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Acknowledgment

I would like to thank my family for being by my side on this journey. First of all, I am grateful to my beautiful mother Juana Yolanda Davila Rodriguez. A strong woman who has always supported my development as much as she could. The best hero a son could have and the best example of love for life and family that I will always cherish. Words are not enough to express my gratitude. Thank you, mother, I love you.

Secondly, my elder brother Andres Gustavo Muñoz a professional always passionate about what he does, with a creative mind and a humble soul; and last but not the least my young brother Felipe Muñoz an artist with a big and wild heart.

Also, I would like to thank all the fantastic people I had the opportunity to meet in all this process. Without them my time to accomplish these studies would have never been as good as it was.

Now it is time to close this chapter and start writing a new one. With new enthusiasm and great experiences, I will be able to apply my fresh knowledge to promote innovations and sustainability urgently needed in the 21st century.

Agradecimientos

Quiero agradecer ante todo a mi familia, empezando por mi hermosa madre Juana Yolanda Dávila Rodríguez una mujer que con su fuerza y energía siempre me ha apoyado en mejoramiento y aprendizaje como persona de la mejor forma que ella ha podido, el mejor héroe que un hijo puede tener y el mejor ejemplo de amor por la vida y la familia que siempre tendré. Las palabras no son suficiente para expresar mi gratitud. Te amo madre

Segundo, a mi hermano mayor Andrés Gustavo Muñoz un profesional siempre apasionado con lo que hace y con un espíritu noble y finalmente pero no menos a mi pequeño hermano Felipe Muñoz un artista con un gran y salvaje corazón.

También quiero agradecer a todas esas fantásticas personas que conocí en esta etapa de mi vida sin ellos este tiempo nunca hubiese sido tan llevadero como lo fue.

Ahora es tiempo de cerrar este capítulo y abrir uno nuevo. Con entusiasmo y nuevas experiencias, tendré la capacidad de aplicar mi nuevo conocimiento para promover innovación y sostenibilidad algo requerido en el siglo 21.

Summary

This project shows the feasibility of change coal and gas technologies for renewables technologies, in this case, will analyze the following: Diesel generator, Photovoltaic, Wind turbine, Solar-Wind hybrid, Solar-Diesel hybrid, Wind-Diesel hybrid, Solar-Wind-Diesel hybrid in Colombia.

For this, I selected 3 main locations because I believe they will be the best because of their position and solar irradiance, that would help in the production of solar energy.
The main locations are the Candelaria, Tatacoa, and Guajira desserts.

The analysis will consider different cost like net present cost (NPC), the levelized cost of energy (COE), the initial capital cost and at the end is selected the best of them being analyzed by comparing this result with the actual price.

For solving this problem, it has been used a software called HOMER, specialized in these kinds of analysis and widely used for economic evaluations.

At the end I found out that the best locations are Guajira, Candelaria and Tatacoa being the Net present Cost $117B, $214B and $235B dollars respectively, and a total cost of energy of $0.363, $0.666 and $0,732 KWh that compared with the actual price of coal and gas technologies of $0.058 and $0.15 KWh respectively, allows me to say that economically a project like this is not feasible at this moment.

Zusammenfassung

Diese Arbeit zeigt die Durchführbarkeit des Umstiegs von Kohle und Gas Technologie zu erneuerbarer Energie. Es werden folgende Fälle in Kolumbien analysiert: Dieselgeneratoren, Photovoltaikanlagen, Windturbinen.

Hierfür wurden drei Hauptstandorte ausgewählt, die aufgrund ihrer Lage und der sich dort befindlichen Sonneneinstrahlung am besten für die Produktion von Solarenergie geeignet sind.
Diese drei Standorte sind Candelaria, Tatacoa und die Guajira Wüste.

Die Analyse wird verschiedene Kosten nach sich ziehen. Darunter fallen Nettogegenwartskosten, Energiekosten und Investitionskosten. Schlussendlich wird das Beste von ihnen ausgewählt, indem die Resultate mit dem tatsächlichen Preis verglichen werden.

Um dieses Problem zu lösen wurde die Software HOMER verwendet, die auf diese Art der Analysen spezialisiert ist und oft für wirtschaftliche Bewertungen verwendet wird.

Schlussendlich hat die Analyse ergeben, dass die besten Standorte Guajira, Candelaria und Tatacoa, mit Nettogegenwartskosten von \$117B, \$214B und \$235B und mit Gesamtkosten der
Energie von \$0.363, \$0.666 und \$0.732 pro KWh, sind. Dieses Ergebnis, im Vergleich mit den
gegenwärtigen Preisen für Kohle und Gas, von \$0.058 und \$0.15 pro KWh, zeigt, dass ein solches Projekt zum jetzigen Zeitpunkt ökonomisch noch nicht durchführbar ist.

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Abbreviations

Abbreviation	**Meaning**
BOP	Balance of payment
C_{cap}	Initial capital cost
CD	Centrally Dispatched
CND	National Dispatch Center
COE	Levelized cost of energy
CRF	Capital Recovery Factor
GHI	Global Horizontal Irradiance
i	Annual Real interest
N	System lifetime
NCD	Non-Centrally Dispatched
NIS	National Interconnected System
NPC	Net Present Cost
PV	Photovoltaic
ROI	Return on Investment
TAC	Total Annualized Cost
UPME	Energy mining projection unit
XM	Operator of the National Interconnected System (NIS) and administrator of the Wholesale Energy Market of Colombia.
ZIN	Non-interconnected Zones

1. Introduction

Renewable energies are going to dramatically change the power segment. The amazing innovation expectations to absorb information and administrative from governmental programs upgrade the expanding infiltration of sustainable energies. (kubli, 2017)

Energy is considered one of the central indexes of social and economic development in any country. Nowadays, almost 80% of the global energy demand is met by means of fossil fuels, resulting in significant environmental impacts. (Alireza Haghighat, 2016).

Photovoltaics (PV) is one of the best technologies for renewable energy with a promising future. PV systems are popularly configured as grid-connected, stand-alone and hybrid systems. This technology is evolving very fast while the prices are decreasing.

Colombia has a big quantity of hydroelectricity and thanks to its big quantity, has a good and clean quantity of energy mix, with an average below the international level of consumption and because its geospatial position equatorial zone, the country could produce a big quantity of energy from non-conventional, solar, wind, biomass, geothermal and solid waste resources. (Andrés Vides-Prado, 31 May 2017)

The utilization of sustainable power source is spreading quickly. This is featured by the way that consistently more sustainable power limit than the (net) capacity of every non-renewable energy source joined is included the world over. Similarly, the aggregate number of nations with sustainable power source approaches expanded by and by in 2015. As per the REN21's 2016 Global Status Report, no less than 173 nations had sustainable power source targets, and an expected 146 nations will report some sort of sustainable power sources at national, state or commonplace level before the year's over Population and electricity access. (Andrés Vides-Prado, 31 May 2017).

There are presently two critical issues worth considering with a specific end goal to address the financial concerns encompassing sustainable power source in Colombia.

