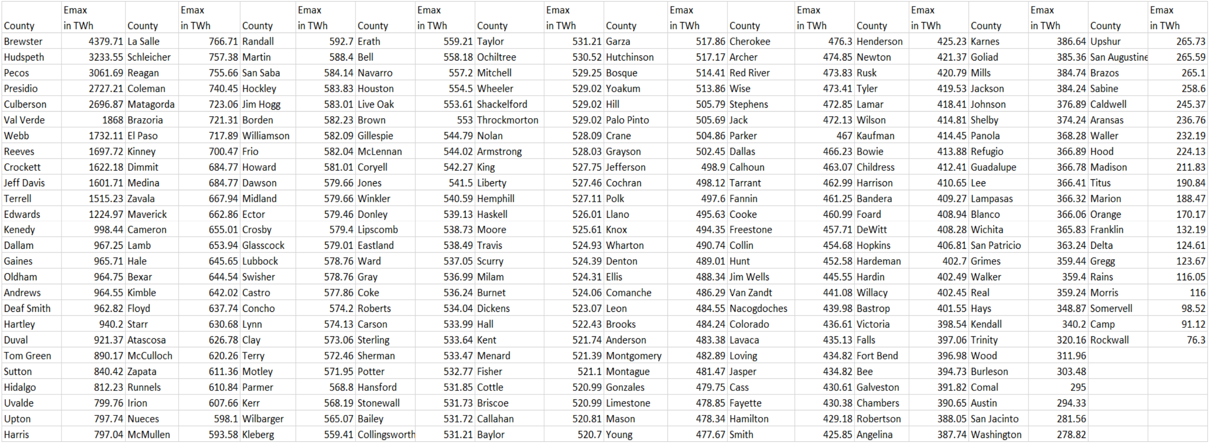
$$E_{Max}(Brewster) = DNI_{avg} * A * \eta_{Avg} * ratio * 365$$

$$E_{Max}(Brewster)= 7.65*16{,}038{,}057{,}000*0.15*0.652*365$$

$$E_{Max}(Brewster)= 4.379 *10^{12} \text{ kWh}$$

$$E_{Max}(Brewster)= 4{,}379.1 \text{ TWh}$$

Texas could power between 139.29 to 156.67 PWh and an average of 147.98 PWh which is almost 33 times more than the electricity consumption in the US. 171 counties in Texas have enough resources to produce more than 450 TWh per year which means one county could power all of Texas by itself based on its resources from CSP from Parabolic trough technology. The maximum energy could produce in Texas counties varies from 4,379.1 TWh in Brewster county to 76.3 TWh Rockwall county. All results are shown in Figure 8.14.



County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh
Brewster	4379.71	La Salle	766.71	Randall	592.7	Erath	559.21	Taylor	531.21	Garza	517.86	Cherokee	476.3	Henderson	425.23	Karnes	386.64	Upshur	265.73
Hudspeth	3233.55	Schleicher	757.38	Martin	588.4	Bell	558.18	Ochiltree	530.52	Hutchinson	517.17	Archer	474.85	Newton	421.37	Goliad	385.36	San Augustine	265.59
Pecos	3061.69	Reagan	755.66	San Saba	584.14	Navarro	557.2	Mitchell	529.25	Bosque	514.41	Red River	473.83	Rusk	420.79	Mills	384.74	Brazos	265.1
Presidio	2727.21	Coleman	740.45	Hockley	583.83	Houston	554.5	Wheeler	529.02	Yoakum	513.86	Wise	473.41	Tyler	419.53	Jackson	384.24	Sabine	258.6
Culberson	2696.87	Matagorda	723.06	Jim Hogg	583.01	Live Oak	553.61	Shackelford	529.02	Hill	505.79	Stephens	472.85	Lamar	418.41	Johnson	376.89	Caldwell	245.37
Val Verde	1868	Brazoria	721.31	Borden	582.23	Brown	553	Throckmorton	529.02	Palo Pinto	505.69	Jack	472.13	Wilson	414.81	Shelby	374.24	Aransas	236.76
Webb	1732.11	El Paso	717.89	Williamson	582.09	Gillespie	544.79	Nolan	528.09	Crane	504.86	Parker	467	Kaufman	414.45	Panola	368.28	Waller	232.19
Reeves	1697.72	Kinney	700.47	Frio	582.04	McLennan	544.02	Armstrong	528.03	Grayson	502.45	Dallas	466.23	Bowie	413.88	Refugio	366.89	Hood	224.13
Crockett	1622.18	Dimmit	684.77	Howard	581.01	Coryell	542.27	King	527.75	Jefferson	498.9	Calhoun	463.07	Childress	412.41	Guadalupe	366.78	Madison	211.83
Jeff Davis	1601.71	Medina	684.77	Dawson	579.66	Jones	541.5	Liberty	527.46	Cochran	498.12	Tarrant	462.99	Harrison	410.65	Lee	366.41	Titus	190.84
Terrell	1515.23	Zavala	667.94	Midland	579.66	Winkler	540.59	Hemphill	527.11	Polk	497.6	Fannin	461.25	Bandera	409.27	Lampasas	366.32	Marion	188.47
Edwards	1224.97	Maverick	662.86	Ector	579.46	Donley	539.13	Haskell	526.01	Llano	495.63	Cooke	460.99	Foard	408.94	Blanco	366.06	Orange	170.17
Kenedy	998.44	Cameron	655.01	Crosby	579.4	Lipscomb	538.73	Moore	525.61	Knox	494.35	Freestone	457.71	DeWitt	408.28	Wichita	365.83	Franklin	132.19
Dallam	967.25	Lamb	653.94	Glasscock	579.01	Eastland	538.49	Travis	524.93	Wharton	490.74	Collin	454.68	Hopkins	406.81	San Patricio	363.24	Delta	124.61
Gaines	965.71	Hale	645.65	Lubbock	578.76	Ward	537.05	Scurry	524.39	Denton	489.01	Hunt	452.58	Hardeman	402.7	Grimes	359.44	Gregg	123.67
Oldham	964.75	Bexar	644.54	Swisher	578.76	Gray	536.99	Milam	524.31	Ellis	488.34	Jim Wells	445.55	Hardin	402.49	Walker	359.4	Rains	116.05
Andrews	964.55	Kimble	642.02	Castro	577.86	Coke	536.24	Burnet	524.06	Comanche	486.29	Van Zandt	441.08	Willacy	402.45	Real	359.24	Morris	116
Deaf Smith	962.82	Floyd	637.74	Concho	574.2	Roberts	534.04	Dickens	523.07	Leon	484.55	Nacogdoches	439.98	Bastrop	401.55	Hays	348.87	Somervell	98.52
Hartley	940.2	Starr	630.68	Lynn	574.13	Carson	533.99	Hall	522.43	Brooks	484.24	Colorado	436.61	Victoria	398.54	Kendall	340.2	Camp	91.12
Duval	921.37	Atascosa	626.78	Clay	573.06	Sterling	533.64	Kent	521.74	Anderson	483.38	Lavaca	435.13	Falls	397.06	Trinity	320.16	Rockwall	76.3
Tom Green	890.17	McCulloch	620.26	Terry	572.46	Sherman	533.47	Menard	521.39	Montgomery	482.89	Loving	434.82	Fort Bend	396.98	Wood	311.96		
Sutton	840.42	Zapata	611.36	Motley	571.95	Potter	532.77	Fisher	521.1	Montague	481.47	Jasper	434.82	Bee	394.73	Burleson	303.48		
Hidalgo	812.23	Runnels	610.84	Parmer	568.8	Hansford	531.85	Cottle	520.99	Gonzales	479.75	Cass	430.61	Galveston	391.82	Comal	295		
Uvalde	799.76	Irion	607.66	Kerr	568.19	Stonewall	531.73	Briscoe	520.99	Limestone	478.85	Fayette	430.38	Chambers	390.65	Austin	294.33		
Upton	797.74	Nueces	598.1	Wilbarger	565.07	Bailey	531.72	Callahan	520.81	Mason	478.34	Hamilton	429.18	Robertson	388.05	San Jacinto	281.56		
Harris	797.04	McMullen	593.58	Kleberg	559.41	Collingsworth	531.21	Baylor	520.7	Young	477.67	Smith	425.85	Angelina	387.74	Washington	278.82		

Figure 8. 14: Maximum Energy from Parabolic Trough system in Texas by counties

8.6.2 Solar Tower System

By using Solar Tower technology to install a CSP plant per square meter in Texas, the method is to take the ratio of direct solar land to the total land required in Table 8.2 and apply Equation 8.7. as the following:

$$E_{Max}(\,Brewster) = DNI_{avg} * A * \eta_{Avg} * ratio * 365$$

$E_{Max}(\,Brewster)$= 7.65*16,038,057,000*0.30*0.89*365

$E_{Max}(\,Brewster)$= 11.956 $*10^{12}$ kWh

$E_{Max}(\,Brewster)$= 11,956.9 TWh

Texas could power between 380.28 to 427.74 PWh and an average of 404 PWh which is almost 90 times more than the electricity consumption in the US. 245 counties in Texas have enough resources to produce more than 450 TWh per year which means one county could power all of Texas by itself based on its resources from CSP from Solar Power technology. The maximum energy could produce in Texas counties varies from 11,956.9 TWh in Brewster county to 208.3 TWh Rockwall county. All results are shown in Figure 8.15.

County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh
Brewster	11956.9	La Salle	2093.2	Randall	1618.1	Erath	1526.7	Taylor	1450.2	Garza	1413.8	Cherokee	1300.3	Henderson	1160.9	Karnes	1055.6	Upshur	725.4
Hudspeth	8827.8	Schleicher	2067.7	Martin	1606.4	Bell	1523.9	Ochiltree	1448.4	Hutchinson	1411.9	Archer	1296.4	Newton	1150.4	Goliad	1052.1	San Augustine	725.1
Pecos	8358.6	Reagan	2063	San Saba	1594.7	Navarro	1521.2	Mitchell	1444.9	Bosque	1404.4	Red River	1293.6	Rusk	1148.8	Mills	1050.4	Brazos	723.7
Presidio	7445.5	Coleman	2021.5	Hockley	1593.9	Houston	1513.8	Wheeler	1444.2	Yoakum	1402.9	Wise	1292.4	Tyler	1145.3	Jackson	1049	Sabine	706
Culberson	7362.6	Matagorda	1974	Jim Hogg	1591.7	Live Oak	1511.4	Shackelford	1444.2	Hill	1380.8	Stephens	1290.9	Lamar	1142.3	Johnson	1028.9	Caldwell	669.9
Val Verde	5099.8	Brazoria	1969.2	Borden	1589.5	Brown	1509.7	Throckmorton	1444.2	Palo Pinto	1380.6	Jack	1288.9	Wilson	1132.5	Shelby	1021.7	Aransas	646.4
Webb	4728.8	El Paso	1959.9	Williamson	1589.1	Gillespie	1487.3	Nolan	1441.7	Crane	1378.3	Parker	1274.9	Kaufman	1131.5	Panola	1005.4	Waller	633.9
Reeves	4634.9	Kinney	1912.3	Frio	1589	McLennan	1485.2	Armstrong	1441.6	Grayson	1371.7	Dallas	1272.8	Bowie	1129.9	Refugio	1001.6	Hood	611.9
Crockett	4428.7	Dimmit	1869.5	Howard	1586.2	Coryell	1480.4	King	1440.8	Jefferson	1362	Calhoun	1264.2	Childress	1125.9	Guadalupe	1001.3	Madison	578.3
Jeff Davis	4372.8	Medina	1869.5	Dawson	1582.5	Jones	1478.3	Liberty	1440	Cochran	1359.9	Tarrant	1264	Harrison	1121.1	Lee	1000.3	Titus	521
Terrell	4136.7	Zavala	1823.5	Midland	1582.5	Winkler	1475.8	Hemphill	1439	Polk	1358.5	Fannin	1259.2	Bandera	1117.3	Lampasas	1000.1	Marion	514.5
Edwards	3344.3	Maverick	1809.6	Ector	1582	Donley	1471.9	Haskell	1436	Llano	1353.1	Cooke	1258.5	Foard	1116.4	Blanco	999.4	Orange	464.6
Kenedy	2725.8	Cameron	1788.2	Crosby	1581.8	Lipscomb	1470.8	Moore	1434.9	Knox	1349.6	Freestone	1249.6	DeWitt	1114.6	Wichita	998.7	Franklin	360.9
Dallam	2640.7	Lamb	1785.3	Glasscock	1580.7	Eastland	1470.1	Travis	1433.1	Wharton	1339.7	Collin	1241.3	Hopkins	1110.6	San Patricio	991.7	Delta	340.2
Gaines	2636.4	Hale	1762.7	Lubbock	1580	Ward	1466.2	Scurry	1431.6	Denton	1335	Hunt	1235.6	Hardeman	1099.4	Grimes	981.3	Gregg	337.6
Oldham	2633.8	Bexar	1759.6	Swisher	1580	Gray	1466	Milam	1431.4	Ellis	1333.2	Jim Wells	1216.4	Hardin	1098.8	Walker	981.2	Rains	316.8
Andrews	2633.3	Kimble	1752.8	Castro	1577.6	Coke	1464	Burnet	1430.7	Comanche	1327.6	Van Zandt	1204.2	Willacy	1098.7	Real	980.7	Morris	316.7
Deaf Smith	2628.6	Floyd	1741.1	Concho	1567.6	Roberts	1458	Dickens	1428	Leon	1322.8	Nacogdoches	1201.2	Bastrop	1096.3	Hays	952.4	Somervell	269
Hartley	2566.8	Starr	1721.8	Lynn	1567.4	Carson	1457.8	Hall	1426.3	Brooks	1322	Colorado	1192	Victoria	1088.1	Kendall	928.8	Camp	248.8
Duval	2515.4	Atascosa	1711.2	Clay	1564.5	Sterling	1456.9	Kent	1424.4	Anderson	1319.7	Lavaca	1187.9	Falls	1084	Trinity	874.1	Rockwall	208.3
Tom Green	2430.2	McCulloch	1693.3	Terry	1562.9	Sherman	1456.4	Menard	1423.4	Montgomery	1318.3	Loving	1187.1	Fort Bend	1083.8	Wood	851.7		
Sutton	2294.4	Zapata	1669.1	Motley	1561.5	Potter	1454.5	Fisher	1422.6	Montague	1314.4	Jasper	1187.1	Bee	1077.6	Burleson	828.5		
Hidalgo	2217.4	Runnels	1667.6	Parmer	1552.9	Hansford	1452	Cottle	1422.3	Gonzales	1309.8	Cass	1175.6	Galveston	1069.7	Comal	805.4		
Uvalde	2183.4	Irion	1659	Kerr	1551.2	Stonewall	1451.7	Briscoe	1422.3	Limestone	1307.3	Fayette	1175	Chambers	1066.5	Austin	803.6		
Upton	2177.9	Nueces	1632.9	Wilbarger	1542.7	Bailey	1451.6	Callahan	1421.8	Mason	1305.9	Hamilton	1171.7	Robertson	1059.4	San Jacinto	768.7		
Harris	2176	McMullen	1620.5	Kleberg	1527.2	Collingsworth	1450.2	Baylor	1421.5	Young	1304.1	Smith	1162.6	Angelina	1058.5	Washington	761.2		

Figure 8. 15: Maximum Energy from Solar Tower system in Texas by counties

8.6.3 Linear Fresnel System

By using Linear Fresnel technology to install a CSP plant per square meter in Texas, the method is to take the ratio of direct solar land to the total land required in Table 8.2 and apply Equation 8.7. as the following:

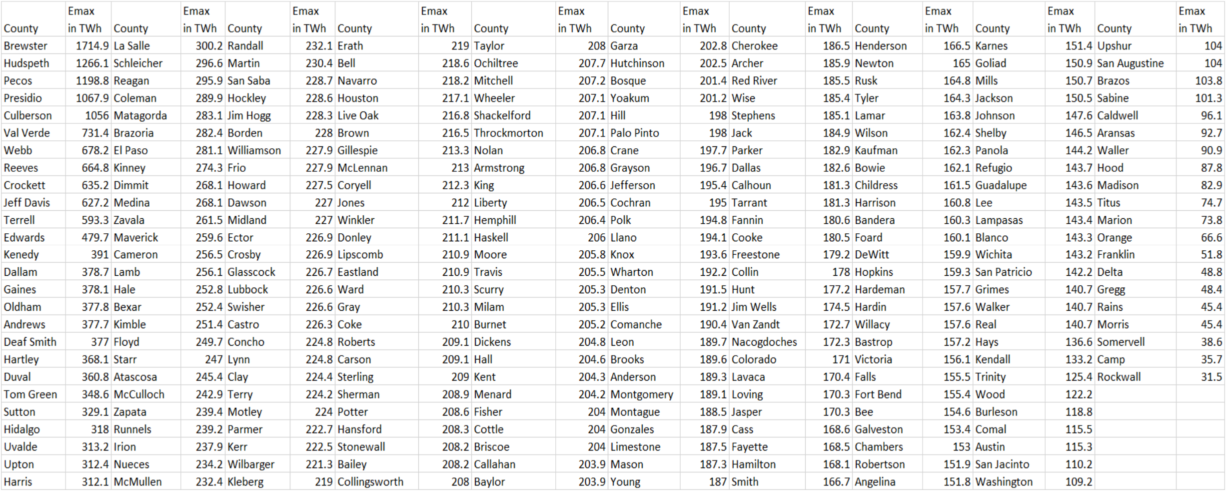
$$E_{Max}(\,Brewster) = DNI_{avg} * A * \eta_{Avg} * ratio * 365$$

$$E_{Max}(\,Brewster)\text{= } 7.65*16{,}038{,}057{,}000*0.09*0.4255*365$$

$$E_{Max}(\,Brewster)\text{= } 1.714 *10^{12} \text{ kWh}$$

$$E_{Max}(\,Brewster)\text{= } 1{,}714.9 \text{ TWh}$$

Texas could power between 54.48 to 61.35 PWh and an average of 57.94 PWh which is almost 13 times more than the electricity consumption in the US. 12 counties in Texas have enough resources to produce more than 450 TWh per year which means one county could power all of Texas by itself based on its resources from CSP from Linear Fresnel technology. The maximum energy could produce in Texas counties varies from 1,714.9 TWh in Brewster county to 31.5 TWh Rockwall county. All results are shown in Figure 8.16.



County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh
Brewster	1714.9	La Salle	300.2	Randall	232.1	Erath	219	Taylor	208	Garza	202.8	Cherokee	186.5	Henderson	166.5	Karnes	151.4	Upshur	104
Hudspeth	1266.1	Schleicher	296.6	Martin	230.4	Bell	218.6	Ochiltree	207.7	Hutchinson	202.5	Archer	185.9	Newton	165	Goliad	150.9	San Augustine	104
Pecos	1198.8	Reagan	295.9	San Saba	228.7	Navarro	218.2	Mitchell	207.2	Bosque	201.4	Red River	185.5	Rusk	164.8	Mills	150.7	Brazos	103.8
Presidio	1067.9	Coleman	289.9	Hockley	228.6	Houston	217.1	Wheeler	207.1	Yoakum	201.2	Wise	185.4	Tyler	164.3	Jackson	150.5	Sabine	101.3
Culberson	1056	Matagorda	283.1	Jim Hogg	228.3	Live Oak	216.8	Shackelford	207.1	Hill	198	Stephens	185.1	Lamar	163.8	Johnson	147.6	Caldwell	96.1
Val Verde	731.4	Brazoria	282.4	Borden	228	Brown	216.5	Throckmorton	207.1	Palo Pinto	198	Jack	184.9	Wilson	162.4	Shelby	146.5	Aransas	92.7
Webb	678.2	El Paso	281.1	Williamson	227.9	Gillespie	213.3	Nolan	206.8	Crane	197.7	Parker	182.9	Kaufman	162.3	Panola	144.2	Waller	90.9
Reeves	664.8	Kinney	274.3	Frio	227.9	McLennan	213	Armstrong	206.8	Grayson	196.7	Dallas	182.6	Bowie	162.1	Refugio	143.7	Hood	87.8
Crockett	635.2	Dimmit	268.1	Howard	227.5	Coryell	212.3	King	206.6	Jefferson	195.4	Calhoun	181.3	Childress	161.5	Guadalupe	143.6	Madison	82.9
Jeff Davis	627.2	Medina	268.1	Dawson	227	Jones	212	Liberty	206.5	Cochran	195	Tarrant	181.3	Harrison	160.8	Lee	143.5	Titus	74.7
Terrell	593.3	Zavala	261.5	Midland	227	Winkler	211.7	Hemphill	206.4	Polk	194.8	Fannin	180.6	Bandera	160.3	Lampasas	143.4	Marion	73.8
Edwards	479.7	Maverick	259.6	Ector	226.9	Donley	211.1	Haskell	206	Llano	194.1	Cooke	180.5	Foard	160.1	Blanco	143.3	Orange	66.6
Kenedy	391	Cameron	256.5	Crosby	226.9	Lipscomb	210.9	Moore	205.8	Knox	193.6	Freestone	179.2	DeWitt	159.9	Wichita	143.2	Franklin	51.8
Dallam	378.7	Lamb	256.1	Glasscock	226.7	Eastland	210.9	Travis	205.5	Wharton	192.2	Collin	178	Hopkins	159.3	San Patricio	142.2	Delta	48.8
Gaines	378.1	Hale	252.8	Lubbock	226.6	Ward	210.3	Scurry	205.3	Denton	191.5	Hunt	177.2	Hardeman	157.7	Grimes	140.7	Gregg	48.4
Oldham	377.8	Bexar	252.4	Swisher	226.6	Gray	210.3	Milam	205.3	Ellis	191.2	Jim Wells	174.5	Hardin	157.6	Walker	140.7	Rains	45.4
Andrews	377.7	Kimble	251.4	Castro	226.3	Coke	210	Burnet	205.2	Comanche	190.4	Van Zandt	172.7	Willacy	157.6	Real	140.7	Morris	45.4
Deaf Smith	377	Floyd	249.7	Concho	224.8	Roberts	209.1	Dickens	204.8	Leon	189.7	Nacogdoches	172.3	Bastrop	157.2	Hays	136.6	Somervell	38.6
Hartley	368.1	Starr	247	Lynn	224.8	Carson	209.1	Hall	204.6	Brooks	189.6	Colorado	171	Victoria	156.1	Kendall	133.2	Camp	35.7
Duval	360.8	Atascosa	245.4	Clay	224.4	Sterling	209	Kent	204.3	Anderson	189.3	Lavaca	170.4	Falls	155.5	Trinity	125.4	Rockwall	31.5
Tom Green	348.6	McCulloch	242.9	Terry	224.2	Sherman	208.9	Menard	204.2	Montgomery	189.1	Loving	170.3	Fort Bend	155.4	Wood	122.2		
Sutton	329.1	Zapata	239.4	Motley	224	Potter	208.6	Fisher	204	Montague	188.5	Jasper	170.3	Bee	154.6	Burleson	118.8		
Hidalgo	318	Runnels	239.2	Parmer	222.7	Hansford	208.3	Cottle	204	Gonzales	187.9	Cass	168.6	Galveston	153.4	Comal	115.5		
Uvalde	313.2	Irion	237.9	Kerr	222.5	Stonewall	208.2	Briscoe	204	Limestone	187.5	Fayette	168.5	Chambers	153	Austin	115.3		
Upton	312.4	Nueces	234.2	Wilbarger	221.3	Bailey	208.2	Callahan	203.9	Mason	187.3	Hamilton	168.1	Robertson	151.9	San Jacinto	110.2		
Harris	312.1	McMullen	232.4	Kleberg	219	Collingsworth	208	Baylor	203.9	Young	187	Smith	166.7	Angelina	151.8	Washington	109.2		

Figure 8. 16: Maximum Energy from Linear Fresnel system in Texas by counties

8.6.4 Parabolic Dish System

By using Parabolic Dish technology to install a CSP plant per square meter in Texas, the method is to take the ratio of direct solar land to the total land required in Table 8.2 and apply Equation 8.7. as the following:

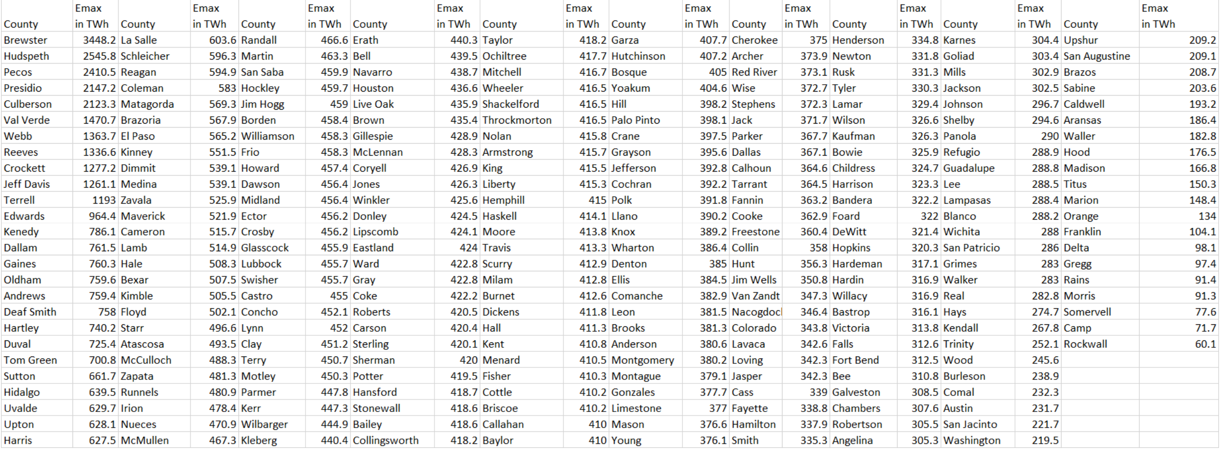
$$E_{Max}(\,Brewster) = DNI_{avg} * A * \eta_{Avg} * ratio * 365$$

$$E_{Max}(\,Brewster) = 7.65*16{,}038{,}057{,}000*0.275*0.28*365$$

$$E_{Max}(\,Brewster) = 3.4482 * 10^{12} \text{ kWh}$$

$$E_{Max}(\,Brewster) = 3{,}448.2 \text{ TWh}$$

Texas could power between 109.66 to 123.35 PWh and an average of 116.51 PWh which is almost 26 times more than the electricity consumption in the US. 73 counties in Texas have enough resources to produce more than 450 TWh per year which means one county could power all of Texas by itself based on its resources from CSP from Parabolic Dish technology. The maximum energy could produce in Texas counties varies from 3,448.2 TWh in Brewster county to 60.1 TWh Rockwall county. All results are shown in Figure 8.17.



County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh	County	Emax in TWh
Brewster	3448.2	La Salle	603.6	Randall	466.6	Erath	440.3	Taylor	418.2	Garza	407.7	Cherokee	375	Henderson	334.8	Karnes	304.4	Upshur	209.2
Hudspeth	2545.8	Schleicher	596.3	Martin	463.3	Bell	439.5	Ochiltree	417.7	Hutchinson	407.2	Archer	373.9	Newton	331.8	Goliad	303.4	San Augustine	209.1
Pecos	2410.5	Reagan	594.9	San Saba	459.9	Navarro	438.7	Mitchell	416.7	Bosque	405	Red River	373.1	Rusk	331.3	Mills	302.9	Brazos	208.7
Presidio	2147.2	Coleman	583	Hockley	459.7	Houston	436.6	Wheeler	416.5	Yoakum	404.6	Wise	372.7	Tyler	330.3	Jackson	302.5	Sabine	203.6
Culberson	2123.3	Matagorda	569.3	Jim Hogg	459	Live Oak	435.9	Shackelford	416.5	Hill	398.2	Stephens	372.3	Lamar	329.4	Johnson	296.7	Caldwell	193.2
Val Verde	1470.7	Brazoria	567.9	Borden	458.4	Brown	435.4	Throckmorton	416.5	Palo Pinto	398.1	Jack	371.7	Wilson	326.6	Shelby	294.6	Aransas	186.4
Webb	1363.7	El Paso	565.2	Williamson	458.3	Gillespie	428.9	Nolan	415.8	Crane	397.5	Parker	367.7	Kaufman	326.3	Panola	290	Waller	182.8
Reeves	1336.6	Kinney	551.5	Frio	458.3	McLennan	428.3	Armstrong	415.7	Grayson	395.6	Dallas	367.1	Bowie	325.9	Refugio	288.9	Hood	176.5
Crockett	1277.2	Dimmit	539.1	Howard	457.4	Coryell	426.9	King	415.5	Jefferson	392.8	Calhoun	364.6	Childress	324.7	Guadalupe	288.8	Madison	166.8
Jeff Davis	1261.1	Medina	539.1	Dawson	456.4	Jones	426.3	Liberty	415.3	Cochran	392.2	Tarrant	364.5	Harrison	323.3	Lee	288.5	Titus	150.3
Terrell	1193	Zavala	525.9	Midland	456.4	Winkler	425.6	Hemphill	415	Polk	391.8	Fannin	363.2	Bandera	322.2	Lampasas	288.4	Marion	148.4
Edwards	964.4	Maverick	521.9	Ector	456.2	Donley	424.5	Haskell	414.1	Llano	390.2	Cooke	362.9	Foard	322	Blanco	288.2	Orange	134
Kenedy	786.1	Cameron	515.7	Crosby	456.2	Lipscomb	424.1	Moore	413.8	Knox	389.2	Freestone	360.4	DeWitt	321.4	Wichita	288	Franklin	104.1
Dallam	761.5	Lamb	514.9	Glasscock	455.9	Eastland	424	Travis	413.3	Wharton	386.4	Collin	358	Hopkins	320.3	San Patricio	286	Delta	98.1
Gaines	760.3	Hale	508.3	Lubbock	455.7	Ward	422.8	Scurry	412.9	Denton	385	Hunt	356.3	Hardeman	317.1	Grimes	283	Gregg	97.4
Oldham	759.6	Bexar	507.5	Swisher	455.7	Gray	422.8	Milam	412.8	Ellis	384.5	Jim Wells	350.8	Hardin	316.9	Walker	283	Rains	91.4
Andrews	759.4	Kimble	505.5	Castro	455	Coke	422.2	Burnet	412.6	Comanche	382.9	Van Zandt	347.3	Willacy	316.9	Real	282.8	Morris	91.3
Deaf Smith	758	Floyd	502.1	Concho	452.1	Roberts	420.5	Dickens	411.8	Leon	381.5	Nacogdocl	346.4	Bastrop	316.1	Hays	274.7	Somervell	77.6
Hartley	740.2	Starr	496.6	Lynn	452	Carson	420.4	Hall	411.3	Brooks	381.3	Colorado	343.8	Victoria	313.8	Kendall	267.8	Camp	71.7
Duval	725.4	Atascosa	493.5	Clay	451.2	Sterling	420.1	Kent	410.8	Anderson	380.6	Lavaca	342.6	Falls	312.6	Trinity	252.1	Rockwall	60.1
Tom Green	700.8	McCulloch	488.3	Terry	450.7	Sherman	420	Menard	410.5	Montgomery	380.2	Loving	342.3	Fort Bend	312.5	Wood	245.6		
Sutton	661.7	Zapata	481.3	Motley	450.3	Potter	419.5	Fisher	410.3	Montague	379.1	Jasper	342.3	Bee	310.8	Burleson	238.9		
Hidalgo	639.5	Runnels	480.9	Parmer	447.8	Hansford	418.7	Cottle	410.2	Gonzales	377.7	Cass	339	Galveston	308.5	Comal	232.3		
Uvalde	629.7	Irion	478.4	Kerr	447.3	Stonewall	418.6	Briscoe	410.2	Limestone	377	Fayette	338.8	Chambers	307.6	Austin	231.7		
Upton	628.1	Nueces	470.9	Wilbarger	444.9	Bailey	418.6	Callahan	410	Mason	376.6	Hamilton	337.9	Robertson	305.5	San Jacinto	221.7		
Harris	627.5	McMullen	467.3	Kleberg	440.4	Collingsworth	418.2	Baylor	410	Young	376.1	Smith	335.3	Angelina	305.3	Washington	219.5		

Figure 8. 17: Maximum Energy from Parabolic Dish system in Texas by counties

As shown in Table 8.5, the Solar Tower system has the highest possible energy due to its high efficiency and the proportion of direct solar energy to land. In contrast, the Linear Fresnel technology has the lowest potential energy and that is due to the lowest efficiency. However, not only Texas, all systems have the capacity to power the entire United States Therefore, before designing a CSP system, more factors should be considered.

Technology	Maximum energy available based on maximum DNI in PWh	Maximum energy available based on maximum DNI in PWh	Maximum energy available based on Average DNI in PWh
Parabolic Trough	139.29	156.677	147.98
Solar Tower	380.28	427.7	404
Linear Fresnel	54.48	61.35	57.94
Parabolic Dish	109.66	123.35	116.51

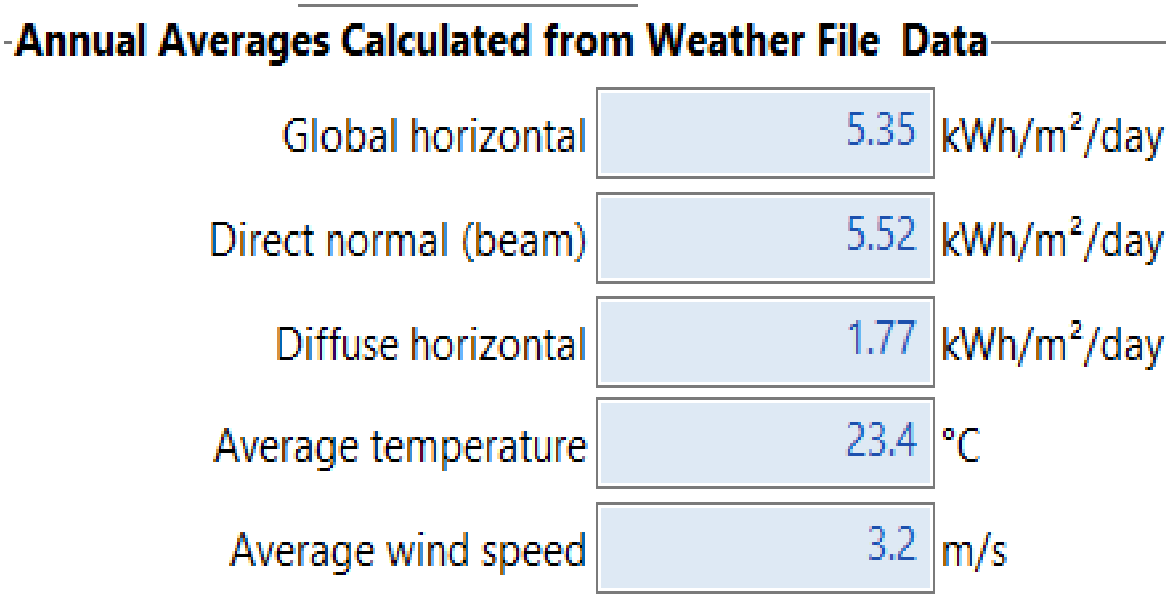
Table 8. 5: Comparison between CSP technologies based on Maximum possible generation

However, the previous results are not practical because it depends on all land in the state of Texas, which is not applicable to apply. Based on 'Brain Post,2021' around 47 % of the land in the US is unhabituated by people. Therefore, in order to obtain more realistic results, a factor of 0.47 is included in the results. Based on this, Texas can provide up to 69.5 PWh based on Parabolic Trough technology,189.88 PWh based on Solar Tower technology,27.23 PWh based on Linear Fresnel technology, and 54.76 PWh based on Parabolic Dish technology. which is still enough to power the entire United States from any of those technologies.

8.7 Proposal System In Edinburg Texas

In this proposal, three CSP systems are discussed in Edinburg, Texas. These three systems come from three different technologies in the CSP factory. However, the CSP system has four different technical parabolic troughs, linear Fresnel, solar tower, and dish parabolic. Dish parabolic systems are not a good idea for storage projects ‘Răboacă et al, 2019’. Moreover, the size of the project depends on Dish parabolic technology does not exceed 25 MW ‘Soomro et al,2019’, hence it is not included in this proposal. The purpose of the proposal is to study the change of power generation from one technology to another and to consider cost and water needed factors in the calculation. All designs have the same capacity of 100 MW, and all results are obtained using NREL's SAM software.

All the following systems are proposed to install in Edinburg Texas which has the following meteorological data as shown in Figure 8.18 ‘SAM,2020’.



Annual Averages Calculated from Weather File Data

Global horizontal 5.35 kWh/m^2/day

Direct normal (beam) 5.52 kWh/m^2/day

Diffuse horizontal 1.77 kWh/m^2/day

Average temperature 23.4 °C

Average wind speed 3.2 m/s

Figure 8. 18: Meteorological data in Texas

8.7.1 Solar Tower Proposal System

100 MW CSP plant based on Solar Tower technology is proposed to install in Edinburg as shown in Figure 8.19 ‘SAM,2020’.

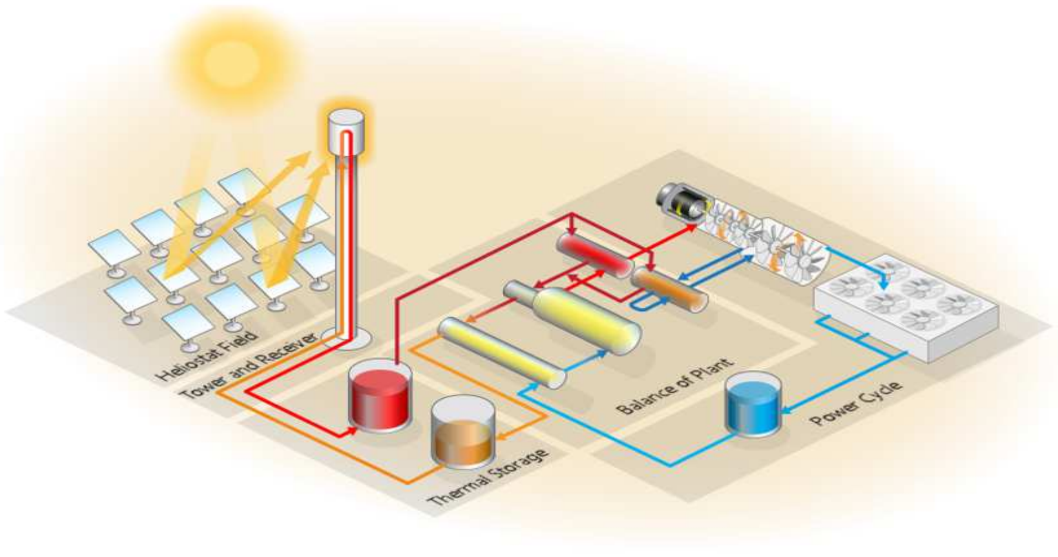


Figure 8. 19: CSP Plant based on Solar Tower technology

According to the number of hours, the storage system capacity was simulated in six ways: 4 hours, 10 hours, 12 hours, 14 hours, and 24 hours without storage at all. Under the 24-hour storage system, the plant generates more energy, which is the largest compared to other solutions. In12 hours of storage design, the power plant has the lowest energy cost at 11.55 cents per kilowatt-hour. The highest capacity factor can be obtained when the storage time is 14 hours, which means that a 100 MW thermal turbine will produce an average of 50 MW on average. In summary, this shows that solar tower factories are the best choice for long-term storage systems. The calculations of the Levelized cost of energy (LCOE) has done using the SAM software based on the following factors: an analysis period of 25 years, Federal Tax is 21% yearly, state income Tax rate is 7% annually, sales tax is 5% from the direct cost, insurance rate is 0.5% yearly and interest rate is 4%. All results are shown in Table 8.6 'SAM,2020'.

Metric	No storage	Storage 4 hours	Storage 10 hours	Storage 12 hours	Storage 14 hours	Storage 24 hours
Annual energy (year 1)	195,107,984 kWh	296,393,248 kWh	385,427,392 kWh	393,010,656kWh	393,842,720 kWh	392,247,392 kWh
Capacity factor (year 1)	24.7%	37.6%	48.9%	49.8%	50.0%	49.8%
Annual Water Usage	71,395 m^3	78,869 m^3	85,338 m^3	85,885 m^3	85,945 m^3	85,850 m^3
Levelized COE (nominal)	25.81 ¢/kWh	17.80 ¢/kWh	14.56 ¢/kWh	14.54 ¢/kWh	14.76 ¢/kWh	16.10 ¢/kWh
Levelized COE (real)	20.49 ¢/kWh	14.13 ¢/kWh	11.56 ¢/kWh	11.55 ¢/kWh	11.72 ¢/kWh	12.78 ¢/kWh

Table 8. 6: Results of 100 MW CSP plants based on Solar Tower technology

8.7.2 linear Fresnel proposal system

It is proposed to install a 100 MW CSP plant based on linear Fresnel technology in Edinburg, Texas. The plant also has different storage capacity options. In the same situation, when the storage capacity is 10 hours, the maximum capacity factor is 31.1% and the most energy is generated. However, with a smaller storage capacity, the CSP plant has the lowest electricity price, and that when the storage size is for 4 hours. The calculations of the Levelized cost of energy (LCOE) has done using the SAM software based on the following factors: an analysis period of 25 years, Federal Tax is 21% yearly, state income Tax rate is 7% annually, sales tax is 5% from the direct cost, insurance rate is 0.5% yearly and interest rate is 4%. All results from this plant as shown in Table 8.7‘SAM,2020’.

Metric	No storage	Storage 4 hours	Storage 10 hours	Storage 12 hours	Storage 14 hours	Storage 24 hours
Annual energy (year 1)	182,542,400 kWh	238,344,832 kWh	244,861,872 kWh	244,789,472 kWh	244,856,880 kWh	243,927,856 kWh
Capacity factor (year 1)	23.2%	30.2%	31.1%	31.0%	31.1%	30.9%
Annual Water Usage	18,175 m^3	22,407 m^3	22,895 m^3	22,894 m^3	22,893 m^3	22,832 m^3
Levelized COE (nominal)	22.74 ¢/kWh	18.77 ¢/kWh	20.10 ¢/kWh	20.71 ¢/kWh	21.31 ¢/kWh	24.42 ¢/kWh
Levelized COE (real)	18.06 ¢/kWh	14.90 ¢/kWh	15.96 ¢/kWh	16.44 ¢/kWh	16.92 ¢/kWh	19.39 ¢/kWh

Table 8. 7: Results of 100 MW CSP plants based on Linear Fresnel technology

8.7.3 Parabolic Trough Proposal System

100 MW CSP plant based on parabolic trough technology is proposed to install in Edinburg as shown in Figure 8.20‘SAM,2020’.