The first one is a national financing plan reserving 32 billion dollars for sustainable power source extends, the remodel and extension of open lighting, indoor or outside lighting, co-generation, and self-generation has been propelled. In this regard, the ministry of mines and energy, adding to this financing plan the “Energy Planning Unit (UPME), the Financial Institution for Development FIDENTER and the Inter-American Development Bank (IDB) announced a special credit line for projects and investments with favorable terms. Second, the Ministry of Mines and Energy and the National Finance Development Institution signed an agreement in October 2016 to promote a program to integrate renewable energies (PER) into the Colombian electricity mix in order to leverage Colombia's massive potential in this respect.” (Andrés Vides-Prado, 31 May 2017)

According to the United Nations estimates Colombia population is 49,507,719 as of Saturday, August 11, 2018 (estimations, n.d.), the National interconnected system (SIN) covers 96% of the population and 48% of the territory the Non- connected zones (ZNI) has a population of approx. 625000 inhabitants this area covers 52% of the territory Figure 1. (Roy, 2017); 17 departments and 1.441 municipalities), and 625 thousand people, currently these zones produce energy with diesel.” (Procolombia, 2015)

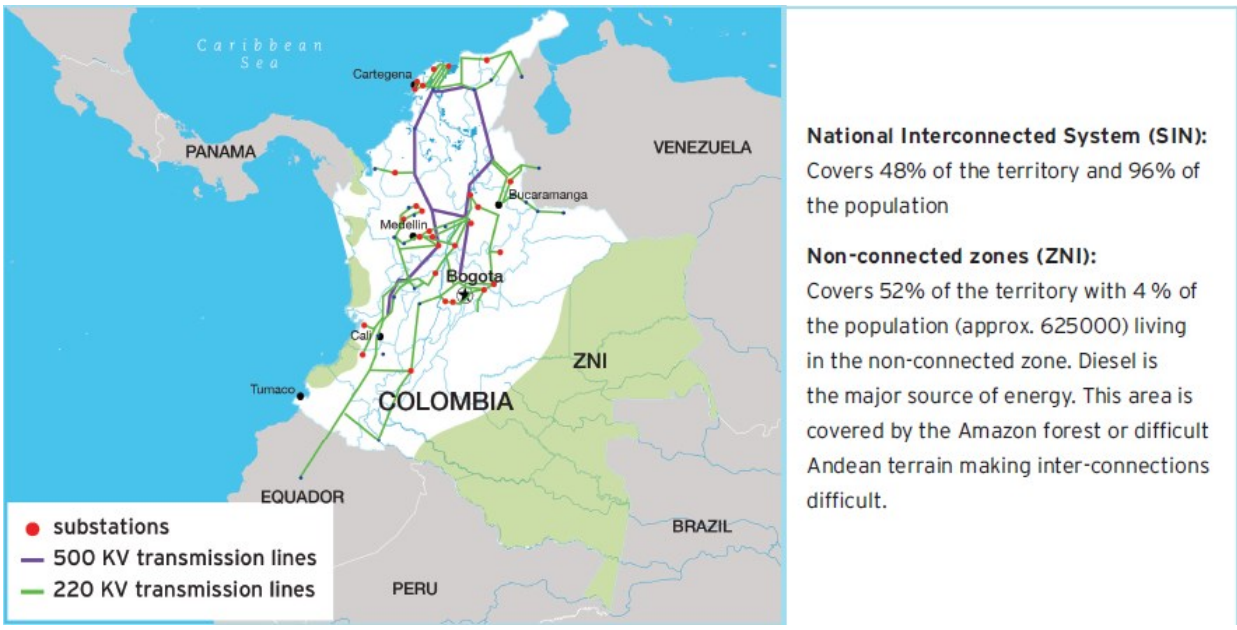


Figure 1: Connected and Non-connected Zones SIN and ZNI (Ferreira, 2016)

The observatory of economic complexity shows “Colombia is in the position 55th as largest export economy in the world. In the year 2016, Colombia imported $43.2B and exported

$32.9B, resulting in a negative trade balance of $10.3B as we can see. In the year 2016, Colombia has a GDP of $282B and its GDP per capita was $14.2k." (complexity, n.d.)

"The top exports of Colombia are Crude Petroleum ($8.26B), Coal Briquettes ($5.44B), Coffee ($2.57B), Refined Petroleum ($1.95B) and Gold ($1.38B)" (complexity, n.d.)

For Colombia, coal is the second biggest resource of export of the country while Europe is the main buyer and consumer of this resource (Figure 2 Main Buyers of Coal from Colombia 2018). Knowing this information and thinking in a future development option for the country, for some another reason as will be explain further, Colombia should switch to new energy business and reconsider the use of coal and gas as Non-renewables sources of energy, some of the main these reasons for me to think about the importance of change of energy model are:
First, being a coal and gas non -renewable, new sources and technologies are important to be taken into consideration as future options. Second, Colombia needs to cover and to find new options for exportation, because the risk for coal as a power source will be reduced in Europe in the near future."

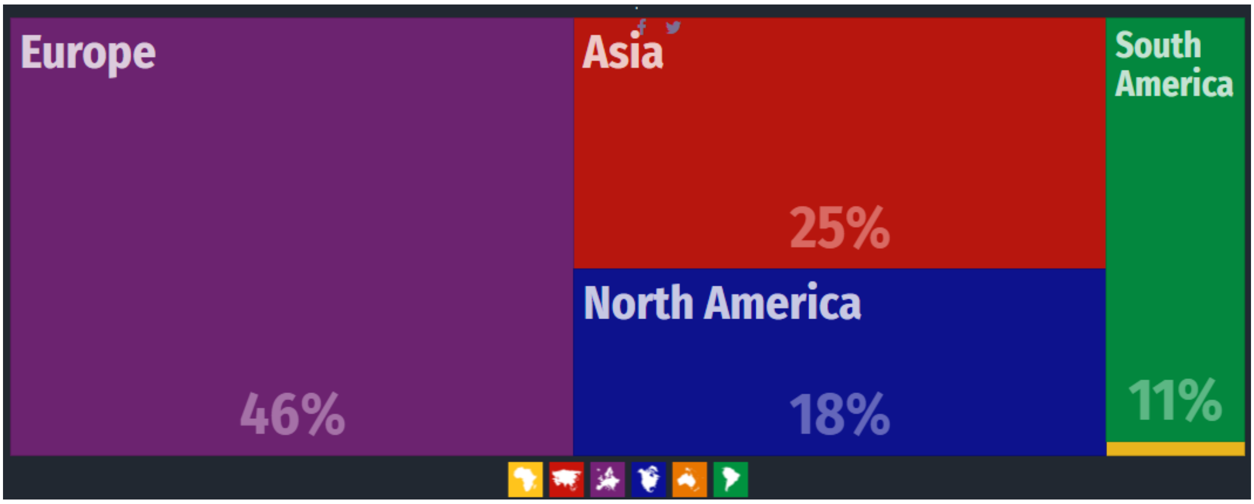


Figure 2 Main Buyers of Coal from Colombia 2018

About this, fact is mentioned in (Analytics, 2018) "that the Coal dependence in Europe is not as big as generally thought; it is around 20% of total power generation share and is lower than in other OECD economies such as the US, Japan, China, and Australia. Eight European states have made a compromise to finish the use of coal completely – Austria, Denmark, France, Finland, Italy, Netherlands, Portugal, and the UK – it means the use of coal as a resource of energy power will continue to decline as more capacity gets retired.