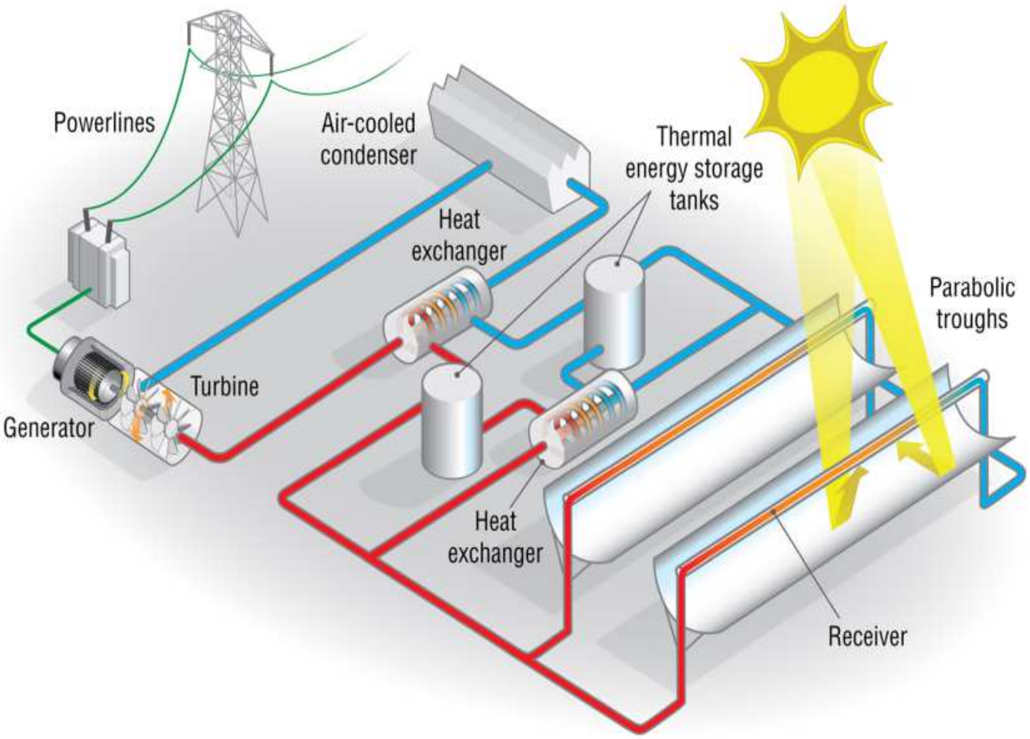


Figure 8. 20: CSP Plant based on Parabolic trough technology

According to the number of hours, the storage system capacity was simulated in six ways: 4 hours, 10 hours, 12 hours, 14 hours, and 24 hours without storage at all. Under the 10-hour storage system, the plant generates more energy, which is the largest compared to other solutions and has the highest capacity factor as well which is 32 %. In 4 hours of storage design, the power plant has the lowest energy cost at 13.81 cents per kilowatt-hour. The calculations of the Levelized cost of energy (LCOE) has done using the SAM software based on the following factors: an analysis period of 25 years, Federal Tax is 21% yearly, state income Tax rate is 7% annually, sales tax is 5% from the direct cost, insurance rate is 0.5% yearly and interest rate is 4%. All results are shown in Table 8.8 'SAM,2020'.

Metric	No storage	Storage 4 hours	Storage 10 hours	Storage 12 hours	Storage 14 hours	Storage 24 hours
Annual energy (year 1)	182,203,680 kWh	245,187,936 kWh	252,035,264 kWh-e	251,388,416 kWh	250,696,496 kWh-e	247,603,040 kWh
Capacity factor (year 1)	23.1%	31.1%	32.0%	31.9%	31.8%	31.4%
Annual Water Usage	57,253 m^3	64,150 m^3	64,939 m^3	64,896 m^3	64,850 m^3	64,673 m^3
Levelized COE (nominal)	19.73 ¢/kWh	17.39 ¢/kWh	20.74 ¢/kWh	22.06 ¢/kWh	23.40 ¢/kWh	30.15 ¢/kWh
Levelized COE (real)	15.66 ¢/kWh	13.81 ¢/kWh	16.46 ¢/kWh	17.52 ¢/kWh	18.58 ¢/kWh	23.94 ¢/kWh

Table 8. 8: Results of 100 MW CSP plants based on Parabolic trough technology

In Edinburg, Texas, a 100-megawatt CSP power plant generates a minimum electricity price of 11.55 cents per kilowatt-hour, and when using solar tower technology, the storage capacity is equal to 12 hours. Generally, for CSP plants with low storage capacity, the parabolic trough system is the best economical choice, and for systems with a storage size of more than 10 hours, solar tower technology is the best. The electricity price of linear Fresnel technology is always higher than that of parabolic and solar tower technology. Therefore, this is not the best choice. Table 8.9 illustrates a comparison of all systems based on the price of electricity generated under different storage capacities.

Metric	No storage	Storage 4 hours	Storage 10 hours	Storage 12 hours	Storage 14 hours	Storage 24 hours
Solar Tower	20.49 ¢/kWh	14.13 ¢/kWh	11.56 ¢/kWh	11.55 ¢/kWh	11.72 ¢/kWh	12.78 ¢/kWh
Linear Fresnel	18.06 ¢/kWh	14.90 ¢/kWh	15.96 ¢/kWh	16.44 ¢/kWh	16.92 ¢/kWh	19.39 ¢/kWh
Parabolic Trough	15.66 ¢/kWh	13.81 ¢/kWh	16.46 ¢/kWh	17.52 ¢/kWh	18.58 ¢/kWh	23.94 ¢/kWh

Table 8. 9: Comparison between the three systems based on the electricity price of energy

8.8 Proposal System From CSP In All Texas

As shown in the previous section, among other technologies with large heat storage capacity, solar tower technology has the lowest electricity price per kilowatt hour. In addition, as mentioned earlier, the efficiency of the solar tower system ranges from 25% to 35%, the highest among all CSP plants. However, The Parabolic Trough CSP plants are dominant in the market and that is due to their lowest price per kWh for low thermal storage size and lowest capital cost compare with Solar Tower technology 'Soomro et al,2019'. Therefore, the Parabolic Trough technology is the option in this proposal.

In this proposed system, it is proposed to install 10 GW in all Texas counties under five different scenarios. Texas counties have five classifications for DNI as shown in Table 8.3. The first scenario is to install an average of 10 GW (39.37 MW per county) across all counties in Texas. Scenario #2 is to focus on classes 2 to 5 and ignore class #1 which has the lowest DNI in Texas, Hence, it is recommended to install an average of 10 GW of CSP in 185 counties (54 MW per county) Scenario 3 is to install all CSP power plants in the first three categories of DNI (category 3, 4 and 5). Therefore, it is recommended to install an average of 10 GW in 102 counties (98 MW per county). In scenario 4, this proposal only includes the first two categories based on DNI, and it is recommended to install 10 GW in 43 counties (232 MW each). In scenario 5, this proposal only includes the first category based on DNI, and it is recommended to install 10 GW in 6 counties (1,667 MW each). All systems have storage system (thermal storage for 6 hours).

8.8.1 Scenario #1

In this scenario, 39.37 MW are proposed to install at every county in Texas, the energy produced depends on the average DNI as the following:

Annual Energy in Brewster = Average DNI* MW rated *365* storage ratio

Annual Energy in Brewster = 7.65 * 39.37 MW *365*1.25

Annual Energy in Brewster = 137.41 GWh

Texas could power up to 26.351 TWh from this scenario. The energy generation varies from 87.11 to 137.41 GWh. All results from this scenario are shown in Figure 8.21.

County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Brewster	137.41	Howard	124.84	Tom Green	112.26	Ochiltree	112.26	Garza	112.26	Starr	99.69	Comanche	99.69	Collin	99.69	Rockwall	99.69	Smith	87.11	Austin	87.11
Hudspeth	137.41	Dawson	124.84	Sutton	112.26	Stonewall	112.26	Hutchinson	112.26	Atascosa	99.69	Ellis	99.69	Hunt	99.69	Harris	87.11	DeWitt	87.11	Wood	87.11
Presidio	137.41	Midland	124.84	Schleicher	112.26	Taylor	112.26	Hall	112.26	McMullen	99.69	Llano	99.69	Nueces	99.69	Brazoria	87.11	Lamar	87.11	Washington	87.11
Culberson	137.41	Glasscock	124.84	Coleman	112.26	Wheeler	112.26	Baylor	112.26	Jim Hogg	99.69	Grayson	99.69	Hamilton	99.69	Houston	87.11	Harrison	87.11	Chambers	87.11
Jeff Davis	137.41	Crosby	124.84	McCulloch	112.26	Shackelford	112.26	Knox	112.26	San Saba	99.69	Montague	99.69	Wilson	99.69	Liberty	87.11	Hardin	87.11	Brazos	87.11
El Paso	137.41	Ector	124.84	Irion	112.26	Throckmorton	112.26	Foard	112.26	Frio	99.69	Mason	99.69	Bandera	99.69	Matagorda	87.11	Bastrop	87.11	Upshur	87.11
Pecos	124.84	Borden	124.84	Runnels	112.26	Nolan	112.26	Childress	112.26	Williamson	99.69	Young	99.69	Kaufman	99.69	Wharton	87.11	Bowie	87.11	San Jacinto	87.11
Reeves	124.84	Lubbock	124.84	Zapata	112.26	Coke	112.26	Hardeman	112.26	Kerr	99.69	Jack	99.69	Hopkins	99.69	Leon	87.11	Victoria	87.11	Caldwell	87.11
Terrell	124.84	Castro	124.84	Motley	112.26	Mitchell	112.26	Lee	112.26	Clay	99.69	Limestone	99.69	Falls	99.69	Gonzales	87.11	Bee	87.11	San Augustine	87.11
Dallam	124.84	Lynn	124.84	Concho	112.26	King	112.26	Wichita	112.26	Erath	99.69	Wise	99.69	Mills	99.69	Anderson	87.11	Jefferson	87.11	Waller	87.11
Gaines	124.84	Swisher	124.84	Wilbarger	112.26	Armstrong	112.26	Webb	99.69	Gillespie	99.69	Parker	99.69	Karnes	99.69	Polk	87.11	Henderson	87.11	Calhoun	87.11
Andrews	124.84	Terry	124.84	Brown	112.26	Potter	112.26	Duval	99.69	Coryell	99.69	Archer	99.69	Johnson	99.69	Cherokee	87.11	Fort Bend	87.11	Sabine	87.11
Oldham	124.84	Parmer	124.84	Lipscomb	112.26	Hemphill	112.26	Hidalgo	99.69	Bell	99.69	Stephens	99.69	Lampasas	99.69	Montgomery	87.11	Robertson	87.11	Madison	87.11
Deaf Smith	124.84	Winkler	124.84	Jones	112.26	Scurry	112.26	Uvalde	99.69	Live Oak	99.69	Cameron	99.69	Guadalupe	99.69	Red River	87.11	Goliad	87.11	Titus	87.11
Hartley	124.84	Ward	124.84	Donley	112.26	Haskell	112.26	La Salle	99.69	McLennan	99.69	Fannin	99.69	Blanco	99.69	Lavaca	87.11	Jackson	87.11	Marion	87.11
Upton	124.84	Bailey	124.84	Eastland	112.26	Kent	112.26	Kenedy	99.69	Milam	99.69	Kleberg	99.69	Real	99.69	Colorado	87.11	Panola	87.11	Galveston	87.11
Reagan	124.84	Yoakum	124.84	Gray	112.26	Menard	112.26	Kinney	99.69	Navarro	99.69	Denton	99.69	San Patricio	99.69	Fayette	87.11	Angelina	87.11	Orange	87.11
Lamb	124.84	Crane	124.84	Roberts	112.26	Dickens	112.26	Dimmit	99.69	Burnet	99.69	Freestone	99.69	Hays	99.69	Nacogdoches	87.11	Shelby	87.11	Franklin	87.11
Hale	124.84	Cochran	124.84	Sterling	112.26	Cottle	112.26	Medina	99.69	Travis	99.69	Cooke	99.69	Kendall	99.69	Jasper	87.11	Grimes	87.11	Gregg	87.11
Floyd	124.84	Loving	124.84	Sherman	112.26	Briscoe	112.26	Zavala	99.69	Bosque	99.69	Dallas	99.69	Willacy	99.69	Cass	87.11	Walker	87.11	Delta	87.11
Martin	124.84	Val Verde	112.26	Carson	112.26	Moore	112.26	Maverick	99.69	Hill	99.69	Jim Wells	99.69	Comal	99.69	Newton	87.11	Refugio	87.11	Aransas	87.11
Randall	124.84	Crockett	112.26	Hansford	112.26	Callahan	112.26	Kimble	99.69	Palo Pinto	99.69	Tarrant	99.69	Hood	99.69	Tyler	87.11	Trinity	87.11	Morris	87.11
Hockley	124.84	Edwards	112.26	Collingsworth	112.26	Fisher	112.26	Bexar	99.69	Brooks	99.69	Van Zandt	99.69	Somervell	99.69	Rusk	87.11	Burleson	87.11	Rains	87.11
																				Camp	87.11

Figure 8. 21: Results from scenario #1 by counties

8.8.2 Scenario #2

In this scenario, 54 MW are proposed to install in 185 counties in Texas, the energy produced depends on the average DNI as the following:

Annual Energy in Brewster = Average DNI* MW rated *365 * storage ratio

Annual Energy in Brewster = 7.65 * 54 MW *365 *1.25

Annual Energy in Brewster = 188.476 GWh

Texas could power up to 27.900 TWh from this scenario. The energy generation varies from 136.74 to 188.48 GWh. All results from this scenario are shown in Figure 8.22.

County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Brewster	188.48	Howard	171.23	Tom Green	153.99	Ochiltree	153.99	Garza	153.99	Starr	136.74	Comanche	136.74	Collin	136.74	Rockwall	136.74
Hudspeth	188.48	Dawson	171.23	Sutton	153.99	Stonewall	153.99	Hutchinson	153.99	Atascosa	136.74	Ellis	136.74	Hunt	136.74		
Presidio	188.48	Midland	171.23	Schleicher	153.99	Taylor	153.99	Hall	153.99	McMullen	136.74	Llano	136.74	Nueces	136.74		
Culberson	188.48	Glasscock	171.23	Coleman	153.99	Wheeler	153.99	Baylor	153.99	Jim Hogg	136.74	Grayson	136.74	Hamilton	136.74		
Jeff Davis	188.48	Crosby	171.23	McCulloch	153.99	Shackelford	153.99	Knox	153.99	San Saba	136.74	Montague	136.74	Wilson	136.74		
El Paso	188.48	Ector	171.23	Irion	153.99	Throckmorton	153.99	Foard	153.99	Frio	136.74	Mason	136.74	Bandera	136.74		
Pecos	171.23	Borden	171.23	Runnels	153.99	Nolan	153.99	Childress	153.99	Williamson	136.74	Young	136.74	Kaufman	136.74		
Reeves	171.23	Lubbock	171.23	Zapata	153.99	Coke	153.99	Hardeman	153.99	Kerr	136.74	Jack	136.74	Hopkins	136.74		
Terrell	171.23	Castro	171.23	Motley	153.99	Mitchell	153.99	Lee	153.99	Clay	136.74	Limestone	136.74	Falls	136.74		
Dallam	171.23	Lynn	171.23	Concho	153.99	King	153.99	Wichita	153.99	Erath	136.74	Wise	136.74	Mills	136.74		
Gaines	171.23	Swisher	171.23	Wilbarger	153.99	Armstrong	153.99	Webb	136.74	Gillespie	136.74	Parker	136.74	Karnes	136.74		
Andrews	171.23	Terry	171.23	Brown	153.99	Potter	153.99	Duval	136.74	Coryell	136.74	Archer	136.74	Johnson	136.74		
Oldham	171.23	Parmer	171.23	Lipscomb	153.99	Hemphill	153.99	Hidalgo	136.74	Bell	136.74	Stephens	136.74	Lampasas	136.74		
Deaf Smith	171.23	Winkler	171.23	Jones	153.99	Scurry	153.99	Uvalde	136.74	Live Oak	136.74	Cameron	136.74	Guadalupe	136.74		
Hartley	171.23	Ward	171.23	Donley	153.99	Haskell	153.99	La Salle	136.74	McLennan	136.74	Fannin	136.74	Blanco	136.74		
Upton	171.23	Bailey	171.23	Eastland	153.99	Kent	153.99	Kenedy	136.74	Milam	136.74	Kleberg	136.74	Real	136.74		
Reagan	171.23	Yoakum	171.23	Gray	153.99	Menard	153.99	Kinney	136.74	Navarro	136.74	Denton	136.74	San Patricio	136.74		
Lamb	171.23	Crane	171.23	Roberts	153.99	Dickens	153.99	Dimmit	136.74	Burnet	136.74	Freestone	136.74	Hays	136.74		
Hale	171.23	Cochran	171.23	Sterling	153.99	Cottle	153.99	Medina	136.74	Travis	136.74	Cooke	136.74	Kendall	136.74		
Floyd	171.23	Loving	171.23	Sherman	153.99	Briscoe	153.99	Zavala	136.74	Bosque	136.74	Dallas	136.74	Willacy	136.74		
Martin	171.23	Val Verde	153.99	Carson	153.99	Moore	153.99	Maverick	136.74	Hill	136.74	Jim Wells	136.74	Comal	136.74		
Randall	171.23	Crockett	153.99	Hansford	153.99	Callahan	153.99	Kimble	136.74	Palo Pinto	136.74	Tarrant	136.74	Hood	136.74		
Hockley	171.23	Edwards	153.99	Collingsworth	153.99	Fisher	153.99	Bexar	136.74	Brooks	136.74	Van Zandt	136.74	Somervell	136.74		

Figure 8. 22: Results from scenario #2 by counties

8.8.3 Scenario # 3

In this scenario, 98MW are proposed to install in 102 counties in Texas, the energy produced depends on the average DNI as the following:

Annual Energy in Brewster = Average DNI* MW rated *365*storage ratio

Annual Energy in Brewster = 7.65 * 98 MW *365*1.25

Annual Energy in Brewster = 342.05 GWh

Texas could power up to 30.037 TWh from this scenario. The energy generation varies from 279.45 to 342.05 GWh. All results from this scenario are shown in Figure 8.23.

County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Brewster	342.05	Martin	310.75	Crane	310.75	Donley	279.45	Potter	279.45	Lee	279.45
Hudspeth	342.05	Randall	310.75	Cochran	310.75	Eastland	279.45	Hemphill	279.45	Wichita	279.45
Presidio	342.05	Hockley	310.75	Loving	310.75	Gray	279.45	Scurry	279.45		
Culberson	342.05	Howard	310.75	Val Verde	279.45	Roberts	279.45	Haskell	279.45		
Jeff Davis	342.05	Dawson	310.75	Crockett	279.45	Sterling	279.45	Kent	279.45		
El Paso	342.05	Midland	310.75	Edwards	279.45	Sherman	279.45	Menard	279.45		
Pecos	310.75	Glasscock	310.75	Tom Green	279.45	Carson	279.45	Dickens	279.45		
Reeves	310.75	Crosby	310.75	Sutton	279.45	Hansford	279.45	Cottle	279.45		
Terrell	310.75	Ector	310.75	Schleicher	279.45	Collingsworth	279.45	Briscoe	279.45		
Dallam	310.75	Borden	310.75	Coleman	279.45	Ochiltree	279.45	Moore	279.45		
Gaines	310.75	Lubbock	310.75	McCulloch	279.45	Stonewall	279.45	Callahan	279.45		
Andrews	310.75	Castro	310.75	Irion	279.45	Taylor	279.45	Fisher	279.45		
Oldham	310.75	Lynn	310.75	Runnels	279.45	Wheeler	279.45	Garza	279.45		
Deaf Smitl	310.75	Swisher	310.75	Zapata	279.45	Shackelford	279.45	Hutchinson	279.45		
Hartley	310.75	Terry	310.75	Motley	279.45	Throckmorton	279.45	Hall	279.45		
Upton	310.75	Parmer	310.75	Concho	279.45	Nolan	279.45	Baylor	279.45		
Reagan	310.75	Winkler	310.75	Wilbarger	279.45	Coke	279.45	Knox	279.45		
Lamb	310.75	Ward	310.75	Brown	279.45	Mitchell	279.45	Foard	279.45		
Hale	310.75	Bailey	310.75	Lipscomb	279.45	King	279.45	Childress	279.45		
Floyd	310.75	Yoakum	310.75	Jones	279.45	Armstrong	279.45	Hardeman	279.45		

Figure 8. 23: Results from scenario #3 by counties

8.8.4 Scenario #4

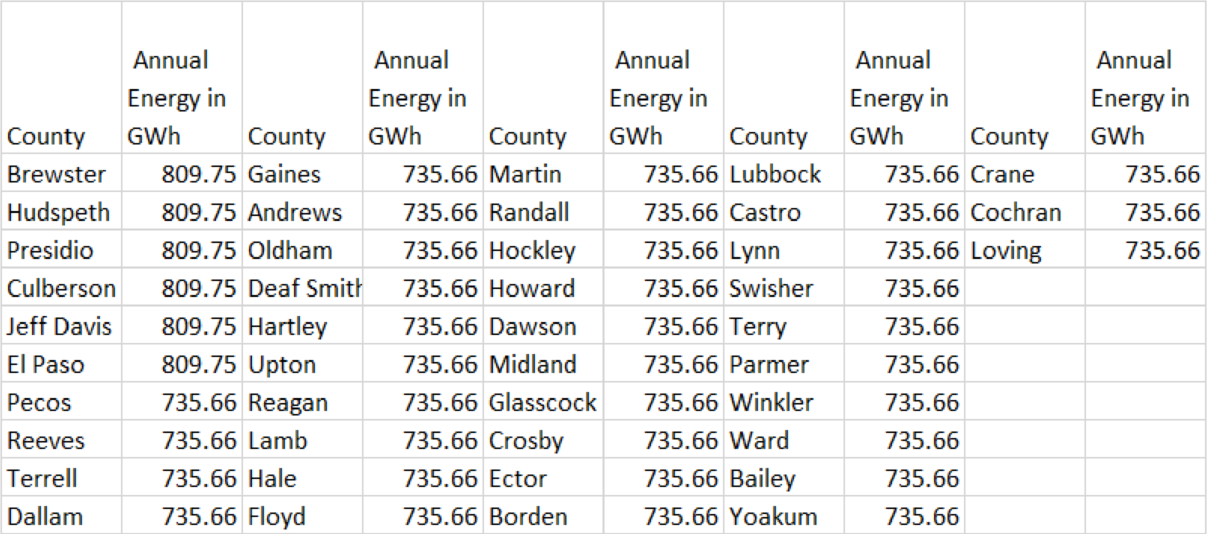
In this scenario, 232MW are proposed to install in 43 counties in Texas, the energy produced depends on the average DNA as the following:

Annual Energy in Brewster = Average DNI* MW rated *365*storage ratio

Annual Energy in Brewster = 7.65 * 232 MW *365*1.25

Annual Energy in Brewster = 809.753 GWh

Texas could power up to 32.077 TWh from this scenario. The energy generation varies from 735.66 to 89.75 GWh. All results from this scenario are shown in Figure 8.24.



County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh	County	Annual Energy in GWh
Brewster	809.75	Gaines	735.66	Martin	735.66	Lubbock	735.66	Crane	735.66
Hudspeth	809.75	Andrews	735.66	Randall	735.66	Castro	735.66	Cochran	735.66
Presidio	809.75	Oldham	735.66	Hockley	735.66	Lynn	735.66	Loving	735.66
Culberson	809.75	Deaf Smith	735.66	Howard	735.66	Swisher	735.66		
Jeff Davis	809.75	Hartley	735.66	Dawson	735.66	Terry	735.66		
El Paso	809.75	Upton	735.66	Midland	735.66	Parmer	735.66		
Pecos	735.66	Reagan	735.66	Glasscock	735.66	Winkler	735.66		
Reeves	735.66	Lamb	735.66	Crosby	735.66	Ward	735.66		
Terrell	735.66	Hale	735.66	Ector	735.66	Bailey	735.66		
Dallam	735.66	Floyd	735.66	Borden	735.66	Yoakum	735.66		

Figure 8. 24: Results from scenario #4 by counties

8.8.5 Scenario #5

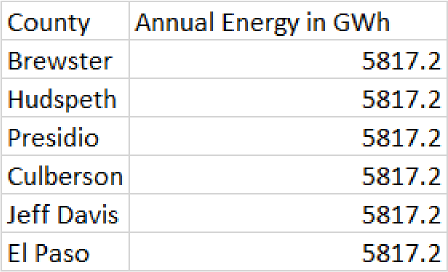
In this scenario, 1,667MW are proposed to install in 6 counties in Texas, the energy produced depends on the average DNA as the following:

Annual Energy in Brewster = Average DNI* MW rated *365*storage ratio

Annual Energy in Brewster = 7.65 * 1,667 MW *365*1.25

Annual Energy in Brewster = 5,817.188 GWh

Texas could power up to 34.903 TWh from this scenario. The energy generation from each county is 5,817 GWh. All results from this scenario are shown in Figure 8.25.



County	Annual Energy in GWh
Brewster	5817.2
Hudspeth	5817.2
Presidio	5817.2
Culberson	5817.2
Jeff Davis	5817.2
El Paso	5817.2

Figure 8. 25: Results from scenario #5 by counties

All previous results for all scenarios are determined based on a CSP plant with parabolic trough technology and storage system for 6 hours, so the energy output will be more with storage system. Scenario # 5 produces 34.903 TWh, which is the highest level among all Scenarios. This is due to the allocability of CSP in the county with the highest DNI in Texas. All results based on Parabolic Trough technology are shown in Table 8.10.

	Energy outputs
Hypothetical results	147.98 PWh
Scenario #1	26.35 TWh
Scenario #2	27.9 TWh
Scenario #3	30.04 TWh
Scenario#4	32.08 TWh
Scenario#5	34.903 TWh

Table 8. 10: Results based on Parabolic Trough technology

CHAPTER IX

OPTIMIZATION SYSTEM

9.1 Electrical Renewable Energy System

The previous chapters discussed six designs and different types of renewable energy. All renewable energy resources are limited, but it depends on geographic location. Hence, in this work the goal is to plan a renewable energy system in Texas, hence Texas has infinity resources from wind and solar energy, or in other words as the results shown in chapters 6,7, and 8 that unlimited resources from Solar and wind energy in terms of CSP, PV, and wind designs are sufficient to meet the electric load required by Texas and more from each system separately. On the other hand, due to the limited resources of biomass and hydropower plants, hence, they are limited resources. Contrasted with previous resources, geothermal energy is more complicated. On the basis of rapid extraction of the heat from the earth which will lead to its consumption and eventually could cause depletion of these resources, geothermal energy is considered to be a limited resource.

In this chapter, the goal is to combine all previous systems in one design. That means picking the required size of the renewable energy system. Texas has 6 resources that can be used according to previous designs. However, some of those resources could be enough to power Texas alone without any combination from the other resources So now the real question is, what is the correct design of all resources. Renewable resources are non-dispatchable recourses, so we cannot use it as the only type of generation, so the combination of renewable energy sources helps to make a combination system from two or more renewable energy system together to increase the efficiency of the whole system and try to make the balance between the generation and the demand. With regard to the importance of renewable energy due to its properties as sustainability and it is a clean resource that pushes us to use it in the best way. Figure 9.1 illustrates the capacity power generation and annual energy generation of the first six designs. Each design has many scenarios and approaches. Therefore, the goal now is to find the best design from all previous systems to plan a renewable grid to meet the needs of Texas.

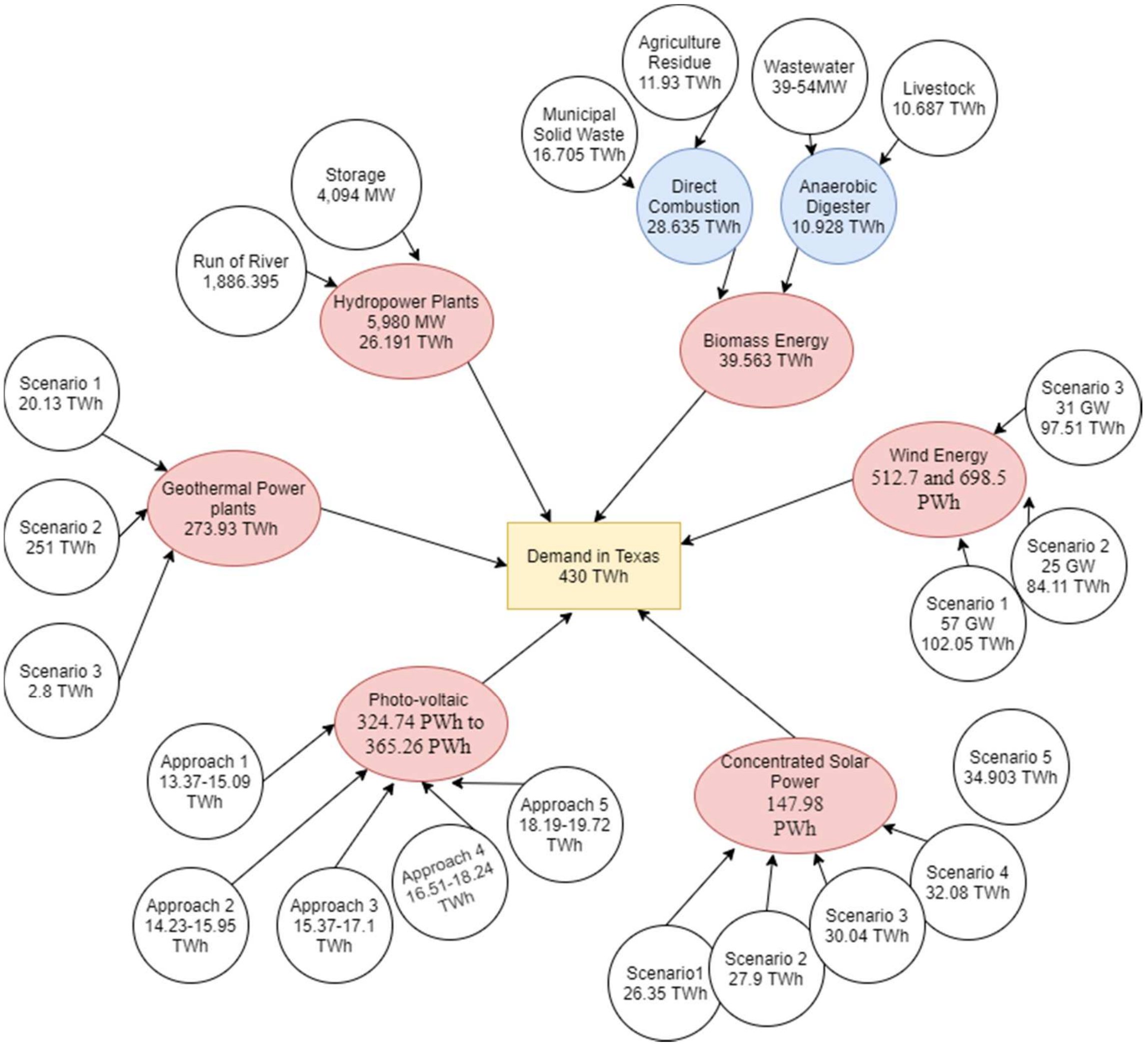


Figure 9. 1: Results from all renewable energy systems

9.2 Optimization Technique

The main goal is to choose the best design of the six renewable systems considering two main factors. The first is to meet the total demand in Texas, and the second is to reduce the annual energy cost. In other words, choose a design that meets the electrical load requirements in an effective economic system. Linear programming is the technique used in this work. However, there are a lot of other optimization techniques such as Genetic algorithms and Particle Swarm.

Linear programming is used in this work due to its simplicity and this method is considered as reliable and has a good convergence characteristic ‘Ebeed et all,2018’.

9.2.1 Linear Programming

Linear programming can be written in many forms. The target function can be to minimize or maximize it. The constraints could be in many forms; inequality (less than or greater than) and equality equations ‘Goemans and Williamson, 1998’.According to ‘Goemans and Williamson, 1998’, Linear programming technique could be written in a polynomial form as the following:

The target function could be minimize or maximize cost represents by C^T

Minimize $C^T x$

Subject to:

$Ax \geq b$

$x \geq 0$

Where:

x is the vector of the output results (the optimal design)

A, b, and c are constants and represent the decision parameters that will determine the output

$(.)^T$ stands for matrix transpose

9.2.2 Simplex Method

The simplex method is one of the famous algorithms of linear programming and it is used in this work. The algorithm is shown in Figure 9.2 ‘Dorrah and Gabr,2009’. The process of the simplex method starts by converting the problem into the standard format of linear programming and then determines whether to maximize or minimize the objective function. The next step is to define the key column, which has more than negative values. Then finding the ratio between the non-negative values on the right side and the positive side in the key column. The key row is the row that has the lowest non-negative percentage. Keep Repeat all the processes until there are no negative numbers in the bottom row.

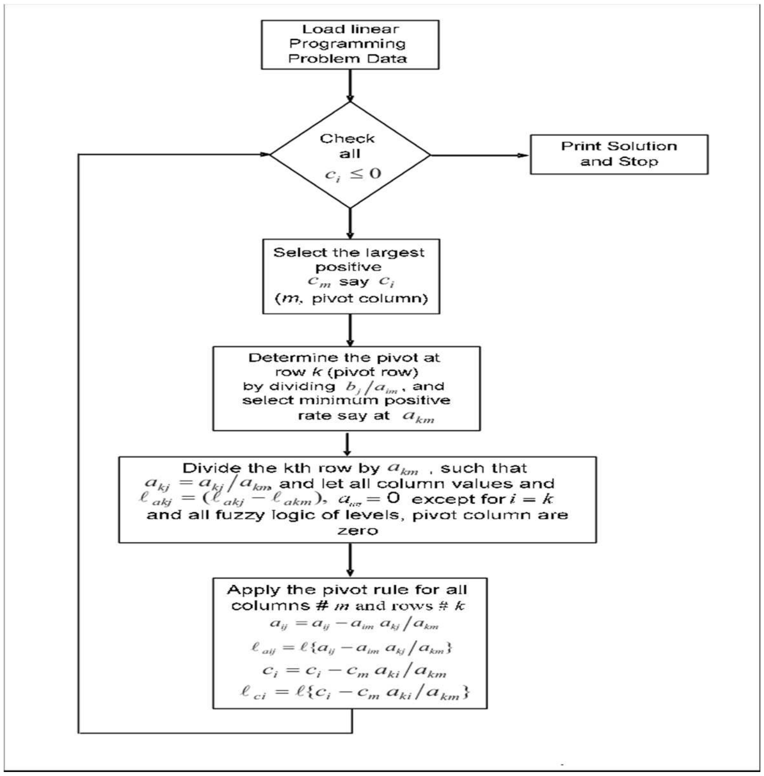


Figure 9. 2: Simplex method algorithm

9.2.3 MATLAB Toolbox

As the simplex method shows, algorithms are experimental methods, so a lot of experimentation is required, which means that it would be better if they were computerized. Therefore, the MATLAB program is used for linear programming based on the simplex method. There are two functions in MATLAB for linear programming and they are Optimvar and linprog.

9.2.3.1 Optimvar

The definition of optimvar function based on ‘optimvar, n.d’ is An optimization variable is a symbolic object that enables you to create expressions for the objective function, and the problem constraints in terms of the variable. The most important feature in this function, It has the ability to write formulaic forms instead of matrix forms. Therefore, constraints can be written in any form that is equal or unequal, regardless of whether the operator is larger or smaller .Hence it is very simple to use.

9.2.3.2 Linprog

The Linprog function is a MATLAB toolbox used to find the minimum value of the objective function by determining the value of the decision variable to solve the linear programming problem. Linprog has the following formula from ‘Linprog,2021’ :

Min $f^T x$ such that

$A. x \leq b$

$Aeq. x = beq$

$lb \leq x \leq ub$

f, x, b, beq, lb, and ub are vectors, and A and Aeq are matrices.

Linear programming has been used in different ways in power systems. According to ‘Ambekar and Mangalvedekar, 2017’ Linear programming is a very accurate method and robust. Linear programming is used to design for picking the size of the generation of the bulk system with respect to electrical constraints from the grid to achieve optimal power operation ‘Chen et al, 1991’.Linear programming is used to design the optimal size of the generation system with respect to the marginal price of the active and reactive power ‘ Seifossadat et al, 2007’.

9.3 Optimization Problem Statement And Formulation

The proposal renewable energy system is shown in Figure 9.3. It has six decision X variables, namely the size of power plants of biomass, hydropower, the photovoltaic, wind, geothermal, and concentrated solar power plants. All the previous decision variables depend on the cost of energy, which is known as the Levelized Cost of energy. There is only one major equality constraint, which depends on the use of capacity factors in calculations to achieve a balance between power generation and demand, and that is due to the annual energy consumption in the electric power. However, there is another constraint and it comes from the peak load which means all systems should be ready to produce at the full rate or to produce enough power to handle the peak load for a short period of time. Finally, all decision variables have side constraints, especially the upper limit of the size of all decision variables. In summation, the initial format of our proposal system depends on the three factors; the capacity factor for each power plant from different, the annual demand energy, and the Levelized Cost of energy for each renewable energy source. The goal is to minimize the cost function which is the annual electricity bill in Texas in order to feed the demand from renewable energy resources in optimal designs .

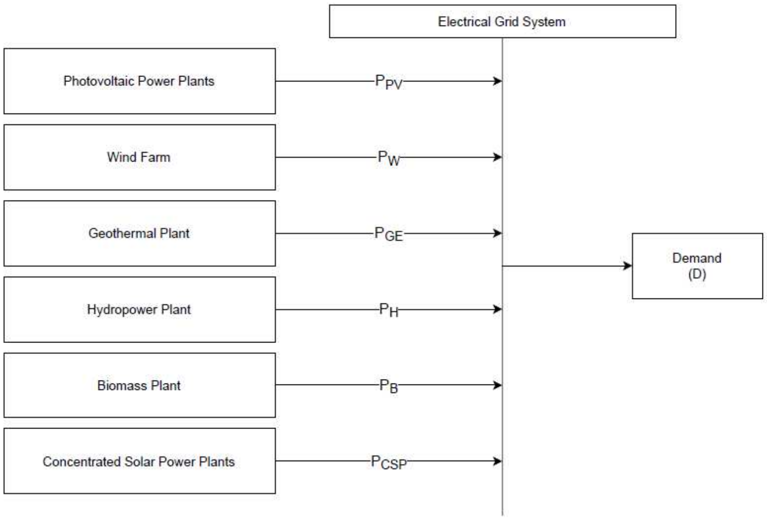


Figure 9. 3: Proposal renewable energy system

So, from all of that, the problem could be written as the following:

Minimize $f(P_{PV},P_W,P_{GE},P_H,P_B,P_{CSP}) = LCOE_{PV}P_{PV}+LCOE_WP_W+LCOE_{GE}P_{GE}+LCOE_HP_H+LCOE_BP_B+LCOE_{CSP}P_{CSP}$ (the objective function)

Subject to:

$CF_{PV}P_{PV}+CF_WP_W+CF_{GE}P_{GE}+CF_HP_H+CF_BP_B+CF_{CSP}P_{CSP} = D_{Avg}$ …….(1) (represent the equality of balance between the annual generation and the demand)

$P_{PV}+P_W+P_{GE}+P_H+P_B+P_{CSP} = D_{Max}$…….(2) (represent the max demand)

Where:

P_{PV} is the size of the Photovoltaic system in MW

P_W is the size of the Wind system in MW

P_{GE} is the size of the Geothermal system in MW

P_H is the size of the Hydropower system in MW

P_B is the size of the Biomass system in MW

P_{CSP} is the size of the Concentrated solar power system in MW

$LCOE_{PV}$ is the levelized cost of energy of the Photovoltaic system

$LCOE_W$ is the levelized cost of energy of the Wind system

$LCOE_{GE}$ is the levelized cost of energy of the Geothermal system

$LCOE_H$ is the levelized cost of energy of the Hydropower system

$LCOE_B$ is the levelized cost of energy of the Biomass system

$LCOE_{CSP}$ is the levelized cost of energy of the Concentrated solar power system

D_{Avg} is the annual average power consumption in Texas in MW

D_{Max} is the peak demand in Texas in MW

CF_{PV} is the capacity factor of the Photovoltaic system

CF_W is the capacity factor of the Wind system

CF_{GE} is the capacity factor of the Geothermal system

CF_H is the capacity factor of the Hydropower system

CF_B is the capacity factor of the Biomass system

CF_{CSP} is the capacity factor of the Concentrated Solar Power system

However, as mentioned in the previous chapters, every system has many scenarios and approaches, so since every system has all the approaches and scenarios inside, the objective function can be written in more detail.

Minimize $f\,(P_{PV},P_{W},P_{GE},P_{H},P_{B},P_{CSP})= LCOE_{PV1}P_{PV1}+ LCOE_{PV2}P_{PV2}+ LCOE_{PV3}P_{PV3}+ LCOE_{PV4}P_{PV4}+ LCOE_{PV5}P_{PV5}+LCOE_{W1}P_{W1}+ LCOE_{W21}P_{W21}+ LCOE_{W22}P_{W22}+ LCOE_{W23}P_{W23}+ LCOE_{W24}P_{W24}+ LCOE_{W25}P_{W25}+ LCOE_{W31}P_{W31}+ LCOE_{W32}P_{W32} +LCOE_{GE1}P_{GE1}+LCOE_{GE2}P_{GE2}+LCOE_{GE3}P_{GE3} +LCOE_{H1}P_{H1} +LCOE_{H2}P_{H2} +LCOE_{B\ Anaerobic}\,P_{B\ Anaerobic} + LCOE_{B\ Combustion}\,P_{B\ Combustion} +LCOE_{CSP1}P_{CSP1} +LCOE_{CSP2}P_{CSP2}+LCOE_{CSP3}P_{CSP3}+LCOE_{CSP4}P_{CSP4} +LCOE_{CSP5}P_{CSP5}$

Subject to:

$CF_{PV1}P_{PV1}+ CF_{PV2}P_{PV2}+ CF_{PV3}P_{PV3}+ CF_{PV4}P_{PV4}+ CF_{PV5}P_{PV5}+ CF_{W1}P_{W1}+ CF_{W21}P_{W21}+ CF_{W22}P_{W22}+ CF_{W23}P_{W23}+ CF_{W24}P_{W24}+ CF_{W25}P_{W25}+ CF_{W31}P_{W31}+ CF_{W32}P_{W32}+ CF_{GE1}P_{GE1}+ CF_{GE2}P_{GE2}+ CF_{GE3}P_{GE3}+ CF_{H1}P_{H1}+ CF_{H2}P_{H2}+ CF_{B\ Anaerobic}\,P_{B\ Anaerobic} + CF_{B\ Combustion}\,P_{B\ Combustion} + CF_{CSP1}P_{CSP1} + CF_{CSP2}P_{CSP2} + CF_{CSP3}P_{CSP3} + CF_{CSP4}P_{CSP4} + CF_{CSP5}P_{CSP5} = D_{Avg}$ ….(1)

$P_{PV1}+ P_{PV2}+ P_{PV3}+ P_{PV4}+ P_{PV5}+ P_{W1}+ P_{W21}+ P_{W22}+ P_{W23}+ P_{W24}+ P_{W25}+ P_{W31}+ P_{W32}+ P_{GE1}+ P_{GE2}+ P_{GE3}+ P_{H1}+ P_{H2}+ P_{B\ Anaerobic} + P_{B\ Combustion} + P_{CSP1} + P_{CSP2} + P_{CSP3} + P_{CSP4} + P_{CSP5} = D_{Max}$ ….(2)

Where:

P_{PV1} is the size of the Photovoltaic system in approach 1in MW

P_{PV2} is the size of the Photovoltaic system in approach 2 in MW

P_{PV3} is the size of the Photovoltaic system in approach 3 in MW

P_{PV4} is the size of the Photovoltaic system in approach 4 in MW

P_{PV5} is the size of the Photovoltaic system in approach 5 in MW

P_{W1} is the size of the Wind system in scenario 1 in MW

P_{W21} is the size of the Wind system in scenario 2 approach 1 in MW

P_{W22} is the size of the Wind system in scenario 2 approach 2 in MW

P_{W23} is the size of the Wind system in scenario 2 approach 3 in MW

P_{W24} is the size of the Wind system in scenario 2 approach 4 in MW

P_{W25} is the size of the Wind system in scenario 2 approach 5 in MW

P_{W31} is the size of the Wind system in scenario 3 approach 1 in MW

P_{W32} is the size of the Wind system in scenario 3 approach 2 in MW

P_{GE1} is the size of the Geothermal system in scenario 1 in MW

P_{GE2} is the size of the Geothermal system in scenario 2 in MW

P_{GE3} is the size of the Geothermal system in scenario 3 in MW

P_{H1} is the size of the Hydropower system in scenario 1 (storage system) in MW

P_{H2} is the size of the Hydropower system in scenario 2 (run of river) in MW

$P_{B\ Anaerobic}$ is the size of the Biomass system from Anaerobic in MW

$P_{B\ Combustion}$ is the size of the Biomass system from Combustion in MW

P_{CSP1} is the size of the Concentrated solar power system in scenario 1 in MW

P_{CSP2} is the size of the Concentrated solar power system in scenario 2 in MW

P_{CSP3} is the size of the Concentrated solar power system in scenario 3 in MW

P_{CSP4} is the size of the Concentrated solar power system in scenario 4 in MW

P_{CSP5} is the size of the Concentrated solar power system in scenario 5 in MW

$LCOE_{PV1}$ is the levelized cost of energy of the Photovoltaic system in approach 1 in \$/MWh

$LCOE_{PV2}$ is the levelized cost of energy of the Photovoltaic system in approach 2 in \$/MWh

$LCOE_{PV3}$ is the levelized cost of energy of the Photovoltaic system in approach 3 in \$/MWh

$LCOE_{PV4}$ is the levelized cost of energy of the Photovoltaic system in approach 4 in \$/MWh

$LCOE_{PV5}$ is the levelized cost of energy of the Photovoltaic system in approach 5 in \$/MWh

$LCOE_{W1}$ is the levelized cost of energy of the Wind system in scenario 1 in \$/MWh

$LCOE_{W21}$ is the levelized cost of energy of the Wind system in scenario 2 approach 1 in \$/MWh

$LCOE_{W22}$ is the levelized cost of energy of the Wind system in scenario 2 approach 2 in \$/MWh

$LCOE_{W23}$ is the levelized cost of energy of the Wind system in scenario 2 approach 3 in \$/MWh

$LCOE_{W24}$ is the levelized cost of energy of the Wind system in scenario 2 approach 4 in \$/MWh

$LCOE_{W25}$ is the levelized cost of energy of the Wind system in scenario 2 approach 5 in \$/MWh

$LCOE_{W31}$ is the levelized cost of energy of the Wind system in scenario 3 approach 1 in \$/MWh

$LCOW_{W32}$ is the levelized cost of energy of the Wind system in scenario 3 approach 2 in \$/MWh

$LCOE_{GE1}$ is the levelized cost of energy of the Geothermal system in scenario 1in \$/MWh

$LCOE_{GE2}$ is the levelized cost of energy of the Geothermal system in scenario 2 in \$/MWh

$LCOE_{GE3}$ is the levelized cost of energy of the Geothermal system in scenario 3 in \$/MWh

$LCOE_{H1}$ is the levelized cost of energy of Hydropower system in storage system in \$/MWh

$LCOE_{H2}$ is the levelized cost of energy of the Hydropower system in run of river in \$/MWh

$LCOE_{B\ Anaerobic}$ is the levelized cost of energy of the Biomass system (Anaerobicb) in \$/MWh

$LCOE_{B\ Combustion}$ is the levelized cost of energy of the Biomass system (Combustion) in \$/MWh

$LCOE_{CSP1}$ is the levelized cost of energy of the CSP system in scenario 1in \$/MWh

$LCOE_{CSP2}$ is the levelized cost of energy of the CSP system in scenario 2in \$/MWh

$LCOE_{CSP3}$ is the levelized cost of energy of the CSP system in scenario 3in \$/MWh

$LCOE_{CSP4}$ is the levelized cost of energy of the CSP system in scenario 4in \$/MWh

$LCOE_{CSP5}$ is the levelized cost of energy of the CSP system in scenario 5in \$/MWh

D_{Avg} is the average power consumption in Texas in MW

D_{Max} is the peak demand in Texas in MW

CF_{PV1} is the capacity factor of the Photovoltaic system in approach 1

CF_{PV2} is the capacity factor of the Photovoltaic system in approach 2

CF_{PV3} is the capacity factor of the Photovoltaic system in approach 3

CF_{PV4} is the capacity factor of the Photovoltaic system in approach 4

CF_{PV5} is the capacity factor of the Photovoltaic system in approach 5

CF_{W1} is the capacity factor of the Wind system in scenario 1

CF_{W21} is the capacity factor of the Wind system in scenario 2 approach 1

CF_{W22} is the capacity factor of the Wind system in scenario 2 approach 2

CF_{W23} is the capacity factor of the Wind system in scenario 2 approach 3

CF_{W24} is the capacity factor of the Wind system in scenario 2 approach 4

CF_{W25} is the capacity factor of the Wind system in scenario 2 approach 5

CF_{W31} is the capacity factor of the Wind system in scenario 3 approach 1

CF_{W32} is the capacity factor of the Wind system in scenario 3 approach 2

CF_{GE1} is the capacity factor of the Geothermal system in scenario 1

CF_{GE2} is the capacity factor of the Geothermal system in scenario 2

CF_{GE3} is the capacity factor of the Geothermal system in scenario 3

CF_{H1} is the capacity factor of the Hydropower system in scenario 1 (storage system)

CF_{H2} is the capacity factor of the Hydropower system in scenario 2 (run of river)

$CF_{B\ Anaerobic}$ is the capacity factor of the Biomass system from Anaerobic

$CF_{B\ Combustion}$ is the capacity factor of the Biomass system from Combustion

CF_{CSP1} is the capacity factor of the Concentrated solar power system in scenario 1

CF_{CSP2} is the capacity factor of the Concentrated solar power system in scenario 2

CF_{CSP3} is the capacity factor of the Concentrated solar power system in scenario 3

CF_{CSP4} is the capacity factor of the Concentrated solar power system in scenario 4

CF_{CSP5} is the capacity factor of the Concentrated solar power system in scenario 5

9.4 Levelized Cost of Energy

Levelized cost of energy is defined in ‘Wikipedia- Levelized cost of energy, 2021’ is the ratio of the total cost of the system over time to the total energy produced as shown in Equations 9.1 ‘Levelized cost of energy, n.d’& 9.2 ‘Masters,2013’.

$$LCOE = \frac{total\ cost\ over\ life\ time}{energy\ produced\ per\ year} \ldots\ldots 9.1$$

However, Equation 9.1 gives the results for only one year of the project while The Levelized Cost of energy over the project time, therefore, the discount rate should take in terms of capital recovery factor which define based on the discount rate and the lifespan of the project as shown in Equation 9.2 ‘Masters,2013’.

$$CRF(i, n) = \frac{i(1+i)^n}{(1+i)^n - 1} \ldots\ldots 9.2$$

Where:

CRF: Capital recovery factor

i: discount rate

n: project years

Therefore, The Levelized Cost of energy can be defined in terms of capacity recovery factor, capital cost, operation and maintenance cost, and annual energy, as shown in Equation 9.3 ‘Masters,2013’.

$$LCOE = \frac{C * CRF + O}{E} \ldots 9.3$$

Where:

LCOE: Levelized Cost of Energy in \$/kWh

C: Capital cost of the project

O: operation and maintenance cost

E: Annual energy in kWh

To calculate LCOE from different renewable energy sources, capital costs and maintenance costs are required, the discount rate is 2%, and the life span is 25 years. The capital cost and maintenance costs for different renewable energy technologies are shown in Table 9.1.

Types of renewable energy source	Capital cost \$ per kW	Maintenance cost \$ per kWh	Maintenance cost \$per kW
Photo-voltaic	1,307 'Alternative Renewables Cost Assumptions in AEO2020,2020'	------	18 'Alternative Renewables Cost Assumptions in AEO2020,2020'
Wind	1,300 'Wind Turbine Cost: How Much? Are They Worth It In 2020?, 2020'	0.01-.02 'Wind Turbine Cost: How Much? Are They Worth It In 2020?, 2020'	42-48 'US wind O&M costs estimated at \$48,000/MW; Falling costs create new industrial uses: IEA ,2017'
Geothermal	Table 4.3	0.01- 0.03'Geothermal Electric Technology ,2016	137.5 'Statista,2021'
Hydropower (storage)	450 'Hydropower ,n.d'	0.04-0.11 ' Hydropower,2010'	42.01 'Statista,2021'
Hydropower (run of river)	600-4,500 'Hydropower, n.d'	0.04-0.11' Hydropower,2010'	------
Biomass (anaerobic digester)	4,104 'Alternative Renewables Cost Assumptions in AEO2020,2020'	------	125.2'Alternative Renewables Cost Assumptions in AEO2020,2020'
Biomass (combustion)	1,557 'Alternative Renewables Cost Assumptions in AEO2020,2020'	------	20.02 'Alternative Renewables Cost Assumptions in AEO2020,2020'
Concentrated Solar Power	3,972 'Soomro et al,2019'	------	85.03 'Alternative Renewables Cost Assumptions in AEO2020,2020'
Battery system	625 'Hoff and Mey ,2020'	------	------

Table 9. 1: The capital cost and maintenance cost for renewable energy resources

Therefore, the CRF will be determined based on Equation 9.2 as the following:

$$CRF(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1}$$

$$CRF = \frac{0.02 * (1+0.02)^{25}}{(1+0.02)^{25} - 1}$$

CRF = 0.05122

The annual electrical energy and the power size from all renewable energy systems are shown in Table 9.2.

Terms	Annual Energy in TWh	Power in GW
PV approach 1	14.2	6.7
PV approach 2	15	6.7
PV approach 3	16.2	6.7
PV approach 4	17.7	6.7
PV approach 5	18.8	6.7
Wind Scenario 1	102	57.7
Wind Scenario 2 approach 1	44.2	25
Wind Scenario 2 approach 2	56.3	25
Wind Scenario 2 approach 3	64.9	25.2
Wind Scenario 2 approach 4	74	25.2
Wind Scenario 2 approach 5	84.1	25.2
Wind Scenario 3 approach 1	78.3	31.1
Wind Scenario 3 approach 2	97.5	31
CSP Scenario 1	26.3	10
CSP Scenario 2	27.9	10
CSP Scenario 3	30	10
CSP Scenario 4	32.0	10
CSP Scenario 5	34.9	10
Hydropower (storage)	17.9	4
Hydropower (Run of river)	8.2	1.8
Biomass (Anaerobic)	10.9	2.1

Biomass (Combustion)	28.6	5.5
Geothermal Scenario 1	20.1	3
Geothermal Scenario 2	251	38.5
Geothermal Scenario 3	2.8	0.429

Table 9. 2: Annual energy and power size from all renewable energy systems

Therefore, the LCOE could be determined as the following:

$$LCOE_{PV1} = \frac{C*CRF+O}{E}$$

$$LCOE_{PV1} = \frac{(6.7*10^6*1307*0.05122)+(6.7*10^6*18)}{15.09*10^9}$$

$LCOE_{PV1}$= 0.0377 \$/kWh

$LCOE_{PV1}$= 37.72 \$/MWh

The LCOE of all renewable energy systems are shown in Table 9.3

Terms	Cost in \$ / MWh
LCOE_{PV1}	39.99
LCOE_{PV2}	37.72
LCOE_{PV3}	35.06
LCOE_{PV4}	32.06
LCOE_{PV5}	30.18
LCOE_{W1}	61.46
LCOE_{W21}	61.46
LCOE_{W22}	48.22
LCOE_{W23}	42.2
LCOE_{W24}	36.99
LCOE_{W25}	32.57
LCOE_{W31}	43.13

LCOE$_{W32}$	34.56
LCOE$_{GE1}$	99.69
LCOE$_{GE2}$	36.82
LCOE$_{GE3}$	61.18
LCOE$_{H1}$	14.85
LCOE$_{H2}$	39.41
LCOE$_{\text{B anaerobic}}$	64.68
LCOE$_{\text{B combustion}}$	39.52
LCOE$_{CSP1}$	109.48
LCOE$_{CSP2}$	103.4
LCOE$_{CSP3}$	96.03
LCOE$_{CSP4}$	89.92
LCOE$_{CSP5}$	82.65

Table 9. 3: LCOE of all renewable energy systems

9.5 Capacity Factor

Capacity factor is defined as the energy generation with respect to the rated power. In other word is the ratio of the total energy to the rated power. Capacity factor could be written as shown in Equation 9.4.

$CF = \frac{Energy\ delivered}{Energy\ at\ full\ power}$ ….9.4 ‘Masters,2013’

Where:

CF: capacity factor

The CF is determined using Equation 9.4 as the following:

$$CF_{PV21} = \frac{15.09 * 10^9}{6.7 * 10^6 * 8760}$$

$CF_{PV21} = 0.257$

The capacity factor of all renewable energy systems is shown in Table 9.4.

Terms	Capacity factor
PV scenario 2 approach 1	0.242
PV scenario 2 approach 2	0.257
PV scenario 2 approach 3	0.277
PV scenario 2 approach 4	0.302
PV scenario 2 approach 5	0.321
Wind Scenario 1	0.202
Wind Scenario 2 approach 1	0.202
Wind Scenario 2 approach 2	0.257
Wind Scenario 2 approach 3	0.294
Wind Scenario 2 approach 4	0.335
Wind Scenario 2 approach 5	0.381
Wind Scenario 3 approach 1	0.287
Wind Scenario 3 approach 2	0.359
CSP Scenario 1	0.301
CSP Scenario 2	0.318
CSP Scenario 3	0.343
CSP Scenario 4	0.366
CSP Scenario 5	0.398
Hydropower (storage)	0.5
Hydropower (Run of river)	0.5
Biomass (Anaerobic)	0.592 ‘Statista,2020’
Biomass (Combustion)	0.592 ‘Statista,2020’
Geothermal Scenario 1	0.744 ‘Statista,2020’
Geothermal Scenario 2	0.744 ‘Statista,2020’
Geothermal Scenario 3	0.744 ‘Statista,2020’

Table 9. 4: Capacity factor of renewable energy systems

9.6 Electricity Demand in Texas

According to ERCOT, the peak demand in Texas occurred in August 2020, as shown in Figure 9.4 ‘Summer 2020 Review,2020’, which was 74,328 MW. However, ERCOT does not cover the entire state of Texas. It covers almost 90% of the load in Texas. Therefore, the demand for this system is based on a peak multiple of 1.1 to cover all of Texas, and a safety factor of 1.1 is also used to avoid any problems caused by insufficient power generation. Therefore, the demand for this system is 90,000 MW. In 2019, The annual energy consumption in Texas was between 429 - 483 TWh ‘Texas Electricity Profile 2019,2020’ Hence, in this study, the largest annual energy consumption was used. Therefore, the average power demand in Texas is 55.136 GW.

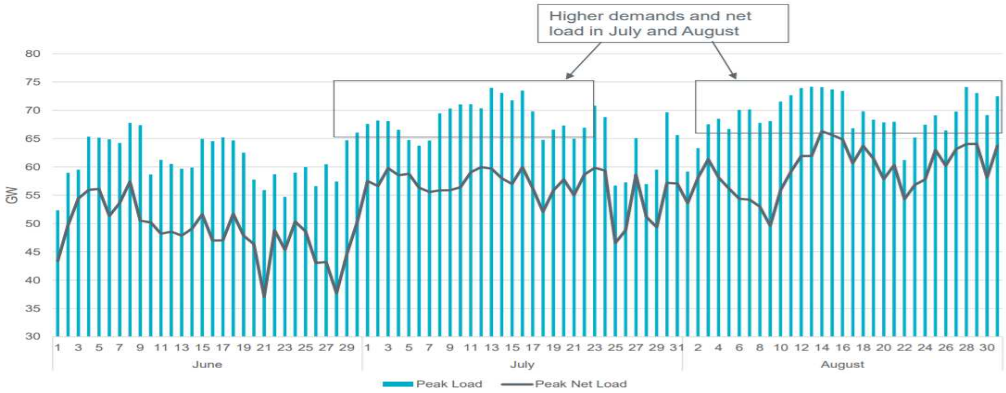


Figure 9. 4: Peak Demand in Texas in 2020

9.7 Side Constraints

In this renewable energy system, there are 6 main types of renewable energy, and 25 systems are provided in different ways. However, most of those scenarios are unlimited but not all of them. Solar and wind energy are unlimited resources, or more precisely, they are enough to provide more electricity for the entire state of Texas. Thus, the upper limit of systems from solar and wind energy (PV, CSP, and wind turbines) is regarded as an infinite resource. As shown in Table 9.5, the edge constraints with higher and lower terms depend on the scheme itself:

Term	Lower term in MW	Upper term in MW
PV scenario 2 approach 1	0	inf
PV scenario 2 approach 2	0	inf
PV scenario 2 approach 3	0	inf
PV scenario 2 approach 4	0	inf
PV scenario 2 approach 5	0	inf
Wind Scenario 1	0	inf
Wind Scenario 2 approach 1	0	inf
Wind Scenario 2 approach 2	0	inf
Wind Scenario 2 approach 3	0	inf
Wind Scenario 2 approach 4	0	inf
Wind Scenario 2 approach 5	0	inf
Wind Scenario 3 approach 1	0	inf
Wind Scenario 3 approach 2	0	inf
CSP Scenario 1	0	inf
CSP Scenario 2	0	inf
CSP Scenario 3	0	inf
CSP Scenario 4	0	inf
CSP Scenario 5	0	inf
Hydropower (storage)	0	4,094
Hydropower (Run of river)	0	1,886
Biomass (Anaerobic)	0	2,107.2
Biomass (Combustion)	0	5,521.68
Geothermal Scenario 1	0	Inf
Geothermal Scenario 2	0	38,512
Geothermal Scenario 3	0	429.6

Table 9. 5: Upper and lower limit for the renewable energy systems

9.8 Numerical Simulations

Therefore, all decision variables are now defined, namely the scale of the renewable energy system. And define the decision-making parameters, namely the capacity factor of the renewable energy system and the fixed capital cost. In addition, the simplest defined constraint represents power demand. Numerical simulation can be written in the following form:

Minimize $f(P_{PV},P_{W},P_{GE},P_{H},P_{B},P_{CSP}) = 39.99P_{PV1} + 37.72P_{PV2} + 35.06P_{PV3} + 32.06P_{PV4} +$

$30.18P_{PV5} + 61.46P_{W1} + 61.46P_{W21} + 48.22P_{W22} + 42.2P_{W23} + 36.99P_{W24} + 32.57P_{W25} +$

$43.13P_{W31} + 34.56P_{W32} + 99.69P_{GE1} + 36.82P_{GE2} + 61.18P_{GE3} + 14.85P_{H1} + 39.41P_{H2} + 64.68P_{B\ Anaerobic} +$

$39.52P_{B\ Combustion} + 109.48P_{CSP1} + 103.4P_{CSP2} + 96.03P_{CSP3} + 89.92P_{CSP4} + 82.65P_{CSP5}$

Subject to:

$0.242P_{PV1} + 0.257P_{PV2} + 0.277P_{PV3} + 0.302P_{PV4} + 0.321P_{PV5} + 0.202P_{W1} + 0.202P_{W21} + 0.257P_{W22} +$
$0.294P_{W23} + 0.335P_{W24} + 0.381P_{W25} + 0.287P_{W31} + 0.359P_{W32} + 0.744P_{GE1} + 0.744P_{GE2} + 0.744P_{GE3} +$
$P_{H1} + P_{H2} + 0.592P_{B\ Anaerobic} + 0.592P_{B\ Combustion} + 0.301P_{CSP1} + 0.318P_{CSP2} + 0.343P_{CSP3} +$
$0.366P_{CSP4} + 0.398P_{CSP5} = 51{,}136$

$P_{PV1} + P_{PV2} + P_{PV3} + P_{PV4} + P_{PV5} + P_{W1} + P_{W21} + P_{W22} + P_{W23} + P_{W24} + P_{W25} + P_{W31} + P_{W32} + P_{GE1} +$
$P_{GE2} + P_{GE3} + P_{H1} + P_{H2+} P_{B\ Anaerobic} + P_{B\ Combustion} + P_{CSP1} + P_{CSP2} + P_{CSP3} + P_{CSP4} + P_{CSP5} = 90{,}000$

$0 \leq P_{PV1} \leq \text{Inf}$

$0 \leq P_{PV2} \leq \text{Inf}$

$0 \leq P_{PV3} \leq \text{Inf}$

$0 \le P_{PV4} \le \mathrm{Inf}$

$0 \le P_{PV5} \le \mathrm{Inf}$

$0 \le P_{W1} \le \mathrm{Inf}$

$0 \le P_{W21} \le \mathrm{Inf}$

$0 \le P_{W22} \le \mathrm{Inf}$

$0 \le P_{W23} \le \mathrm{Inf}$

$0 \le P_{W24} \le \mathrm{Inf}$

$0 \le P_{W25} \le \mathrm{Inf}$

$0 \le P_{W31} \le \mathrm{Inf}$

$0 \le P_{W32} \le \mathrm{Inf}$

$0 \le P_{CSP1} \le \mathrm{Inf}$

$0 \le P_{CSP2} \le \mathrm{Inf}$

$0 \le P_{CSP3} \le \mathrm{Inf}$

$0 \le P_{CSP4} \le \mathrm{Inf}$

$0 \le P_{CSP5} \le \mathrm{Inf}$

$0 \le P_{H1} \le 4{,}094$

$0 \le P_{H2} \le 1886$

$0 \le P_{GE1} \le \mathrm{Inf}$

$0 \leq P_{GE2} \leq 38{,}512$

$0 \leq P_{GE3} \leq 429.6$

$0 \leq P_{B\ Anaerobic} \leq 2{,}107$

$0 \leq P_{B\ Combustion} \leq 5.521$

Use the MATLAB program to find the best design of the previous model using the code shown in Annex 1. The optimal design is shown in Table 9.6.

Term	Optimal design in MW
PV scenario 2 approach 1	0
PV scenario 2 approach 2	0
PV scenario 2 approach 3	0
PV scenario 2 approach 4	0
PV scenario 2 approach 5	33,343
Wind Scenario 1	0
Wind Scenario 2 approach 1	0
Wind Scenario 2 approach 2	0
Wind Scenario 2 approach 3	0
Wind Scenario 2 approach 4	0
Wind Scenario 2 approach 5	6,646
Wind Scenario 3 approach 1	0
Wind Scenario 3 approach 2	0
CSP Scenario 1	0
CSP Scenario 2	0
CSP Scenario 3	0
CSP Scenario 4	0
CSP Scenario 5	0
Hydropower (storage)	4,094

Hydropower (Run of river)	1,886
Biomass (Anaerobic)	0
Biomass (Combustion)	5,522
Geothermal Scenario 1	0
Geothermal Scenario 2	38,512
Geothermal Scenario 3	0
Total Capacity of the system	90,000

Table 9. 6: Optimal design

The previous results are preliminary results, not final results. However, the first trend that can be noticed is that the previous model can be simplified. This is because of the lowest cost of solar and wind energy based on the scheme. In addition, the geothermal system in design 1 is still theoretical due to the need for exploration and drilling research. Therefore, it will be ignored in the calculation. The simple model is as follows:

Minimize $f(P_{PV},P_{W},P_{GE},P_{H},P_{B},P_{CSP})=$

$30.18P_{PV}+ 32.57P_{W25}+99.69P_{GE1}+36.82P_{GE2}+61.18P_{GE3} +14.85P_{H1} +39.41P_{H2} +64.68P_{B\ Anaerobic}+ 39.52P_{B\ Combustion} +82.65P_{CSP}$

Subject to:

$0.321P_{PV} + 0.381P_{W}+ 0.744P_{GE1}+ 0.744P_{GE2}+ 0.744P_{GE3}+ P_{H1}+ P_{H2}+ 0.592P_{B\ Anaerobic} + 0.592P_{B\ Combustion} +0.398P_{CSP} = 51,136$

$0 \le P_{PV} \le \text{Inf}$

$0 \le P_{W} \le \text{Inf}$

$0 \leq P_{CSP} \leq$ Inf

$0 \leq P_{H1} \leq 4{,}094$

$0 \leq P_{H2} \leq 1886$

$0 \leq P_{GE1} \leq$ Inf

$0 \leq P_{GE2} \leq 38{,}512$

$0 \leq P_{GE3} \leq 429.6$

$0 \leq P_{B\ Anaerobic} \leq 2{,}107$

$0 \leq P_{B\ Combustion} \leq 5.521$

9.9 Trends In The Electricity Load In Texas

In 2020, based on ERCOT, The average electricity load in ERCOT zone in Texas is 43.4 GW, and roughly for the whole Texas state is 47.74 GW. However, the average electricity load per month is different. August is the peak month in Texas due to the electricity load with an average of around 60.374 GW and April is the lowest month due to average electricity demand of 41.1 GW. The maximum electricity load could reach up to 81 GW in July and August. However, in 2020, there were 2,218hours, where the electricity load was more than 52.48 GW which forms 25 % of the total time of the system. As shown in Figure 9.5 ‘Load ,2021’.

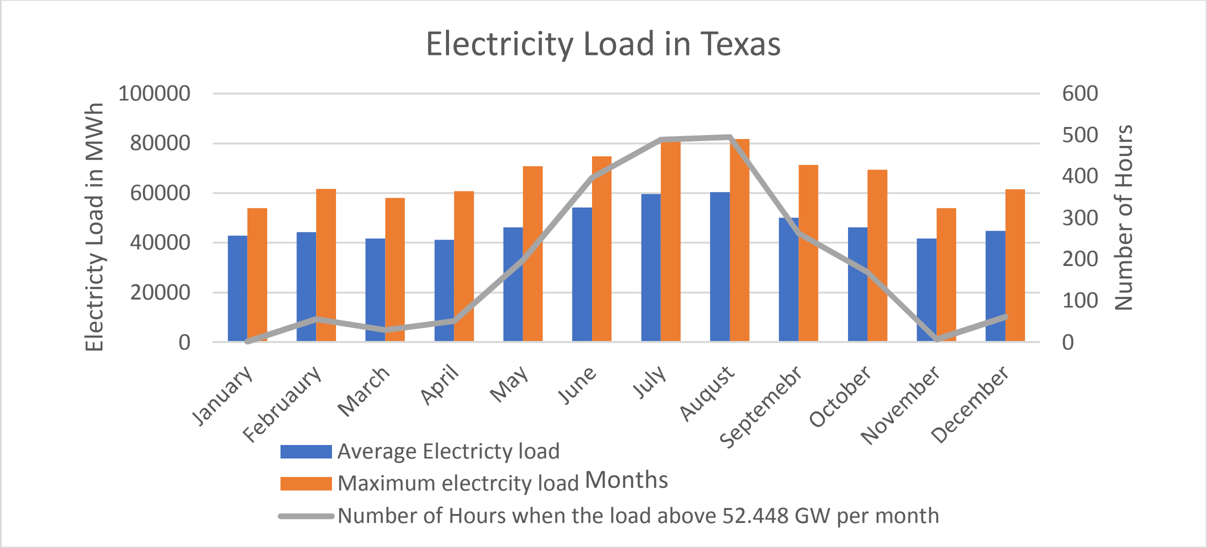


Figure 9. 5: Electricity Load in Texas in 2020

The definition of the peak load-interval in this work is when the load is greater than 52 GWh (which equals to the maximum capacity of the limited resources: Geothermal;, Biomass, and Hydropower) for the most number of hours in a row. The peak time interval varies from one month to another. January is the lowest month of 2020, with only one hour and 53.9 GWh. On the other hand, August has the longest interval peak load at 44 hours and 2.8 TWh. All month's data and the peak load-interval are shown in Figure 9.6 ‘Load ,2021’.

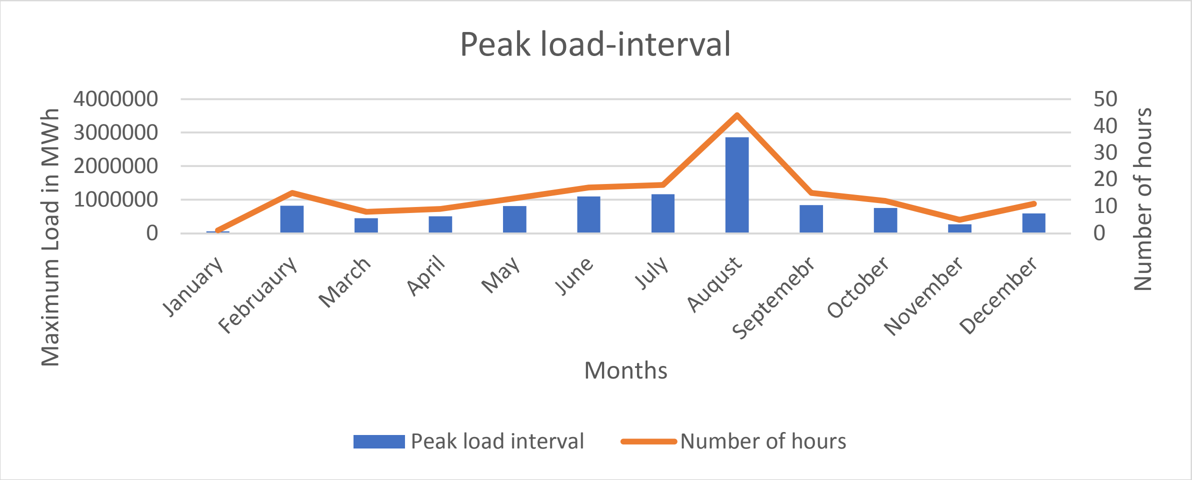


Figure 9. 6: Electricity Load in Texas in 2020

9.10 Storage System

Table 9.6 shows the optimal design, which is the optimal size of the Texas renewable energy system based on electricity prices in order to achieve a balance between annual demand and power generation. Not only that but to maintain maximum demand. In spite of that. Because of the fact that the natural characteristics of solar and wind energy come from, the previous results of this system can be described as an unreliable system. In other words, The sun is not available almost for 4380 hours annually (half of the year) and the wind speed could be lower than 3.5 m/s or above 25 m/s at any moment without the ability to predict that. Hence, the size of the proposed renewable energy system will fail to supply the demand at a certain time even if that could happen only for few hours in the year. Hence, the storage system is the option to compensate for the differences between the generation side and the demand in the absence of wind and sun energy. The traditional storage system depends on the electric batteries that charge from the wind farm and the PV farm. The geothermal, Biomass, and Hydropower systems represent the base load which equals 52.4 GW as shown in Table 9.6. Hence, the peak load could reach more than 81 GW. Thus, the battery bank is used to keep the balance between the generation and demand. In 2020, Texas consumed around 22 TWh above the baseload (52.4 GW) and the peak load-interval was 44 hours and 2.8 TWh in that period. The methodology of the storage system is shown in the flowchart in Figure 9.7.The storage system also needs to be charged from renewable energy sources, so PV and wind farms must be used. To achieve a higher level of reliability for this system, the storage system should compensate for the differences between the load and generation without depending on the Solar energy (PV +CSP) and the wind energy for the longest peak load-interval, which is in Texas 44 hours. This will make the storage system's capacity so huge, but it will make the system safe and reliable and avoid any power outages due to lack of power generation. The relation between the storage system energy and the capacity of the PV and wind are used to charge it is shown in Equation 9.5. The annual power generation of photovoltaic and wind power plants should be greater than 1.1 times the total energy storage. The coefficient 1.1 refers to the loss during charging, which depends on the efficiency of the storage system, which is assumed to be 90% in this study.

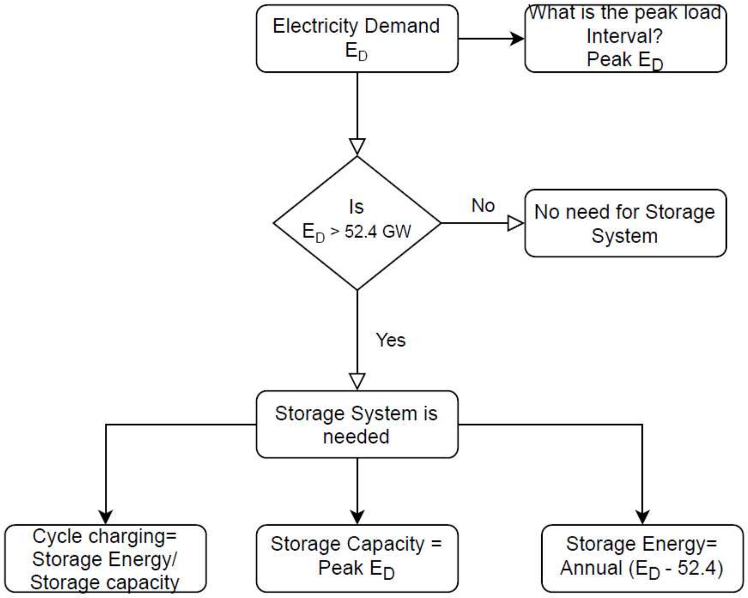


Figure 9. 7: Flowchart of the Storage system

$CF_{PV}P_{PV}+CF_{W}P_{W} \geq 1.1 * (E_{SPV} + E_{SW})$ ………………9.5

Where:

E_{SPV}: is the annual storage energy that charged from PV in GWh

E_{SW}: is the annual storage energy that charged from Wind in GWh

In order to express the problem in the form of optimization techniques, the Levelized Cost of Energy of storage system energy should be determined as follows based on Equations 9.2 & 9.3:

$$LCOE_{SPV} = \frac{C*CRF+O}{E}$$

$$LCOE_{SPV} = \frac{(625*0.05122)+(0.030*40*1.1)}{40}$$

$LCOE_{SPV}$ = 0.833 \$/kWh

$LCOE_{SPV}$= 833.31 \$/MWh

$$LCOE_{SW} = \frac{C*CRF+O}{E}$$

$$LCOE_{SW} = \frac{(625*0.05122)+(0.0325*40*1.1)}{40}$$

$LCOE_{SW}$ = 0.836 \$/kWh

$LCOE_{SW}$ = 836.0 \$/MWh

In order to design a more reliable renewable energy system to supply the electricity demand in Texas, 37 constraints are added to the problem to solve it. The main constraint, which is common from the previous model is the annual electricity demand. The following 12 constraints are about the average electricity consumption every month in the year. The next 12 constraints are about the maximum peak load for each month. Then, the next 12 constraints are about the peak interval load for each month. The last constraints are about the relation between the storage system from one side and on the other side the wind turbine and PV plants. To paraphrase, the storage system is the panacea to compensate for the mismatch between the renewable energy resources and the electricity demand at the peak load based on four main constraints: the annual load, average monthly load, monthly peak load, and the peak interval load monthly as the following:

Minimize f (P_{PV},P_W,P_{GE},P_H,P_B,P_{CSP})=

$30.18P_{PV}+ 32.57P_W+99.69P_{GE1}+36.82P_{GE2}+61.18P_{GE3} +14.85P_{H1} +39.41P_{H2} +64.68P_{B\ \text{Anaerobic}}+$

$39.52P_{B\ \text{Combustion}} +82.65P_{CSP} + 833E_{SPV} +836E_{SW}$

Subject to:

$0.321*8760*P_{PV} + 0.381*8760*P_W+ 0.744*8760*P_{GE2}+ 0.744*8760*P_{GE3}+ 8760*P_{H1}+ 8760*P_{H2}+ 0.592*8760*P_{B\ \text{Anaerobic}} + 0.592*8760*P_{B\ \text{Combustion}} +0.398*8760*P_{CSP} +40*(E_{SPV} +E_{SW})= 483*10^6$

$$\sum_{i=1}^{12} 0.321 * P_{PV} + 0.381 * P_W + 0.398 * P_{CSP} + 0.744 * P_{GE2} + 0.744 * P_{GE3} + P_{H1} + P_{H2} + 0.592 * P_{PB\ \text{Anaerobic}} + 0.592 * P_{\text{B Combustion}} + \text{ESPV} + \text{ESW} = P_{monthly}$$

$$\sum_{i=1}^{12} P_{GE2} + P_{GE3} + P_{H1} + P_{H2} + P_{\text{B Anaerobic}} + P_{B\ Combustion} + E_{SPV} + E_{SW} = P_{Peak\ Monthly}$$

$$\sum_{i=1}^{12} t * P_{GE2} + t * P_{GE3} + t * P_{H1} + t * P_{H2} + t * P_{PB\ \text{Anaerobic}} + t * P_{B\ Combustion} + E_{SPV} + E_{SW} = E_{Peak\ Monthly}$$

$$0.321 * 8760 * P_{PV} \geq 1.1 * 40 * E_{SPV}$$

$$0.381 * 8760 * P_W \geq 1.1 * 40 * E_{SW}$$

Where:

i: the month of the year (January=1, …,December=12)

t: The number of hours of the peal load interval during the month.

To solve the above optimization problem, the MATLB code in Annex 2 are used, and the results are the following as shown in Table 9.7:

System	P_{PV}	P_W	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	P_B Anaerobic	P_B Combustion	E_S	Total Power
Size in MW	8,700	34,500	0	38,500	429	4,000	1,800	2,000	5,500	558.1 GWh	95,400

Table 9. 7: The optimal design of the storage system

In the previous design, the storage system was too large, with a capacity of 558 GWh. However, the storage system is designed based on the traditional battery system. In chapter 8, It shows the CSP technology that could use the thermal storage system which could be a way to decrease the capacity of the storage system. In this system, the CSP is only used to generate electricity at the peak time hours or especially between 4-10 PM. The storage system in the CSP plants should use during the same day and it will not postpone to the next day. However, the generation at the peak load will lead to a decrease in the normal storage capacity. In spite of that, To maintain the higher level of reliability achieved in the previous design. Thus, this design should have a traditional power storage system to avoid the unbalance between the generation and demand in the peak time which could come from the absence of the sun for a day especially in the winter months (October- February). Therefore, the LCOE of the CSP system will be changed due to the delay in the generation from the intermediate time to the peak hours. In order to achieve this goal, the capacity of the turbine will be doubled, and the thermal storage system will also be doubled. Hence, the LCOE of the CSP will be doubled from 82.65 $/MWh to 165.3

\$/MWh. Compared with the previous design, the form of the optimization problem is almost the same. It will keep the five main constraints from the previous model, which are: annual energy consumption, the average monthly consumption, maximum peak load, peak load during the longest interval each month, and the correlation between the storage systems and the wind and PV power plants. In addition, because the availability of CSP comes from the thermal storage system, the generation of CSP will be added to peak hours. Therefore, the optimization problem could be written as the following:

Minimize f (P_{PV},P_W,P_{GE},P_H,P_B,P_{CSP})=

$30.18P_{PV}+ 32.57P_W+99.69P_{GE1}+36.82P_{GE2}+61.18P_{GE3} +14.85P_{H1} +39.41P_{H2} +64.68P_{B\ Anaerobic}+ 39.52P_{B\ Combustion} +165.3P_{CSP} + 833E_{SPV} +836E_{SW}$

Subject to:

$0.321*8760*P_{PV} + 0.381*8760*P_W+ 0.744*8760*P_{GE2}+ 0.744*8760*P_{GE3}+ 8760*P_{H1}+ 8760*P_{H2}+ ..+0.592*8760*P_{B\ Anaerobic} + 0.592*8760*P_{B\ Combustion} +0.398*8760*P_{CSP} +40*(E_{SPV} +E_{SW}) = 483*10^6$

$$\sum_{i=1}^{12} 0.321 * P_{PV} + 0.381 * P_W + 0.398 * P_{CSP} + 0.744 * P_{GE2} + 0.744 * P_{GE3} + P_{H1} + P_{H2} + 0.592 * P_{PB\ \mathrm{Anaerobic}} + 0.592 * P_{\mathrm{B\ Combustion}} + \mathrm{ESPV} + \mathrm{ESW} = P_{monthly}$$

$$\sum_{i=1}^{12} P_{GE2} + P_{GE3} + P_{H1} + P_{H2} + P_{\mathrm{B\ Anaerobic}} + P_{B\ Combustion} + E_{SPV} + E_{SW} + P_{CSP} = P_{Peak\ Monthly}$$

$$\sum_{i=1}^{12} t * P_{GE2} + t * P_{GE3} + t * P_{H1} + t * P_{H2} + t * P_{\mathrm{PB\ Anaerobic}} + t * P_{B\ Combustion} + E_{SPV}$$

$$+ E_{SW} + 6 * P_{CSP} = E_{Peak\ Monthly}$$

$$0.321 * 8760 * P_{PV} \geq 1.1 * 40 * E_{SPV}$$

$$0.381 * 8760 * P_{W} \geq 1.1 * 40 * E_{SW}$$

To solve the above optimization problem, the MATLB code in Annex 3 are used, and the results are the following as shown in Table 9.8:

System	P_{PV}	P_W	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	$P_{B\ \mathrm{Anaerobic}}$	$P_{B\ \mathrm{Combustion}}$	E_S	Total Power
Size in MW	1,800	15,800	36,600	38,500	429.6	4,000	1,800	2,000	5,500	118.3 GWh	106.246

Table 9. 8: The optimal design of the storage system based on CSP

9.11 Summary

Three design schemes were proposed to integrate the renewable resources of Texas into a power grid to meet the power needs of Texas. The first design is the simplest one and it has a capacity of 90 GW, however, it is not a secure and reliable system and it could fail to keep the balance between the demand and the generation sides especially under abnormal weather conditions such as storms, hurricanes, or even the absence of the sun for days. Even so, the system may be the most economically efficient. If a few hours of nuclear reactors or even natural gas turbines are integrated into the grid as a backup power plant within a year, this system may be the best choice. Contrary to the first system, the second design is safe and reliable. Even in the worst cases, the second design has enough resources to maintain the balance between power generation and load. This is due to the use of large-capacity storage. However, it is very expensive and complicated due to the batteries. The total capacity of the system without batteries is 96 GW, and the battery storage capacity is 558.1 GWh. The third design is a compromise between the first and second designs to achieve a safe and reliable power supply system, and it is also economically effective. The third design is also applicable to all renewable energy systems with storage systems. The total capacity of the system is 107 GW, excluding the storage system and battery system with a capacity of 118.3 GWh. All design for the all three design is shown in Table 9.9.

System	P_{PV} In GW	P_{W} In GW	P_{CSP} In GW	P_{GE2} In GW	P_{GE3} In GW	P_{H1} In GW	P_{H2} In GW	$P_{B\ Anaerobic}$ In GW	$P_{B\ Combustion}$ In GW	E_{S} In GWh
Design 1(no storage)	33.3	6.6	0	38.5	0	4	1.8	0	5.5	0
Design 2(traditional storage)	8.7	34.5	0	38.5	0.4	4	1.8	2.	5.5	558.1
Design 3(traditional storage + CSP)	1.8	15.8	36.6	38.5	0.4	4	1.8	2.	5.5	118.3

Table 9. 9: The optimal designs of the renewable energy power system in Texas

CHAPTER X

SMART GRID AND MICROGRID

10.1 What Is The Smart Grid And Microgrid?

Smart Grid is a new concept for the electrical grid which does not have a clear definition ‘Ekanayake et al, 2012’. A smart grid could be considered as an electric grid with different generation technologies. It also could be an electrical grid where the is a communication system to communicate between the load and generation using the internet ‘Bansal and Singh,2016’. Smart metering is also attached with the concept of the smart grid, hence, there are a lot of definitions for a smart grid. However, based on ‘Ekanayake et al, 2012’ a smart grid could achieve one of the following terms: First, communicate between the customer, and the power station through smart metering to maintain a quick response of the power station based on load behavior. Second, The microgrid concept, the storage system, and the non-traditional electricity generation form a major part of the system. Thirdly, the smart grid has a positive impact on the environment and less harmful compared with the traditional power system to fewer greenhouse gas emissions. Finally, the smart grid has a higher level of reliability and stability. Microgrid could be defined based on ‘Ray and Biswal,2020’ as a low voltage grid-connected in the distribution side with a distributed generator, in addition to a renewable energy source and storage system. Microgrids need a smart controllable system to communicate between the grid from one side and the generation side or storage to match with the requirements of the grid ‘Ray and Biswal,2020’.However, the microgrid has two operating options: island mode, which is not connected to the grid and operates independently of the grid; the second option is connected to the grid and compatible with the grid which knows as conjunction mode ‘Ray and Biswal,2020’. The microgrid requires very smart control and protection systems ‘Ray and Biswal,2020’. The purpose of that smart control and protection system is the potential issues that come with the smart grid which is based on ‘Ray and Biswal,2020’ are the following: bidirectional power flow, short circuit capacity, stability, intermittent output, and protection coordination issue. In summation, microgrid and smart grid are related concepts, but microgrid is usually a low-voltage system, which is connected to the power distribution side. On the other hand, the smart grid is a broader connection. It discusses the entire power system, including all parts of power generation, transmission, and distribution.