In 2016- 2017, 14 gigawatts of coal as energy producer were retired in Europe, and there is little capacity in the construction or planning phase (with the few of them mainly located in Poland and South Eastern Europe).” (unit, 2108) in addition to this, there is a plan of the European Union (EU), that was voted in December 2017 by the European Council to achieve the goals for 2030 on climate and energy framework, in particular, the target of 27 percent on the energy consumption, saying that half of this would be completed using wind, solar, and biomass by year 2030. (Parliament, 2017) This because “with the signature of the Paris Agreement, the European Union has joined the international community in officially committing to the reach as goal limiting global warming to “well under 2°C and to follow this effort to limit temperature increases to a max 1.5°C above pre-industrial levels.” (Analytics, 2018)

“For the European Union to reach this goal, it will need to rapidly decarbonize its power sector. A very important portion of the EU’s emissions comes from coal, especially from the plants fired by coal, and ending coal in the electricity sector is one of the most cost-effective methods to reach emissions reductions. Decreasing coal usage will also give significant benefits in terms of air quality, health, and energy security. The European Union has more than 300 power plants (date from July 2016) with 738 separate generating units. These are not equally distributed through the individual member states and those most depending on coal are Poland, Germany, Bulgaria, the Czech Republic, and Romania. Germany and Poland those countries alone are together responsible for 51% of the installed coal capacity and 54% of emissions from coal in the EU’s.” (Analytics, 2018), all this will affect the exportation of coal, as explained before Europe is our main buyer of coal for Colombia, and third in an environmental point of view, as is well known that burned coal leaves a substance called coal ash that is considered very contaminant.

Those are the reasons I want to know if, would be possible for Colombia to replace energy consumption of coal and gas for PV or mix-PV, I will only take into consideration the economical point of view.

1.1. Types of electric power sources in Colombia

Electric power can be generated from different sources. In Colombia the most used are:

- Hydro: it is produced thanks to the use of the kinetic energy of the water accumulated in a reservoir, to move turbines and generate electrical energy. It is a type of renewable energy.

- Biomass: it is a type of renewable energy from the use of organic matter (plants, animals, etc.) that is converted into electrical energy by a thermochemical and thermoelectric process. There are different types of biomass such as bagasse, biogas, biodiesel, etc.

- Solar: is obtained from the use of electromagnetic radiation from the Sun. It is a type of renewable energy that generates electrical energy through a photovoltaic or thermoelectric process. There are different types of solar energy such as photovoltaic or solar thermal (also called solar thermal).

- Fossil fuel: it is a type of non-renewable energy, obtained by fossil sources such as liquids (fuel oil, ACPM, jet A1) that are derived from oil, gas, coal, and mixture (gas-jet A1). These fuels passing through a thermochemical and thermoelectric process are converted into electrical energy. This type of energy is commonly referred to in Colombia as thermal energy.

- Wind: is obtained from the use of air currents (wind) that allow the movement of the blades of a wind turbine for the generation of electrical energy. It is a type of renewable energy.

1.2. Classification By generation in Colombia

In addition to classifying the generation by the energy source, it can also be classified by the type of dispatch as:

- Centrally dispatched (CD): it is considered centrally dispatched to the generation plants with installed capacity greater than or equal to 20MW. These power plants have access to the central office and participate in the Wholesale Energy Market.
- Not dispatched centrally (NDC): it is considered not centrally dispatched to the generation plants with installed capacity of less than 20 MW. These power plants have the option of having access to the central office if their installed capacity is between 10 MW and 20 MW.

1.3. Classification by productive activity.

The generation can also be classified according to its main productive activity such as:

- Co-Generators: combined production process of electrical energy and thermal energy, which is part of the production process whose main activity is not the production of electrical energy, both intended for own consumption or for third parties and whose use is made in industrial or commercial processes.

- Self-Generators: the process of production of electrical energy whose main activity is to attend to own consumption and which can deliver its surplus energy to the National Interconnected System.

- Generators: the process of production of electrical energy whose main activity is the generation of electrical energy. This classification includes the smaller plants that, by definition, have an installed capacity of less than 20 MW and exclude auto generators and co-generators from it. (XM, XM.com.co, n.d.)

2. Actual technologies used in Colombia and its percentage of Electricity Generation

The next Table shows the number of electric plants in Colombia at this moment.

Table 1:
Number of Plants for Electric Generation in Colombia

Concept	Quantity
Hydro generation plants CD	32
Thermal generation plants CD	32
Hydraulic generation plants NDC	111
Thermal generation plants NDC	11
Solar generation plants NDC	1
Wind generation plants NDC	1
Dam	24

Data from: (XM, Informe de Operacion SIN y Administracion del Mercado 2017, 2018)

Net Effective Capacity by Resource in 2017

Table 2 has the net effective capacity in (Mega Watts) MW of those plants

Table 2:
Net Effective Capacity by Resource

Resource	Net Effective Capacity (MW)
Hydro CD	10,943
Thermal CD	4,729
Hydraulic NDC	779.1
Thermal NDC	141
Wind NDC	18.42
Solar NDC	9.8
Co-generators	122.5
Self-generators	36
Total NIS	**16,778.82**

Data from: (XM, Informe de Operacion SIN y Administracion del Mercado 2017, 2018)

2.1. Thermal Electricity capacity

The thermal capacity in Colombia is the combination of different resources Gas, Coal Fuel-Oil (Fuel Oil, Diesel, Jet 1, Gas Jet A1) as shown in Table 3.

Only gas and coal will be considered for this analysis, the net capacity of carbon and gas at the end of 2016, comes from the thermal CD (Centrally Dispatched) with a value of 4,728 (MW).

Capacity participation of coal and gas in the year 2016 is 3,457 MW and represents around 21% of the total capacity we can see it in Table 3 this come from the sum net capacity of Gas and Coal, obtained from XM, that are the data we require for the simulations. It would mean a load of around 9,471.23 KW /day 2016 had 365 days

2.1.1. Division of net thermal capacity by resource

In the next table, we can see the thermal capacity during the years 2016 and 2017 in Megawatts.