10.2 Smart Power System Vs Traditional Power system

Figure 10.1 ‘Ekanayake et al, 2012’ shows the traditional power system which has a generation part that is usually located in the remote area, then there is the transmission system which is usually in the high voltage and transmits the power to the distribution side which is located beside the load. The control system maintains the balance between power generation and load, and realizes the best operation of the power generation unit according to the power generation and type. On the other hand, as shown in Figure 10.2 ‘Al-Badi et all, 2020’, the smart grid system is more complex. It has more components, such as more power generation resources (such as renewable energy) and transportation systems (such as electric vehicles).Therefore, the task of the control system is more important and complex.

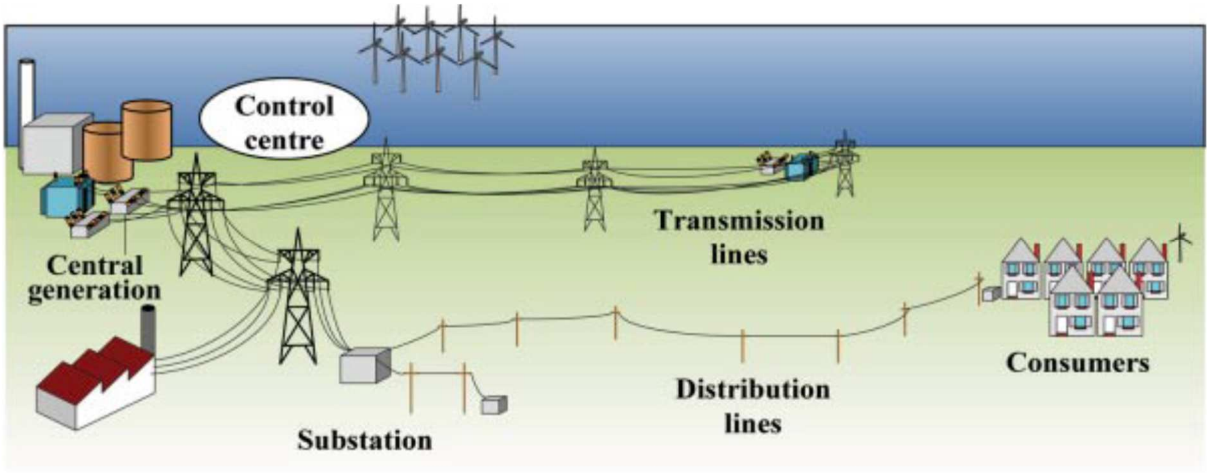


Figure 10. 1: Traditional Power system

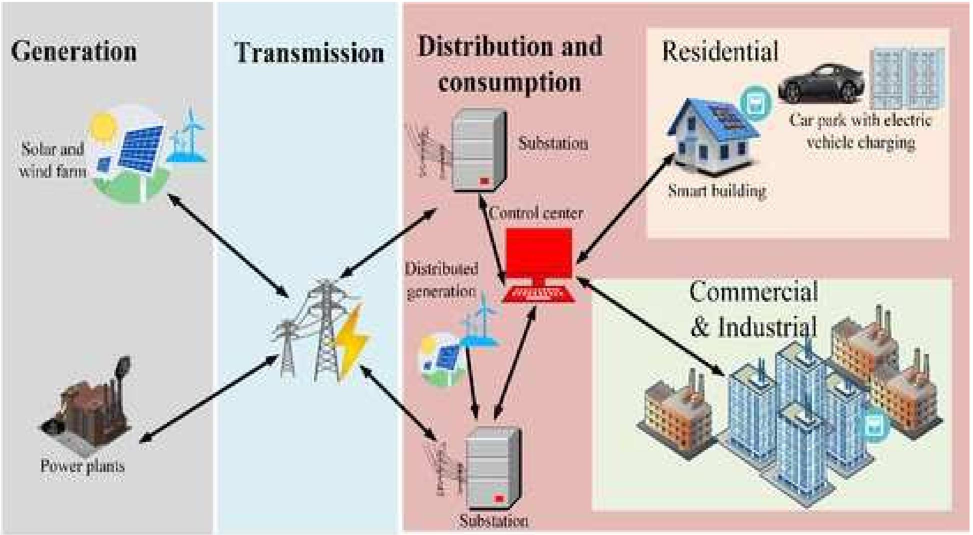


Figure 10. 2: Smart Power system

Table 10.1 ‘Al-Badi et all, 2020’ shows the differences between the smart grid system and the traditional system in several aspects. The generation side is very bulky, and few generators are available in the traditional power system, however, in the smart grid a lot of electric generators are available and each point in the system could work as a generator, in addition, the size of the generators is varied and not bulky. The power flow in the traditional system is only in one way from generation to the load while it is bidirectional in the smart system which means the power flow could be in both ways from the customers to the grid or the grid to the customer depends on many factors such as the generation status and the price of the electricity. The scheme of the traditional power system is simpler and has fewer components compared to the smart power system as shown in Figures 10.1 &10.2. The smart grid system requires a lot of smart metering and electric sensors, however, the traditional system requires less. Smart grid systems achieve a higher level of reliability and security and avoid power outages for a wide area in the case of emergencies in contrast to the traditional power system. The control system in the smart grid has a lot of tasks and functions while it is more limited in the traditional system. Owing to the number of sensors that available in the smart system will have more data about the load, generation, and the transmission compared to the traditional power system.

Term	Traditional Power system	Smart Power system
Generation	Limited number of generators and very large rated power	A lot of generators in variety capacity
Power flow	One directional	Bidirectional
Simplicity	Simple	complex
Electrical sensors	A few	A lot
Response during emergencies	Slow	Very quick
Reliability	Good	Very reliable and secure
Load zones	Few and limited number of load zones	A lot of load zones
Control function	Restricted	Wide-ranging
Volume of data available	Small	Very large

Table 10. 1: Comparison between traditional and smart power system

10.3 The Purpose Of The Smart Power System

Based on ‘Ekanayake et al, 2012’, There are many reasons due to the implementation of the smart grid: Ageing assets and lack of circuit capacity, Thermal constraints, Operational constraints, Security of supply, and National initiatives.

10.3.1 Aging Assets And Lack Of Circuit Capacity

Based on ERCOT, the rate of the growth of the electricity demand will increase by 11% by 2030 compared to the current demand rate in 2020. This is one of the results of the improvements in technology worldwide and it is the case almost everywhere. Therefore, there is a need to increase the capacity of generation from time to time and in some cases may be by every year. Maximizing the power rated requires changing the capacity of the circuit breaker which could be impossible due to reaching the limits especially in the circuit breaker attached with the large generators and even if it is available it requires a higher initial cost ‘Ekanayake et al, 2012’. In addition to that, there is the aging factor which requires dismantling the power plants after a specific period of time or at least change their components. All of that adds more problems for the traditional power system to face. On the other hand, the smart grid system is more flexible and has the capacity to face the increase in demand rapidly due to its features which do not depend on one place for a generation while it converts all load points to generation point as well.

10.3.2 Thermal Constraints

The carrying capacity of overhead transmission lines and underground cables is limited, depending on their materials (copper, aluminum, etc.) and cross-sectional area. Therefore, in order to meet the requirements based on the traditional power grid, it is necessary to implement new transmission lines or replace wires with other materials or wires with a larger cross-sectional area to avoid damage due to overload. Otherwise, thermal failure due to overload current or short circuit will cause a large number of interruptions. The smart grid system once again solves this problem, because its configuration makes the load and generation side ubiquitous and unrestricted in a small part of the system, so the system will not face any overload or any problem due to thermal constraints.

10.3.3 Operational Constraints

The traditional power supply system is not flexible enough to open or close the power generation side in a short period of time. The traditional power generators from the fossil fuel required starting up time, which could reach up to 6 hours for the central fossil generator 'Ekanayake et al, 2012'. Hence, in most cases, it is recommended to keep the generator in the on mode even if it is not loaded, which will reduce efficiency and increase system loss. Otherwise, the system may face power outages, especially during peak hours. On the other hand, a smart power system based on renewable energy is more flexible, especially the generation part that comes from the sun and wind energy like PV, CSP, and the wind turbine is accessible to turn on or off at any time without the need for long starting uptime.

10.3.4 Security Of Supply

The traditional power system relies on a small number of generators, which depends on the total capacity of the system. Hence, losing any of these generators will result in a power outage. However, most of the traditional power systems tend to use the (N+1) rule which means to install one more extra generator at each power plant in order to any failure that happens to one of the generators to be as a backup of the system. Although the cost of the backup generator could be not enough to compensate more than one generator or in case a blackout happens such as the one that happened in Texas in 2021 '2021 Texas power crisis,2021'. The smart grid naturally solves this problem. It does not rely on a few generators. When there are many generators and not restricted in one area, the situation is completely opposite.

10.3.5 National Initiatives

In many countries, they encourage to convert into the smart grid concept for two main reasons: reaching to the most efficient and economical price of electricity and more than that low carbon energy ‘Ekanayake et al, 2012’.

10.4 Microgrid System

Microgrids share with the smart power system a lot of advantages, The microgrid system from renewable energy is eco-friendly so, it has a less or negligible effect on the environment compared with the fossil plants ‘Ray and Biswal,2020’ The microgrid is directly connected to the load on the distribution side, so the loss is less, and the operation is more flexible. Microgrids help reduce outages in particular by reducing peak loads or shifting peak loads when connecting the microgrid to the storage system. The microgrid can be classified according to the connection side into three types: the DC microgrid, the AC microgrid, and the DC/AC microgrid, As shown in Figure 10.3 ‘Ray and Biswal,2020’. Moreover, based on ‘Ray and Biswal,2020’ microgrid systems could be classified depending on their capacity into the following: simple microgrid if the capacity less than 2 MW, corporate microgrid If the capacity is between 2-5 MW, it is a feeder microgrid: if the capacity is between 5-20 MW, it is a substation microgrid, if the capacity exceeds 20 MW.

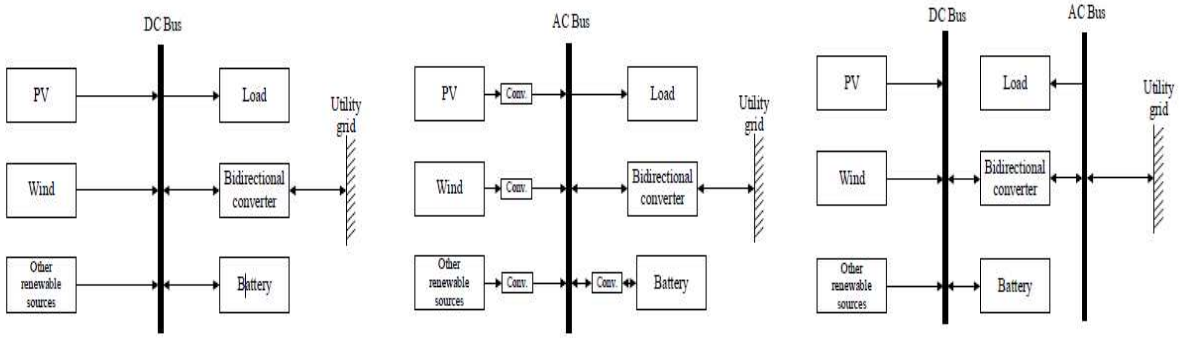


Figure 10. 3: Microgrid multiple configuration

10.5 Smart Grid In Texas

In the previous chapter, the optimal designs for a renewable power system in Texas are designed based on one electric grid in all Texas, which still related to the traditional power system somehow. The results are based on six renewable energy systems and storage systems in all counties in Texas that make up the power generation sites in Texas. However, if Texas is converted into a small area to implement more provisions regarding the concept of smart grids and microgrids, the results may be completely different. By Turning one electrical grid into many grids, many benefits could be achieved. First of all, reaching a higher level of reliability and security because now each small grid will have a dependency on the other parts, so in the case of any problem that could lead to a power outage the other small systems could work as backup grids. Hence, more small grids tend to mean more reliability and security. Another benefit could be achieved which is the lower price of electricity. In one grid system, The lowest LCOE is approximately 30$/MWh however, that was for the whole of Texas not for a specific zone of it. In other words, split one electrical grid into many zones would produce different prices of electricity from different resources based on the potential energy from each zone based on the renewable energy resources there. In spite of that, the electricity price could go up in some zones and down on others and that varies from one renewable energy to another.

In this work, there are two paths to apply the concept of smart grid and microgrid. The first one is by converting Texas into 10 electric load zones based on geographic borders, which are already used in ERCOT grid .So, in this track, there are the following zones: South, Central South, North, Central North, Coast, East, West, Far West, and not-ERCOT counties, which is in the Far East and north in Texas. Hence, each zone will have enough resources to meet the demand for the potential energy of renewable energy at every zone. Path number 2 depends on each county by converting the Texas big grid into 254 grids, and each grid has enough resources to meet demand at any time, moreover, could work as a backup system for any other grid or more than one grid. The second system will achieve a higher level of reliability and security. More than that could achieve a very low price of electricity depending on some renewable energy in some counties. Overall, the system can be made economically efficient and reliable. So, In this work, there are three design for Texas as one zone, for Texas as 9 zones and for Texas in 254 zones as shown in Figure 10.4. In order to obtain the best design for each track, each county in Texas uses the annual energy from all the designs in Chapters 3-8. Then calculate the LCOE for each region or county based on the trajectory. Finally, apply the MATLAB code in Annex 4 to get the optimal design for every smart grid based on one condition which maintains the balance between the annual generation from renewable energy resources with the annual energy electricity consumption as shown in Figure 10.5.

Figure 10. 4: Smart Gird scenarios in this work

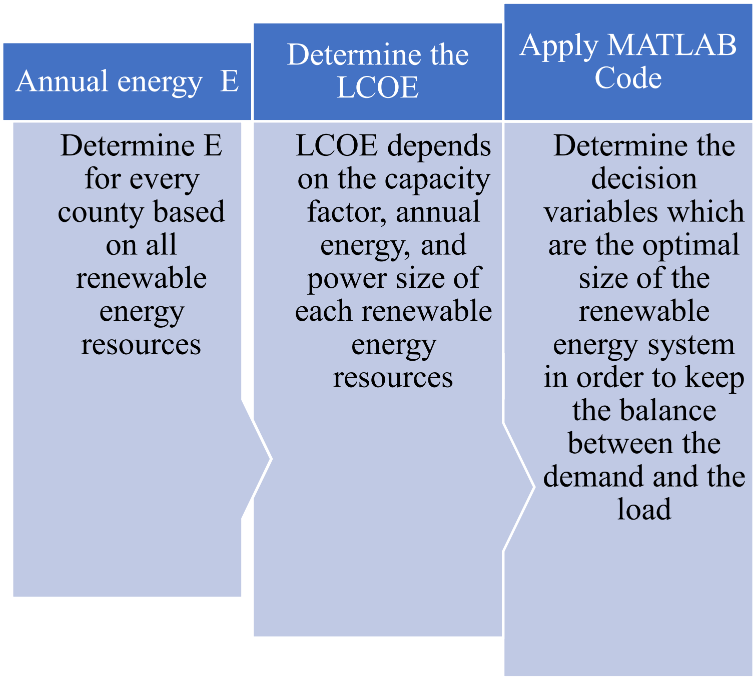
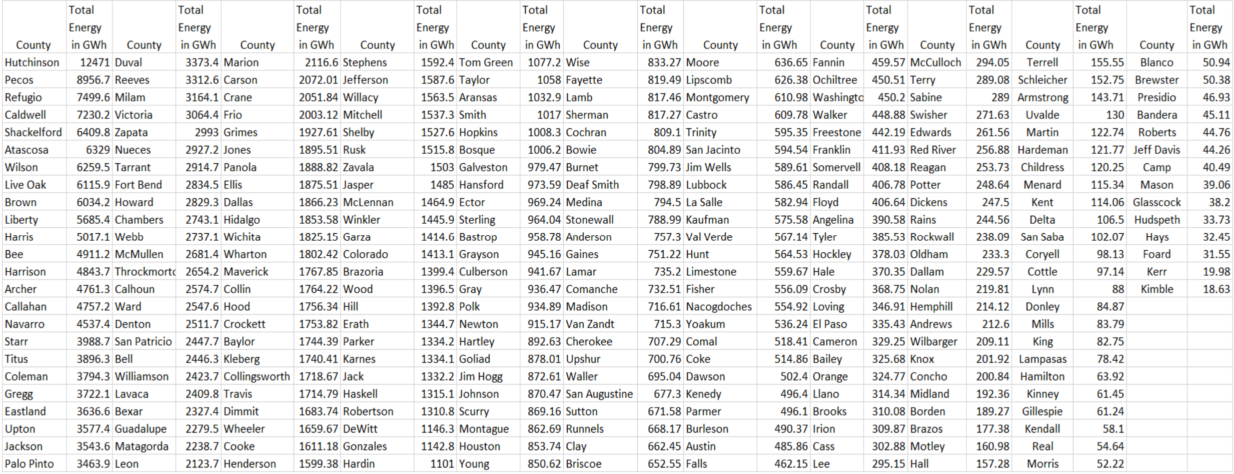


Figure 10. 5: Process of the smart grid concepts in Texas

10.6 Renewable Energy In Texas By County

The renewable energy resources in Texas are available from all types in many places in the state of Texas. Geothermal energy, Biomass, and hydropower plants are limited resources and the potential energy varies from one county to another based on many factors. Figure 3.13 shows the potential energy from the storage water in Texas by county. Figure 3.14 illustrates the variation in the potential energy based on the ROR in Texas by county. Figure 3.14 shows the geothermal energy potential based on the depleted oil and gas wells. Figure 4.2 shows the potential energy from geothermal energy based on converting the coal-fired power plant into the geothermal power plant. Figure 5.26 expresses the potential energy in biomass energy based on anaerobic digester technology. Figure 5.27 shows the potential energy in biomass energy based on direct combustion technology.

Though of limited resources of geothermal, biomass, and hydropower plants, it could power up to 344 TWh annually, which forms around 71 % of the total energy consumption in Texas per year. The Geothermal, biomass, and hydropower plants have very high capacity factors as mentioned in chapter 9; 0.744,0.592, and 0.5 respectively. Moreover, due to their stability and dispatch capacity at every time, therefore, they are used to feed the baseload. The annual generation from the geothermal, biomass, hydropower plants varies from one county to another from 12.4TWh to18 .63 GWh. There are 102 counties in Texas that have enough resources from geothermal, biomass, and hydropower to power more than 1 TWh annually, hence they could be classified as very rich counties from renewable energy resources. Texas has 125 counties with potential renewable energy resources to power more than 100 GWh and less than 1 TWh per year, thus they could be classified as good counties for renewable energy resources. In only 27 counties in Texas, their potential energy from renewable resources does not exceed 100 GWh, as shown in Figure 10.6.



County	Total Energy in GWh	County	Total Energy in GWh	County	Total Energy in GWh	County	Total Energy in GWh	County	Total Energy in GWh	County	Total Energy in GWh	County	Total Energy in GWh	County	Total Energy in GWh	County	Total Energy in GWh	County	Total Energy in GWh	County	Total Energy in GWh
Hutchinson	12471	Duval	3373.4	Marion	2116.6	Stephens	1592.4	Tom Green	1077.2	Wise	833.27	Moore	636.65	Fannin	459.57	McCulloch	294.05	Terrell	155.55	Blanco	50.94
Pecos	8956.7	Reeves	3312.6	Carson	2072.01	Jefferson	1587.6	Taylor	1058	Fayette	819.49	Lipscomb	626.38	Ochiltree	450.51	Terry	289.08	Schleicher	152.75	Brewster	50.38
Refugio	7499.6	Milam	3164.1	Crane	2051.84	Willacy	1563.5	Aransas	1032.9	Lamb	817.46	Montgomery	610.98	Washingto	450.2	Sabine	289	Armstrong	143.71	Presidio	46.93
Caldwell	7230.2	Victoria	3064.4	Frio	2003.12	Mitchell	1537.3	Smith	1017	Sherman	817.27	Castro	609.78	Walker	448.88	Swisher	271.63	Uvalde	130	Bandera	45.11
Shackelford	6409.8	Zapata	2993	Grimes	1927.61	Shelby	1527.6	Hopkins	1008.3	Cochran	809.1	Trinity	595.35	Freestone	442.19	Edwards	261.56	Martin	122.74	Roberts	44.76
Atascosa	6329	Nueces	2927.2	Jones	1895.51	Rusk	1515.8	Bosque	1006.2	Bowie	804.89	San Jacinto	594.54	Franklin	411.93	Red River	256.88	Hardeman	121.77	Jeff Davis	44.26
Wilson	6259.5	Tarrant	2914.7	Panola	1888.82	Zavala	1503	Galveston	979.47	Burnet	799.73	Jim Wells	589.61	Somervell	408.18	Reagan	253.73	Childress	120.25	Camp	40.49
Live Oak	6115.9	Fort Bend	2834.5	Ellis	1875.51	Jasper	1485	Hansford	973.59	Deaf Smith	798.89	Lubbock	586.45	Randall	406.78	Potter	248.64	Menard	115.34	Mason	39.06
Brown	6034.2	Howard	2829.3	Dallas	1866.23	McLennan	1464.9	Ector	969.24	Medina	794.5	La Salle	582.94	Floyd	406.64	Dickens	247.5	Kent	114.06	Glasscock	38.2
Liberty	5685.4	Chambers	2743.1	Hidalgo	1853.58	Winkler	1445.9	Sterling	964.04	Stonewall	788.99	Kaufman	575.58	Angelina	390.58	Rains	244.56	Delta	106.5	Hudspeth	33.73
Harris	5017.1	Webb	2737.1	Wichita	1825.15	Garza	1414.6	Bastrop	958.78	Anderson	757.3	Val Verde	567.14	Tyler	385.53	Rockwall	238.09	San Saba	102.07	Hays	32.45
Bee	4911.2	McMullen	2681.4	Wharton	1802.42	Colorado	1413.1	Grayson	945.16	Gaines	751.22	Hunt	564.53	Hockley	378.03	Oldham	233.3	Coryell	98.13	Foard	31.55
Harrison	4843.7	Throckmortc	2654.2	Maverick	1767.85	Brazoria	1399.4	Culberson	941.67	Lamar	735.2	Limestone	559.67	Hale	370.35	Dallam	229.57	Cottle	97.14	Kerr	19.98
Archer	4761.3	Calhoun	2574.7	Collin	1764.22	Wood	1396.5	Gray	936.47	Comanche	732.51	Fisher	556.09	Crosby	368.75	Nolan	219.81	Lynn	88	Kimble	18.63
Callahan	4757.2	Ward	2547.6	Hood	1756.34	Hill	1392.8	Polk	934.89	Madison	716.61	Nacogdoches	554.92	Loving	346.91	Hemphill	214.12	Donley	84.87		
Navarro	4537.4	Denton	2511.7	Crockett	1753.82	Erath	1344.7	Newton	915.17	Van Zandt	715.3	Yoakum	536.24	El Paso	335.43	Andrews	212.6	Mills	83.79		
Starr	3988.7	San Patricio	2447.7	Baylor	1744.39	Parker	1334.2	Hartley	892.63	Cherokee	707.29	Comal	518.41	Cameron	329.25	Wilbarger	209.11	King	82.75		
Titus	3896.3	Bell	2446.3	Kleberg	1740.41	Karnes	1334.1	Goliad	878.01	Upshur	700.76	Coke	514.86	Bailey	325.68	Knox	201.92	Lampasas	78.42		
Coleman	3794.3	Williamson	2423.7	Collingsworth	1718.67	Jack	1332.2	Jim Hogg	872.61	Waller	695.04	Dawson	502.4	Orange	324.77	Concho	200.84	Hamilton	63.92		
Gregg	3722.1	Lavaca	2409.8	Travis	1714.79	Haskell	1315.1	Johnson	870.47	San Augustine	677.3	Kenedy	496.4	Llano	314.34	Midland	192.36	Kinney	61.45		
Eastland	3636.6	Bexar	2327.4	Dimmit	1683.74	Robertson	1310.8	Scurry	869.16	Sutton	671.58	Parmer	496.1	Brooks	310.08	Borden	189.27	Gillespie	61.24		
Upton	3577.4	Guadalupe	2279.5	Wheeler	1659.67	DeWitt	1146.3	Montague	862.69	Runnels	668.17	Burleson	490.37	Irion	309.87	Brazos	177.38	Kendall	58.1		
Jackson	3543.6	Matagorda	2238.7	Cooke	1611.18	Gonzales	1142.8	Houston	853.74	Clay	662.45	Austin	485.86	Cass	302.88	Motley	160.98	Real	54.64		
Palo Pinto	3463.9	Leon	2123.7	Henderson	1599.38	Hardin	1101	Young	850.62	Briscoe	652.55	Falls	462.15	Lee	295.15	Hall	157.28	Morris	52.22		

Figure 10. 6: Annual energy from Geothermal, Biomass, and Hydropower in Texas

Solar and wind energy in all counties in Texas are unlimited, so annual power generation depends on the installed PV, CSP, and wind turbine capacity.

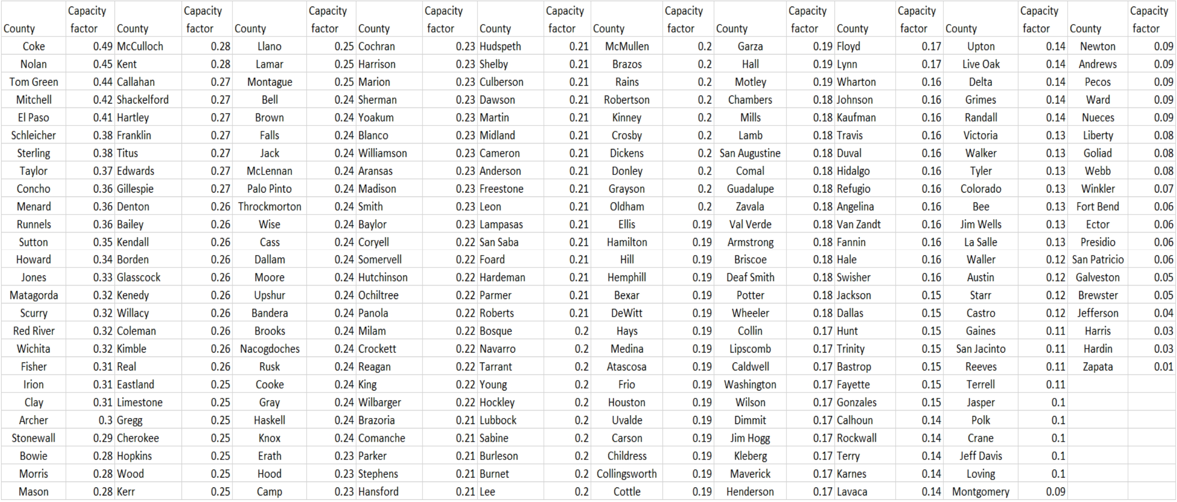
10.7 Capacity Factor In Texas By County

As mentioned earlier, the capacity factors for geothermal, biomass, and hydropower will be constant, but the capacity factors for wind turbines will vary from one county to another in Texas. Calculating the wind energy capacity factor using Equation 6.22 as shown below. The capacity coefficient of wind energy varies from 0.49 to 0.01, which indicates that the energy from one county to another is very different, as shown in Figure 10.7.will be constant, but the capacity factors for wind turbines will vary from one county to another in Texas.

$$CF\ at\ Coke = 0.087 V_{avg} - \frac{P_r}{D^2}$$

$$CF\ at\ Coke = 0.087 * 11.06 - \frac{7580}{127^2}$$

$$CF\ at\ Coke = 0.49$$



County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor
Coke	0.49	McCulloch	0.28	Llano	0.25	Cochran	0.23	Hudspeth	0.21	McMullen	0.2	Garza	0.19	Floyd	0.17	Upton	0.14	Newton	0.09
Nolan	0.45	Kent	0.28	Lamar	0.25	Harrison	0.23	Shelby	0.21	Brazos	0.2	Hall	0.19	Lynn	0.17	Live Oak	0.14	Andrews	0.09
Tom Green	0.44	Callahan	0.27	Montague	0.25	Marion	0.23	Culberson	0.21	Rains	0.2	Motley	0.19	Wharton	0.16	Delta	0.14	Pecos	0.09
Mitchell	0.42	Shackelford	0.27	Bell	0.24	Sherman	0.23	Dawson	0.21	Robertson	0.2	Chambers	0.18	Johnson	0.16	Grimes	0.14	Ward	0.09
El Paso	0.41	Hartley	0.27	Brown	0.24	Yoakum	0.23	Martin	0.21	Kinney	0.2	Mills	0.18	Kaufman	0.16	Randall	0.14	Nueces	0.09
Schleicher	0.38	Franklin	0.27	Falls	0.24	Blanco	0.23	Midland	0.21	Crosby	0.2	Lamb	0.18	Travis	0.16	Victoria	0.13	Liberty	0.08
Sterling	0.38	Titus	0.27	Jack	0.24	Williamson	0.23	Cameron	0.21	Dickens	0.2	San Augustine	0.18	Duval	0.16	Walker	0.13	Goliad	0.08
Taylor	0.37	Edwards	0.27	McLennan	0.24	Aransas	0.23	Anderson	0.21	Donley	0.2	Comal	0.18	Hidalgo	0.16	Tyler	0.13	Webb	0.08
Concho	0.36	Gillespie	0.27	Palo Pinto	0.24	Madison	0.23	Freestone	0.21	Grayson	0.2	Guadalupe	0.18	Refugio	0.16	Colorado	0.13	Winkler	0.07
Menard	0.36	Denton	0.26	Throckmorton	0.24	Smith	0.23	Leon	0.21	Oldham	0.2	Zavala	0.18	Angelina	0.16	Bee	0.13	Fort Bend	0.06
Runnels	0.36	Bailey	0.26	Wise	0.24	Baylor	0.23	Lampasas	0.21	Ellis	0.19	Val Verde	0.18	Van Zandt	0.16	Jim Wells	0.13	Ector	0.06
Sutton	0.35	Kendall	0.26	Cass	0.24	Coryell	0.22	San Saba	0.21	Hamilton	0.19	Armstrong	0.18	Fannin	0.16	La Salle	0.13	Presidio	0.06
Howard	0.34	Borden	0.26	Dallam	0.24	Somervell	0.22	Foard	0.21	Hill	0.19	Briscoe	0.18	Hale	0.16	Waller	0.12	San Patricio	0.06
Jones	0.33	Glasscock	0.26	Moore	0.24	Hutchinson	0.22	Hardeman	0.21	Hemphill	0.19	Deaf Smith	0.18	Swisher	0.16	Austin	0.12	Galveston	0.05
Matagorda	0.32	Kenedy	0.26	Upshur	0.24	Ochiltree	0.22	Parmer	0.21	Bexar	0.19	Potter	0.18	Jackson	0.15	Starr	0.12	Brewster	0.05
Scurry	0.32	Willacy	0.26	Bandera	0.24	Panola	0.22	Roberts	0.21	DeWitt	0.19	Wheeler	0.18	Dallas	0.15	Castro	0.12	Jefferson	0.04
Red River	0.32	Coleman	0.26	Brooks	0.24	Milam	0.22	Bosque	0.2	Hays	0.19	Collin	0.17	Hunt	0.15	Gaines	0.11	Harris	0.03
Wichita	0.32	Kimble	0.26	Nacogdoches	0.24	Crockett	0.22	Navarro	0.2	Medina	0.19	Lipscomb	0.17	Trinity	0.15	San Jacinto	0.11	Hardin	0.03
Fisher	0.31	Real	0.26	Rusk	0.24	Reagan	0.22	Tarrant	0.2	Atascosa	0.19	Caldwell	0.17	Bastrop	0.15	Reeves	0.11	Zapata	0.01
Irion	0.31	Eastland	0.25	Cooke	0.24	King	0.22	Young	0.2	Frio	0.19	Washington	0.17	Fayette	0.15	Terrell	0.11		
Clay	0.31	Limestone	0.25	Gray	0.24	Wilbarger	0.22	Hockley	0.2	Houston	0.19	Wilson	0.17	Gonzales	0.15	Jasper	0.1		
Archer	0.3	Gregg	0.25	Haskell	0.24	Brazoria	0.21	Lubbock	0.2	Uvalde	0.19	Dimmit	0.17	Calhoun	0.14	Polk	0.1		
Stonewall	0.29	Cherokee	0.25	Knox	0.24	Comanche	0.21	Sabine	0.2	Carson	0.19	Jim Hogg	0.17	Rockwall	0.14	Crane	0.1		
Bowie	0.28	Hopkins	0.25	Erath	0.23	Parker	0.21	Burleson	0.2	Childress	0.19	Kleberg	0.17	Terry	0.14	Jeff Davis	0.1		
Morris	0.28	Wood	0.25	Hood	0.23	Stephens	0.21	Burnet	0.2	Collingsworth	0.19	Maverick	0.17	Karnes	0.14	Loving	0.1		
Mason	0.28	Kerr	0.25	Camp	0.23	Hansford	0.21	Lee	0.2	Cottle	0.19	Henderson	0.17	Lavaca	0.14	Montgomery	0.09		

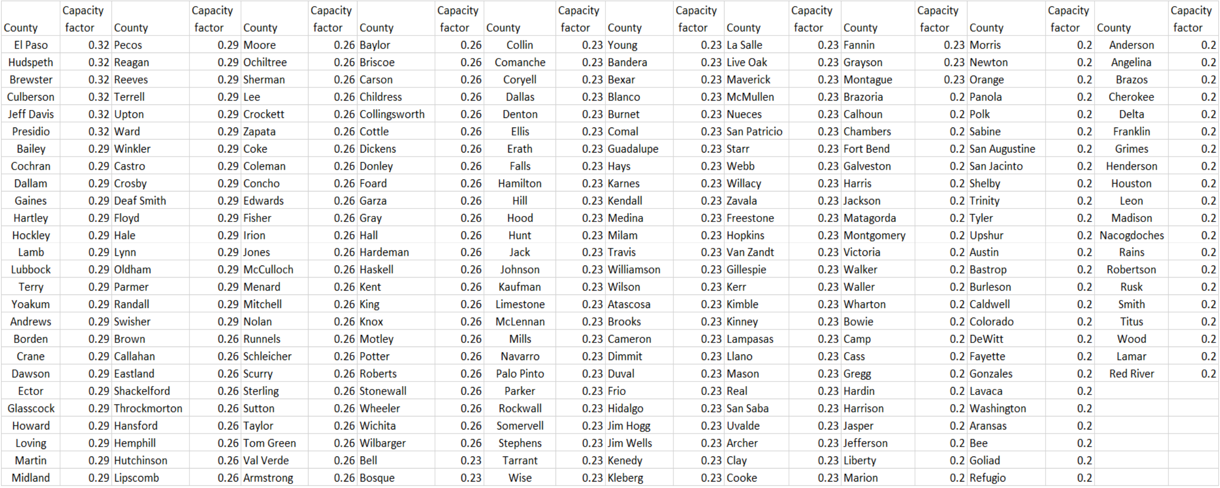
Figure 10. 7: Capacity factor for wind turbine in Texas counties

The capacity factor of the photovoltaic system is calculated using Equation 9.4, as shown below. The capacity factor varies from 0.32 to 0.2, as shown in Figure 10.8.

$$CF\ at\ EL\ Paso = \frac{Energy\ delivered}{Energy\ at\ full\ power}$$

$$CF\ at\ EL\ Paso = \frac{74.2\ GWh}{26.58\ MW * 8760}$$

$$CF\ at\ EL\ Paso = 0.318$$



County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor
El Paso	0.32	Pecos	0.29	Moore	0.26	Baylor	0.26	Collin	0.23	Young	0.23	La Salle	0.23	Fannin	0.23	Morris	0.2	Anderson	0.2
Hudspeth	0.32	Reagan	0.29	Ochiltree	0.26	Briscoe	0.26	Comanche	0.23	Bandera	0.23	Live Oak	0.23	Grayson	0.23	Newton	0.2	Angelina	0.2
Brewster	0.32	Reeves	0.29	Sherman	0.26	Carson	0.26	Coryell	0.23	Bexar	0.23	Maverick	0.23	Montague	0.23	Orange	0.2	Brazos	0.2
Culberson	0.32	Terrell	0.29	Lee	0.26	Childress	0.26	Dallas	0.23	Blanco	0.23	McMullen	0.23	Brazoria	0.2	Panola	0.2	Cherokee	0.2
Jeff Davis	0.32	Upton	0.29	Crockett	0.26	Collingsworth	0.26	Denton	0.23	Burnet	0.23	Nueces	0.23	Calhoun	0.2	Polk	0.2	Delta	0.2
Presidio	0.32	Ward	0.29	Zapata	0.26	Cottle	0.26	Ellis	0.23	Comal	0.23	San Patricio	0.23	Chambers	0.2	Sabine	0.2	Franklin	0.2
Bailey	0.29	Winkler	0.29	Coke	0.26	Dickens	0.26	Erath	0.23	Guadalupe	0.23	Starr	0.23	Fort Bend	0.2	San Augustine	0.2	Grimes	0.2
Cochran	0.29	Castro	0.29	Coleman	0.26	Donley	0.26	Falls	0.23	Hays	0.23	Webb	0.23	Galveston	0.2	San Jacinto	0.2	Henderson	0.2
Dallam	0.29	Crosby	0.29	Concho	0.26	Foard	0.26	Hamilton	0.23	Karnes	0.23	Willacy	0.23	Harris	0.2	Shelby	0.2	Houston	0.2
Gaines	0.29	Deaf Smith	0.29	Edwards	0.26	Garza	0.26	Hill	0.23	Kendall	0.23	Zavala	0.23	Jackson	0.2	Trinity	0.2	Leon	0.2
Hartley	0.29	Floyd	0.29	Fisher	0.26	Gray	0.26	Hood	0.23	Medina	0.23	Freestone	0.23	Matagorda	0.2	Tyler	0.2	Madison	0.2
Hockley	0.29	Hale	0.29	Irion	0.26	Hall	0.26	Hunt	0.23	Milam	0.23	Hopkins	0.23	Montgomery	0.2	Upshur	0.2	Nacogdoches	0.2
Lamb	0.29	Lynn	0.29	Jones	0.26	Hardeman	0.26	Jack	0.23	Travis	0.23	Van Zandt	0.23	Victoria	0.2	Austin	0.2	Rains	0.2
Lubbock	0.29	Oldham	0.29	McCulloch	0.26	Haskell	0.26	Johnson	0.23	Williamson	0.23	Gillespie	0.23	Walker	0.2	Bastrop	0.2	Robertson	0.2
Terry	0.29	Parmer	0.29	Menard	0.26	Kent	0.26	Kaufman	0.23	Wilson	0.23	Kerr	0.23	Waller	0.2	Burleson	0.2	Rusk	0.2
Yoakum	0.29	Randall	0.29	Mitchell	0.26	King	0.26	Limestone	0.23	Atascosa	0.23	Kimble	0.23	Wharton	0.2	Caldwell	0.2	Smith	0.2
Andrews	0.29	Swisher	0.29	Nolan	0.26	Knox	0.26	McLennan	0.23	Brooks	0.23	Kinney	0.23	Bowie	0.2	Colorado	0.2	Titus	0.2
Borden	0.29	Brown	0.26	Runnels	0.26	Motley	0.26	Mills	0.23	Cameron	0.23	Lampasas	0.23	Camp	0.2	DeWitt	0.2	Wood	0.2
Crane	0.29	Callahan	0.26	Schleicher	0.26	Potter	0.26	Navarro	0.23	Dimmit	0.23	Llano	0.23	Cass	0.2	Fayette	0.2	Lamar	0.2
Dawson	0.29	Eastland	0.26	Scurry	0.26	Roberts	0.26	Palo Pinto	0.23	Duval	0.23	Mason	0.23	Gregg	0.2	Gonzales	0.2	Red River	0.2
Ector	0.29	Shackelford	0.26	Sterling	0.26	Stonewall	0.26	Parker	0.23	Frio	0.23	Real	0.23	Hardin	0.2	Lavaca	0.2		
Glasscock	0.29	Throckmorton	0.26	Sutton	0.26	Wheeler	0.26	Rockwall	0.23	Hidalgo	0.23	San Saba	0.23	Harrison	0.2	Washington	0.2		
Howard	0.29	Hansford	0.26	Taylor	0.26	Wichita	0.26	Somervell	0.23	Jim Hogg	0.23	Uvalde	0.23	Jasper	0.2	Aransas	0.2		
Loving	0.29	Hemphill	0.26	Tom Green	0.26	Wilbarger	0.26	Stephens	0.23	Jim Wells	0.23	Archer	0.23	Jefferson	0.2	Bee	0.2		
Martin	0.29	Hutchinson	0.26	Val Verde	0.26	Bell	0.23	Tarrant	0.23	Kenedy	0.23	Clay	0.23	Liberty	0.2	Goliad	0.2		
Midland	0.29	Lipscomb	0.26	Armstrong	0.26	Bosque	0.23	Wise	0.23	Kleberg	0.23	Cooke	0.23	Marion	0.2	Refugio	0.2		

Figure 10. 8: Capacity factor for PV in Texas counties

The capacity factor of the concentrated solar power is calculated using Equation 9.4, as shown below. The capacity factor varies from 0.4 to 0.25, as shown in Figure 10.9.

$$CF\ at\ EL\ Paso = \frac{Energy\ delivered}{Energy\ at\ full\ power}$$

$$CF\ at\ EL\ Paso = \frac{137.41\ GWh}{39.7MW * 8760}$$

$$CF\ at\ EL\ Paso = 0.395$$

County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor	County	Capacity factor
El Paso	0.4	Pecos	0.36	Moore	0.32	Baylor	0.32	Collin	0.29	Young	0.29	La Salle	0.29	Fannin	0.29	Morris	0.25	Anderson	0.25
Hudspeth	0.4	Reagan	0.36	Ochiltree	0.32	Briscoe	0.32	Comanche	0.29	Bandera	0.29	Live Oak	0.29	Grayson	0.29	Newton	0.25	Angelina	0.25
Brewster	0.4	Reeves	0.36	Sherman	0.32	Carson	0.32	Coryell	0.29	Bexar	0.29	Maverick	0.29	Montague	0.29	Orange	0.25	Brazos	0.25
Culberson	0.4	Terrell	0.36	Lee	0.32	Childress	0.32	Dallas	0.29	Blanco	0.29	McMullen	0.29	Brazoria	0.25	Panola	0.25	Cherokee	0.25
Jeff Davis	0.4	Upton	0.36	Crockett	0.32	Collingsworth	0.32	Denton	0.29	Burnet	0.29	Nueces	0.29	Calhoun	0.25	Polk	0.25	Delta	0.25
Presidio	0.4	Ward	0.36	Zapata	0.32	Cottle	0.32	Ellis	0.29	Comal	0.29	San Patricio	0.29	Chambers	0.25	Sabine	0.25	Franklin	0.25
Bailey	0.36	Winkler	0.36	Coke	0.32	Dickens	0.32	Erath	0.29	Guadalupe	0.29	Starr	0.29	Fort Bend	0.25	San Augustine	0.25	Grimes	0.25
Cochran	0.36	Castro	0.36	Coleman	0.32	Donley	0.32	Falls	0.29	Hays	0.29	Webb	0.29	Galveston	0.25	San Jacinto	0.25	Henderson	0.25
Dallam	0.36	Crosby	0.36	Concho	0.32	Foard	0.32	Hamilton	0.29	Karnes	0.29	Willacy	0.29	Harris	0.25	Shelby	0.25	Houston	0.25
Gaines	0.36	Deaf Smith	0.36	Edwards	0.32	Garza	0.32	Hill	0.29	Kendall	0.29	Zavala	0.29	Jackson	0.25	Trinity	0.25	Leon	0.25
Hartley	0.36	Floyd	0.36	Fisher	0.32	Gray	0.32	Hood	0.29	Medina	0.29	Freestone	0.29	Matagorda	0.25	Tyler	0.25	Madison	0.25
Hockley	0.36	Hale	0.36	Irion	0.32	Hall	0.32	Hunt	0.29	Milam	0.29	Hopkins	0.29	Montgomery	0.25	Upshur	0.25	Nacogdoches	0.25
Lamb	0.36	Lynn	0.36	Jones	0.32	Hardeman	0.32	Jack	0.29	Travis	0.29	Van Zandt	0.29	Victoria	0.25	Austin	0.25	Rains	0.25
Lubbock	0.36	Oldham	0.36	McCulloch	0.32	Haskell	0.32	Johnson	0.29	Williamson	0.29	Gillespie	0.29	Walker	0.25	Bastrop	0.25	Robertson	0.25
Terry	0.36	Parmer	0.36	Menard	0.32	Kent	0.32	Kaufman	0.29	Wilson	0.29	Kerr	0.29	Waller	0.25	Burleson	0.25	Rusk	0.25
Yoakum	0.36	Randall	0.36	Mitchell	0.32	King	0.32	Limestone	0.29	Atascosa	0.29	Kimble	0.29	Wharton	0.25	Caldwell	0.25	Smith	0.25
Andrews	0.36	Swisher	0.36	Nolan	0.32	Knox	0.32	McLennan	0.29	Brooks	0.29	Kinney	0.29	Bowie	0.25	Colorado	0.25	Titus	0.25
Borden	0.36	Brown	0.32	Runnels	0.32	Motley	0.32	Mills	0.29	Cameron	0.29	Lampasas	0.29	Camp	0.25	DeWitt	0.25	Wood	0.25
Crane	0.36	Callahan	0.32	Schleicher	0.32	Potter	0.32	Navarro	0.29	Dimmit	0.29	Llano	0.29	Cass	0.25	Fayette	0.25	Lamar	0.25
Dawson	0.36	Eastland	0.32	Scurry	0.32	Roberts	0.32	Palo Pinto	0.29	Duval	0.29	Mason	0.29	Gregg	0.25	Gonzales	0.25	Red River	0.25
Ector	0.36	Shackelford	0.32	Sterling	0.32	Stonewall	0.32	Parker	0.29	Frio	0.29	Real	0.29	Hardin	0.25	Lavaca	0.25		
Glasscock	0.36	Throckmorton	0.32	Sutton	0.32	Wheeler	0.32	Rockwall	0.29	Hidalgo	0.29	San Saba	0.29	Harrison	0.25	Washington	0.25		
Howard	0.36	Hansford	0.32	Taylor	0.32	Wichita	0.32	Somervell	0.29	Jim Hogg	0.29	Uvalde	0.29	Jasper	0.25	Aransas	0.25		
Loving	0.36	Hemphill	0.32	Tom Green	0.32	Wilbarger	0.32	Stephens	0.29	Jim Wells	0.29	Archer	0.29	Jefferson	0.25	Bee	0.25		
Martin	0.36	Hutchinson	0.32	Val Verde	0.32	Bell	0.29	Tarrant	0.29	Kenedy	0.29	Clay	0.29	Liberty	0.25	Goliad	0.25		
Midland	0.36	Lipscomb	0.32	Armstrong	0.32	Bosque	0.29	Wise	0.29	Kleberg	0.29	Cooke	0.29	Marion	0.25	Refugio	0.25		

Figure 10. 9: Capacity factor for CSP in Texas counties

10.8 Levelized Cost Of Energy In Texas By County

In Chapter 9, LCOEs are provided for all Texas states, but the LCOE for each renewable energy will vary from county to county. The LCOE of geothermal, biomass, and hydropower are constant for all counties because of the capacity factor which is constant, hence the LCOE for geothermal, biomass, and hydropower for all counties equal to the value of the LCOE for the whole of Texas as shown in Table 10.2.