Table 3:
Net thermal Capacity by resource

Resource	2015(MW)	2016(MW)	Participation from 100% capacity	Variation
Thermal	***4,723***	***4,728***	***28,49%***	***-0.32%***
Gas	1,548	2,128		
Coal	1,339	1,329		
Fuel-Oil	--	--		
Fuel oil	299	187		
Diesel	1,247	774		
Jet 1	46	46		
Gas Jet A1	264	264		

Data from: (XM, Informe de Operacion SIN y Administracion del Mercado 2017, 2018)

2.1.2. Actual average offer price Gas and Coal

According to the annual report 2017 of Concentra (Energia, 2017), the price by technology is in Col pesos Table 4 and in dollars Table 5:

Table 4:

Average offer price by technology, in Colombian peso ($/kWh)

Month	Hydro	Coal	liquids	Gas
January	113.1	162.1	537.1	383.9
February	132.8	158.8	541.3	377.2
March	116.7	160.7	504.1	404.9
April	99.4	162.1	509.6	403.3
May	77.7	166.5	516.8	398.2
June	73	173.2	533.4	392.3
July	73.8	171.8	556.1	389.9
August	83.4	173	535.8	398
September	102.6	170.1	518.7	410.4
October	112.7	168.2	540.4	432.4
November	122.8	176.8	585.5	435.3
December	88.7	175.4	558	454.5

Table created with the statistical data from (Energia, 2017)

Table 5:

Average offer price by technology, in USA dollars ($/kWh)

Month	Hydro	Coal	liquids	Gas
January	0.037323	0.053493	0.177243	0.126687
February	0.043824	0.052404	0.178629	0.124476
March	0.038511	0.053031	0.166353	0.133617
April	0.032802	0.053493	0.168168	0.133089
May	0.025641	0.054945	0.170544	0.131406
June	0.02409	0.057156	0.176022	0.129459
July	0.024354	0.056694	0.183513	0.128667
August	0.027522	0.05709	0.176814	0.13134
September	0.033858	0.056133	0.171171	0.135432
October	0.037191	0.055506	0.178332	0.142692
November	0.040524	0.058344	0.193215	0.143649
December	0.029271	0.057882	0.18414	0.149985

This table was made using the currency exchange from 19/9/2018

The whole system is calculated in dollars, thus the exchange rate from peso to dollar at 17-Sept-2018 is 1 Peso = 0.00033 dollar.

During the year 2017, the hydroelectric plants declared an average offer price of 0.033 $ / kWh, showing a decrease of 66% with respect to the previous year, this happened given that in the year 2017 there was no El Niño phenomenon.

On the same year the power plants that generated energy with natural gas declared an average offer price of 0.13 $ / kWh, increasing 17% compared to the previous year; coal prices of 0.053 $ / kWh, increasing 8.5% and the of liquid fuels of 0.18 $ / kWh, decreasing 7.8%.

2.2. Total Energy Demand in Colombia

National energy demand growth from 2016 to 2017 1.3%. having a total demand of 66.893 MW/h. In 2017, UPME carried out the revisions in the projection of demand scenarios, the first in the month of February and the second in the month of July. For the energetic planning, the scenario was selected. UPME because the behavior that was presented was the energy consumption in the last months before the execution of the study

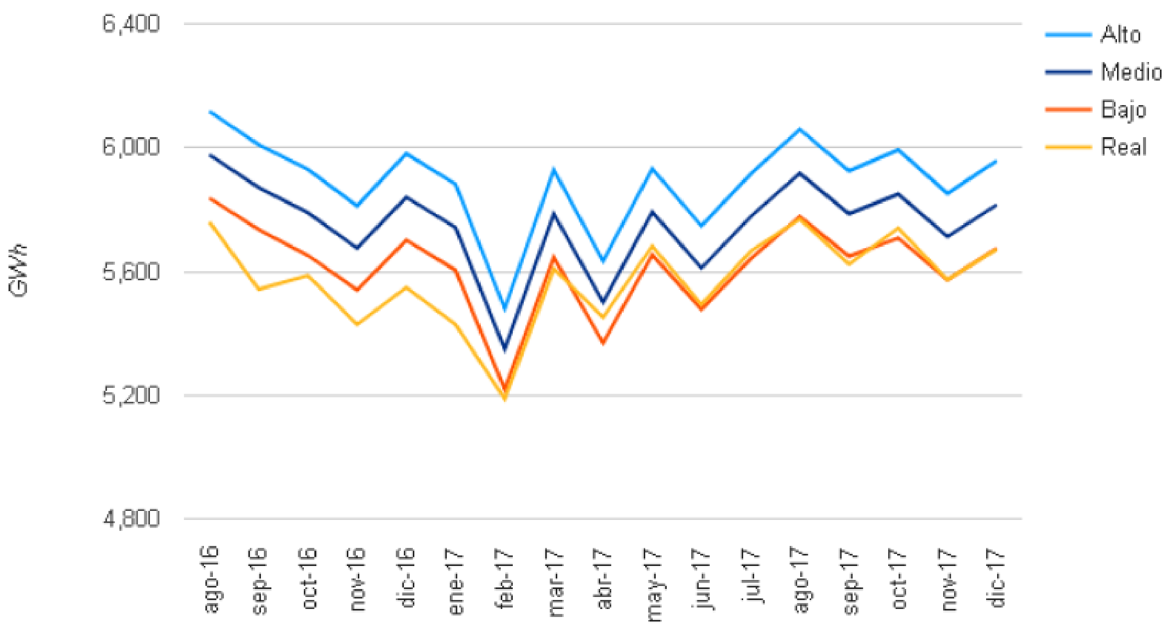


Figure 3 Scenarios UPME Vs Real Demand of NIS in 2016-2017, High, Medium, Low and real

Source: (XM, Informe de Operacion SIN y Administracion del Mercado 2017, 2018)

As we can see in Figure 3 the actual demand values of the SIN are relatively close located to the low scenario in the during the whole year 2017. For the simulations in energy, the CND selected the average scenario in the same year 2017 with the objective of considering a slightly unfavorable case for reliability, in such a way in the event of an increase in demand with respect to what was observed is covered.

The yearly difference between the real demand and the average UPME scenario was 1.65 TWh, a quantity that represents 2.5% more than the real one. (XM, Informe de Operacion SIN y Administracion del Mercado 2017, 2018)

2.3. Historical Demand in Colombia:

The consumption of energy demand in Colombia is marked by a trend depending on the type of day, for example, between Monday and Friday an average consumption is maintained, which can be classified as an ordinary day. On Saturday maintains a particular consumption, which can continue to be identified in this way, while on Sundays and holidays it is possible to group them given their consumption of similar electrical energy.

Additionally, there are 3 important points that characterize the energy demand curve, these are dawn (05:00 to 07:00), tip one (11:00 to 13:00) and tip two (18:00 a 21:00), this last point is the one with the highest power consumption in the country Figure 4

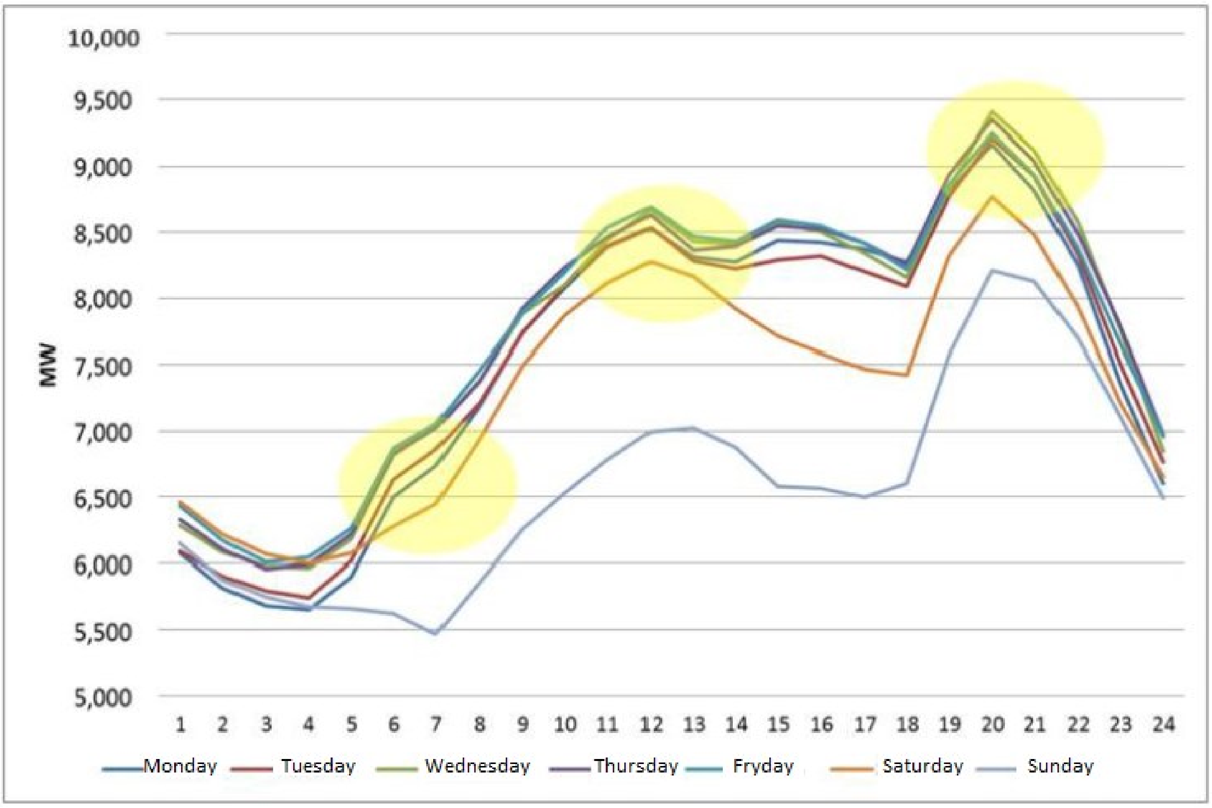


Figure 4 Historical Demand Colombia during the year and behavior

Source: (XM, Informe de Operacion SIN y Administracion del Mercado 2017, 2018)

3. Description of Study Area

For this project, I decided to choose some deserts from the country. Colombia has three main deserts where a project for renewable energy wind, wind-Solar or solar could be implemented without major damage to the environment or population. This may bring a big potential for energy generation for different factors as low quantity of clouds that will improve the efficiency on photovoltaic Panels PV.

The following information, are the locations and resources for each area.

3.1. Guajira Desert

The Guajira Desert Figure 5 is located in the northernmost part of Colombia, 1,100 km, (680 mi) north of Bogota, in the La Guajira Department, covering most of La Guajira Peninsula including Venezuelan territory.

The Location of Guajira dessert is: long, latitude: 12.188953, -72.134160 (Google maps)", has an area of 20.848 km^2 a temp from 27°C to 35°C. The area holds immense coal reserves, exploited in a zone known as El Cerrejon. Guajira is also home to the indigenous Wayuu people. The Wayuu are mostly herders. They also are master deep-sea divers. They dive to collect pearls. There is also a variety of desert flora and fauna, the altitude of Guajira is from 0 to 450 m.a.s.l "meters above the sea level". (Ministerio de Comercio, Ministerio de Comercio, Industria y Turismo, Guia Turistica Guajira).

Figure 5 Location Guajira Desert

Guajira Solar GHI Resource

Guajira dessert has a scaled annual Solar Global Horizontal Irradiance (GHI) Figure 7 average of 6.57 (kWh/m2 /day) data from NASA surface meteorology and Solar Energy Data Base, averaged values over a 22-year period (July 1983-June 2005)

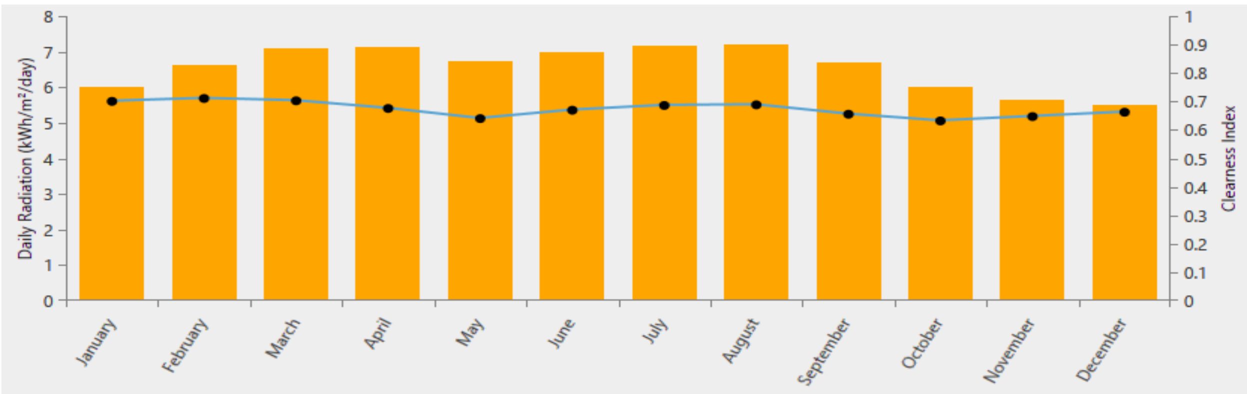


Figure 6 Guajira Solar Monthly GHI, graph from Homer software

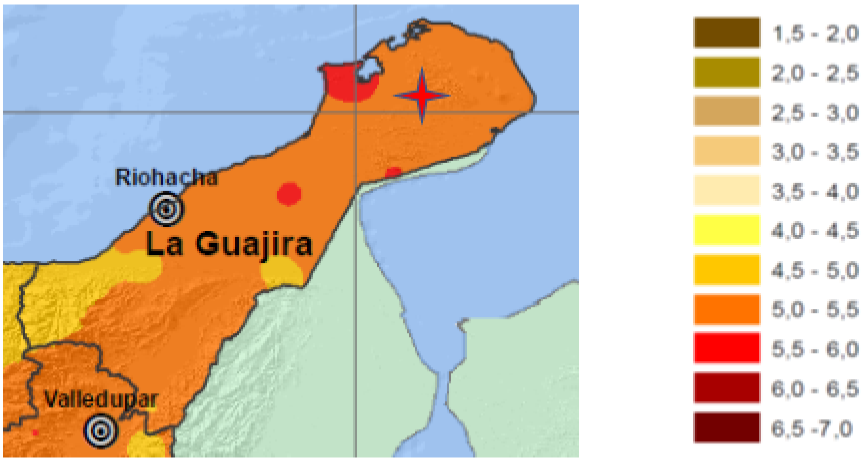


Figure 7 Solar Irradiance Guajira (Kwh/m^2/day)

Guajira Wind average Resource

Guajira dessert has a Scaled Annual Average wind speed of 7.33 (m/s)

Figure 8 data from NASA surface meteorology and Solar Energy Data Base.