Term	LCOE in $/MWh
Geothermal Scenario 2	36.8
Geothermal Scenario 3	61.1
Hydropower storage	14.8
Hydropower ROR	39.4
Biomass Anaerobic digester	64.6
Biomass Direct combustion	39.5

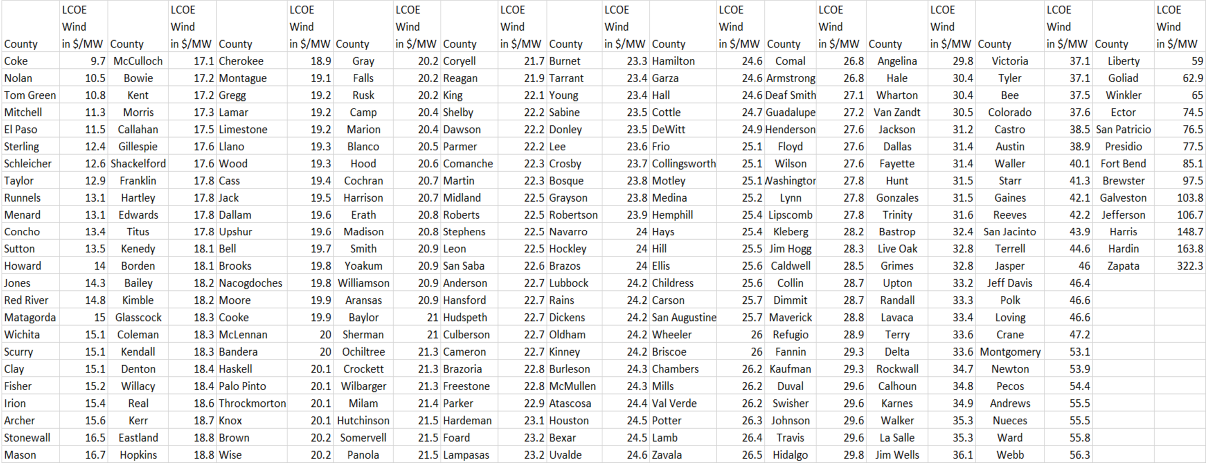
Table 10. 2: LCOE for geothermal, biomass, and hydropower

The LCOE of wind energy and solar energy is also different. Use Equation 9.3 to calculate the LCOE of the wind turbine as shown below. The LCOE value of wind turbines varies from state to state, from $9.7/MWh to $322.3/MWh. As shown in Figure 10.10.

$$LCOE\ at\ Coke\ from\ Wind = \frac{C * CRF + O}{E}$$

$$LCOE\ at\ Coke\ from\ Wind = \frac{225.4 * 1000 * .05122 + 42 * 1000 * 225.4}{981\ GWh}$$

$$LCOE\ at\ Coke\ from\ Wind = 9.655\ \$/MWh$$



County	LCOE Wind in $/MW	County	LCOE Wind in $/MW	County	LCOE Wind in $/MW	County	LCOE Wind in $/MW	County	LCOE Wind in $/MW	County	LCOE Wind in $/MW	County	LCOE Wind in $/MW	County	LCOE Wind in $/MW	County	LCOE Wind in $/MW	County	LCOE Wind in $/MW	County	LCOE Wind in $/MW
Coke	9.7	McCulloch	17.1	Cherokee	18.9	Gray	20.2	Coryell	21.7	Burnet	23.3	Hamilton	24.6	Comal	26.8	Angelina	29.8	Victoria	37.1	Liberty	59
Nolan	10.5	Bowie	17.2	Montague	19.1	Falls	20.2	Reagan	21.9	Tarrant	23.4	Garza	24.6	Armstrong	26.8	Hale	30.4	Tyler	37.1	Goliad	62.9
Tom Green	10.8	Kent	17.2	Gregg	19.2	Rusk	20.2	King	22.1	Young	23.4	Hall	24.6	Deaf Smith	27.1	Wharton	30.4	Bee	37.5	Winkler	65
Mitchell	11.3	Morris	17.3	Lamar	19.2	Camp	20.4	Shelby	22.2	Sabine	23.5	Cottle	24.7	Guadalupe	27.2	Van Zandt	30.5	Colorado	37.6	Ector	74.5
El Paso	11.5	Callahan	17.5	Limestone	19.2	Marion	20.4	Dawson	22.2	Donley	23.5	DeWitt	24.9	Henderson	27.6	Jackson	31.2	Castro	38.5	San Patricio	76.5
Sterling	12.4	Gillespie	17.6	Llano	19.3	Blanco	20.5	Parmer	22.2	Lee	23.6	Frio	25.1	Floyd	27.6	Dallas	31.4	Austin	38.9	Presidio	77.5
Schleicher	12.6	Shackelford	17.6	Wood	19.3	Hood	20.6	Comanche	22.3	Crosby	23.7	Collingsworth	25.1	Wilson	27.6	Fayette	31.4	Waller	40.1	Fort Bend	85.1
Taylor	12.9	Franklin	17.8	Cass	19.4	Cochran	20.7	Martin	22.3	Bosque	23.8	Motley	25.1	Washingtor	27.8	Hunt	31.5	Starr	41.3	Brewster	97.5
Runnels	13.1	Hartley	17.8	Jack	19.5	Harrison	20.7	Midland	22.5	Grayson	23.8	Medina	25.2	Lynn	27.8	Gonzales	31.5	Gaines	42.1	Galveston	103.8
Menard	13.1	Edwards	17.8	Dallam	19.6	Erath	20.8	Roberts	22.5	Robertson	23.9	Hemphill	25.4	Lipscomb	27.8	Trinity	31.6	Reeves	42.2	Jefferson	106.7
Concho	13.4	Titus	17.8	Upshur	19.6	Madison	20.8	Stephens	22.5	Navarro	24	Hays	25.4	Kleberg	28.2	Bastrop	32.4	San Jacinto	43.9	Harris	148.7
Sutton	13.5	Kenedy	18.1	Bell	19.7	Smith	20.9	Leon	22.5	Hockley	24	Hill	25.5	Jim Hogg	28.3	Live Oak	32.8	Terrell	44.6	Hardin	163.8
Howard	14	Borden	18.1	Brooks	19.8	Yoakum	20.9	San Saba	22.6	Brazos	24	Ellis	25.6	Caldwell	28.5	Grimes	32.8	Jasper	46	Zapata	322.3
Jones	14.3	Bailey	18.2	Nacogdoches	19.8	Williamson	20.9	Anderson	22.7	Lubbock	24.2	Childress	25.6	Collin	28.7	Upton	33.2	Jeff Davis	46.4		
Red River	14.8	Kimble	18.2	Moore	19.9	Aransas	20.9	Hansford	22.7	Rains	24.2	Carson	25.7	Dimmit	28.7	Randall	33.3	Polk	46.6		
Matagorda	15	Glasscock	18.3	Cooke	19.9	Baylor	21	Hudspeth	22.7	Dickens	24.2	San Augustine	25.7	Maverick	28.8	Lavaca	33.4	Loving	46.6		
Wichita	15.1	Coleman	18.3	McLennan	20	Sherman	21	Culberson	22.7	Oldham	24.2	Wheeler	26	Refugio	28.9	Terry	33.6	Crane	47.2		
Scurry	15.1	Kendall	18.3	Bandera	20	Ochiltree	21.3	Cameron	22.7	Kinney	24.2	Briscoe	26	Fannin	29.3	Delta	33.6	Montgomery	53.1		
Clay	15.1	Denton	18.4	Haskell	20.1	Crockett	21.3	Brazoria	22.8	Burleson	24.3	Chambers	26.2	Kaufman	29.3	Rockwall	34.7	Newton	53.9		
Fisher	15.2	Willacy	18.4	Palo Pinto	20.1	Wilbarger	21.3	Freestone	22.8	McMullen	24.3	Mills	26.2	Duval	29.6	Calhoun	34.8	Pecos	54.4		
Irion	15.4	Real	18.6	Throckmorton	20.1	Milam	21.4	Parker	22.9	Atascosa	24.4	Val Verde	26.2	Swisher	29.6	Karnes	34.9	Andrews	55.5		
Archer	15.6	Kerr	18.7	Knox	20.1	Hutchinson	21.5	Hardeman	23.1	Houston	24.5	Potter	26.3	Johnson	29.6	Walker	35.3	Nueces	55.5		
Stonewall	16.5	Eastland	18.8	Brown	20.2	Somervell	21.5	Foard	23.2	Bexar	24.5	Lamb	26.4	Travis	29.6	La Salle	35.3	Ward	55.8		
Mason	16.7	Hopkins	18.8	Wise	20.2	Panola	21.5	Lampasas	23.2	Uvalde	24.6	Zavala	26.5	Hidalgo	29.8	Jim Wells	36.1	Webb	56.3		

Figure 10. 10: LCOE for wind Turbine in all counties in state of Texas

Use Equation 9.3 to calculate the LCOE of the PV as shown below. The LCOE value of PV varies from state to state, from $30.4/MWh to $47.9/MWh. As shown in Figure 10.11.

$$LCOE\ at\ EL\ Paso\ from\ PV = \frac{C * CRF + O}{E}$$

$$LCOE\ at\ EL\ Paso\ from\ PV = \frac{26.58 * 1307 * .05122 + 18 * 26.58}{74.2\ GWh}$$

$$LCOE\ at\ EL\ Paso\ from\ PV = 30.42\ \$/MWh$$

County	LCOE PV in $/MW	County	LCOE PV in $/MW	County	LCOE PV in $/MW	County	LCOE PV in $/MW	County	LCOE PV in $/MW	County	LCOE PV in $/MW	County	LCOE PV in $/MW	County	LCOE PV in $/MW	County	LCOE PV in $/MW	County	LCOE PV in $/MW	County	LCOE PV in $/MW
El Paso	30.4	Martin	33.5	Hansford	37.3	Sterling	37.3	Potter	37.3	McLennan	42	Wilson	42	Van Zandt	42	Matagorda	47.9	Shelby	47.9	Grimes	47.9
Hudspeth	30.4	Midland	33.5	Hemphill	37.3	Sutton	37.3	Roberts	37.3	Mills	42	Atascosa	42	Gillespie	42	Montgomery	47.9	Trinity	47.9	Henderson	47.9
Brewster	30.4	Pecos	33.5	Hutchinson	37.3	Taylor	37.3	Stonewall	37.3	Navarro	42	Brooks	42	Kerr	42	Victoria	47.9	Tyler	47.9	Houston	47.9
Culberson	30.4	Reagan	33.5	Lipscomb	37.3	Tom Green	37.3	Wheeler	37.3	Palo Pinto	42	Cameron	42	Kimble	42	Walker	47.9	Upshur	47.9	Leon	47.9
Jeff Davis	30.4	Reeves	33.5	Moore	37.3	Val Verde	37.3	Wichita	37.3	Parker	42	Dimmit	42	Kinney	42	Waller	47.9	Austin	47.9	Madison	47.9
Presidio	30.4	Terrell	33.5	Ochiltree	37.3	Armstrong	37.3	Wilbarger	37.3	Rockwall	42	Duval	42	Lampasas	42	Wharton	47.9	Bastrop	47.9	Nacogdoches	47.9
Bailey	33.5	Upton	33.5	Sherman	37.3	Baylor	37.3	Bell	42	Somervell	42	Frio	42	Llano	42	Bowie	47.9	Burleson	47.9	Rains	47.9
Cochran	33.5	Ward	33.5	Lee	37.3	Briscoe	37.3	Bosque	42	Stephens	42	Hidalgo	42	Mason	42	Camp	47.9	Caldwell	47.9	Robertson	47.9
Dallam	33.5	Winkler	33.5	Crockett	37.3	Carson	37.3	Collin	42	Tarrant	42	Jim Hogg	42	Real	42	Cass	47.9	Colorado	47.9	Rusk	47.9
Gaines	33.5	Castro	33.5	Zapata	37.3	Childress	37.3	Comanche	42	Wise	42	Jim Wells	42	San Saba	42	Gregg	47.9	DeWitt	47.9	Smith	47.9
Hartley	33.5	Crosby	33.5	Coke	37.3	Collingsworth	37.3	Coryell	42	Young	42	Kenedy	42	Uvalde	42	Hardin	47.9	Fayette	47.9	Titus	47.9
Hockley	33.5	Deaf Smith	33.5	Coleman	37.3	Cottle	37.3	Dallas	42	Bandera	42	Kleberg	42	Archer	42	Harrison	47.9	Gonzales	47.9	Wood	47.9
Lamb	33.5	Floyd	33.5	Concho	37.3	Dickens	37.3	Denton	42	Bexar	42	La Salle	42	Clay	42	Jasper	47.9	Lavaca	47.9	Lamar	47.9
Lubbock	33.5	Hale	33.5	Edwards	37.3	Donley	37.3	Ellis	42	Blanco	42	Live Oak	42	Cooke	42	Jefferson	47.9	Washington	47.9	Red River	47.9
Terry	33.5	Lynn	33.5	Fisher	37.3	Foard	37.3	Erath	42	Burnet	42	Maverick	42	Fannin	42	Liberty	47.9	Aransas	47.9		
Yoakum	33.5	Oldham	33.5	Irion	37.3	Garza	37.3	Falls	42	Comal	42	McMullen	42	Grayson	42	Marion	47.9	Bee	47.9		
Andrews	33.5	Parmer	33.5	Jones	37.3	Gray	37.3	Hamilton	42	Guadalupe	42	Nueces	42	Montague	42	Morris	47.9	Goliad	47.9		
Borden	33.5	Randall	33.5	McCulloch	37.3	Hall	37.3	Hill	42	Hays	42	San Patricio	42	Brazoria	47.9	Newton	47.9	Refugio	47.9		
Crane	33.5	Swisher	33.5	Menard	37.3	Hardeman	37.3	Hood	42	Karnes	42	Starr	42	Calhoun	47.9	Orange	47.9	Anderson	47.9		
Dawson	33.5	Brown	37.3	Mitchell	37.3	Haskell	37.3	Hunt	42	Kendall	42	Webb	42	Chambers	47.9	Panola	47.9	Angelina	47.9		
Ector	33.5	Callahan	37.3	Nolan	37.3	Kent	37.3	Jack	42	Medina	42	Willacy	42	Fort Bend	47.9	Polk	47.9	Brazos	47.9		
Glasscock	33.5	Eastland	37.3	Runnels	37.3	King	37.3	Johnson	42	Milam	42	Zavala	42	Galveston	47.9	Sabine	47.9	Cherokee	47.9		
Howard	33.5	Shackelford	37.3	Schleicher	37.3	Knox	37.3	Kaufman	42	Travis	42	Freestone	42	Harris	47.9	San Augustine	47.9	Delta	47.9		
Loving	33.5	Throckmorton	37.3	Scurry	37.3	Motley	37.3	Limestone	42	Williamson	42	Hopkins	42	Jackson	47.9	San Jacinto	47.9	Franklin	47.9		

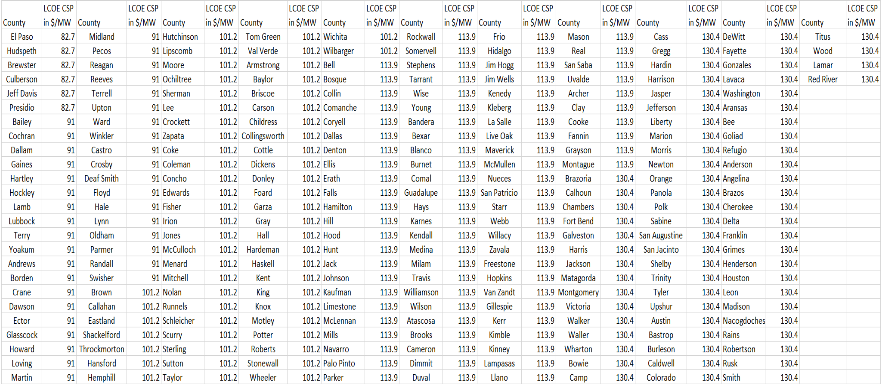
Figure 10. 11: LCOE for PV in all counties in state of Texas

Use Equation 9.3 to calculate the LCOE of the CSP as shown below. The LCOE value of CSP systems varies from state to state, from $82.7/MWh to $130.4 /MWh. As shown in Figure 10.12.

$$LCOE\ at\ EL\ Paso\ from\ CSP = \frac{C * CRF + O}{E}$$

$$LCOE\ at\ EL\ Paso\ from\ CSP = \frac{39.37 * 3972 * .05122 + 85.03 * 39.37}{137.41\ GWh}$$

$$LCOE\ at\ EL\ Paso\ from\ CSP = 82.65\ \$/MWh$$



County	LCOE CSP in $/MW	County	LCOE CSP in $/MW	County	LCOE CSP in $/MW	County	LCOE CSP in $/MW	County	LCOE CSP in $/MW	County	LCOE CSP in $/MW	County	LCOE CSP in $/MW	County	LCOE CSP in $/MW	County	LCOE CSP in $/MW	County	LCOE CSP in $/MW	County	LCOE CSP in $/MW
El Paso	82.7	Midland	91	Hutchinson	101.2	Tom Green	101.2	Wichita	101.2	Rockwall	113.9	Frio	113.9	Mason	113.9	Cass	130.4	DeWitt	130.4	Titus	130.4
Hudspeth	82.7	Pecos	91	Lipscomb	101.2	Val Verde	101.2	Wilbarger	101.2	Somervell	113.9	Hidalgo	113.9	Real	113.9	Gregg	130.4	Fayette	130.4	Wood	130.4
Brewster	82.7	Reagan	91	Moore	101.2	Armstrong	101.2	Bell	113.9	Stephens	113.9	Jim Hogg	113.9	San Saba	113.9	Hardin	130.4	Gonzales	130.4	Lamar	130.4
Culberson	82.7	Reeves	91	Ochiltree	101.2	Baylor	101.2	Bosque	113.9	Tarrant	113.9	Jim Wells	113.9	Uvalde	113.9	Harrison	130.4	Lavaca	130.4	Red River	130.4
Jeff Davis	82.7	Terrell	91	Sherman	101.2	Briscoe	101.2	Collin	113.9	Wise	113.9	Kenedy	113.9	Archer	113.9	Jasper	130.4	Washington	130.4		
Presidio	82.7	Upton	91	Lee	101.2	Carson	101.2	Comanche	113.9	Young	113.9	Kleberg	113.9	Clay	113.9	Jefferson	130.4	Aransas	130.4		
Bailey	91	Ward	91	Crockett	101.2	Childress	101.2	Coryell	113.9	Bandera	113.9	La Salle	113.9	Cooke	113.9	Liberty	130.4	Bee	130.4		
Cochran	91	Winkler	91	Zapata	101.2	Collingsworth	101.2	Dallas	113.9	Bexar	113.9	Live Oak	113.9	Fannin	113.9	Marion	130.4	Goliad	130.4		
Dallam	91	Castro	91	Coke	101.2	Cottle	101.2	Denton	113.9	Blanco	113.9	Maverick	113.9	Grayson	113.9	Morris	130.4	Refugio	130.4		
Gaines	91	Crosby	91	Coleman	101.2	Dickens	101.2	Ellis	113.9	Burnet	113.9	McMullen	113.9	Montague	113.9	Newton	130.4	Anderson	130.4		
Hartley	91	Deaf Smith	91	Concho	101.2	Donley	101.2	Erath	113.9	Comal	113.9	Nueces	113.9	Brazoria	130.4	Orange	130.4	Angelina	130.4		
Hockley	91	Floyd	91	Edwards	101.2	Foard	101.2	Falls	113.9	Guadalupe	113.9	San Patricio	113.9	Calhoun	130.4	Panola	130.4	Brazos	130.4		
Lamb	91	Hale	91	Fisher	101.2	Garza	101.2	Hamilton	113.9	Hays	113.9	Starr	113.9	Chambers	130.4	Polk	130.4	Cherokee	130.4		
Lubbock	91	Lynn	91	Irion	101.2	Gray	101.2	Hill	113.9	Karnes	113.9	Webb	113.9	Fort Bend	130.4	Sabine	130.4	Delta	130.4		
Terry	91	Oldham	91	Jones	101.2	Hall	101.2	Hood	113.9	Kendall	113.9	Willacy	113.9	Galveston	130.4	San Augustine	130.4	Franklin	130.4		
Yoakum	91	Parmer	91	McCulloch	101.2	Hardeman	101.2	Hunt	113.9	Medina	113.9	Zavala	113.9	Harris	130.4	San Jacinto	130.4	Grimes	130.4		
Andrews	91	Randall	91	Menard	101.2	Haskell	101.2	Jack	113.9	Milam	113.9	Freestone	113.9	Jackson	130.4	Shelby	130.4	Henderson	130.4		
Borden	91	Swisher	91	Mitchell	101.2	Kent	101.2	Johnson	113.9	Travis	113.9	Hopkins	113.9	Matagorda	130.4	Trinity	130.4	Houston	130.4		
Crane	91	Brown	101.2	Nolan	101.2	King	101.2	Kaufman	113.9	Williamson	113.9	Van Zandt	113.9	Montgomery	130.4	Tyler	130.4	Leon	130.4		
Dawson	91	Callahan	101.2	Runnels	101.2	Knox	101.2	Limestone	113.9	Wilson	113.9	Gillespie	113.9	Victoria	130.4	Upshur	130.4	Madison	130.4		
Ector	91	Eastland	101.2	Schleicher	101.2	Motley	101.2	McLennan	113.9	Atascosa	113.9	Kerr	113.9	Walker	130.4	Austin	130.4	Nacogdoches	130.4		
Glasscock	91	Shackelford	101.2	Scurry	101.2	Potter	101.2	Mills	113.9	Brooks	113.9	Kimble	113.9	Waller	130.4	Bastrop	130.4	Rains	130.4		
Howard	91	Throckmorton	101.2	Sterling	101.2	Roberts	101.2	Navarro	113.9	Cameron	113.9	Kinney	113.9	Wharton	130.4	Burleson	130.4	Robertson	130.4		
Loving	91	Hansford	101.2	Sutton	101.2	Stonewall	101.2	Palo Pinto	113.9	Dimmit	113.9	Lampasas	113.9	Bowie	130.4	Caldwell	130.4	Rusk	130.4		
Martin	91	Hemphill	101.2	Taylor	101.2	Wheeler	101.2	Parker	113.9	Duval	113.9	Llano	113.9	Camp	130.4	Colorado	130.4	Smith	130.4		

Figure 10. 12: LCOE for CSP in all counties in state of Texas

10.9 Smart Grid In Texas Track 1

As mentioned earlier, 90% of the electrical load in Texas comes from ERCOT. Owing to the electrical load, ERCOT divides Texas into 8 main regions, as shown in Figure 10.13 ‘Maps,2019’. Hence, in this track, an optimal design will be added for 9 zones including ERCORT's zones plus one zone is the load outside the ERCOT area. Among all zones, the largest annual electrical load in Texas is located in the north-central zone, which is approximately 116.5 TWh. In addition, its maximum peak electrical load is 26 GW. The Coast zone has the maximum annual electric load and peak load per county by 8.4 TWh and 1.6 GW and in total 109.9 TWh as an annual electricity load and 20.8 peak load, which is the second maximum peak and annual consumption among all Texas zones. Based on an annual power load of only 7 TWh and a peak load of 1.8 GW, the North zone is the lowest zone based on electricity consumption. However, it has the largest number of counties in each region. Table 10.3 ‘Load,2021’ lists all annual consumption, peak load, average annual consumption of each county, and a peak load of each county in all regions.

Figure 10. 13: Smart grid in Texas track 1

Zone	COAST	EAST	FWEST	NORTH	NCENT	SOUTH	SCENT	WEST	**Out-ERCOT**
Annual electrical load in TWh in 2020	109.9	13.7	32.6	7	116.5	30.9	60.2	10.6	101
Peak electricity Load in 2021 (predictions) in GW	20.8	2.7	4.8	1.8	26	5.8	12.9	2	21
Number of counties	13	21	22	43	34	26	25	29	41
Annual average electricity demand per county	8.4 TWh	654 GWh	1.4TWh	163 GWh	3.4 TWh	1.1 TWh	2.4TWh	368 GWh	2.4 TWh
Average peak load per county	1.6 GW	129 MW	220 MW	44 MW	766 MW	223 MW	518 MW	71 MW	512 MW

Table 10. 3: Electricity demand in Texas zones Track 1

The mathematical model for the power system analysis in every zone is as the following:

Minimize $f\,(P_{PV}, P_{W}, P_{GE}, P_{H}, P_{B}, P_{CSP})=$

$LCOE_{PV}\ P_{PV}+ LCOE_{W}\ P_{W}+36.82P_{GE2}+61.18P_{GE3} +14.85P_{H1} +39.41P_{H2} +64.68P_{B\ Anaerobic}+$

$39.52P_{B\ Combustion} + LCOE_{CSP}\ P_{CSP}$

Subject to:

$CF_{PV}\ P_{PV} + CF_{W}\ P_{W}+ 0.744P_{GE1}+ 0.744P_{GE2}+ 0.744P_{GE3}+ P_{H1}+ P_{H2}+ 0.592P_{B\ Anaerobic} +$

$0.592P_{B\ Combustion} +CF_{CSP}\ P_{CSP} = E_{A}$

$0 \leq P_{PV} \leq Inf$

$0\leq P_{W}\leq Inf$

$0\leq P_{CSP}\leq Inf$

$0\leq P_{H1}\leq \max P_{H1}$

$0\leq P_{H2}\leq \max P_{H2}$

$0\leq P_{GE2}\leq \max P_{GE2}$

$0\leq P_{GE3}\leq \max P_{GE3}$

$0\leq P_{B\ Anaerobic}\leq \max P_{B\ Anaerobic}$

$0\leq P_{B\ Combustion}\leq \max P_{B\ Combustion}$

As the model shows, there are some similarities in the optimization problems in all regions, such as the capacity factor and the LCOE of the base load source. However, there are 4 main different variables in the model: the LCOE of the PV, CSP, and wind turbine, which vary from one zone to another. The capacity factor of PV, CSP, and wind turbine systems varies as well from one zone to another. The annual energy consumption of each region. Finally, the limited resources of the baseload generation sources depend on the zone itself. The optimization has only one constraint based on the annual energy consumption.

10.9.1 Coast Zone

In the Coast zone, there are 13 counties. The average LCOE of wind, PV, and CSP are 51.06,47.9, and 130.3 $/MWh respectively. The average capacity factor of wind, PV, and CSP is 0.13,0.2, and 0.25 respectively. The annual energy consumption is 109 TWh. Potential energy from biomass resources based on anaerobic digester technology in this zone is 89.1 MW and based on direct combustion is 1,003 MW. Potential energy from hydropower resources based on storage technology in this zone is 36.2 MW and based on ROR is 106.2 MW. Potential energy from geothermal resources based on depleted oil and gas wells in this zone is 3,202 MW and based on the fired-coal power plant is 25 MW. By using the process shown in Figure 10.5 and the MATLAB code (shown in Annex 4) for this zone, the best design for each region can be achieved as the following in Table 10.4.

System	P_{PV}	P_W	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	$P_{B\ Anaerobic}$	$P_{B\ Combustion}$	Total size
Size in MW	46,779	0	0	3,202	25	36.2	106.2	89.1	1,003	51,240.5

Table 10. 4: Optimal design for power system in Coast zone

From the optimal results, the size of the coast power system depends on all baseload generating sources and solar energy. The total size of the coastal system is 51,240.5 MW, 91% of which are based on photovoltaic systems as shown in Table 10.4.

10.9.2 North Central Zone

In the North Central zone, there are 34 counties. The average LCOE of wind, PV, and CSP are 23.10,41.27, and 112.05 $/MWh respectively. The average capacity factor of wind, PV, and CSP is 0.21,0.23, and 0.29 respectively. The annual energy consumption is 116 TWh. Potential energy from biomass resources based on anaerobic digester technology in this zone is 319.9 MW and based on direct combustion is 1,257.9 MW. Potential energy from hydropower resources based on storage technology in this zone is 2099.9 MW and based on ROR is 352.5 MW. Potential energy from geothermal resources based on depleted oil and gas wells in this zone is 5003.5 MW and based on the fired-coal power plant is 25 MW. By using the process shown in Figure 10.5 and the MATLAB code (shown in Annex 4) for this zone, the best design for each region can be achieved as the following:

System	P_{PV}	P_{W}	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	$P_{B\ Anaerobic}$	$P_{B\ Combustion}$	Total Size
Size in MW	0	29,117	0	5,003	25	2,099.9	352.5	319.9	1,257.9	38,175.2

Table 10. 5: Optimal design for power system in North Central zone

From the optimal results, the size of the North Central power system depends on all baseload generating sources and Wind energy. The total size of the North Central system is 38,175.2 MW, 76% of which are based on wind turbine as shown in Table 10.5.

10.9.3 Out-ERCOT Zone

In the Out-ERCOT zone, there are 41 counties. The average LCOE of wind, PV, and CSP are 31.15,41.73, and 113.45 $/MWh respectively. The average capacity factor of wind, PV, and CSP is 0.19,0.23, and 0.29 respectively. The annual energy consumption is 101 TWh. Potential energy from biomass resources based on anaerobic digester technology in this zone is 391.5 MW and based on direct combustion is 826.8 MW. Potential energy from hydropower resources based on storage technology in this zone is 221.38 MW and based on ROR is 416.26 MW. Potential energy from geothermal resources based on depleted oil and gas wells in this zone is 6195.5 MW and based on the fired-coal power plant is 71.5 MW. By using the process shown in Figure 10.5 and the MATLAB code (shown in Annex 4) for this zone, the best design for each region can be achieved as the following:

System	P_{PV}	P_{W}	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	$P_{B\ Anaerobic}$	$P_{B\ Combustion}$	Total size
Size in MW	0	28,247	0	6,195.5	71.5	221.38	416.26	391.5	826.89	36,370

Table 10. 6: Optimal design for power system in Out-ERCOT zone

From the optimal results, the size of the out-ERCOT power system depends on all baseload generating sources and Wind energy. The total size of the Out-ERCOT system is 36,370 MW, 77% of which are based on wind turbine as shown in Table 10.6.

10.9.4 South Central Zone

In the South Central zone, there are 25 counties. The average LCOE of wind, PV, and CSP are 27.20,44.16, and 119.9 $/MWh respectively. The average capacity factor of wind, PV, and CSP is 0.18,0.22, and 0.27 respectively. The annual energy consumption is 60.2 TWh. Potential energy from biomass resources based on anaerobic digester technology in this zone is 241.5 MW and based on direct combustion is 660.45 MW. Potential energy from hydropower resources based on storage technology in this zone is 360 MW and based on ROR is 113.75 MW. Potential energy from geothermal resources based on depleted oil and gas wells in this zone is 4524.8 MW and based on the fired-coal power plant is 50 MW. By using the process shown in Figure 10.5 and the MATLAB code (shown in Annex 4) for this zone, the best design for each region can be achieved as the following:

System	P_{PV}	P_W	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	$P_{B\ Anaerobic}$	$P_{B\ Combustion}$	Total size
Size in MW	0	13,671	0	4,524.8	50	360	113.75	241.54	660.45	19,621.54

Table 10. 7: Optimal design for power system in South Central zone

From the optimal results, the size of the South Central power system depends on all baseload generating sources and Wind energy. The total size of the South Central system is 19,621 MW, 69% of which are based on wind turbine as shown in Table 10.7.

10.9.5 Far West zone

In the Far West zone, there are 22 counties. The average LCOE of wind, PV, and CSP are 41.98,33.11, and 89.9 $/MWh respectively. The average capacity factor of wind, PV, and CSP is 0.15,0.29, and 0.36 respectively. The annual energy consumption is 32.6 TWh. Potential energy from biomass resources based on anaerobic digester technology in this zone is 45 MW and based on direct combustion is 116 MW. Potential energy from hydropower resources based on ROR is 41 MW. Potential energy from geothermal resources based on depleted oil and gas wells in this zone is 4502.5 MW. By using the process shown in Figure 10.5 and the MATLAB code (shown in Annex 4) for this zone, the best design for each region can be achieved as the following:

System	P_{PV}	P_W	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	$P_{B\ Anaerobic}$	$P_{B\ Combustion}$	Total Size
Size in MW	811.34	0	0	4,502.5	0	0	41	45	116	5,515.8

Table 10. 8: Optimal design for power system in Far West zone

From the optimal results, the size of the Far West power system depends on all baseload generating sources and Solar energy. The total size of the Far West system is 5,515.8 MW, 81.6% of which are based on Geothermal energy based on depleted oil and gas wells as shown in Table 10.8.

10.9.6 South Zone

In the South zone, there are 26 counties. The average LCOE of wind, PV, and CSP are 44.57,42.7, and 115.9 $/MWh respectively. The average capacity factor of wind, PV, and CSP is 0.15,0.22, and 0.28 respectively. The annual energy consumption is 30.9 TWh. Potential energy from biomass resources based on anaerobic digester technology in this zone is 128.73 MW and based on direct combustion is 472.4 MW. Potential energy from hydropower resources based on storage technology in this zone is 13.4 MW and based on ROR is 43.8 MW. Potential energy from geothermal resources based on depleted oil and gas wells in this zone is 9,057.5 MW and based on the fired-coal power plant is 85.8 MW. By using the process shown in Figure 10.5 and the MATLAB code (shown in Annex 4) for this zone, the best design for each region can be achieved as the following:

System	P_{PV}	P_{W}	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	$P_{B\ Anaerobic}$	$P_{B\ Combustion}$	Total size
Size in MW	0	0	0	4,664.2	0	13.4	43.80	0	0	4,721.4

Table 10. 9: Optimal design for power system in South zone

From the optimal results, the size of the South power system depends on geothermal energy based on depleted oil and gas wells and Hydropower plants based in storage and ROR technology. The total size of the South system is 4,721.4 MW, 98.7% of which are based on Geothermal energy based on depleted oil and gas wells as shown in Table 10.9.

10.9.7 East Zone

In the South zone, there are 21 counties. The average LCOE of wind, PV, and CSP are 23.48,47, and 128 $/MWh respectively. The average capacity factor of wind, PV, and CSP is 0.21,0.20, and 0.25 respectively. The annual energy consumption is 13.7 TWh. Potential energy from biomass resources based on anaerobic digester technology in this zone is 195.1 MW and based on direct combustion is 108 MW. Potential energy from hydropower resources based on storage technology in this zone is 501.2 MW and based on ROR is 323.8 MW. Potential energy from geothermal resources based on depleted oil and gas wells in this zone is 1,834.3 MW and based on the fired-coal power plant is 171.6 MW. By using the process shown in Figure 10.5 and the MATLAB code (shown in Annex 4) for this zone, the best design for each region can be achieved as the following:

System	P_{PV}	P_{W}	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	$P_{B\ Anaerobic}$	$P_{B\ Combustion}$	Total size
Size in MW	0	0	0	1,000.8	0	501.21	323.84	0	0	1,825.8

Table 10. 10: Optimal design for power system in East zone

From the optimal results, the size of the East power system depends on geothermal energy based on depleted oil and gas wells and Hydropower plants based in storage and ROR technology. The total size of the East system is 1,825.8 MW, 54% of which are based on Geothermal energy based on depleted oil and gas wells and 46 % from hydropower plants as shown in Table 10.10.

10.9.8 West Zone

In the South zone, there are 21 counties. The average LCOE of wind, PV, and CSP are 16.42,38.88, and 105.5 $/MWh respectively. The average capacity factor of wind, PV, and CSP is 0.31,0.25, and 0.31 respectively. The annual energy consumption is 10.6 TWh. Potential energy from biomass resources based on anaerobic digester technology in this zone is 118.87 MW and based on direct combustion is 133 MW. Potential energy from hydropower resources based on storage technology in this zone is 343.4 MW and based on ROR is 80 MW. Potential energy from geothermal resources based on depleted oil and gas wells in this zone is 1,778.3 MW. By using the process shown in Figure 10.5 and the MATLAB code (shown in Annex 4) for this zone, the best design for each region can be achieved as the following:

System	P_{PV}	P_{W}	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	$P_{B\ Anaerobic}$	$P_{B\ Combustion}$	Total Size
Size in MW	0	0	0	1,067.8	0	343.47	80.09	0	0	1,411.2

Table 10. 11: Optimal design for power system in West zone

From the optimal results, the size of the West power system depends on geothermal energy based on depleted oil and gas wells and Hydropower plants based in storage and ROR technology . The total size of the West system is 1,491.36 MW, 71% of which are based on Geothermal energy based on depleted oil and gas wells and 29 % from hydropower plants as shown in Table 10.11.

10.9.9 North Zone

In the South zone, there are 43 counties. The average LCOE of wind, PV, and CSP are 23.52,37.53, and 101.9$/MWh respectively. The average capacity factor of wind, PV, and CSP is 0.21,0.26, and 0.32 respectively. The annual energy consumption is 7 TWh. Potential energy from biomass resources based on anaerobic digester technology in this zone is 576.84 MW and based on direct combustion is 507.13 MW. Potential energy from hydropower resources based on storage technology in this zone is 635.8 MW and based on ROR is 405 MW. Potential energy from geothermal resources based on depleted oil and gas wells in this zone is 2,413.4 MW and based on the fired-coal power plant is 10.7 MW. By using the process shown in Figure 10.5 and the MATLAB code (shown in Annex 4) for this zone, the best design for each region can be achieved as the following:

System	P_{PV}	P_W	P_{CSP}	P_{GE2}	P_{GE3}	P_{H1}	P_{H2}	$P_{B\ Anaerobic}$	$P_{B\ Combustion}$	Total Size
Size in MW	0	0	0	0	0	635.8	163.2	0	0	799

Table 10. 12: Optimal design for power system in North zone

From the optimal results, the size of the East power system depends on hydropower plants based on storage and ROR technologies. The total size of the East system is 799 MW, 79% of which are based on hydropower plants based on storage technology and 21% based on hydropower plants from ROR, as shown in Table 10.12.

10.10 Smart Grid In Texas Track 2

It can be seen from the optimal results for the load zones in Texas that some zone depends on the photovoltaic system as the main power source for electricity generation, such as coastal areas. Some other zones rely on wind energy as the main source of power generation, such as the North Central region, the Out-ERCOT region, and the South Central zone. Some other zones depend on geothermal energy as the main source like the South, West, and East zone. Some zone depends on hydroelectric power plants as the main sources of electricity generation such as North zone. In summation, Every zone has different conditions thus the optimal design for renewable energy sources varies from one zone to another. Consequently, applying the optimal technique for each county will lead to a more secure and economically efficient power system. In this Track, optimization techniques are applied to every county in Texas in order to obtain the best design for the renewable energy system. The MATLAB code is shown in Annex 5. The code depends on the LCOE, capacity factor, renewable energy, and the annual energy consumption of each county, as shown in Annex 6.

The optimized design of renewable energy systems in Texas counties shows some trends, as shown below: The photovoltaic system has attracted 46 counties to become one of the main sources of renewable energy systems. The size of the photovoltaic system varies from county to county, ranging from 4,519 MW to 9 MW. In those 46 counties, the percentage of photovoltaic systems in the total power system size varies from 99% to 6%.The wind turbine system has attracted 122 counties to become one of the main sources of renewable energy systems. The size of the wind turbine system varies from county to county, ranging from 4,859 MW to 2 MW. In those 122 counties, the percentage of wind turbine systems in the total power system size varies from 100% to 6.4%.The Geothermal energy system has attracted 163 counties to become one of the main sources of renewable energy systems. The size of the Geothermal energy system varies from county to county, ranging from 526 MW to 1 MW. In those 163 counties, the percentage of wind turbine systems in the total power system size varies from 100% to less than 1%.The Hydropower plant system has attracted 193 counties to become one of the main sources of renewable energy systems. The size of the Hydropower plant system varies from county to county, ranging from 223 MW to 1 MW. In those 193 counties, the percentage of hydropower plant systems in the total power system size varies from 100% to less than 1%.The Biomass power plant system has attracted 140 counties to become one of the main sources of renewable energy systems. The size of the Biomass power plant system varies from county to county, ranging from 361 MW to 1 MW. In those 140 counties, the percentage of Biomass power plant systems in the total power system size varies from 100% to less than 1%.

According to the optimized design of the renewable energy system of the counties in Texas, 7 counties completely rely on wind energy as the main and only renewable resource system. There are 17 counties that rely on geothermal energy as the main and only renewable resource system. There are 26 counties in Texas that rely on hydroelectric power plants as their main and only renewable resource system. Only one county in Texas can use biomass power plants to meet all its needs. The optimal design of the renewable power system at every county in Texas is shown in Annex6.

CHAPTER XI

CONCLUSION

11.1 Baseload Renewable Energy Resources in Texas

Renewable energy resources depend mainly on five major types: Solar, Wind, Geothermal, Biomass, and Water energy. That energy could be classified into two main categories; baseload resources, which are geothermal, biomass, and water energy, solar energy, and wind energy could be classified as peak or intermediate load renewable energy resources. In the state of Texas as shown in this work, all of those energies have the potential to produce electricity or in other words, they are available. Although the availability of renewable energy resources in Texas, they are limited and varies in capacity from one type to another. Solar and Wind Energy are the only unlimited resources in Texas and they could power even more than the total electricity consumption in the US. However, the Geothermal resources in Texas based on the depleted oil and gas wells could generate up to 250 TWh annually and it is the most abundant baseload renewable energy source in Texas. Followed up with Water energy, which is known by hydropower plants Based on the storage and ROR technology, could power up to 53 TWh per year. Finally, Biomass energy could produce electricity up to 37 TWh based on the anaerobic digester and direct combustion technologies. The total annual energy that could be achieved from all baseload renewable energy in Texas is 344 TWh, as shown in Figure 11.1.

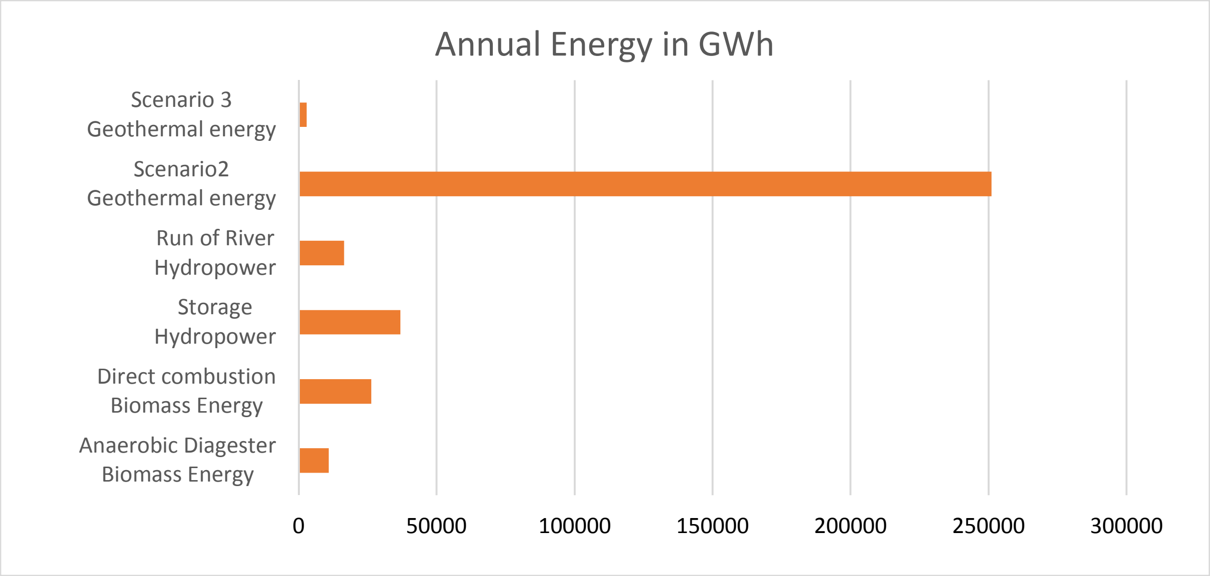


Figure 11. 1: Baseload renewable energy capacity in Texas

11.2 Hypothetical Resources Of Wind And Solar Energy In Texas

The peak or mid-level renewable energy resources in Texas have enough potential to power all the electricity in the United States. Wind energy in Texas can provide an average of approximately 605.6 PWh of electricity per year. The photovoltaic system can generate 345 TWh per year on average. The CSP is the lowest technology for the annual electricity generation among solar and wind energy technologies with generation range from 57-404 PWh depending on the technology which could be the maximum using the solar tower and the minimum using the Linear Fresnel technology, as shown in Figure 11.2.

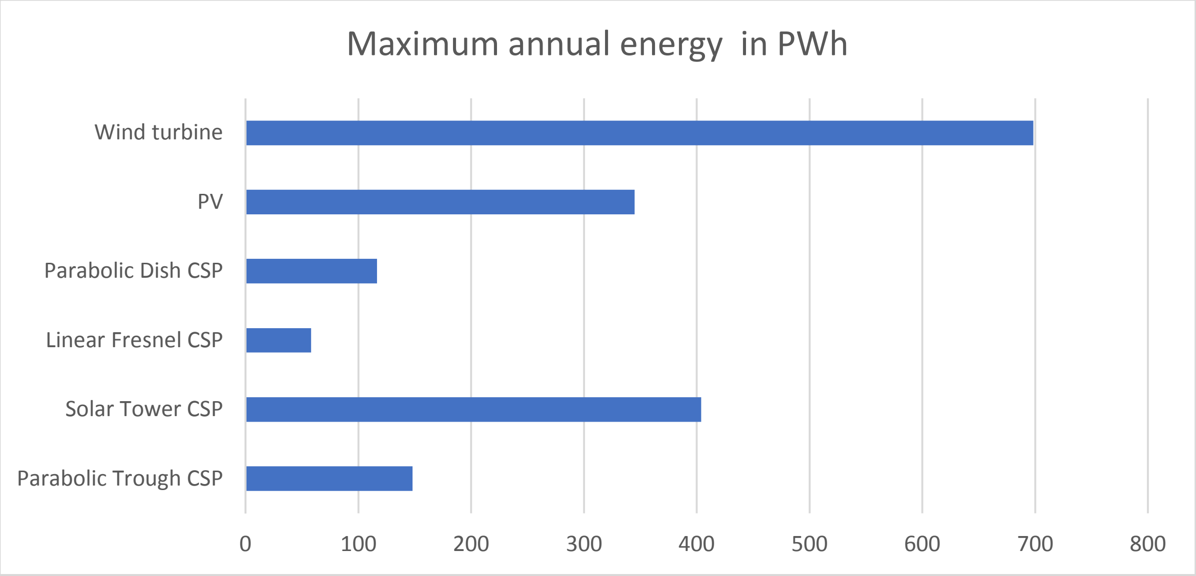


Figure 11. 2: Maximum annual generation of solar and wind energy technologies in Texas

11.3 Capacity of 100% Renewable Power system In Texas

This work involves three renewable energy systems to generate electricity throughout Texas. The first one has a total capacity of 90 GW which is the smallest system however, it requires a backup system in order to avoid power outages for some emergency cases such as abnormal environmental conditions. This system mainly depends on geothermal energy and PV, which form around 80% of the total capacity. The second system has a storage capacity of around 558 GWh, which is a battery bank and a total capacity of 95 GW from different renewable resources and the PV system is used only for charging the battery. The storage system protects the system from facing issues such as power outages for any reason. However, in this system, wind energy and geothermal energy form around 77 % of the total capacity. In the previous two system, CSP is not involved in the system due to its high cost, however, the third system depends on CSP technology in order to broaden the resources of the system to comprehensive all renewable energy resources and furthermore to reduce the traditional battery bank to only 118 GWh. The total capacity of the third system is about 107 GW, the solar, wind, and geothermal energy form 87, as shown in Figure 11.3

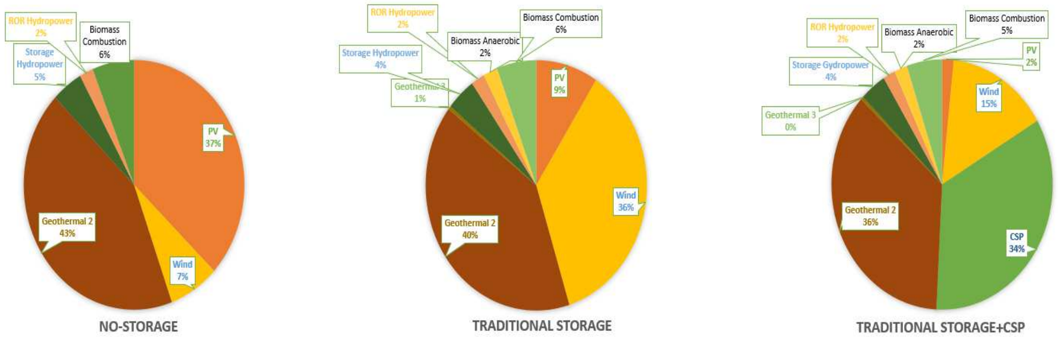


Figure 11. 3: The capacity of the renewable power system in different approaches

11.4 IRP In Texas

Geothermal energy design in all systems is 38.5 GW, nevertheless, the installed geothermal energy in Texas is less than 1 GW. Therefore, the integrated resource plan (IRP) of the utilities should focus on this field. Although The CSP capacity in one of the designs around 36 GW, Texas does not have CSP projects with a capacity of more than 500 MW. In all designs, hydropower forms the main part of a generation with a capacity of 6 GW, however, there are only around 500 MW of hydropower plants are installed in Texas. Biomass energy has capacity varies from 5 -7.5 GW between the three designs of the renewable system, in spite of that the biomass power plant is installed in Texas are less than 500 MW. Wind energy is the only renewable resource where the current installed capacity is near to the optimal design in the systems. Figure 11.4 illustrates the IRP in Texas and it shows that the state of Texas should work more on all renewable energy resources in order to enhance the grid to become 100% from renewable resources.

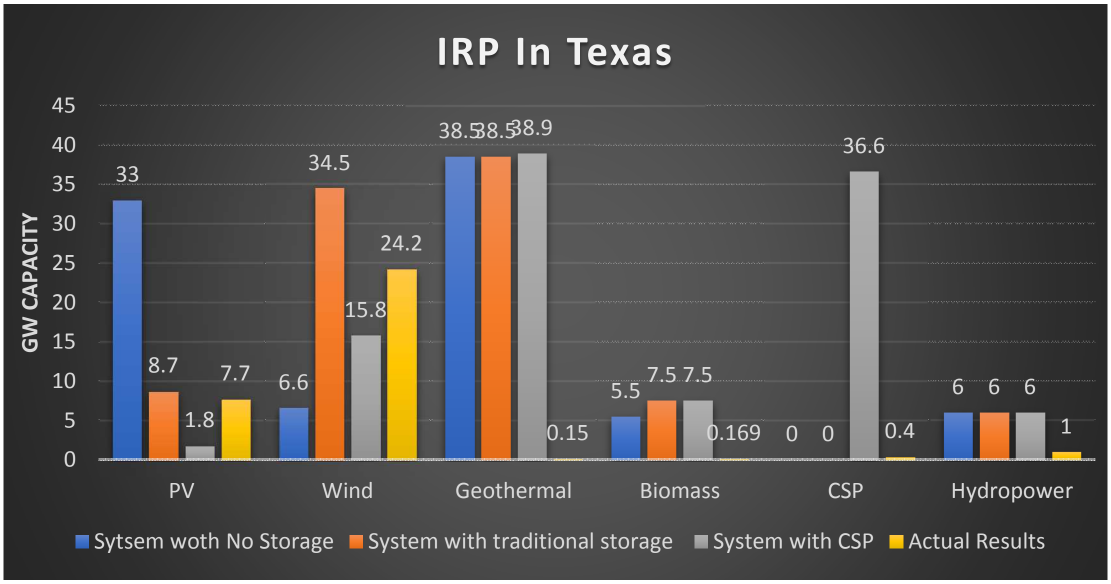
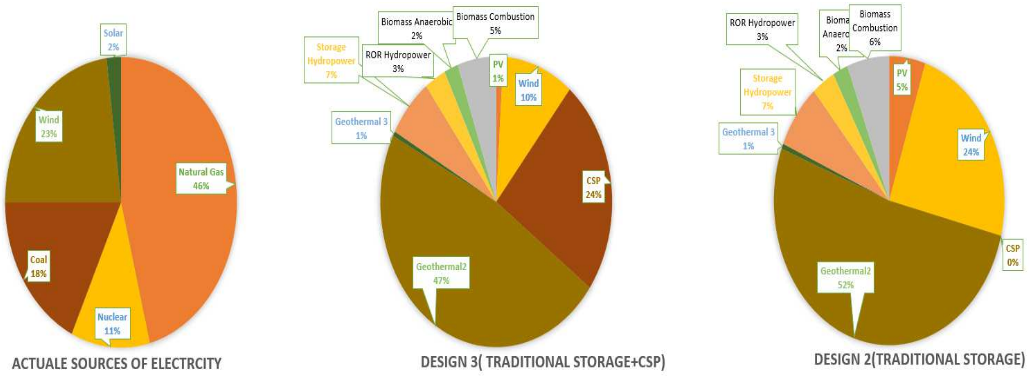


Figure 11. 4: Integrated resource plan of state of Texas

11.5 Annual Energy Shares

Based on 'McCarthy,2021 'The current electricity grid in Texas depends on Natural gas as the main source with 47 % of the total electricity generation comes from it. Then, wind energy will account for 23% of the total electricity. Then the coal and nuclear by 18% and 11 % respectively of the total energy consumption. On the other hand, the renewable power system is addressed in this work depends on 100% renewable energy resources, geothermal energy forms 47 -52 % of the total energy consumption, followed up with solar energy with a range from 5-25 % of the total consumption. Then, with wind energy with a range from 10-24 % of the total consumption. The hydropower and biomass energy production from 10% and 8 % respectively of the annual electricity consumption in Texas. As shown in Figure 11.5.


ACTUALE SOURCES OF ELECTRCITY

DESIGN 3(TRADITIONAL STORAGE+CSP)

DESIGN 2(TRADITIONAL STORAGE)

Figure 11. 5: Annual energy shares in Texas and from the proposal systems

11.6 Greenhouse Gases Emissions

Based o ‘PJM,2019’ every 1 kWh of electricity produce emissions of 0.851 Ib of CO2, 0.00045 Ib of nitrogen oxides, and 0.00055 of SO2. The renewable power system will produce 483 TWh annually with zero-emission or with low carbon energy, therefore, the proposed renewable energy system could save 186 million metric tons of CO2 , and 98 thousand metric tons of nitrogen oxides, and 120 thousand tons of SO2 every year. The system has addressed in this work could reduce the annual CO2 emissions in Texas by 26 % with respect to the total CO2 emissions in Texas ‘Wikipedia contributors,2021’.

However, renewable energy resources could produce some greenhouse gases especially CO_2 ‘Kari,2019’. Figure 11.7 illustrates the estimated CO_2 emissions from the renewable power system which could reach up to 15,980 thousand tons depending on the estimated annual energy of the renewable power system and their corresponding emission according to ‘Kari,2019’, However, the actual emission of the CO_2 from the electricity generation in the state of Texas in 2019 was 217,556 thousand tons ‘Texas Electricity Profile 2019,2020’ . Therefore, depending on the renewable energy system, the estimated system can reduce carbon dioxide emissions by

92%.Based on the available technologies of renewable energy and the proposal power systems in this work, reaching 100 % of zero emissions is so close and could be achievable and in the worst case could reach up to only 8 % of emissions compared with the current electric grid depending on traditional power resources.

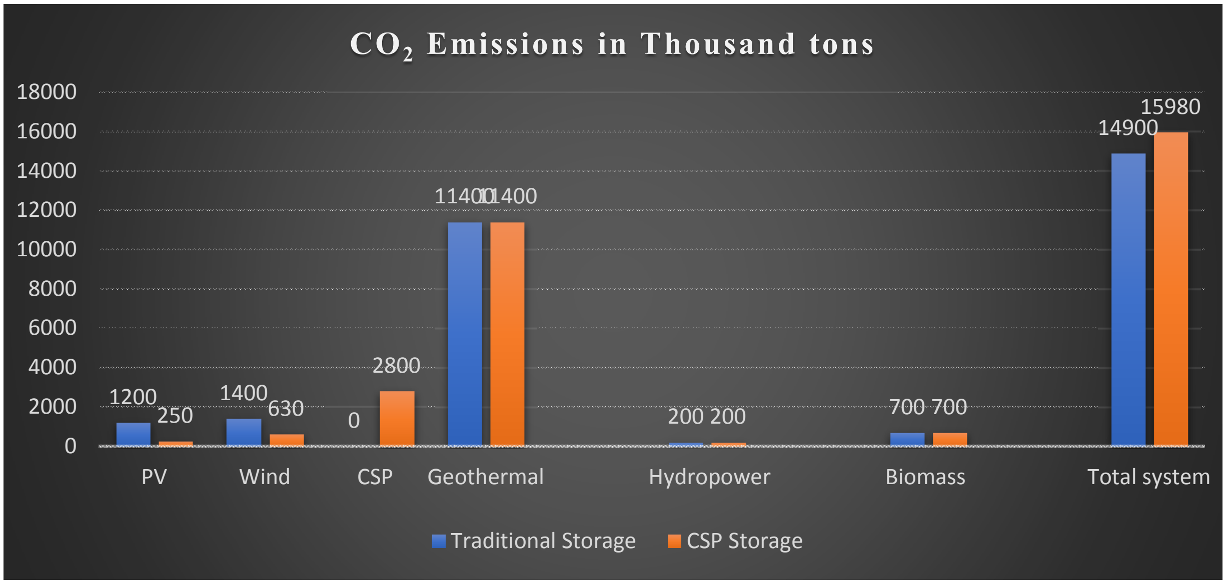


Figure 11. 6: CO_2 Emissions in Thousand tons

11.7 Estimated Cost Of The Proposal System

The LCOE of the renewable power system in Texas varies from one source to another. The LCOE of wind energy is the lowest among all renewable energy resources varies from 9.6 to 322 $/MWh from one county to another. The LCOE of the PV varies from 30.4 to 47.9 $/MWh. The LCOE of the CSP is the most expensive among renewable energy resources which vary from 82.6 to 130.3 $/MWh. The LCOE of geothermal energy based on the depleted oil and gas wells is 36.8 $/MWh, and for the coal-fired geothermal energy is 61.2 $/MWh. The LCOE of the biomass-based on the anaerobic digester is 65 $/MWh and for direct combustion is 39.5 $/MWh. The LCOE of the hydropower plants based on storage technology is 14.8 $/MWh and based on

ROR technology is 39.4 $/MWh. As shown in Figure 11.7. The annual electricity bills in the first three systems are different. In the system with no storage, The electricity bill reaches up to 15 billion dollars per year in Texas. For the second system with traditional storage, the electricity bill cost is 17.3 billion dollars per year. In the system which depends on the CSP system as storage, the electricity bill cost reaches up to 24.8 billion dollars per year. All electricity bill costs from before are cheaper compare with the current electricity bill in Texas based on retail price which could reach up to 36.9 billion dollars ‘ State electricity profiles,2020’. Hence, the renewable power system is more economically efficient compare with the traditional power system as shown in Table 11.1. However, the first system without storage could save up to 21.9 billion dollars yearly but it is not secure and reliable. The second system of the traditional storage bank can save 19.6 electricity bills, and has good reliability and security. The third system based on the CSP system and traditional storage can save 12.1 billion US dollars in electricity bills, and achieve a higher level of reliability and safety.

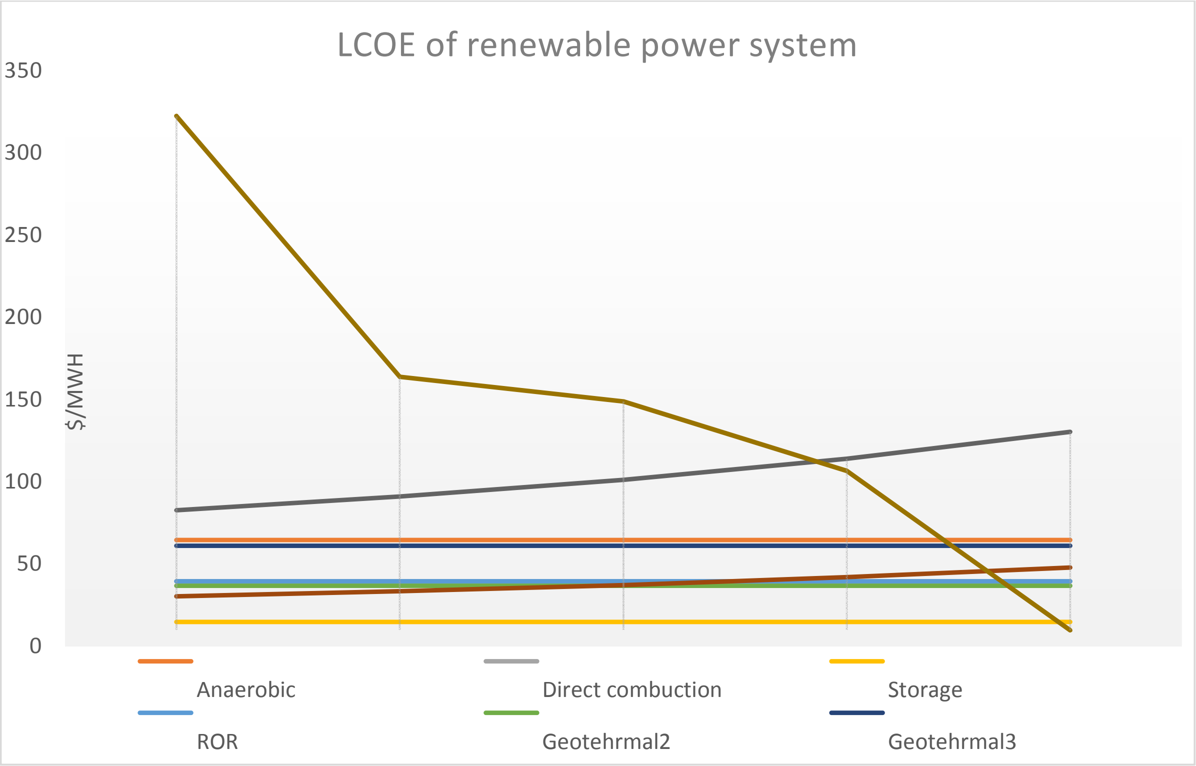


Figure 11. 7: LCOE’s of the renewable power system in Texas

System	Annual electricity bill in billions dollar	Saving compare with current electricity bill in billions dollar	Reliability
Renewable power system without storage system (first design)	15	21.9	Not secure
Renewable power system with storage system (second design)	17.3	19.6	Secure and reliable
Renewable power system with CSP + storage system (third	24.8	12.1	Very reliable and secure
Actual electricity bill in Texas	36.9		

Table 11. 1: Estimated Annual electricity bill cost in Texas

11.8 Smart Power System

Renewable energy resources are not distributed evenly among the counties in the state of Texas, due to change in the geographic and environmental conditions from one location to another. Thus, the optimal design for a smart grid shown variation in the renewable generation sources from one zone to another. Geothermal energy is the only source needed to feed the demand in the south zone. The Far North part depends more on biomass, hydropower, and geothermal energy. The North zone depends only on the hydropower plant. The Coast zone of Texas and the largest Western region should depend on solar energy, especially photovoltaic systems. The Far West, central North, and South depend more on Wind energy and geothermal energy. The proposal distribution of renewable energy resources based on the smart grid design is shown in Figure 11.8 'Maps,2019'.

Figure 11. 8 : Distribution of Renewable energy resources based on smart grid zones

11.9 Micro Power System

Although the smart grid zones design is more specified based on the renewable resources compare with the whole of Texas, Smart grid based on counties by converting the electric power system of Texas into 254 power systems gives more details about renewable energy resources in Texas by counties. Photovoltaic projects are attractive to 46 counties in Texas most of them in the West of Texas. Wind energy is attractive for 122 counties in Texas most of them in the center of Texas. Geothermal energy is the second popular renewable energy among Texas counties in 163 and it locates almost everywhere south and north. Hydropower plants are the most popular renewable resource in 193 counties in Texas. Biomass power plants are attractive as well in all parts of Texas especially in 140 counties and most part of the generation is in the Panhandle area in the Far North of Texas. However, this design will achieve a higher level of security and reliability for each county in Texas but the overall power capacity of the renewable power system will be 177,280 MW while it is 118GW for the smart grid by zones. Figure 11.9 illustrates the difference between the number of counties based on the type of renewable energy and the total power generation of each renewable resource.

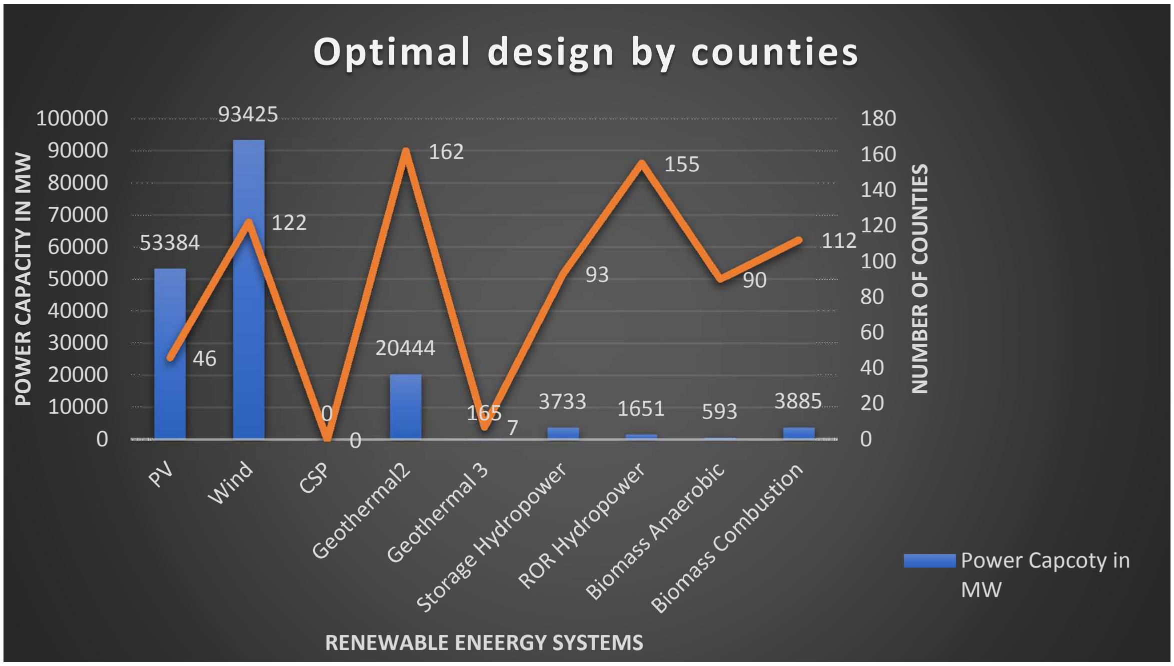


Figure 11. 9: Optimal design by counties capacity

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APPENDIX

Annex 1- matlab code for renewable power system without storage system

```
clear all
close all
clc
% ANNEX 1 simple design with no storage
LCEO_PV1=39.99; % the LCOE OF PV SCENARIO1
LCEO_PV2=37.72;% the LCOE OF PV SCENARIO2
LCEO_PV3=35.06;% the LCOE OF PV SCENARIO3
LCEO_PV4=32.06;% the LCOE OF PV SCENARIO4
LCEO_PV5=30.18;% the LCOE OF PV SCENARIO5
LCEO_W1=61.46; % THE LCOE OF WIND SCENARIO 1
LCEO_W21=61.46;% THE LCOE OF WIND SCENARIO 2 APPROACH1
LCEO_W22=48.22;% THE LCOE OF WIND SCENARIO 1 APPROACH2
LCEO_W23=42.2;% THE LCOE OF WIND SCENARIO 1 APPROACH3
LCEO_W24=36.99;% THE LCOE OF WIND SCENARIO 1 APPROACH4
LCEO_W25=32.57;% THE LCOE OF WIND SCENARIO 1 APPROACH5
LCEO_W31=43.13;% THE LCOE OF WIND SCENARIO 3 APPROACH 1
LCEO_W32=34.56;% THE LCOE OF WIND SCENARIO 3 APPROACH2
LCEO_GE1=99.69;% THE LCOE OF GEOTHERMAL ENERGY SCENARIO 1
LCEO_GE2=36.82;% THE LCOE OF GEOTHERMAL ENERGY SCENARIO 2
LCEO_GE3=61.82;% THE LCOE OF GEOTHERMAL ENERGY SCENARIO 3
LCEO_BANAEROBIC=64.68;% THE LCOE OF BIOMASS ANAEROBIC DIAGESTER
LCEO_BCOMBUSTION=39.52;% THE LCOE OF BIOMASS DIRECT COMBUSTION
LCEO_CSP1=109.48;% THE LCOE OF CSP SCENARIO 1
LCEO_CSP2=103.4;% THE LCOE OF CSP SCENARIO 2
LCEO_CSP3=96.03;% THE LCOE OF CSP SCENARIO 3
LCEO_CSP4=89.92;% THE LCOE OF CSP SCENARIO 4
LCEO_CSP5=82.65;% THE LCOE OF CSP SCENARIO 5
LCEO_H1=14.85; % THE LCOE OF HYDROPOWER STORAGE
LCEO_H2=39.41;%THE LCOE OF HYDROPOWER ROR
CF_PV1=0.242;%THE CAPACITY FACTOR OF PV SCENARIO 1
```

```
CF_PV2=0.257;%THE CAPACITY FACTOR OF PV SCENARIO 2
CF_PV3=0.277;%THE CAPACITY FACTOR OF PV SCENARIO 3
CF_PV4=0.302;%THE CAPACITY FACTOR OF PV SCENARIO 4
CF_PV5=0.321;%THE CAPACITY FACTOR OF PV SCENARIO 5
CF_W1=0.202;%THE CAPACITY FACTOR OF WIND SCENARIO 1
CF_W21=0.202;%THE CAPACITY FACTOR OF WIND SCENARIO 2 APPROACH 1
CF_W22=0.257;%THE CAPACITY FACTOR OF WIND SCENARIO 2 APPROACH 2
CF_W23=0.294;%THE CAPACITY FACTOR OF WIND SCENARIO 2 APPROACH 3
CF_W24=0.335;%THE CAPACITY FACTOR OF WIND SCENARIO 2 APPROCAH 4
CF_W25=0.381;%THE CAPACITY FACTOR OF WIND SCENARIO 2 APPROACH 5
CF_W31=0.287;%THE CAPACITY FACTOR OF WIND SCENARIO 3 APPROACH2
CF_W32=0.359;%THE CAPACITY FACTOR OF WIND SCENARIO 3 APPROACH 2
CF_GE1=0.744;% THE CAPCITY FACTOR OF GEOTEHRMAL SCENARIO1
CF_GE2=0.744;% THE CAPCITY FACTOR OF GEOTEHRMAL SCENARIO2
CF_GE3=0.744;% THE CAPCITY FACTOR OF GEOTEHRMAL SCENARIO3
CF_BANAEROBIC=0.592;% THE CAPACITY FACTOR OF BIOMASS ANAEROBIC
CF_BCOMBUSTION=0.592;% THE CAPACITY FACTOR OF BIOMASS DIRECT COMBUSTION
CF_CSP1=0.301;% THE CAPACITY FACTOR OF CSP SCENARIO 1
CF_CSP2=0.318;% THE CAPACITY FACTOR OF CSP SCENARIO 2
CF_CSP3=0.343;% THE CAPACITY FACTOR OF CSP SCENARIO 3
CF_CSP4=0.366;% THE CAPACITY FACTOR OF CSP SCENARIO 4
CF_CSP5=0.398;% THE CAPACITY FACTOR OF CSP SCENARIO 5
CF_H1=1;% THE CAPACITY FACTOR OF HYDROPOWER STORAGE
CF_H2=1;% THE CAPACITY FACTOR OF HYDROPOWER ROR
F1=LCEO_PV1;
F2=LCEO_PV2;
F3=LCEO_PV3;
F4=LCEO_PV4;
F5=LCEO_PV5;
F6=LCEO_W1;
F7=LCEO_W21;
```

```
F8=LCEO_W22;
F9=LCEO_W23;
F10=LCEO_W24;
F11=LCEO_W25;
F12=LCEO_W31;
F13=LCEO_W32;
F14=LCEO_GE1;
F15=LCEO_GE2;
F16=LCEO_GE3;
F17=LCEO_BANAEROBIC;
F18=LCEO_BCOMBUSTION;
F19=LCEO_CSP1;
F20=LCEO_CSP2;
F21=LCEO_CSP3;
F22=LCEO_CSP4;
F23=LCEO_CSP5;
F24=LCEO_H1;
F25=LCEO_H2;
c=[ F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19 F20 F21 F22 F23 F24 F25 ];
Aeq=[CF_PV1, CF_PV2, CF_PV3, CF_PV4, CF_PV5, CF_W1, CF_W21, CF_W22, CF_W23, CF_W24, CF_W25, CF_W31, CF_W32, CF_GE1, CF_GE2, CF_GE3, CF_BANAEROBIC, CF_BCOMBUSTION, CF_CSP1, CF_CSP2, CF_CSP3, CF_CSP4, CF_CSP5, CF_H1, CF_H2;1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1];
Beq=[ 51136;90*(10^3)];
A=[];
b=[];
Ib=[0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];
ub=[inf;inf;inf;inf;inf;inf;inf;inf;inf;inf;inf;inf;inf;inf;38512;429.6;2107.2;5521.68;inf;inf;inf;inf;inf;4094;1886];
x0=[];
options=optimset(‘Algorithm’,’dual-simplex’);
[x,fval,exitflag,ouput]=linprog(c,A,b,Aeq,Beq,Ib,ub,x0,options);
```

Annex 2- matlab code for renewable power system with storage system

```
clear all
close all
clc
% Renewable power system with storage bank
prob = optimproblem;
x1 = optimvar('x1','LowerBound',0);%PV size in MW
x2 = optimvar('x2','LowerBound',0);%wind size in MW
x3 = optimvar('x3','LowerBound',0);%CSP size
x4 = optimvar('x4','LowerBound',0,'UpperBound',38500);%Geothermal size sceanrio2
x5=optimvar('x5','LowerBound',0,'UpperBound',429.6);%Geothermal size sceanrio3
x6=optimvar('x6','LowerBound',0,'UpperBound',4094.1);%Hydropower size sceanrio1
x7=optimvar('x7','LowerBound',0,'UpperBound',1886);%Hydropower size sceanrio2
x8=optimvar('x8','LowerBound',0,'UpperBound',2017.2);%Biomass anaerobic size
x9=optimvar('x9','LowerBound',0,'UpperBound',5521.68);%Biomass combustion size
x10=optimvar('x10','LowerBound',0);% energy storgae size based on PV
x11=optimvar('x11','LowerBound',0);% energy storgae size based on Wind
x12=optimvar('x12','LowerBound',0);% PV size based on Storage
x13=optimvar('x13','LowerBound',0);% Wind size based on Storage
prob.Objective =
30.18*x1+32.5*x2+82.6*x3+36.82*x4+61.18*x5+14.85*x6+39.41*x7+64.68*x8+39.52*x9+ 833*x10+
836*x11+30.18*x12+32.5*x13;% objective function
cons1=.321*8760*x1+ 0.3817*8760*x2+
0.398*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9+4
0*(x10+x11)>=483*(10^6);%  constraint about the annual energy consumtion
cons2=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=42927;% constarint about the
average energy consumtion in January
cons3=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=44260;% constarint about the
average energy consumtion in February
cons4=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=41756;% constarint about the
average energy consumtion in March
```

```
cons5=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=41186;% constarint about the
average energy consumtion in April

cons6=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=46235;% constarint about the
average energy consumtion in May

cons7=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=54249;% constarint about the
average energy consumtion in June

cons8=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=59598;% constarint about the
average energy consumtion in July

cons9=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=60374;% constarint about the
average energy consumtion in August

cons10=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=50076;% constarint about the
average energy consumtion in September

cons11=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=46212;% constarint about the
average energy consumtion in october

cons12=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=41689;% constarint about the
average energy consumtion in November

cons13=.321*x1+ 0.3817*x2+
0.398*x3+0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11>=44786;% constarint about the
average energy consumtion in December

cons14=x4+x5+x6+x7+x8+x9+x10+x11>=53962;% constraint abount the peak load in Jaunray

cons15=x4+x5+x6+x7+x8+x9+x10+x11>=61727;% constraint abount the peak load in February

cons16=x4+x5+x6+x7+x8+x9+x10+x11>=58100;% constraint abount the peak load in March

cons17=x4+x5+x6+x7+x8+x9+x10+x11>=60722;% constraint abount the peak load in April

cons18=x4+x5+x6+x7+x8+x9+x10+x11>=70835;% constraint abount the peak load in May

cons19=x4+x5+x6+x7+x8+x9+x10+x11>=74847;% constraint abount the peak load in June

cons20=x4+x5+x6+x7+x8+x9+x10+x11>=81742;% constraint abount the peak load in July

cons21=x4+x5+x6+x7+x8+x9+x10+x11>=81760;% constraint abount the peak load in August

cons22=x4+x5+x6+x7+x8+x9+x10+x11>=71274;% constraint abount the peak load in September

cons23=x4+x5+x6+x7+x8+x9+x10+x11>=69365;% constraint abount the peak load in October

cons24=x4+x5+x6+x7+x8+x9+x10+x11>=53913;% constraint abount the peak load in November
```

```
cons25=x4+x5+x6+x7+x8+x9+x10+x11>=61494;% constraint abount the peak load in December
cons26= 0.321*8760*x12>=1.1*40*(x10); % constraint the realyion between the solar  with the storage system
cons27=x4+x5+x6+x7+x8+x9+x10+x11>=53962;% constraint abount the peak interval in January
cons28=15*x4+15*x5+15*x6+15*x7+15*x8+15*x9+x10+x11>=823726.9;% constraint abount the peak interval in February
cons29=8*x4+8*x5+8*x6+8*x7+8*x8+8*x9+x10+x11>=446821.147;% constraint abount the peak interval in March
cons30=9*x4+9*x5+9*x6+9*x7+9*x8+9*x9+x10+x11>=503503.4;% constraint abount the peak interval in April
cons31=13*x4+13*x5+13*x6+13*x7+13*x8+13*x9+x10+x11>=812033.8;% constraint abount the peak interval in May
cons32=17*x4+17*x5+17*x6+17*x7+17*x8+17*x9+x10+x11>=1096806.3;% constraint abount the peak interval in June
cons33=18*x4+18*x5+18*x6+18*x7+18*x8+18*x9+x10+x11>=1274925.726;% constraint abount the peak interval in July
cons34=44*x4+44*x5+44*x6+44*x7+44*x8+44*x9+x10+x11>=2865854.685;% constraint abount the peak interval in August
cons35=15*x4+15*x5+15*x6+15*x7+15*x8+15*x9+x10+x11>=917638.3368;% constraint abount the peak interval in September
cons36=12*x4+12*x5+12*x6+12*x7+12*x8+12*x9+x10+x11>=747763.73;% constraint abount the peak interval in October
cons37=5*x4+5*x5+5*x6+5*x7+5*x8+5*x9+x10+x11>=266094.8499;% constraint abount the peak interval in November
cons38=11*x4+11*x5+11*x6+11*x7+11*x8+11*x9+x10+x11>=591479.5984;% constraint abount the peak interval in December
cons39=0.3817*8760*x2>=1.1*40*x11;% constraint the realyion between the wind  with the storage system
prob.Constraints.cons1 = cons1;% solving related to constraint number 1
prob.Constraints.cons2 = cons2;% solving related to constraint number 2
prob.Constraints.cons3 = cons3;% solving related to constraint number 3
prob.Constraints.cons4 = cons4;% solving related to constraint number 4
prob.Constraints.cons5 = cons5;% solving related to constraint number 5
prob.Constraints.cons6 = cons6;% solving related to constraint number 6
prob.Constraints.cons7 = cons7;% solving related to constraint number 7
prob.Constraints.cons8 = cons8;% solving related to constraint number 8
```

```
prob.Constraints.cons9 = cons9;% solving related to constraint number 9
prob.Constraints.cons10 = cons10;% solving related to constraint number 10
prob.Constraints.cons11 = cons11;% solving related to constraint number 11
prob.Constraints.cons12 = cons12;% solving related to constraint number 12
prob.Constraints.cons13 = cons13;% solving related to constraint number 13
prob.Constraints.cons14 = cons14;% solving related to constraint number 14
prob.Constraints.cons15 = cons15;% solving related to constraint number 15
prob.Constraints.cons16 = cons16;% solving related to constraint number 16
prob.Constraints.cons17 = cons17;% solving related to constraint number 17
prob.Constraints.cons18 = cons18;% solving related to constraint number 18
prob.Constraints.cons19 = cons19;% solving related to constraint number 19
prob.Constraints.cons20 = cons20;% solving related to constraint number 20
prob.Constraints.cons21 = cons21;% solving related to constraint number 21
prob.Constraints.cons22 = cons22;% solving related to constraint number 22
prob.Constraints.cons23 = cons23;% solving related to constraint number 23
prob.Constraints.cons24 = cons24;% solving related to constraint number 24
prob.Constraints.cons25 = cons25;% solving related to constraint number 25
prob.Constraints.cons26 = cons26;% solving related to constrain number 26
prob.Constraints.cons27 = cons27;% solving related to constrain number 27
prob.Constraints.cons28 = cons28;% solving related to constrain number 28
prob.Constraints.cons29 = cons29;% solving related to constrain number 29
prob.Constraints.cons30 = cons30;% solving related to constrain number 30
prob.Constraints.cons31 = cons31;% solving related to constrain number 31
prob.Constraints.cons32 = cons32;% solving related to constrain number 32
prob.Constraints.cons33 = cons33;% solving related to constrain number 33
prob.Constraints.cons34 = cons34;% solving related to constrain number 34
prob.Constraints.cons35 = cons35;% solving related to constrain number 35
prob.Constraints.cons36 = cons36;% solving related to constrain number 36
prob.Constraints.cons37 = cons37;% solving related to constrain number 37
prob.Constraints.cons38 = cons38;% solving related to constrain number 38
prob.Constraints.cons39 = cons39;% solving related to constrain number 39
```

```
sol = solve(prob,'Solver', 'linprog');%to use the linprog function
```