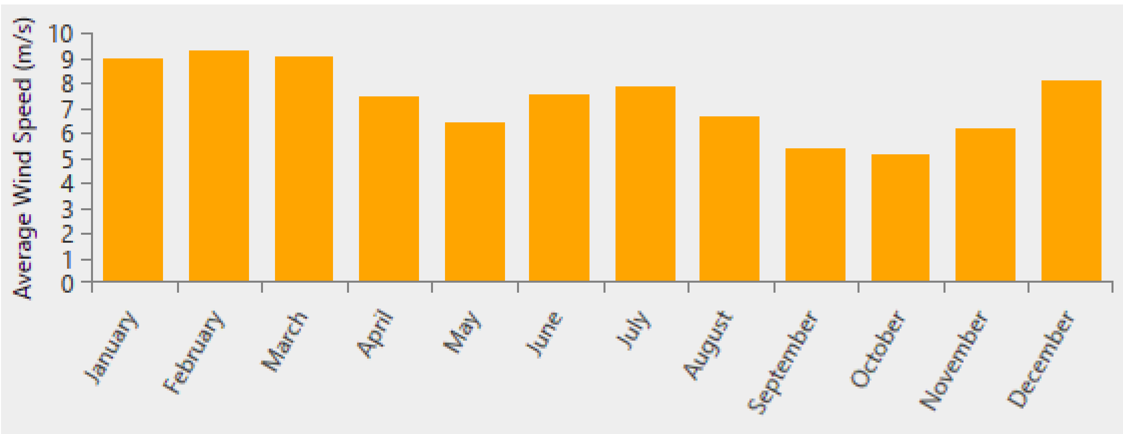


Figure 8 Guajira Monthly Average Wind Speed, Graph from Homer Software

Wind speed at 50m above the surface of the air for terrain similar to airports monthly averaged values over a 10-year period (July 1983-June 1993)

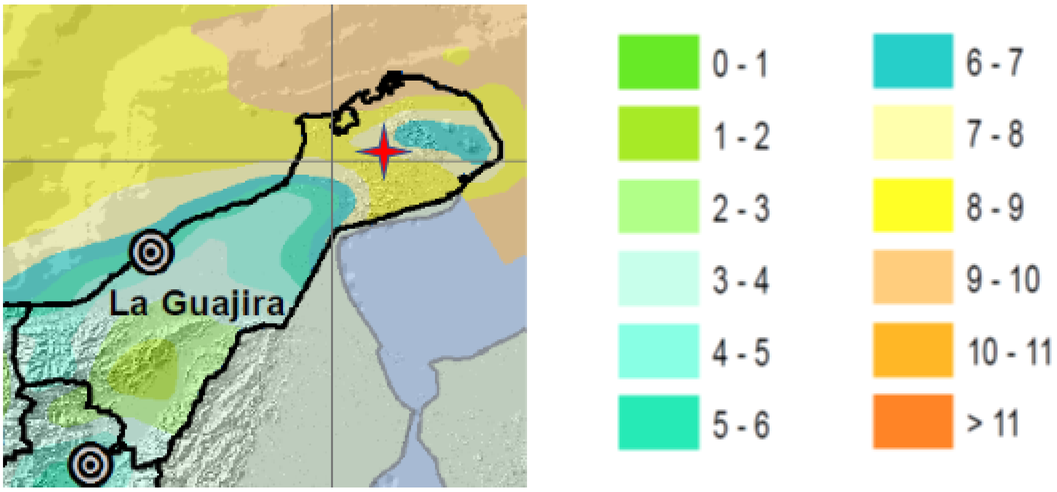


Figure 9 Wind Probability Guajira at 10 mt (M/s)

Guajira Temperature Average Resource

La Guajira dessert has an Annual Average temperature of 26.01 °C Figure 10 data from NASA surface meteorology and Solar Energy Data Base.

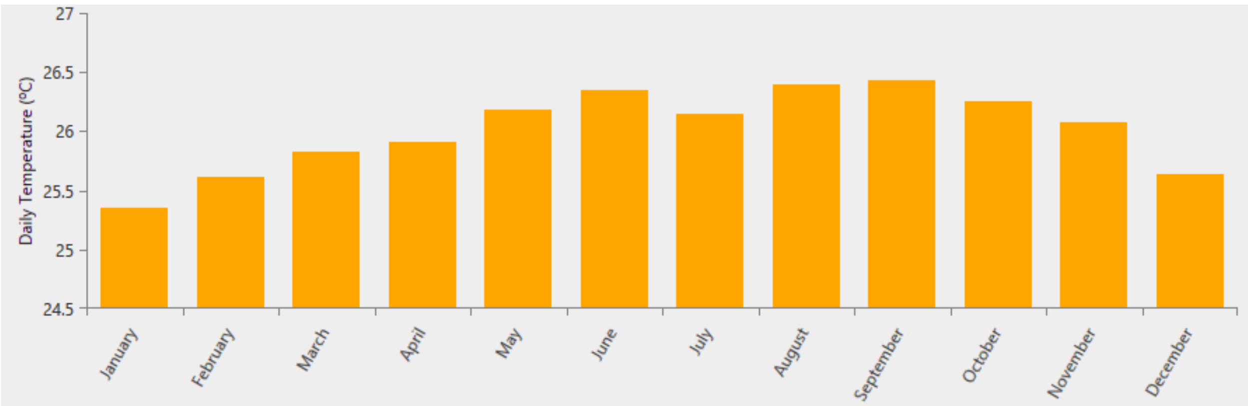


Figure 10 Guajira Temperature Monthly Average, graph from Homer Software

Air temperature, monthly averaged values over a 22-year period (July 1983-June 2005)

3.2. Tatacoa Desert

The Tatacoa Desert Figure 11 is the second largest arid zone in Colombia after the Guajira Peninsula. It occupies 380 Km^2 but has an estimate of his expansion of around 1000 km^2 of land the location is: long, latitude: 3.232386, -75.168776 (Google maps)". This dessert that is considered semi-arid is ubicated north of the department of Huila Department, 38 km from the city of Neiva in Colombia and limit with the municipality Natagaima in Tolima and the south with the population of Baraya. It is a rich deposit of fossils that is why carry out constantly scientific research and is a great tourist destination. (Ministerio de Comercio, Ministerio de Comercio, Industria y Turismo, Guia Turistica Huila)

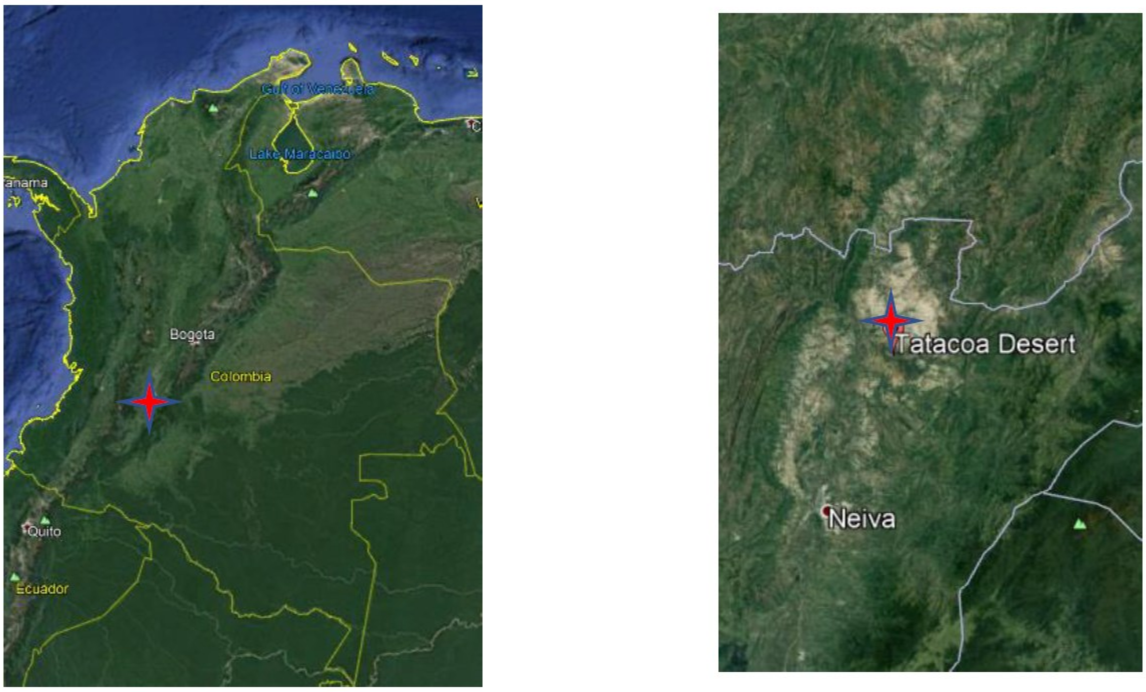


Figure 11 Location Tatacoa Desert

Tatacoa Solar GHI Resource

Tatacoa dessert has a scaled annual Solar Global Horizontal Irradiance (GHI) Figure 11 annual average of 4.42 (kWh/m2 /day) data from NASA surface meteorology and Solar Energy Data Base, averaged values over a 22-year period (July 1983-June 2005).

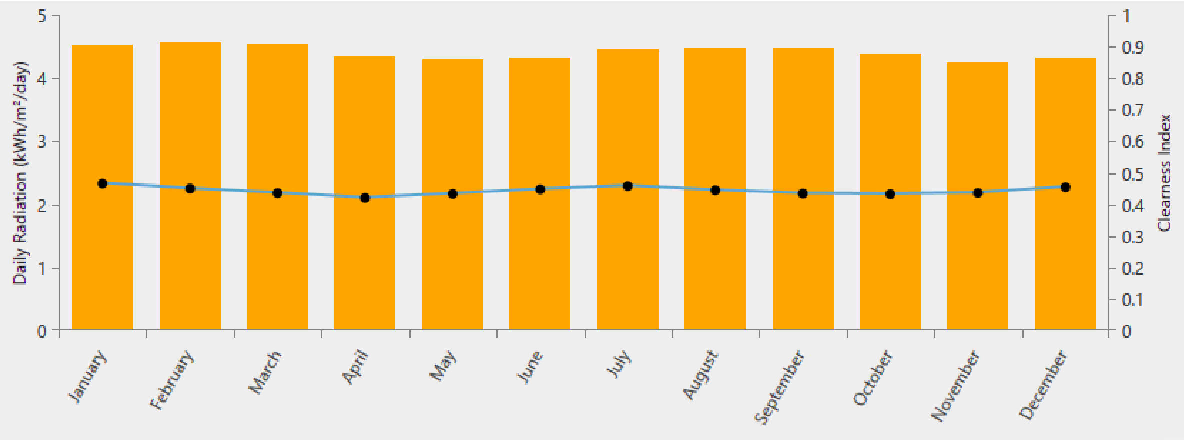


Figure 12 Tatacoa Solar Monthly GHI, graph from Homer software

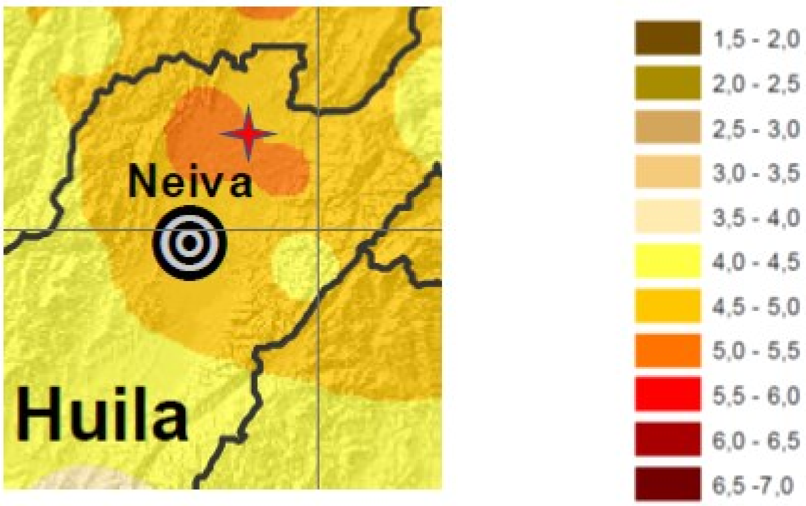


Figure 13 Solar Irradiance Tatacoa (Kwh/m^2/day)

Tatacoa Wind average Resource

Tatacoa dessert has a Scaled Annual Average wind speed of 1.90 (m/s) Figure 14 data from NASA surface meteorology and Solar Energy Data Base.

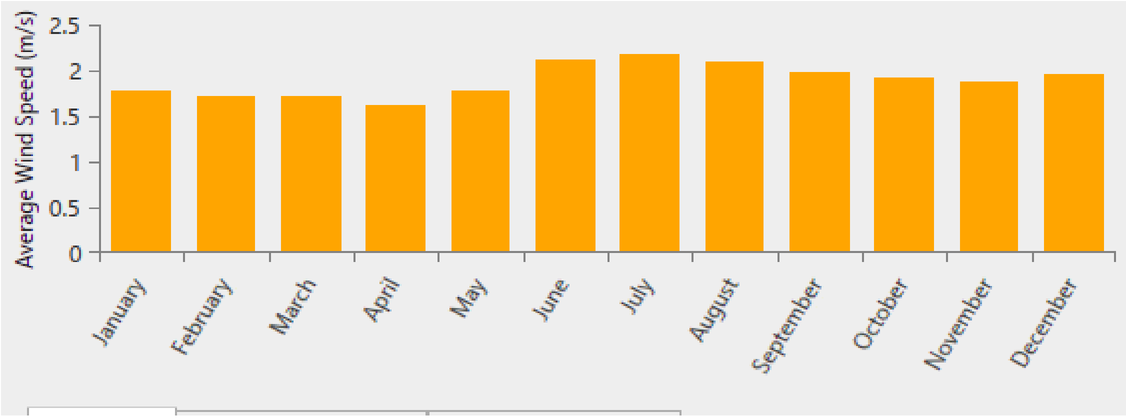


Figure 14 Tatacoa Monthly Average Wind Speed, Graph from Homer Software

Wind speed at 50m above the surface of the air for terrain similar to airports monthly averaged values over a 10-year period (July 1983-June 1993).