Annex 3- matlab code for renewable power system with csp and storage

```
close all
clc
clear all
% Renewable power system with CSP and storage
prob = optimproblem;
x1 = optimvar('x1','LowerBound',0);%PV size in MW
x2 = optimvar('x2','LowerBound',0);%wind size in MW
x3 = optimvar('x3','LowerBound',0);%CSP size
x4 = optimvar('x4','LowerBound',0,'UpperBound',38500);%Geothermal size sceanrio2
x5=optimvar('x5','LowerBound',0,'UpperBound',429.6);%Geothermal size sceanrio3
x6=optimvar('x6','LowerBound',0,'UpperBound',4094.1);%Hydropower size sceanrio1
x7=optimvar('x7','LowerBound',0,'UpperBound',1886);%Hydropower size sceanrio2
x8=optimvar('x8','LowerBound',0,'UpperBound',2017.2);%Biomass anaerobic size
x9=optimvar('x9','LowerBound',0,'UpperBound',5521.68);%Biomass combustion size
x10=optimvar('x10','LowerBound',0);% energy storgae size based on PV
x11=optimvar('x11','LowerBound',0);% energy storgae size based on Wind
x12=optimvar('x12','LowerBound',0);% PV size based on Storage
x13=optimvar('x13','LowerBound',0);% Wind size based on Storage
prob.Objective = 30.18*x1+32.5*x2+165.3*x3+36.82*x4+61.18*x5+14.85*x6+39.41*x7+64.68*x8+39.52*x9+ 833*x10+ 836*x11+30.18*x12+32.5*x13;% objective function
cons1=.321*8760*x1+ 0.3817*8760*x2+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9+ 0.398*8760*x3+40*(x10+x11)>=483*10^6;%  constraint about the annual energy consumtion
cons2=.321*x1+ 0.3817*x2+ 0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=42927;% constarint about the average energy consumtion in January
cons3=.321*x1+ 0.3817*x2+ 0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=44260;% constarint about the average energy consumtion in February
cons4=.321*x1+ 0.3817*x2+ 0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=41756;% constarint about the average energy consumtion in March
```

```
cons5=.321*x1+ 0.3817*x2+
0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=41186;% constarint about the
average energy consumtion in April

cons6=.321*x1+ 0.3817*x2+
0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=46235;% constarint about the
average energy consumtion in May

cons7=.321*x1+ 0.3817*x2+
0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=54249;% constarint about the
average energy consumtion in June

cons8=.321*x1+ 0.3817*x2+
0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=59598;% constarint about the
average energy consumtion in July

cons9=.321*x1+ 0.3817*x2+
0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=60374;% constarint about the
average energy consumtion in August

cons10=.321*x1+ 0.3817*x2+
0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=50076;% constarint about the
average energy consumtion in September

cons11=.321*x1+ 0.3817*x2+
0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=46212;% constarint about the
average energy consumtion in October

cons12=.321*x1+ 0.3817*x2+
0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=41689;% constarint about the
average energy consumtion in November

cons13=.321*x1+ 0.3817*x2+
0.744*x4+.744*x5+x6+x7+0.592*x8+0.592*x9+x10+x11+0.398*x3>=44786;% constarint about the
average energy consumtion in Decemeber

cons14=x3+x4+x5+x6+x7+x8+x9+x10+x11>=53962;% constraint abount the peak load in Jaunray

cons15=x3+x4+x5+x6+x7+x8+x9+x10+x11>=61727;% constraint abount the peak load in February

cons16=x3+x4+x5+x6+x7+x8+x9+x10+x11>=58100;% constraint abount the peak load in March

cons17=x3+x4+x5+x6+x7+x8+x9+x10+x11>=60722;% constraint abount the peak load in April

cons18=x3+x4+x5+x6+x7+x8+x9+x10+x11>=70835;% constraint abount the peak load in May

cons19=x3+x4+x5+x6+x7+x8+x9+x10+x11>=74847;% constraint abount the peak load in June

cons20=x3+x4+x5+x6+x7+x8+x9+x10+x11>=81742;% constraint abount the peak load in July

cons21=x3+x4+x5+x6+x7+x8+x9+x10+x11>=81760;% constraint abount the peak load in August

cons22=x3+x4+x5+x6+x7+x8+x9+x10+x11>=71274;% constraint abount the peak load in September

cons23=x3+x4+x5+x6+x7+x8+x9+x10+x11>=69365;% constraint abount the peak load in October

cons24=x3+x4+x5+x6+x7+x8+x9+x10+x11>=53913;% constraint abount the peak load in November
```

```
cons25=x3+x4+x5+x6+x7+x8+x9+x10+x11>=61494;% constraint abount the peak load in December
cons26= 0.321*8760*x12>=1.1*40*(x10); % constraint the relation between the solar and  with the storage system
cons27=0*x3+15*x4+15*x5+15*x6+15*x7+15*x8+15*x9+x10+x11>=823726.9;% constraint abount the peak interval in February
cons28=0*x3+8*x4+8*x5+8*x6+8*x7+8*x8+8*x9+x10+x11>=446821.147;% constraint abount the peak interval in March
cons29=6*x3+9*x4+9*x5+9*x6+9*x7+9*x8+9*x9+x10+x11>=503503.4;% constraint abount the peak interval in April
cons30=6*x3+13*x4+8*x5+13*x6+13*x7+13*x8+13*x9+x10+x11>=812033.8;% constraint abount the peak interval in May
cons31=6*x3+17*x4+17*x5+17*x6+17*x7+17*x8+17*x9+x10+x11>=1096806.3;% constraint abount the peak interval in June
cons32=6*x3+18*x4+18*x5+18*x6+18*x7+18*x8+18*x9+x10+x11>=1159023.387;% constraint abount the peak interval in July
cons33=12*x3+44*x4+44*x5+44*x6+44*x7+44*x8+44*x9+x10+x11>=2865854.685;% constraint abount the peak interval in August
cons34=6*x3+15*x4+15*x5+15*x6+15*x7+15*x8+15*x9+x10+x11>=834216.6;% constraint abount the peak interval in September
cons35=0*x3+12*x4+12*x5+12*x6+12*x7+12*x8+12*x9+x10+x11>=747763.73;% constraint abount the peak interval in October
cons36=0*x3+5*x4+5*x5+5*x6+5*x7+5*x8+5*x9+x10+x11>=266094.8499;% constraint abount the peak interval in November
cons37=0*x3+11*x4+11*x5+11*x6+11*x7+11*x8+11*x9+x10+x11>=591479.5984;% constraint abount the peak interval in Decemebr
cons38=0.3817*8760*x13>=1.1*40*x11;% constraint the relation between the solar and  with the storage system
prob.Constraints.cons1 = cons1;% solving related to constraint number 1
prob.Constraints.cons2 = cons2;% solving related to constraint number 2
prob.Constraints.cons3 = cons3;% solving related to constraint number 3
prob.Constraints.cons4 = cons4;% solving related to constraint number 4
prob.Constraints.cons5 = cons5;% solving related to constraint number 5
prob.Constraints.cons6 = cons6;% solving related to constraint number 6
prob.Constraints.cons7 = cons7;% solving related to constraint number 7
prob.Constraints.cons8 = cons8;% solving related to constraint number 8
prob.Constraints.cons9 = cons9;% solving related to constraint number 9
```

```matlab
prob.Constraints.cons10 = cons10;% solving related to constraint number 10
prob.Constraints.cons11 = cons11;% solving related to constraint number 11
prob.Constraints.cons12 = cons12;% solving related to constraint number 12
prob.Constraints.cons13 = cons13;% solving related to constraint number 13
prob.Constraints.cons14 = cons14;% solving related to constraint number 14
prob.Constraints.cons15 = cons15;% solving related to constraint number 15
prob.Constraints.cons16 = cons16;% solving related to constraint number 16
prob.Constraints.cons17 = cons17;% solving related to constraint number 17
prob.Constraints.cons18 = cons18;% solving related to constraint number 18
prob.Constraints.cons19 = cons19;% solving related to constraint number 19
prob.Constraints.cons20 = cons20;% solving related to constraint number 20
prob.Constraints.cons21 = cons21;% solving related to constraint number 21
prob.Constraints.cons22 = cons22;% solving related to constraint number 22
prob.Constraints.cons23 = cons23;% solving related to constraint number 23
prob.Constraints.cons24 = cons24;% solving related to constraint number 24
prob.Constraints.cons25 = cons25;% solving related to constraint number 25
prob.Constraints.cons26 = cons26;% solving related to constraint number 26
prob.Constraints.cons27 = cons27;% solving related to constraint number 27
prob.Constraints.cons28 = cons28;% solving related to constraint number 28
prob.Constraints.cons29 = cons29;% solving related to constraint number 29
prob.Constraints.cons30 = cons30;% solving related to constraint number 30
prob.Constraints.cons31 = cons31;% solving related to constraint number 31
prob.Constraints.cons32 = cons32;% solving related to constraint number 32
prob.Constraints.cons33 = cons33;% solving related to constraint number 33
prob.Constraints.cons34 = cons34;% solving related to constraint number 34
prob.Constraints.cons35 = cons35;% solving related to constraint number 35
prob.Constraints.cons36 = cons36;% solving related to constraint number 36
prob.Constraints.cons37 = cons37;% solving related to constraint number 37
prob.Constraints.cons38 = cons38;% solving related to constraint number 38
sol = solve(prob,'Solver', 'linprog')%to use the linprog function
```

Annex 4 - matlab code for track 1

Coast zone

```
prob = optimproblem;
x1 = optimvar('x1','LowerBound',0);%PV size in MW
x2 = optimvar('x2','LowerBound',0);%wind size in MW
x3 = optimvar('x3','LowerBound',0);%CSP size in MW
x4 = optimvar('x4','LowerBound',0,'UpperBound',3202);%Geothermal size sceanrio2 in MW
x5=optimvar('x5','LowerBound',0,'UpperBound',25);%Geothermal size sceanrio3 in MW
x6=optimvar('x6','LowerBound',0,'UpperBound',36.2);%Hydropower size sceanrio1 in MW
x7=optimvar('x7','LowerBound',0,'UpperBound',106.2);%Hydropower size sceanrio2 in MW
x8=optimvar('x8','LowerBound',0,'UpperBound',89.1);%Biomass anaerobic size in MW
x9=optimvar('x9','LowerBound',0,'UpperBound',1003);%Biomass combustion size  in MW
prob.Objective = 47.9*x1+51.06*x2+130.379*x3+36.8*x4+61.1*x5+14.8*x6+39.4*x7+64.6*x8+39.5*x9;% objective function of the Coast zone
cons1=.20*8760*x1+ 0.135*8760*x2+0.25*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9>=109.9*10^6;
prob.Constraints.cons1 = cons1;% solving related to constraint number 1
sol = solve(prob,'Solver', 'linprog');%to use the linprog function
```

North Central

```
prob = optimproblem;
x1 = optimvar('x1','LowerBound',0);%PV size in MW
x2 = optimvar('x2','LowerBound',0);%wind size in MW
x3 = optimvar('x3','LowerBound',0);%CSP size in MW
x4 = optimvar('x4','LowerBound',0,'UpperBound',5003);%Geothermal size sceanrio2 in MW
x5=optimvar('x5','LowerBound',0,'UpperBound',25);%Geothermal size sceanrio3 in MW
x6=optimvar('x6','LowerBound',0,'UpperBound',2099.98);%Hydropower size sceanrio1 in MW
x7=optimvar('x7','LowerBound',0,'UpperBound',352.55);%Hydropower size sceanrio2 in MW
x8=optimvar('x8','LowerBound',0,'UpperBound',319.98);%Biomass anaerobic size in MW
x9=optimvar('x9','LowerBound',0,'UpperBound',1257.9);%Biomass combustion size in MW
prob.Objective = 41.27*x1+23.1094*x2+112.05*x3+36.8*x4+61.1*x5+14.8*x6+39.4*x7+64.6*x8+39.5*x9;%Objective function of North Central zone
```

```
cons1=.23*8760*x1+ 0.21*8760*x2+ 0.29*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9>=116*10^6;

prob.Constraints.cons1 = cons1;% solving related to constraint number 1

sol = solve(prob,'Solver', 'linprog')%to use the linprog function
```

Out-ERCOT zone

```
prob = optimproblem;

x1 = optimvar('x1','LowerBound',0);%PV size in MW

x2 = optimvar('x2','LowerBound',0);%wind size in MW

x3 = optimvar('x3','LowerBound',0);%CSP size in MW

x4 = optimvar('x4','LowerBound',0,'UpperBound',6195.5);%Geothermal size sceanrio2 in MW

x5=optimvar('x5','LowerBound',0,'UpperBound',71.5);%Geothermal size sceanrio3 in MW

x6=optimvar('x6','LowerBound',0,'UpperBound',221.38);%Hydropower size sceanrio1 in MW

x7=optimvar('x7','LowerBound',0,'UpperBound',416.26);%Hydropower size sceanrio2 in MW

x8=optimvar('x8','LowerBound',0,'UpperBound',391.5);%Biomass anaerobic size in MW

x9=optimvar('x9','LowerBound',0,'UpperBound',826.89);%Biomass combustion size in MW

prob.Objective = 41.73*x1+31.15*x2+113.453*x3+36.8*x4+61.1*x5+14.8*x6+39.4*x7+64.6*x8+39.5*x9;% Objective function of Out-ERCOT zone

cons1=.239*8760*x1+ 0.195*8760*x2+ 0.296*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9>= 101*10^6;

prob.Constraints.cons1 = cons1;% solving related to constraint number 1

sol = solve(prob,'Solver', 'linprog')%to use the linprog function
```

South Central zone

```
prob = optimproblem;

x1 = optimvar('x1','LowerBound',0);%PV size in MW

x2 = optimvar('x2','LowerBound',0);%wind size in MW

x3 = optimvar('x3','LowerBound',0);%CSP size in MW

x4 = optimvar('x4','LowerBound',0,'UpperBound',4524.82);%Geothermal size sceanrio2 in MW

x5=optimvar('x5','LowerBound',0,'UpperBound',50);%Geothermal size sceanrio3 in MW

x6=optimvar('x6','LowerBound',0,'UpperBound',360);%Hydropower size sceanrio1 in MW

x7=optimvar('x7','LowerBound',0,'UpperBound',113.75);%Hydropower size sceanrio2 in MW
```

```
x8=optimvar('x8','LowerBound',0,'UpperBound',241.54);%Biomass anaerobic size in MW

x9=optimvar('x9','LowerBound',0,'UpperBound',660.45);%Biomass combustion size in MW

prob.Objective = 44.16*x1+27.2*x2+119.9*x3+36.8*x4+61.1*x5+14.8*x6+39.4*x7+64.6*x8+39.5*x9;%Objective function of South Central zone

cons1=.22*8760*x1+ 0.18*8760*x2+ 0.27*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9>=60.2*10^6;

prob.Constraints.cons1 = cons1;% solving related to constraint number 1

sol = solve(prob,'Solver', 'linprog')%to use the linprog function
```

Far west zone

```
prob = optimproblem;

x1 = optimvar('x1','LowerBound',0);%PV size in MW

x2 = optimvar('x2','LowerBound',0);%wind size in MW

x3 = optimvar('x3','LowerBound',0);%CSP size in MW

x4 = optimvar('x4','LowerBound',0,'UpperBound',4502.5);%Geothermal size sceanrio2 in MW

x5=optimvar('x5','LowerBound',0,'UpperBound',0);%Geothermal size sceanrio3 in MW

x6=optimvar('x6','LowerBound',0,'UpperBound',0);%Hydropower size sceanrio1 in MW

x7=optimvar('x7','LowerBound',0,'UpperBound',41);%Hydropower size sceanrio2 in MW

x8=optimvar('x8','LowerBound',0,'UpperBound',45);%Biomass anaerobic size in MW

x9=optimvar('x9','LowerBound',0,'UpperBound',116);%Biomass combustion size in MW

prob.Objective = 33.11*x1+41.98*x2+89.9*x3+36.8*x4+61.1*x5+14.8*x6+39.4*x7+64.6*x8+39.5*x9;% Objective function of far West zone

cons1=0.29*8760*x1+ 0.15*8760*x2+ 0.36*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9>=32.6*10^6;

prob.Constraints.cons1 = cons1;% solving related to constraint number 1

sol = solve(prob,'Solver', 'linprog')%to use the linprog function
```

South zone

```
prob = optimproblem;

x1 = optimvar('x1','LowerBound',0);%PV size in MW

x2 = optimvar('x2','LowerBound',0);%wind size in MW

x3 = optimvar('x3','LowerBound',0);%CSP size in MW

x4 = optimvar('x4','LowerBound',0,'UpperBound',9057.54);%Geothermal size sceanrio2 in MW
```

```
x5=optimvar('x5','LowerBound',0,'UpperBound',85.8);%Geothermal size sceanrio3 in MW
x6=optimvar('x6','LowerBound',0,'UpperBound',13.4);%Hydropower size sceanrio1 in MW
x7=optimvar('x7','LowerBound',0,'UpperBound',43.8);%Hydropower size sceanrio2 in MW
x8=optimvar('x8','LowerBound',0,'UpperBound',128.733);%Biomass anaerobic size in MW
x9=optimvar('x9','LowerBound',0,'UpperBound',472.448);%Biomass combustion size in MW
prob.Objective = 42.7*x1+44.75*x2+115.9*x3+36.8*x4+61.1*x5+14.8*x6+39.4*x7+64.6*x8+39.5*x9;%Objective function of South zone
cons1=0.22*8760*x1+ 0.157*8760*x2+ 0.28*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9>=30.9*10^6;
prob.Constraints.cons1 = cons1;% solving related to constraint number 1
sol = solve(prob,'Solver', 'linprog')%to use the linprog function
```

East Zone

```
prob = optimproblem;
x1 = optimvar('x1','LowerBound',0);%PV size in MW
x2 = optimvar('x2','LowerBound',0);%wind size in MW
x3 = optimvar('x3','LowerBound',0);%CSP size in MW
x4 = optimvar('x4','LowerBound',0,'UpperBound',1834.43);%Geothermal size sceanrio2 in MW
x5=optimvar('x5','LowerBound',0,'UpperBound',171.6);%Geothermal size sceanrio3 in MW
x6=optimvar('x6','LowerBound',0,'UpperBound',501.218);%Hydropower size sceanrio1 in MW
x7=optimvar('x7','LowerBound',0,'UpperBound',323.847);%Hydropower size sceanrio2 in MW
x8=optimvar('x8','LowerBound',0,'UpperBound',195.19);%Biomass anaerobic size in MW
x9=optimvar('x9','LowerBound',0,'UpperBound',108.04);%Biomass combustion size in MW
prob.Objective = 47.08*x1+23.488*x2+128.02*x3+36.8*x4+61.1*x5+14.8*x6+39.4*x7+64.6*x8+39.5*x9; % Objective function of East
cons1=0.206*8760*x1+ 0.21*8760*x2+ 0.255*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9>= 13.75*10^6;
prob.Constraints.cons1 = cons1;% solving related to constraint number 1
sol = solve(prob,'Solver', 'linprog')%to use the linprog function
```

West Zone

```
prob = optimproblem;
```

```
x1 = optimvar('x1','LowerBound',0);%PV size in MW
x2 = optimvar('x2','LowerBound',0);%wind size in MW
x3 = optimvar('x3','LowerBound',0);%CSP size in MW
x4 = optimvar('x4','LowerBound',0,'UpperBound',1778.35);%Geothermal size sceanrio2 in MW
x5=optimvar('x5','LowerBound',0,'UpperBound',0);%Geothermal size sceanrio3 in MW
x6=optimvar('x6','LowerBound',0,'UpperBound',343.479);%Hydropower size sceanrio1 in MW
x7=optimvar('x7','LowerBound',0,'UpperBound',80.09);%Hydropower size sceanrio2 in MW
x8=optimvar('x8','LowerBound',0,'UpperBound',118.87);%Biomass anaerobic size in MW
x9=optimvar('x9','LowerBound',0,'UpperBound',133.072);%Biomass combustion size in MW
prob.Objective = 38.88*x1+16.42*x2+105.56*x3+36.8*x4+61.1*x5+14.8*x6+39.4*x7+64.6*x8+39.5*x9; % Objective function of West zone
cons1=0.25*8760*x1+ 0.31*8760*x2+ 0.31*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9>=10.67*10^6;
prob.Constraints.cons1 = cons1;% solving related to constraint number 1
sol = solve(prob,'Solver', 'linprog')%to use the linprog function
```

North zone

```
prob = optimproblem;
x1 = optimvar('x1','LowerBound',0);%PV size in MW
x2 = optimvar('x2','LowerBound',0);%wind size in MW
x3 = optimvar('x3','LowerBound',0);%CSP size in MW
x4 = optimvar('x4','LowerBound',0,'UpperBound',2413.4);%Geothermal size sceanrio2 in MW
x5=optimvar('x5','LowerBound',0,'UpperBound',10);%Geothermal size sceanrio3 in MW
x6=optimvar('x6','LowerBound',0,'UpperBound',635.8);%Hydropower size sceanrio1 in MW
x7=optimvar('x7','LowerBound',0,'UpperBound',405);%Hydropower size sceanrio2 in MW
x8=optimvar('x8','LowerBound',0,'UpperBound',576.8);%Biomass anaerobic size in MW
x9=optimvar('x9','LowerBound',0,'UpperBound',507.13);%Biomass combustion size in MW
prob.Objective = 37.53*x1+23.524*x2+101.9*x3+36.8*x4+61.1*x5+14.8*x6+39.4*x7+64.6*x8+39.5*x9; % Objective function of North zone
cons1=0.26*8760*x1+ 0.21*8760*x2+ 0.32*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9>=7.0*10^6;
```

```
prob.Constraints.cons1 = cons1;% solving related to constraint number 1
sol = solve(prob,'Solver', 'linprog')%to use the linprog function
```

Annex 5 - matlab code for track 2

```
clc
clear all
close all
A=xlsread('code_data.xlsx'); % the row data of the county
E_A=A(:,1); % the annual energy in the county
P_BA=A(:,2); % the Biomass resources based on the anaerobic diagester in the county
P_BC=A(:,3); % the biomass resources based on the direct combustion in the county
P_H1=A(:,4); % the hydropower plant based on the storage in the county
P_H2=A(:,5); % the hydropower plant based on the ROR in the county
P_GE2=A(:,6); % the Geotehrmal energy resources based on the depleted oil and gas wells in the county
P_GE3=A(:,7); % the Geotehrmal energy resources based on the fire-coal plant in the county
CF_W=A(:,8); % the capcity factor of the wind energy in the county
CF_PV=A(:,9);% the capacity factor of the PV in the county
CF_CSP=A(:,10); % the capacity factor of the CSP in the county
LCOE_W=A(:,11); % the LCOE of the Wind energy in the county
LCOE_PV=A(:,12); % the LCOE of the PV in the county
LCOE_CSP=A(:,13); % the LCOE of the CSP in the county
answer=zeros (14,9);
for n=1:length(E_A)
prob = optimproblem;
x1 = optimvar('x1','LowerBound',0);%PV size in MW
x2 = optimvar('x2','LowerBound',0);%wind size in MW
x3 = optimvar('x3','LowerBound',0);%CSP size
x4 = optimvar('x4','LowerBound',0,'UpperBound',P_GE2(n));%Geothermal size sceanrio2
x5=optimvar('x5','LowerBound',0,'UpperBound',P_GE3(n));%Geothermal size sceanrio3
x6=optimvar('x6','LowerBound',0,'UpperBound',P_H1(n));%Hydropower size sceanrio1
x7=optimvar('x7','LowerBound',0,'UpperBound',P_H2(n));%Hydropower size sceanrio2
x8=optimvar('x8','LowerBound',0,'UpperBound',P_BA(n));%Biomass anaerobic size
```

```
x9=optimvar('x9','LowerBound',0,'UpperBound',P_BC(n));%Biomass combustion size

prob.Objective = LCOE_PV(n)*x1+LCOE_W(n)*x2+LCOE_CSP(n)*x3+36.8*x4+61.1*x5+14.8*x6+39.4*x7+64.6*x8+39.5*x9;% objective functiion

cons1=CF_PV(n)*8760*x1+ CF_W(n)*8760*x2+ CF_CSP(n)*8760*x3+0.744*8760*x4+.744*8760*x5+8760*x6+8760*x7+0.592*8760*x8+0.592*8760*x9>=E_A(n);

prob.Constraints.cons1 = cons1;% solving related to constraint number 1

sol(n) = solve(prob);%to use the linprog function

answer=sol;

end
```

Annex 6 - row data of counties

county	Electricity Consumption annually in MWh	power anaerobic limit in MW	Power combustion limit in MW	Power storage limit in MW	Power ROR limit in MW	Power GE2 limit in MW	Power GE3 limit in MW	Capacity factor Wind Energy	Capacity factor PV	Capacity factor CSP	LCOE Wind in $/MWh	LCOE PV in $/MWh	LCOE CSP in $/MWh
Anderson	654850.4558	10.75219055	0.063633839	7.579908676	30.8196347	55.97750037	#VALUE!	0.209661813	0.202284136	0.2504802	22.69447	47.93686	130.3788
Andrews	1485044.981	1.897445391	1.21675614	#VALUE!	#VALUE!	30.14220307	#VALUE!	0.085750371	0.289468169	0.35897082	55.48733	33.4989	90.9748
Angelina	654850.4558	3.291604961	9.940377021	#VALUE!	13.26027397	31.57681544	#VALUE!	0.159677197	0.202284136	0.2504802	29.79862	47.93686	130.3788
Aransas	1190573.53	0.485931137	20.10058003	#VALUE!	#VALUE!	142.0956695	#VALUE!	0.227303442	0.202284136	0.2504802	20.9332	47.93686	130.3788
Archer	163510.0202	12.92538257	#VALUE!	20.09018265	#VALUE!	693.2568616	#VALUE!	0.304170539	0.231059161	0.286653325	15.6429	41.96702	113.9261
Armstrong	163510.0202	5.331744416	4.440870665	#VALUE!	10.61986301	#VALUE!	#VALUE!	0.177738865	0.260263665	0.322797695	26.77045	37.25785	101.1696
Atascosa	1190573.53	12.61299827	0.341308775	#VALUE!	0	914.2945696	46.47683753	0.194960455	0.231059161	0.286653325	24.40545	41.96702	113.9261
Austin	2408670.674	10.40509688	2.788319141	15.14041096	18.63013699	18.65916679	#VALUE!	0.122293746	0.202284136	0.2504802	38.90786	47.93686	130.3788
Bailey	2439024.39	21.36168703	9.969301493	#VALUE!	18.63013699	#VALUE!	#VALUE!	0.261326583	0.289468169	0.35897082	18.20763	33.4989	90.9748
Bandera	2408670.674	1.525283845	1.041281007	3.630136986	#VALUE!	#VALUE!	#VALUE!	0.237804411	0.231059161	0.286653325	20.00875	41.96702	113.9261
Bastrop	2408670.674	12.67084722	#VALUE!	#VALUE!	5.840182648	129.1780208	#VALUE!	0.147076034	0.202284136	0.2504802	32.35151	47.93686	130.3788
Baylor	163510.0202	9.082284339	3.033213008	79.89041096	18.63013699	125.5891884	#VALUE!	0.226883403	0.260263665	0.322797695	20.97165	37.25785	101.1696
Bee	1190573.53	5.100348636	15.65778107	#VALUE!	#VALUE!	737.0332523	#VALUE!	0.126914172	0.202284136	0.2504802	37.49049	47.93686	130.3788

Bell	3427875.393	6.621775885	80.67999506	222.7705479	#VALUE!	6.459591496	#VALUE!	0.241164721	0.231059161	0.286653325	19.7297	41.96702	113.9261
Bexar	2408670.674	9.903739356	170.9417037	#VALUE!	1.720319635	185.8735945	25.02516325	0.194120378	0.231059161	0.286653325	24.51148	41.96702	113.9261
Blanco	2408670.674	3.168193879	0.341308775	#VALUE!	#VALUE!	5.023444788	#VALUE!	0.231923868	0.231059161	0.286653325	20.5159	41.96702	113.9261
Borden	1485044.981	2.178976922	11.82625262	#VALUE!	5.840182648	10.04688958	#VALUE!	0.262166661	0.289468169	0.35897082	18.1494	33.4989	90.9748
Bosque	3427875.393	8.444017648	1.482861286	90.35958904	18.63013699	#VALUE!	#VALUE!	0.200000921	0.231059161	0.286653325	23.79043	41.96702	113.9261
Bowie	2439024.39	10.47065902	12.54165124	9.25	13.47945205	74.63666716	0	0.277288057	0.202284136	0.2504802	17.15972	47.93686	130.3788
Brazoria	8456425.196	11.83203752	87.63922313	#VALUE!	18.63013699	110.518854	0	0.208401696	0.202284136	0.2504802	22.83168	47.93686	130.3788
Brazos	654850.4558	10.75411884	#VALUE!	#VALUE!	#VALUE!	18.65916679	0	0.198320765	0.202284136	0.2504802	23.99217	47.93686	130.3788
Brewster	1485044.981	4.506432803	1.864664322	#VALUE!	1.979452055	#VALUE!	0	0.048786958	0.318672672	0.39511519	97.53391	30.42892	82.6526
Briscoe	163510.0202	3.584706282	13.42866839	53.80022831	10.61986301	#VALUE!	0	0.18277933	0.260263665	0.322797695	26.03226	37.25785	101.1696
Brooks	1190573.53	4.20561829	8.686983216	#VALUE!	#VALUE!	37.31833358	0	0.240744683	0.231059161	0.286653325	19.76426	41.96702	113.9261
Brown	3427875.393	7.794181167	8.802681106	24.93949772	#VALUE!	879.1289218	0	0.236124256	0.260263665	0.322797695	20.15083	37.25785	101.1696
Burleson	2408670.674	9.267400963	3.312816241	#VALUE!	18.63013699	40.18909265	0	0.195800533	0.202284136	0.2504802	24.30096	47.93686	130.3788
Burnet	2408670.674	4.487149821	1.041281007	82.1803653	5.840182648	#VALUE!	0	0.20378127	0.231059161	0.286653325	23.34913	41.96702	113.9261
Caldwell	2408670.674	6.615990991	4.936443293	#VALUE!	#VALUE!	1100.168164	0	0.166817857	0.202284136	0.2504802	28.5226	47.93686	130.3788
Calhoun	8456425.196	2.524142293	10.36653091	#VALUE!	4.359589041	378.9233196	0	0.136575064	0.202284136	0.2504802	34.83917	47.93686	130.3788
Callahan	3427875.393	8.164414414	0.023139578	#VALUE!	#VALUE!	723.3975303	0	0.271827553	0.260263665	0.322797695	17.50419	37.25785	101.1696
Cameron	1190573.53	2.859666173	57.28588177	#VALUE!	1.979452055	#VALUE!	0	0.209241774	0.231059161	0.286653325	22.74021	41.96702	113.9261
Camp	2439024.39	3.401517956	0.063633839	1.060502283	1.510273973	#VALUE!	0	0.232763946	0.202284136	0.2504802	20.44201	47.93686	130.3788
Carson	163510.0202	3.278106874	49.92942429	#VALUE!	#VALUE!	275.5805961	0	0.185299563	0.260263665	0.322797695	25.67822	37.25785	101.1696
Cass	2439024.39	4.059067629	0.063633839	#VALUE!	4.369863014	37.31833358	0	0.24494507	0.202284136	0.2504802	19.42523	47.93686	130.3788
Castro	163510.0202	76.53801061	9.575928668	#VALUE!	18.63013699	#VALUE!	0	0.123553862	0.289468169	0.35897082	38.51107	33.4989	90.9748
Chambers	8456425.196	3.954939529	38.96897754	#VALUE!	17.56050228	363.1349119	0	0.181519214	0.202284136	0.2504802	26.21296	47.93686	130.3788
Cherokee	654850.4558	9.032148587	9.681985067	45.18949772	13.26027397	15.07033436	0	0.251245652	0.202284136	0.2504802	18.93813	47.93686	130.3788

Childress	163510.0202	2.362165247	2.886662347	#VALUE!	10.61986301	#VALUE!	0	0.185719602	0.260263665	0.322797695	25.61992	37.25785	101.1696
Clay	163510.0202	12.73062446	#VALUE!	20.09018265	10.61986301	50.23598223	0	0.31425147	0.231059161	0.286653325	15.14113	41.96702	113.9261
Cochran	2439024.39	1.631340244	9.178699247	#VALUE!	#VALUE!	115.5422988	0	0.229823674	0.289468169	0.35897082	20.70367	33.4989	90.9748
Coke	368029.3109	2.381448229	0.699972233	36.15981735	5.840182648	20.09377915	0	0.492767953	0.260263665	0.322797695	9.655917	37.25785	101.1696
Coleman	368029.3109	7.296680242	4.010860175	39.36986301	5.840182648	512.4067118	0	0.260066467	0.260263665	0.322797695	18.29584	37.25785	101.1696
Collin	3427875.393	8.463300629	94.80477909	122.6997717	17.56050228	#VALUE!	0	0.165977779	0.231059161	0.286653325	28.66753	41.96702	113.9261
Collingsworth	163510.0202	3.2511107	7.254257682	122.6997717	#VALUE!	90.42507488	0	0.189499951	0.260263665	0.322797695	25.10886	37.25785	101.1696
Colorado	2408670.674	11.56593237	32.79263853	#VALUE!	5.840182648	173.6724849	0	0.126494133	0.202284136	0.2504802	37.61547	47.93686	130.3788
Comal	2408670.674	2.921371714	39.34113908	29.80022831	4.359589041	#VALUE!	0	0.177738865	0.231059161	0.286653325	26.77045	41.96702	113.9261
Comanche	3427875.393	19.36975503	1.448151919	48.86986301	#VALUE!	30.14220307	0	0.213022123	0.231059161	0.286653325	22.33615	41.96702	113.9261
Concho	368029.3109	4.64527027	0.699972233	8.550228311	#VALUE!	15.07033436	0	0.355415271	0.260263665	0.322797695	13.38749	37.25785	101.1696
Cooke	163510.0202	13.95895039	2.493289522	30.14041096	28.1803653	155.7313915	0	0.239484566	0.231059161	0.286653325	19.86825	41.96702	113.9261
Coryell	3427875.393	9.105423917	3.503717759	#VALUE!	#VALUE!	5.023444788	0	0.219322705	0.231059161	0.286653325	21.69454	41.96702	113.9261
Cottle	163510.0202	3.453582007	2.651409972	#VALUE!	#VALUE!	10.04688958	0	0.192440222	0.260263665	0.322797695	24.72504	37.25785	101.1696
Crane	1485044.981	0.530281994	0.349021967	#VALUE!	1.979452055	311.4627829	0	0.100871768	0.289468169	0.35897082	47.17003	33.4989	90.9748
Crockett	1485044.981	2.877020856	0.699972233	#VALUE!	#VALUE!	266.2502455	0	0.223103054	0.260263665	0.322797695	21.32697	37.25785	101.1696
Crosby	163510.0202	1.660264717	9.174842651	17.05022831	18.63013699	#VALUE!	0	0.200840998	0.289468169	0.35897082	23.69112	33.4989	90.9748
Culberson	1485044.981	2.439297174	0.563063063	#VALUE!	#VALUE!	142.0956695	0	0.209241774	0.318672672	0.39511519	22.74021	30.42892	82.6526
Dallam	2439024.39	38.95740775	5.310533136	#VALUE!	#VALUE!	#VALUE!	0	0.243264915	0.289468169	0.35897082	19.55951	33.4989	90.9748
Dallas	3427875.393	5.582423177	246.9340059	45.98972603	17.56050228	#VALUE!	0	0.15169646	0.231059161	0.286653325	31.36655	41.96702	113.9261
Dawson	1485044.981	0.935224608	10.31639516	#VALUE!	5.840182648	60.2828718	0	0.214702278	0.289468169	0.35897082	22.16172	33.4989	90.9748
Deaf Smith	163510.0202	97.07438603	39.03646797	#VALUE!	10.61986301	#VALUE!	0	0.175638671	0.289468169	0.35897082	27.09027	33.4989	90.9748
Delta	654850.4558	3.137341108	0.846522893	6.939497717	2.859589041	#VALUE!	0	0.14161553	0.202284136	0.2504802	33.59924	47.93686	130.3788
Denton	3427875.393	7.78068308	209.7487042	140.390411	17.56050228	#VALUE!	0	0.258386312	0.231059161	0.286653325	18.41492	41.96702	113.9261

DeWitt	2408670.674	14.90960138	0.341308775	#VALUE!	4.359589041	157.8840772	0	0.191180106	0.202284136	0.2504802	24.888	47.93686	130.3788
Dickens	163510.0202	4.082207207	12.07693138	#VALUE!	#VALUE!	25.11722394	0	0.19664061	0.260263665	0.322797695	24.19735	37.25785	101.1696
Dimmit	1190573.53	3.44008392	0.973790571	#VALUE!	1.649543379	252.6145235	0	0.165977779	0.231059161	0.286653325	28.66753	41.96702	113.9261
Donley	163510.0202	9.290540541	7.074925953	#VALUE!	#VALUE!	#VALUE!	0	0.202521153	0.260263665	0.322797695	23.4944	37.25785	101.1696
Duval	1190573.53	5.071424164	0.541851783	#VALUE!	#VALUE!	513.1247852	0	0.160937314	0.231059161	0.286653325	29.56532	41.96702	113.9261
Eastland	3427875.393	7.219548315	#VALUE!	100.6495434	#VALUE!	416.9581922	0	0.252925807	0.260263665	0.322797695	18.81259	37.25785	101.1696
Ector	1485044.981	1.640981735	46.36207269	#VALUE!	#VALUE!	110.518854	0	0.063908355	0.289468169	0.35897082	74.45091	33.4989	90.9748
Edwards	368029.3109	2.414229298	1.041281007	#VALUE!	1.649543379	35.16564786	#VALUE!	0.267207126	0.260263665	0.322797695	17.80707	37.25785	101.1696
El Paso	2439024.39	2.242610761	40.478835	11.02054795	1.979452055	#VALUE!	#VALUE!	0.412960584	0.318672672	0.39511519	11.522	30.42892	82.6526
Ellis	3427875.393	8.586711712	159.7382914	96.89041096	17.56050228	#VALUE!	#VALUE!	0.185719602	0.231059161	0.286653325	25.61992	41.96702	113.9261
Erath	3427875.393	30.13930026	1.86659262	#VALUE!	#VALUE!	180.8501498	#VALUE!	0.228983597	0.231059161	0.286653325	20.77946	41.96702	113.9261
Falls	3427875.393	18.9821671	0.782889053	#VALUE!	18.63013699	30.14220307	#VALUE!	0.235284178	0.231059161	0.286653325	20.22306	41.96702	113.9261
Fannin	163510.0202	12.35846291	8.85088856	22.68949772	13.47945205	5.023444788	#VALUE!	0.162617469	0.231059161	0.286653325	29.25957	41.96702	113.9261
Fayette	2408670.674	15.78890534	4.78217944	#VALUE!	6.689497717	75.35320617	25.02516325	0.15169646	0.202284136	0.2504802	31.36655	47.93686	130.3788
Fisher	368029.3109	3.280035172	3.033213008	#VALUE!	18.63013699	55.25942701	0	0.313411392	0.260263665	0.322797695	15.18187	37.25785	101.1696
Floyd	163510.0202	9.317536715	31.31170554	#VALUE!	18.63013699	5.023444788	0	0.1726984	0.289468169	0.35897082	27.55173	33.4989	90.9748
Foard	163510.0202	3.432370727	2.651409972	#VALUE!	#VALUE!	#VALUE!	0	0.205461425	0.260263665	0.322797695	23.15858	37.25785	101.1696
Fort Bend	8456425.196	6.477153523	230.8327163	#VALUE!	18.63013699	221.0377081	0	0.055927618	0.202284136	0.2504802	85.07625	47.93686	130.3788
Franklin	654850.4558	5.796464272	0.063633839	4.479452055	4.369863014	46.6471498	0	0.267627165	0.202284136	0.2504802	17.77901	47.93686	130.3788
Freestone	654850.4558	11.40974022	#VALUE!	#VALUE!	17.56050228	35.16564786	0	0.208401696	0.231059161	0.286653325	22.83168	41.96702	113.9261
Frio	1190573.53	8.918378995	0.341308775	#VALUE!	#VALUE!	299.9797466	0	0.18991999	0.231059161	0.286653325	25.05311	41.96702	113.9261
Gaines	2439024.39	1.957222634	10.31832346	#VALUE!	#VALUE!	105.4954092	0	0.113052892	0.289468169	0.35897082	42.08857	33.4989	90.9748
Galveston	8456425.196	2.238754165	77.5002314	#VALUE!	#VALUE!	86.83624245	0	0.045846687	0.202284136	0.2504802	103.7813	47.93686	130.3788
Garza	163510.0202	1.920584969	12.22541034	78.42009132	18.63013699	75.35320617	0	0.1932803	0.260263665	0.322797695	24.6178	37.25785	101.1696

Gillespie	368029.3109	7.674626681	4.134271258	#VALUE!	#VALUE!	#VALUE!	0	0.270987475	0.231059161	0.286653325	17.55867	41.96702	113.9261
Glasscock	1485044.981	0.996930149	0.055920647	#VALUE!	#VALUE!	5.023444788	0	0.260066467	0.289468169	0.35897082	18.29584	33.4989	90.9748
Goliad	1190573.53	6.629489078	0.341308775	6.390410959	1.720319635	78.94203859	39.32679089	0.07566944	0.202284136	0.2504802	62.87876	47.93686	130.3788
Gonzales	2408670.674	20.04851598	3.548068617	#VALUE!	4.359589041	150.7079467	0	0.150856383	0.202284136	0.2504802	31.54086	47.93686	130.3788
Gray	163510.0202	13.11628409	15.9412409	#VALUE!	#VALUE!	120.5657436	0	0.235704217	0.260263665	0.322797695	20.18688	37.25785	101.1696
Grayson	163510.0202	8.968514748	29.03438541	53.47945205	28.1803653	5.023444788	0	0.200000921	0.231059161	0.286653325	23.79043	41.96702	113.9261
Gregg	2439024.39	1.575419598	17.47038134	#VALUE!	17.97945205	531.783952	0	0.248305381	0.202284136	0.2504802	19.1625	47.93686	130.3788
Grimes	654850.4558	9.446732692	36.10738307	140.369863	4.189497717	40.18909265	25.02516325	0.14497584	0.202284136	0.2504802	32.81975	47.93686	130.3788
Guadalupe	2408670.674	8.272399111	64.05613662	#VALUE!	4.359589041	286.345559	0	0.175218632	0.231059161	0.286653325	27.15547	41.96702	113.9261
Hale	163510.0202	21.68949772	11.94195051	#VALUE!	18.63013699	5.023444788	0	0.156736926	0.289468169	0.35897082	30.3579	33.4989	90.9748
Hall	163510.0202	4.946084783	7.443230902	#VALUE!	10.61986301	#VALUE!	0	0.1932803	0.260263665	0.322797695	24.6178	37.25785	101.1696
Hamilton	3427875.393	10.84282056	1.482861286	#VALUE!	#VALUE!	#VALUE!	0	0.1932803	0.231059161	0.286653325	24.6178	41.96702	113.9261
Hansford	2439024.39	41.50276132	76.78676108	#VALUE!	#VALUE!	55.25942701	0	0.209241774	0.260263665	0.322797695	22.74021	37.25785	101.1696
Hardeman	163510.0202	2.890518944	2.651409972	#VALUE!	10.61986301	#VALUE!	0	0.205881464	0.260263665	0.322797695	23.11115	37.25785	101.1696
Hardin	2439024.39	1.399944465	0.001928298	#VALUE!	13.26027397	149.9898733	0	0.029045135	0.202284136	0.2504802	163.8152	47.93686	130.3788
Harris	8456425.196	11.35381957	349.7200111	18.47031963	4.189497717	427.0050817	25.02516325	0.031985407	0.202284136	0.2504802	148.7499	47.93686	130.3788
Harrison	2439024.39	4.66648155	0.063633839	3.239726027	19.48972603	662.3965852	46.47683753	0.229403635	0.202284136	0.2504802	20.74127	47.93686	130.3788
Hartley	2439024.39	65.0164291	107.1092497	#VALUE!	#VALUE!	#VALUE!	0	0.267207126	0.289468169	0.35897082	17.80707	33.4989	90.9748
Haskell	163510.0202	4.38302172	3.856596322	44.32990868	#VALUE!	135.6376123	0	0.236964334	0.260263665	0.322797695	20.07954	37.25785	101.1696
Hays	2408670.674	2.971507466	3.285820067	#VALUE!	#VALUE!	#VALUE!	0	0.186979718	0.231059161	0.286653325	25.44727	41.96702	113.9261
Hemphill	2439024.39	10.76761693	4.253825744	#VALUE!	0.600456621	20.09377915	0	0.187399757	0.260263665	0.322797695	25.39069	37.25785	101.1696
Henderson	654850.4558	9.81503764	0.063633839	83.43949772	30.8196347	83.96548338	0	0.1726984	0.202284136	0.2504802	27.55173	47.93686	130.3788
Hidalgo	1190573.53	6.338316056	124.9691472	#VALUE!	1.979452055	177.2613173	0	0.159677197	0.231059161	0.286653325	29.79862	41.96702	113.9261
Hill	3427875.393	10.01750895	82.90525114	80.48972603	#VALUE!	31.57681544	0	0.186559679	0.231059161	0.286653325	25.50479	41.96702	113.9261

Hockley	2439024.39	1.542638529	20.84490312	#VALUE!	#VALUE!	40.18909265	0	0.198320765	0.289468169	0.35897082	23.99217	33.4989	90.9748
Hood	3427875.393	3.779464396	0.699972233	138.1004566	18.63013699	55.25942701	0	0.230663752	0.231059161	0.286653325	20.62797	41.96702	113.9261
Hopkins	654850.4558	20.52673393	0.063633839	2.880136986	2.859589041	130.6141675	0	0.252505769	0.231059161	0.286653325	18.84363	41.96702	113.9261
Houston	654850.4558	11.34417808	#VALUE!	33.76027397	30.8196347	35.16564786	0	0.194540416	0.202284136	0.2504802	24.45835	47.93686	130.3788
Howard	1485044.981	1.777890905	3.592419474	#VALUE!	5.840182648	421.981637	0	0.340713913	0.289468169	0.35897082	13.96524	33.4989	90.9748
Hudspeth	2439024.39	2.015071578	1.145409108	#VALUE!	1.979452055	#VALUE!	0	0.209241774	0.318672672	0.39511519	22.74021	30.42892	82.6526
Hunt	3427875.393	10.16020301	15.08314822	46.64041096	2.859589041	#VALUE!	0	0.151276422	0.231059161	0.286653325	31.45295	41.96702	113.9261
Hutchinson	2439024.39	3.97422251	30.97039677	0.720319635	0.600456621	1883.848566	0	0.221422899	0.260263665	0.322797695	21.48895	37.25785	101.1696
Irion	368029.3109	2.231040972	0.699972233	#VALUE!	#VALUE!	45.21253744	0	0.308790966	0.260263665	0.322797695	15.40894	37.25785	101.1696
Jack	3427875.393	6.263112427	#VALUE!	#VALUE!	17.56050228	175.8251706	0	0.244104993	0.231059161	0.286653325	19.49234	41.96702	113.9261
Jackson	8456425.196	5.985437492	38.39627299	1.5	0.850456621	505.2305813	0	0.152536538	0.202284136	0.2504802	31.19313	47.93686	130.3788
Jasper	2439024.39	2.396874614	#VALUE!	66.73972603	13.26027397	118.4130579	0	0.103392	0.202284136	0.2504802	46.02032	47.93686	130.3788
Jeff Davis	1485044.981	4.627915587	0.563063063	#VALUE!	1.979452055	#VALUE!	0	0.102551923	0.318672672	0.39511519	46.39652	30.42892	82.6526
Jefferson	2439024.39	6.488723312	74.31853943	#VALUE!	13.26027397	161.4729096	0	0.04458657	0.202284136	0.2504802	106.7141	47.93686	130.3788
Jim Hogg	1190573.53	3.787177589	0.327810687	#VALUE!	#VALUE!	130.6141675	0	0.168077973	0.231059161	0.286653325	28.30878	41.96702	113.9261
Jim Wells	1190573.53	6.024003456	11.08385783	#VALUE!	1.649543379	74.63666716	0	0.131954638	0.231059161	0.286653325	36.05853	41.96702	113.9261
Johnson	3427875.393	10.5902135	58.9307201	44.32990868	#VALUE!	18.65916679	0	0.160517275	0.231059161	0.286653325	29.64299	41.96702	113.9261
Jones	368029.3109	3.738970135	34.90605331	47.73972603	#VALUE!	195.9204841	0	0.333573254	0.260263665	0.322797695	14.26409	37.25785	101.1696
Karnes	2408670.674	7.776826484	0.341308775	#VALUE!	1.720319635	195.9204841	0	0.136155025	0.231059161	0.286653325	34.94707	41.96702	113.9261
Kaufman	3427875.393	13.48651734	#VALUE!	33.22031963	17.56050228	9.328816222	0	0.16219743	0.231059161	0.286653325	29.33564	41.96702	113.9261
Kendall	2408670.674	2.797960632	1.041281007	#VALUE!	4.359589041	#VALUE!	0	0.259646428	0.231059161	0.286653325	18.32556	41.96702	113.9261
Kenedy	1190573.53	5.98736579	8.658058744	#VALUE!	18.63013699	39.4710193	0	0.263006738	0.231059161	0.286653325	18.09121	41.96702	113.9261
Kent	163510.0202	2.803745526	11.82625262	#VALUE!	4.359589041	#VALUE!	0	0.276868018	0.260263665	0.322797695	17.18555	37.25785	101.1696
Kerr	368029.3109	2.057494138	1.795245588	#VALUE!	#VALUE!	#VALUE!	0	0.254605962	0.231059161	0.286653325	18.68833	41.96702	113.9261

Kimble	368029.3109	2.447010367	1.145409108	#VALUE!	#VALUE!	#VALUE!	0	0.260906544	0.231059161	0.286653325	18.23706	41.96702	113.9261
King	163510.0202	4.130414661	11.82625262	#VALUE!	#VALUE!	#VALUE!	0	0.215122317	0.260263665	0.322797695	22.11828	37.25785	101.1696
Kinney	368029.3109	1.843453042	0.349021967	#VALUE!	1.979452055	5.023444788	0	0.196220572	0.231059161	0.286653325	24.24873	41.96702	113.9261
Kleberg	1190573.53	4.568138344	23.48088671	#VALUE!	#VALUE!	244.7203196	0	0.168918051	0.231059161	0.286653325	28.16828	41.96702	113.9261
Knox	163510.0202	4.433157473	3.033213008	#VALUE!	18.63013699	#VALUE!	0	0.236544295	0.260263665	0.322797695	20.11533	37.25785	101.1696
La Salle	1190573.53	1.951437739	0.341308775	#VALUE!	1.649543379	85.40163009	0	0.134894909	0.231059161	0.286653325	35.27351	41.96702	113.9261
Lamar	163510.0202	14.66470752	30.97232506	43.4303653	13.47945205	#VALUE!	0	0.248305381	0.202284136	0.2504802	19.1625	47.93686	130.3788
Lamb	2439024.39	29.69579168	46.07475626	#VALUE!	18.63013699	15.07033436	25.02516325	0.180259098	0.289468169	0.35897082	26.39619	33.4989	90.9748
Lampasas	368029.3109	4.556568555	0.699972233	#VALUE!	5.840182648	#VALUE!	0	0.205041386	0.231059161	0.286653325	23.20564	41.96702	113.9261
Lavaca	2408670.674	16.80126188	#VALUE!	#VALUE!	0.850456621	355.240708	0	0.142455607	0.202284136	0.2504802	33.4015	47.93686	130.3788
Lee	2408670.674	12.50501358	0.214041096	#VALUE!	#VALUE!	35.16564786	0	0.201681076	0.260263665	0.322797695	23.59264	37.25785	101.1696
Leon	654850.4558	15.99137665	#VALUE!	13.64041096	17.56050228	246.1564663	25.02516325	0.211341968	0.202284136	0.2504802	22.51388	47.93686	130.3788
Liberty	2439024.39	7.944588424	#VALUE!	#VALUE!	21.75	836.7871434	0	0.080709906	0.202284136	0.2504802	58.95226	47.93686	130.3788
Limestone	3427875.393	12.78076021	8.964658151	13.64041096	#VALUE!	50.23598223	0	0.247465303	0.231059161	0.286653325	19.22741	41.96702	113.9261
Lipscomb	2439024.39	7.258114279	4.394591509	#VALUE!	#VALUE!	86.83624245	0	0.171018244	0.260263665	0.322797695	27.82266	37.25785	101.1696
Live Oak	1190573.53	5.777181291	0.341308775	5.760273973	#VALUE!	925.7776059	0	0.14497584	0.231059161	0.286653325	32.81975	41.96702	113.9261
Llano	368029.3109	5.923731951	1.041281007	25.92009132	5.840182648	#VALUE!	0	0.247045264	0.231059161	0.286653325	19.26023	41.96702	113.9261
Loving	1485044.981	0.416512403	#VALUE!	#VALUE!	1.979452055	50.23598223	0	0.102131884	0.289468169	0.35897082	46.58808	33.4989	90.9748
Lubbock	2439024.39	7.063356164	49.29887079	#VALUE!	18.63013699	20.09377915	0	0.19664061	0.289468169	0.35897082	24.19735	33.4989	90.9748
Lynn	163510.0202	1.376804887	15.59221893	#VALUE!	#VALUE!	#VALUE!	0	0.171438283	0.289468169	0.35897082	27.75422	33.4989	90.9748
Madison	654850.4558	7.504936443	#VALUE!	#VALUE!	17.56050228	80.3781853	0	0.228563558	0.202284136	0.2504802	20.8178	47.93686	130.3788
Marion	2439024.39	0.798315439	0.063633839	3.600456621	1.510273973	317.2043011	0	0.232763946	0.202284136	0.2504802	20.44201	47.93686	130.3788
Martin	1485044.981	0.628625201	0.547636678	#VALUE!	5.840182648	10.04688958	0	0.213022123	0.289468169	0.35897082	22.33615	33.4989	90.9748
Mason	368029.3109	6.290108602	1.241824016	#VALUE!	#VALUE!	#VALUE!	0	0.284428716	0.231059161	0.286653325	16.72875	41.96702	113.9261

Matagorda	8456425.196	8.889454523	16.08393496	#VALUE!	5.840182648	315.7696887	0	0.317191741	0.202284136	0.2504802	15.00094	47.93686	130.3788
Maverick	1190573.53	4.491006417	5.663411699	#VALUE!	1.979452055	260.5087274	0	0.165137701	0.231059161	0.286653325	28.81306	41.96702	113.9261
McCulloch	368029.3109	5.061782673	1.467434901	12.64954338	5.840182648	15.07033436	0	0.278548173	0.260263665	0.322797695	17.0821	37.25785	101.1696
McLennan	3427875.393	14.53165494	61.52620943	79.56050228	20.27968037	5.023444788	25.02516325	0.237804411	0.231059161	0.286653325	20.00875	41.96702	113.9261
McMullen	1190573.53	2.572349747	0.385659632	#VALUE!	#VALUE!	409.0639883	0	0.195800533	0.231059161	0.286653325	24.30096	41.96702	113.9261
Medina	2408670.674	9.462159077	17.65356967	3.630136986	#VALUE!	95.44851966	0	0.189079912	0.231059161	0.286653325	25.16486	41.96702	113.9261
Menard	368029.3109	2.599345921	0.701900531	#VALUE!	#VALUE!	15.07033436	0	0.362135891	0.260263665	0.322797695	13.13918	37.25785	101.1696
Midland	1485044.981	1.359450204	29.42004505	#VALUE!	#VALUE!	5.023444788	0	0.211762007	0.289468169	0.35897082	22.46958	33.4989	90.9748
Milam	2408670.674	13.18955942	16.10900284	#VALUE!	#VALUE!	462.1707296	0	0.221842937	0.231059161	0.286653325	21.4481	41.96702	113.9261
Mills	3427875.393	5.592064667	0.699972233	#VALUE!	5.840182648	#VALUE!	0	0.181519214	0.231059161	0.286653325	26.21296	41.96702	113.9261
Mitchell	368029.3109	2.688047637	3.750539923	27.55022831	5.840182648	185.8735945	0	0.419681205	0.260263665	0.322797695	11.33746	37.25785	101.1696
Montague	163510.0202	13.32839689	#VALUE!	44.78995434	28.1803653	23.68261158	0	0.249145458	0.231059161	0.286653325	19.09802	41.96702	113.9261
Montgomery	8456425.196	3.964581019	54.05212576	16.26141553	4.189497717	20.09377915	0	0.08953072	0.202284136	0.2504802	53.14463	47.93686	130.3788
Moore	2439024.39	21.77434284	72.71612366	0.720319635	#VALUE!	21.52992586	0	0.239484566	0.260263665	0.322797695	19.86825	37.25785	101.1696
Morris	2439024.39	2.624413797	0.063633839	#VALUE!	4.369863014	#VALUE!	0	0.275187863	0.202284136	0.2504802	17.29057	47.93686	130.3788
Motley	163510.0202	3.68112119	14.73412625	#VALUE!	#VALUE!	10.04688958	0	0.189499951	0.260263665	0.322797695	25.10886	37.25785	101.1696
Nacogdoches	654850.4558	5.703905961	6.529217574	18.72945205	#VALUE!	50.23598223	0	0.240744683	0.202284136	0.2504802	19.76426	47.93686	130.3788
Navarro	3427875.393	13.61956991	18.48273787	134.3401826	17.56050228	466.476101	0	0.198320765	0.231059161	0.286653325	23.99217	41.96702	113.9261
Newton	2439024.39	0.711542021	26.01852709	46.64041096	17.97945205	32.29488879	0	0.088270604	0.202284136	0.2504802	53.90324	47.93686	130.3788
Nolan	368029.3109	2.306244601	3.307031346	6.819634703	0	20.09377915	0	0.451604152	0.260263665	0.322797695	10.53606	37.25785	101.1696
Nueces	1190573.53	2.27539183	103.017401	#VALUE!	1.649543379	363.1349119	0	0.085750371	0.231059161	0.286653325	55.48733	41.96702	113.9261
Ochiltree	2439024.39	14.03415402	52.99541836	#VALUE!	#VALUE!	15.78840772	0	0.223103054	0.260263665	0.322797695	21.32697	37.25785	101.1696
Oldham	163510.0202	14.42174195	4.298176601	#VALUE!	0.600456621	20.09377915	0	0.19664061	0.289468169	0.35897082	24.19735	33.4989	90.9748
Orange	2439024.39	1.737396643	#VALUE!	#VALUE!	31.23972603	6.459591496	0	xx	0.202284136	0.2504802	-	47.93686	130.3788

Palo Pinto	3427875.393	7.125061706	0.699972233	203.9703196	18.63013699	226.0611528	0	0.236544295	0.231059161	0.286653325	20.11533	41.96702	113.9261
Panola	2439024.39	5.125416512	0.063633839	27.97945205	17.97945205	223.9084671	0	0.22100286	0.202284136	0.2504802	21.52995	47.93686	130.3788
Parker	3427875.393	12.13670863	15.11014439	40.18949772	36.18949772	80.3781853	0	0.207981657	0.231059161	0.286653325	22.87797	41.96702	113.9261
Parmer	163510.0202	55.01820313	9.174842651	#VALUE!	18.63013699	#VALUE!	0	0.2138622	0.289468169	0.35897082	22.24859	33.4989	90.9748
Pecos	1485044.981	4.890164137	1.621698754	#VALUE!	1.979452055	1366.41841	0	0.087430526	0.289468169	0.35897082	54.4232	33.4989	90.9748
Polk	2439024.39	2.232969271	17.15799704	23.31050228	30.8196347	55.25942701	0	0.102131884	0.202284136	0.2504802	46.58808	47.93686	130.3788
Potter	163510.0202	4.643341972	27.59201839	0.720319635	0.600456621	#VALUE!	10.72506997	0.181099175	0.260263665	0.322797695	26.274	37.25785	101.1696
Presidio	1485044.981	4.523787486	1.182046773	#VALUE!	1.979452055	#VALUE!	0	0.061388122	0.318672672	0.39511519	77.50711	30.42892	82.6526
Rains	654850.4558	4.097633592	0.063633839	#VALUE!	17.97945205	10.04688958	0	0.19664061	0.202284136	0.2504802	24.19735	47.93686	130.3788
Randall	163510.0202	34.75371776	24.15964766	0.939497717	10.61986301	#VALUE!	0	0.142875646	0.289468169	0.35897082	33.30292	33.4989	90.9748
Reagan	1485044.981	3.63869863	1.093345057	#VALUE!	#VALUE!	35.16564786	0	0.217222511	0.289468169	0.35897082	21.90461	33.4989	90.9748
Real	368029.3109	0.395301123	1.041281007	#VALUE!	1.649543379	5.023444788	0	0.256286118	0.231059161	0.286653325	18.5657	41.96702	113.9261
Red River	163510.0202	14.97709182	0.063633839	#VALUE!	13.47945205	9.328816222	0	0.32097209	0.202284136	0.2504802	14.82428	47.93686	130.3788
Reeves	1485044.981	1.872377515	2.205973096	#VALUE!	1.979452055	502.3598223	0	0.112632853	0.289468169	0.35897082	42.24426	33.4989	90.9748
Refugio	1190573.53	4.417731087	20.10058003	#VALUE!	1.720319635	1128.874221	0	0.164717663	0.202284136	0.2504802	28.88682	47.93686	130.3788
Roberts	163510.0202	3.362951993	4.253825744	#VALUE!	0.600456621	#VALUE!	0	0.211762007	0.260263665	0.322797695	22.46958	37.25785	101.1696
Robertson	654850.4558	15.39938912	#VALUE!	13.64041096	18.63013699	95.44851966	50.05032651	0.199160843	0.202284136	0.2504802	23.89117	47.93686	130.3788
Rockwall	3427875.393	0.86002098	#VALUE!	9.109589041	17.56050228	#VALUE!	0	0.136995103	0.231059161	0.286653325	34.73193	41.96702	113.9261
Runnels	368029.3109	6.531145872	3.30317475	8.550228311	5.840182648	75.35320617	0	0.363816046	0.260263665	0.322797695	13.07845	37.25785	101.1696
Rusk	654850.4558	6.772183142	16.41945884	66.64954338	17.97945205	75.35320617	25.02516325	0.235284178	0.202284136	0.2504802	20.22306	47.93686	130.3788
Sabine	2439024.39	1.907086881	#VALUE!	#VALUE!	17.97945205	18.65916679	0	0.202521153	0.202284136	0.2504802	23.4944	47.93686	130.3788
San Augustine	2439024.39	1.629411946	#VALUE!	#VALUE!	#VALUE!	102.6246502	0	0.184879524	0.202284136	0.2504802	25.73679	47.93686	130.3788
San Jacinto	2439024.39	2.364093546	#VALUE!	27.10045662	21.75	23.68261158	0	0.108432466	0.202284136	0.2504802	43.88123	47.93686	130.3788
San Patricio	1190573.53	2.651409972	20.10058003	#VALUE!	1.649543379	355.240708	0	0.062228199	0.231059161	0.286653325	76.46293	41.96702	113.9261

San Saba	368029.3109	9.116993706	0.699972233	#VALUE!	5.840182648	#VALUE!	0	0.210921929	0.231059161	0.286653325	22.55889	41.96702	113.9261
Schleicher	368029.3109	3.002360237	1.199401456	#VALUE!	#VALUE!	20.09377915	0	0.377677326	0.260263665	0.322797695	12.59849	37.25785	101.1696
Scurry	368029.3109	3.731256942	15.08700481	18.69977169	5.840182648	85.40163009	0	0.315091547	0.260263665	0.322797695	15.10084	37.25785	101.1696
Shackelford	3427875.393	4.884379242	#VALUE!	#VALUE!	#VALUE!	979.6008862	0	0.270567436	0.260263665	0.322797695	17.58571	37.25785	101.1696
Shelby	2439024.39	7.146272985	#VALUE!	#VALUE!	17.97945205	204.5327613	0	0.214702278	0.202284136	0.2504802	22.16172	47.93686	130.3788
Sherman	2439024.39	33.68351228	115.7923763	#VALUE!	#VALUE!	6.459591496	0	0.226043325	0.260263665	0.322797695	21.04989	37.25785	101.1696
Smith	654850.4558	7.558928792	18.46731149	27.80022831	31.23972603	55.97750037	0	0.228143519	0.202284136	0.2504802	20.85582	47.93686	130.3788
Somervell	3427875.393	1.218684438	0.699972233	45.46004566	#VALUE!	#VALUE!	0	0.22100286	0.231059161	0.286653325	21.52995	41.96702	113.9261
Starr	1190573.53	7.568570283	0.622840306	#VALUE!	1.979452055	602.8317867	0	0.115153086	0.231059161	0.286653325	41.31978	41.96702	113.9261
Stephens	3427875.393	3.818030359	0.001928298	63.64954338	#VALUE!	155.7313915	0	0.211341968	0.231059161	0.286653325	22.51388	41.96702	113.9261
Sterling	368029.3109	2.105701592	0.699972233	#VALUE!	#VALUE!	145.6845019	0	0.382297753	0.260263665	0.322797695	12.44612	37.25785	101.1696
Stonewall	163510.0202	3.99543379	3.033213008	#VALUE!	18.63013699	90.42507488	0	0.289049143	0.260263665	0.322797695	16.46146	37.25785	101.1696
Sutton	368029.3109	2.190546711	1.041281007	#VALUE!	#VALUE!	100.4719645	0	0.351634922	0.260263665	0.322797695	13.53141	37.25785	101.1696
Swisher	163510.0202	36.04374923	16.33461372	#VALUE!	#VALUE!	#VALUE!	0	0.160937314	0.289468169	0.35897082	29.56532	33.4989	90.9748
Tarrant	3427875.393	5.499506356	182.1721122	204.0605023	17.56050228	#VALUE!	0	0.202941192	0.231059161	0.286653325	23.44616	41.96702	113.9261
Taylor	368029.3109	6.965012958	3.033213008	51.3196347	#VALUE!	85.40163009	0	0.368436473	0.260263665	0.322797695	12.91451	37.25785	101.1696
Terrell	1485044.981	0.825311613	0.572704554	#VALUE!	1.979452055	20.09377915	0	0.106752311	0.289468169	0.35897082	44.57251	33.4989	90.9748
Terry	2439024.39	2.965722572	11.34610638	#VALUE!	5.840182648	25.11722394	0	0.14161553	0.289468169	0.35897082	33.59924	33.4989	90.9748
Throckmorton	3427875.393	6.839673578	#VALUE!	#VALUE!	18.63013699	376.7690995	0	0.236544295	0.260263665	0.322797695	20.11533	37.25785	101.1696
Titus	654850.4558	4.735900284	9.610638035	3.199771689	2.859589041	531.783952	46.47683753	0.266787087	0.202284136	0.2504802	17.83488	47.93686	130.3788
Tom Green	368029.3109	6.737473775	22.0230933	49.88013699	#VALUE!	75.35320617	0	0.439002989	0.260263665	0.322797695	10.83859	37.25785	101.1696
Travis	2408670.674	5.152412687	196.0037949	67.09018265	5.840182648	5.023444788	0	0.160517275	0.231059161	0.286653325	29.64299	41.96702	113.9261
Trinity	2439024.39	3.212544737	#VALUE!	#VALUE!	30.82077626	47.36522316	0	0.150436344	0.202284136	0.2504802	31.62928	47.93686	130.3788
Tyler	2439024.39	2.337097371	#VALUE!	#VALUE!	13.26027397	39.4710193	0	0.128174288	0.202284136	0.2504802	37.12194	47.93686	130.3788

Upshur	2439024.39	8.341817845	0.063633839	#VALUE!	19.48972603	74.63666716	0	0.243264915	0.202284136	0.2504802	19.55951	47.93686	130.3788
Upton	1485044.981	0.769390966	0.894730347	#VALUE!	#VALUE!	547.5723597	0	0.143295685	0.289468169	0.35897082	33.20492	33.4989	90.9748
Uvalde	368029.3109	7.07878255	15.2027027	#VALUE!	1.649543379	#VALUE!	0	0.193700339	0.231059161	0.286653325	24.56421	41.96702	113.9261
Val Verde	368029.3109	1.579276194	5.015503517	10.27054795	1.979452055	65.30631659	0	0.181519214	0.260263665	0.322797695	26.21296	37.25785	101.1696
Van Zandt	654850.4558	14.74762434	0.063633839	#VALUE!	31.23972603	55.97750037	0	0.155896848	0.231059161	0.286653325	30.52116	41.96702	113.9261
Victoria	8456425.196	8.197195483	29.6745804	#VALUE!	4.359589041	434.1827466	0	0.128174288	0.202284136	0.2504802	37.12194	47.93686	130.3788
Walker	8456425.196	6.38652351	#VALUE!	#VALUE!	17.56050228	40.18909265	0	0.134894909	0.202284136	0.2504802	35.27351	47.93686	130.3788
Waller	8456425.196	7.894452672	#VALUE!	#VALUE!	4.189497717	94.73044631	0	0.118513396	0.202284136	0.2504802	40.14887	47.93686	130.3788
Ward	1485044.981	0.703828829	1.077918672	#VALUE!	1.979452055	386.8175234	0	0.085330333	0.289468169	0.35897082	55.76153	33.4989	90.9748
Washington	2408670.674	11.14749167	#VALUE!	#VALUE!	18.63013699	35.16564786	0	0.171438283	0.202284136	0.2504802	27.75422	47.93686	130.3788
Webb	1190573.53	8.108493768	35.61566704	#VALUE!	1.979452055	382.5106177	0	0.084490255	0.231059161	0.286653325	56.31481	41.96702	113.9261
Wharton	8456425.196	9.483370357	70.2633284	#VALUE!	5.840182648	205.2493003	0	0.156316887	0.202284136	0.2504802	30.43882	47.93686	130.3788
Wheeler	163510.0202	9.749475503	7.238831297	#VALUE!	#VALUE!	241.1330216	0	0.183199369	0.260263665	0.322797695	25.97234	37.25785	101.1696
Wichita	163510.0202	6.731688881	31.38112427	3.239726027	10.61986301	231.086132	0	0.315511586	0.260263665	0.322797695	15.08066	37.25785	101.1696
Wilbarger	163510.0202	7.105778724	2.651409972	#VALUE!	10.61986301	10.04688958	0	0.223103054	0.260263665	0.322797695	21.32697	37.25785	101.1696
Willacy	1190573.53	1.781747501	11.98630137	#VALUE!	#VALUE!	228.9319119	0	0.258386312	0.231059161	0.286653325	18.41492	41.96702	113.9261
Williamson	2408670.674	13.87410527	90.96168086	158.5502283	#VALUE!	75.35320617	0	0.22772348	0.231059161	0.286653325	20.89444	41.96702	113.9261
Wilson	2408670.674	14.31954214	5.576638282	#VALUE!	1.720319635	942.2825527	0	0.172278361	0.231059161	0.286653325	27.61916	41.96702	113.9261
Winkler	1485044.981	1.012356535	#VALUE!	#VALUE!	#VALUE!	221.0377081	0	0.073149208	0.289468169	0.35897082	65.04938	33.4989	90.9748
Wise	3427875.393	13.34767987	#VALUE!	69.65981735	17.56050228	#VALUE!	0	0.236124256	0.231059161	0.286653325	20.15083	41.96702	113.9261
Wood	654850.4558	7.37188387	0.063633839	32.92009132	17.97945205	139.9429837	0	0.246205187	0.202284136	0.2504802	19.32581	47.93686	130.3788
Yoakum	2439024.39	1.507929162	9.955803406	#VALUE!	5.840182648	65.30631659	0	0.22772348	0.289468169	0.35897082	20.89444	33.4989	90.9748
Young	3427875.393	6.286252005	#VALUE!	#VALUE!	18.63013699	100.4719645	0	0.202941192	0.231059161	0.286653325	23.44616	41.96702	113.9261
Zapata	1190573.53	2.838454893	0.509070715	1.319634703	1.979452055	452.12384	0	0.014763817	0.260263665	0.322797695	322.2831	37.25785	101.1696

Zavala	1190573.53	8.270470813	0.973790571	#VALUE!	1.649543379	221.0377081	0	0.17941902	0.231059161	0.286653325	26.51953	41.96702	113.9261

ANNEX 7 - OPTIMAL DESIGN FOR TEXAS COUNTIES

county	PV size in MW	Wind size in MW	CSP size in MW	GE2 size in MW	GE3 size in MW	H1 size in MW	H2 size in MW	Biomass anaerobic size in MW	Biomass Combustion size in MW	Total capacity in MW
Anderson	0	0	0	49	0	8	31	0	0	88
Andrews	502	0	0	30	0	0	0	2	1	535
Angelina	0	189	0	32	0	0	13	3	10	247
Aransas	0	80	0	142	0	0	0	0	20	242
Archer	0	0	0	0	0	19	0	0	0	19
Armstrong	9	0	0	0	0	0	11	5	4	29
Atascosa	0	0	0	183	0	0	0	0	0	183
Austin	1085	0	0	19	0	15	19	10	3	1151
Bailey	0	972	0	0	0	0	19	0	10	1001
Bandera	0	1138	0	0	0	4	0	0	1	1143
Bastrop	0	1125	0	129	0	0	6	13	0	1273
Baylor	0	0	0	0	0	19	0	0	0	19
Bee	0	0	0	183	0	0	0	0	0	183
Bell	0	481	0	6	0	223	0	0	81	791
Bexar	0	48	0	186	25	0	2	10	171	442
Blanco	0	1169	0	5	0	0	0	0	0	1174
Borden	0	569	0	10	0	0	6	0	12	597
Bosque	0	1382	0	0	0	90	19	8	1	1500
Bowie	0	722	0	75	0	9	13	0	0	819
Brazoria	0	3866	0	111	0	0	19	12	88	4096
Brazos	0	275	0	19	0	0	0	11	0	305
Brewster	522	0	0	0	0	0	2	0	2	526
Briscoe	0	0	0	0	0	19	0	0	0	19
Brooks	0	428	0	37	0	0	0	0	9	474
Brown	0	0	0	492	0	25	0	0	0	517
Burleson	0	1118	0	40	0	0	19	9	3	1189

Burnet	0	901	0	0	0	82	6	4	1	994
Caldwell	0	0	0	370	0	0	0	0	0	370
Calhoun	3319	0	0	379	0	0	4	3	10	3715
Callahan	0	0	0	526	0	0	0	0	0	526
Cameron	0	478	0	0	0	0	2	0	57	537
Camp	0	1185	0	0	0	1	2	0	0	1188
Carson	0	0	0	25	0	0	0	0	0	25
Cass	0	1005	0	37	0	0	4	0	0	1046
Castro	0	0	0	0	0	0	19	0	0	19
Chambers	0	3593	0	363	0	0	18	4	39	4017
Cherokee	0	0	0	15	0	45	13	0	9	82
Childress	0	27	0	0	0	0	11	2	3	43
Clay	0	0	0	0	0	19	0	0	0	19
Cochran	0	814	0	116	0	0	0	0	9	939
Coke	0	12	0	0	0	36	0	0	0	48
Coleman	0	0	0	0	0	39	3	0	0	42
Collin	0	1144	0	0	0	123	18	8	95	1388
Collingsworth	0	0	0	0	0	19	0	0	0	19
Colorado	562	0	0	174	0	0	6	12	33	787
Comal	0	1214	0	0	0	30	4	3	39	1290
Comanche	0	1498	0	30	0	49	0	0	1	1578
Concho	0	94	0	0	0	9	0	0	0	103
Cooke	0	0	0	0	0	19	0	0	0	19
Coryell	0	1758	0	5	0	0	0	0	4	1767
Cottle	0	39	0	10	0	0	0	3	3	55
Crane	0	0	0	225	0	0	2	0	0	227
Crockett	0	0	0	228	0	0	0	0	0	228
Crosby	0	0	0	0	0	17	2	0	0	19
Culberson	199	0	0	142	0	0	0	0	1	342
Dallam	0	1132	0	0	0	0	0	0	5	1137
Dallas	772	0	0	0	0	46	18	6	247	1089
Dawson	0	525	0	60	0	0	6	0	10	601

Deaf Smith	0	0	0	0	0	0	11	0	14	25
Delta	309	0	0	0	0	7	3	3	1	323
Denton	0	423	0	0	0	140	18	0	210	791
DeWitt	0	754	0	158	0	0	4	15	0	931
Dickens	0	0	0	25	0	0	0	0	0	25
Dimmit	0	0	0	180	0	0	2	0	0	182
Donley	0	44	0	0	0	0	0	9	7	60
Duval	0	0	0	183	0	0	0	0	0	183
Eastland	0	0	0	391	0	101	0	0	0	492
Ector	203	0	0	111	0	0	0	2	46	362
Edwards	0	53	0	35	0	0	2	0	0	90
El Paso	0	648	0	0	0	11	0	0	0	659
Ellis	0	954	0	0	0	97	18	9	160	1238
Erath	0	1116	0	181	0	0	0	0	2	1299
Falls	0	1487	0	30	0	0	19	0	1	1537
Fannin	0	0	0	0	0	19	0	0	0	19
Fayette	0	1196	0	75	25	0	7	16	5	1324
Fisher	0	75	0	0	0	0	19	0	0	94
Floyd	0	0	0	0	0	0	19	0	0	19
Foard	0	73	0	0	0	0	0	3	3	79
Fort Bend	3173	0	0	221	0	0	19	6	231	3650
Franklin	0	117	0	47	0	4	4	0	0	172
Freestone	0	116	0	35	0	0	18	11	0	180
Frio	0	0	0	183	0	0	0	0	0	183
Gaines	666	0	0	105	0	0	0	2	10	783
Galveston	4219	0	0	87	0	0	0	2	78	4386
Garza	0	0	0	0	0	19	0	0	0	19
Gillespie	0	155	0	0	0	0	0	0	0	155
Glasscock	0	637	0	5	0	0	0	0	0	642
Goliad	176	0	0	79	39	6	2	7	0	309
Gonzales	0	958	0	151	0	0	4	20	4	1137
Gray	0	0	0	25	0	0	0	0	0	25

Grayson	0	0	0	0	0	19	0	0	0	19
Gregg	0	0	0	350	0	0	18	0	0	368
Grimes	0	0	0	0	0	75	0	0	0	75
Guadalupe	0	84	0	286	0	0	4	8	64	446
Hale	0	0	0	0	0	0	19	0	0	19
Hall	0	4	0	0	0	0	11	5	7	27
Hamilton	0	1987	0	0	0	0	0	11	1	1999
Hansford	0	917	0	55	0	0	0	0	77	1049
Hardeman	0	23	0	0	0	0	11	3	3	40
Hardin	755	0	0	150	0	0	13	1	0	919
Harris	1941	0	0	427	25	18	4	11	350	2776
Harrison	0	0	0	344	0	3	19	0	0	366
Hartley	0	1042	0	0	0	0	0	0	0	1042
Haskell	0	0	0	0	0	19	0	0	0	19
Hays	0	1451	0	0	0	0	0	3	3	1457
Hemphill	0	1355	0	20	0	0	1	11	4	1391
Henderson	0	0	0	0	0	75	0	0	0	75
Hidalgo	0	0	0	177	0	0	2	0	3	182
Hill	0	1245	0	32	0	80	0	10	83	1450
Hockley	813	0	0	40	0	0	0	2	21	876
Hood	0	837	0	55	0	138	19	0	1	1050
Hopkins	0	0	0	93	0	3	3	0	0	99
Houston	0	0	0	14	0	34	31	0	0	79
Howard	0	480	0	0	0	0	6	0	0	486
Hudspeth	865	0	0	0	0	0	2	0	1	868
Hunt	1415	0	0	0	0	47	3	10	15	1490
Hutchinson	0	0	0	372	0	1	1	0	0	374
Irion	0	27	0	45	0	0	0	0	0	72
Jack	0	995	0	176	0	0	18	0	0	1189
Jackson	0	3677	0	505	0	2	1	6	38	4229
Jasper	538	0	0	118	0	67	13	2	0	738
Jeff Davis	525	0	0	0	0	0	2	0	1	528

Jefferson	480	0	0	161	0	0	13	6	74	734
Jim Hogg	0	216	0	131	0	0	0	4	0	351
Jim Wells	297	0	0	75	0	0	2	6	11	391
Johnson	1263	0	0	19	0	44	0	11	59	1396
Jones	0	0	0	0	0	42	0	0	0	42
Karnes	531	0	0	196	0	0	2	8	0	737
Kaufman	0	2007	0	9	0	33	18	13	0	2080
Kendall	0	1040	0	0	0	0	4	0	1	1045
Kenedy	0	315	0	39	0	0	19	0	9	382
Kent	0	52	0	0	0	0	4	0	0	56
Kerr	0	161	0	0	0	0	0	0	2	163
Kimble	0	158	0	0	0	0	0	0	1	159
King	0	54	0	0	0	0	0	0	12	66
Kinney	0	178	0	5	0	0	2	2	0	187
Kleberg	0	0	0	183	0	0	0	0	0	183
Knox	0	0	0	0	0	0	19	0	0	19
La Salle	300	0	0	85	0	0	2	2	0	389
Lamar	0	0	0	0	0	19	0	0	0	19
Lamb	639	0	0	15	25	0	19	30	46	774
Lampasas	0	161	0	0	0	0	6	5	1	173
Lavaca	0	0	0	355	0	0	1	17	0	373
Lee	0	1196	0	35	0	0	0	13	0	1244
Leon	0	0	0	59	0	14	18	0	0	91
Liberty	0	0	0	345	0	0	22	0	0	367
Limestone	0	1354	0	50	0	14	0	0	9	1427
Lipscomb	795	0	0	87	0	0	0	7	4	893
Live Oak	0	0	0	175	0	6	0	0	0	181
Llano	0	39	0	0	0	26	6	0	1	72
Loving	449	0	0	50	0	0	2	0	0	501
Lubbock	731	0	0	20	0	0	19	7	49	826
Lynn	30	0	0	0	0	0	0	1	16	47
Madison	0	0	0	77	0	0	18	0	0	95

Marion	0	160	0	317	0	4	2	0	0	483
Martin	0	732	0	10	0	0	6	0	1	749
Mason	0	148	0	0	0	0	0	0	0	148
Matagorda	0	3025	0	0	0	0	6	0	0	3031
Maverick	0	0	0	180	0	0	2	0	0	182
McCulloch	0	44	0	15	0	13	6	0	0	78
McLennan	0	978	0	5	25	80	20	0	62	1170
McMullen	0	0	0	183	0	0	0	0	0	183
Medina	0	975	0	95	0	4	0	9	18	1101
Menard	0	116	0	0	0	0	0	0	0	116
Midland	0	701	0	5	0	0	0	0	29	735
Milam	0	0	0	370	0	0	0	0	0	370
Mills	0	2103	0	0	0	0	6	6	1	2116
Mitchell	0	34	0	0	0	28	0	0	0	62
Montague	0	0	0	0	0	19	0	0	0	19
Montgomery	4427	0	0	20	0	16	4	4	54	4525
Moore	0	913	0	22	0	1	0	0	73	1009
Morris	0	996	0	0	0	0	4	0	0	1000
Motley	0	2	0	10	0	0	0	4	15	31
Nacogdoches	0	61	0	50	0	19	0	0	7	137
Navarro	0	0	0	322	0	134	18	0	0	474
Newton	860	0	0	32	0	47	18	1	26	984
Nolan	0	78	0	0	0	7	0	0	0	85
Nueces	0	0	0	180	0	0	2	0	0	182
Ochiltree	0	1055	0	16	0	0	0	0	53	1124
Oldham	0	0	0	20	0	0	1	1	4	26
Orange	1193	0	0	6	0	0	31	2	0	1232
Palo Pinto	0	0	0	226	0	204	19	0	1	450
Panola	0	298	0	224	0	28	18	0	0	568
Parker	0	1149	0	80	0	40	36	12	15	1332
Parmer	0	0	0	0	0	0	19	0	0	19
Pecos	0	0	0	225	0	0	2	0	0	227

Polk	849	0	0	55	0	23	31	2	17	977
Potter	0	0	0	0	1	1	1	0	28	31
Presidio	524	0	0	0	0	0	2	0	1	527
Rains	0	238	0	10	0	0	18	4	0	270
Randall	0	0	0	0	0	1	11	0	12	24
Reagan	0	657	0	35	0	0	0	0	1	693
Real	0	141	0	5	0	0	2	0	1	149
Red River	0	16	0	0	0	0	13	0	0	29
Reeves	0	0	0	225	0	0	2	0	0	227
Refugio	0	0	0	180	0	0	2	0	0	182
Roberts	0	73	0	0	0	0	1	0	4	78
Robertson	0	0	0	57	0	14	19	0	0	90
Rockwall	1576	0	0	0	0	9	18	1	0	1604
Runnels	0	92	0	0	0	9	0	0	0	101
Rusk	0	0	0	0	0	67	8	0	0	75
Sabine	0	1212	0	19	0	0	18	2	0	1251
San Augustine	0	1088	0	103	0	0	0	2	0	1193
San Jacinto	1041	0	0	24	0	27	22	2	0	1116
San Patricio	0	0	0	180	0	0	2	0	0	182
San Saba	0	170	0	0	0	0	6	0	1	177
Schleicher	0	111	0	0	0	0	0	0	0	111
Scurry	0	55	0	0	0	19	6	0	0	80
Shackelford	0	0	0	526	0	0	0	0	0	526
Shelby	0	504	0	205	0	0	18	0	0	727
Sherman	0	907	0	6	0	0	0	0	116	1029
Smith	0	0	0	21	0	28	31	0	0	80
Somervell	0	1563	0	0	0	45	0	0	1	1609
Starr	0	0	0	180	0	0	2	0	0	182
Stephens	0	1002	0	156	0	64	0	0	0	1222
Sterling	0	110	0	0	0	0	0	0	0	110
Stonewall	0	0	0	0	0	0	19	0	0	19
Sutton	0	119	0	0	0	0	0	0	0	119

Swisher	0	0	0	0	0	0	0	15	16	31
Tarrant	0	289	0	0	0	204	18	5	182	698
Taylor	0	0	0	0	0	42	0	0	0	42
Terrell	524	0	0	20	0	0	2	1	1	548
Terry	848	0	0	25	0	0	6	3	11	893
Throckmorton	0	390	0	377	0	0	19	0	0	786
Titus	0	0	0	92	0	3	3	0	0	98
Tom Green	0	0	0	0	0	42	0	0	0	42
Travis	343	0	0	5	0	67	6	5	196	622
Trinity	0	1399	0	47	0	0	31	3	0	1480
Tyler	1159	0	0	39	0	0	13	2	0	1213
Upshur	0	836	0	75	0	0	19	0	0	930
Upton	0	0	0	228	0	0	0	0	0	228
Uvalde	0	140	0	0	0	0	2	7	15	164
Val Verde	0	0	0	40	0	10	2	0	0	52
Van Zandt	0	0	0	56	0	0	31	3	0	90
Victoria	3043	0	0	434	0	0	4	8	30	3519
Walker	4519	0	0	40	0	0	18	6	0	4583
Waller	4380	0	0	95	0	0	4	8	0	4487
Ward	0	0	0	225	0	0	2	0	0	227
Washington	0	1304	0	35	0	0	19	11	0	1369
Webb	0	0	0	180	0	0	2	0	0	182
Wharton	0	4859	0	205	0	0	6	9	70	5149
Wheeler	0	0	0	25	0	0	0	0	0	25
Wichita	0	15	0	0	0	3	11	0	0	29
Wilbarger	0	0	0	10	0	0	11	0	1	22
Willacy	0	0	0	183	0	0	0	0	0	183
Williamson	0	29	0	75	0	159	0	0	91	354
Wilson	0	0	0	367	0	0	2	0	0	369
Winkler	15	0	0	221	0	0	0	1	0	237
Wise	0	1288	0	0	0	70	18	0	0	1376
Wood	0	0	0	32	0	33	18	0	0	83

Yoakum	0	958	0	65	0	0	6	0	10	1039
Young	0	1450	0	100	0	0	19	6	0	1575
Zapata	0	0	0	178	0	1	2	0	0	181
Zavala	0	0	0	180	0	0	2	0	0	182

BIOGRAPHICAL SKETCH

Ghaleb S. AL Duhni was born in Irbid, Jordan, and raised in Irbid, Jordan. He attended high school in Irbid High School, Jordan and graduated in 2007, and received his undergraduate degree in Electrical Power Engineering at the Yarmouk University in 2012. He also graduated in 2021 with his Master of Science in Electrical Engineering at UTRGV as well. He can be reached at galeb_90@outlook.com. He has worked as a Senior Engineer in KAWAR Energy in Jordan, and as an Maintenance Engineer at a the Electrical Distribution Company.