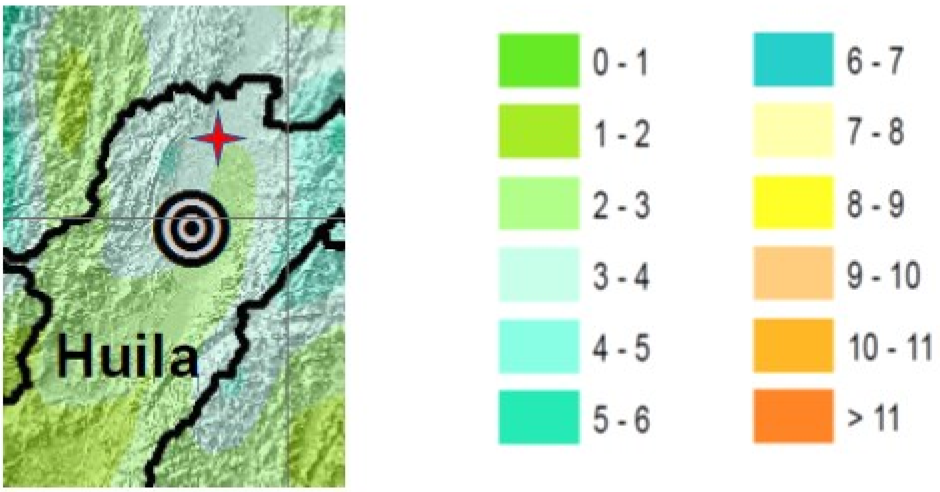


Figure 15: Wind Probability Tatacoa at 10 mts (m/s)

Tatacoa Temperature Average Resource

Tatacoa dessert has an Annual Average temperature of 20.15 °C Figure 16 data from NASA surface meteorology and Solar Energy Data Base.

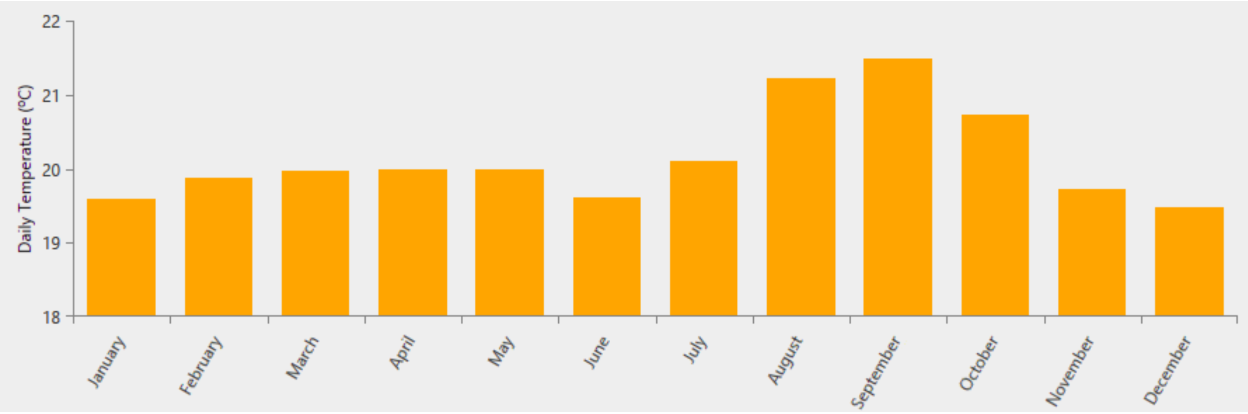


Figure 16 Tatacoa Temperature Monthly Average, graph from Homer Software

Air temperature, monthly averaged values over a 22-year period (July 1983-June 2005).

3.3. Candelaria Desert

The desert of the Candelaria Figure 17 is a desert located to the west of the department of Boyacá, in Colombia where is located as well the first monastery of Augustinian Recollects Order in Colombia. It is located 7 km north-east of the municipality of Ráquira and 32 km southwest of Villa de Leyva, “Location: long, latitude: 5.5765, -73.593768. (Google maps)”. The territory is in a hollow crossed by a small river of the same name, which descends from 2,600 meters to 2,000 above sea level. (Ministerio de Comercio, Ministerio de Comercio, Industria y Turismo, Guia Turistica Boyaca)

Figure 17 Location Candelaria Dessert

Candelaria Solar GHI Resource

Candelaria dessert has a scaled annual Solar Global Horizontal Irradiance (GHI) Figure 18 annual average of 5.04 (kWh/m2 /day) data from NASA surface meteorology and Solar Energy Data Base, averaged values over a 22-year period (July 1983-June 2005).

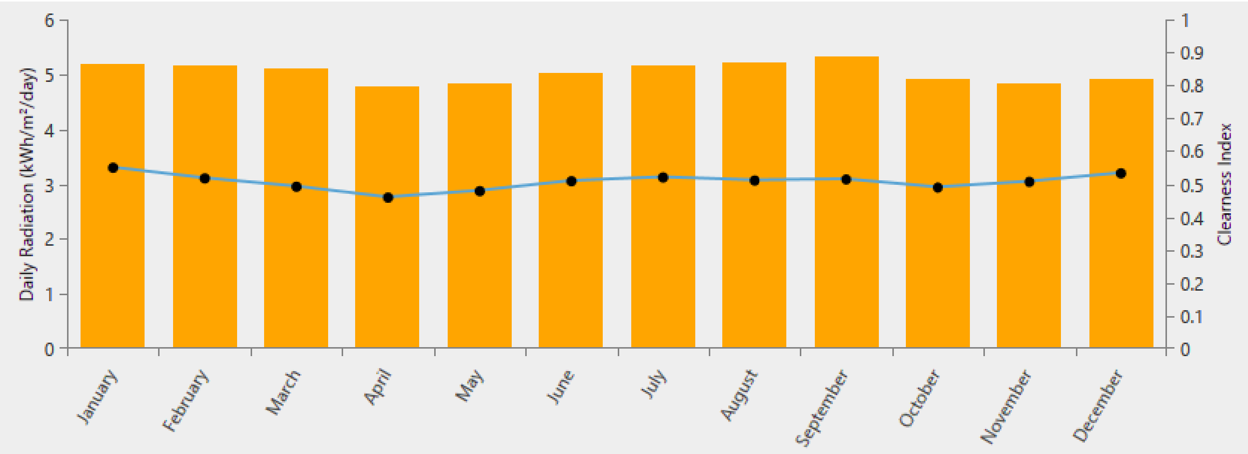


Figure 18 la Candelaria Solar Monthly GHI, graph from Homer software

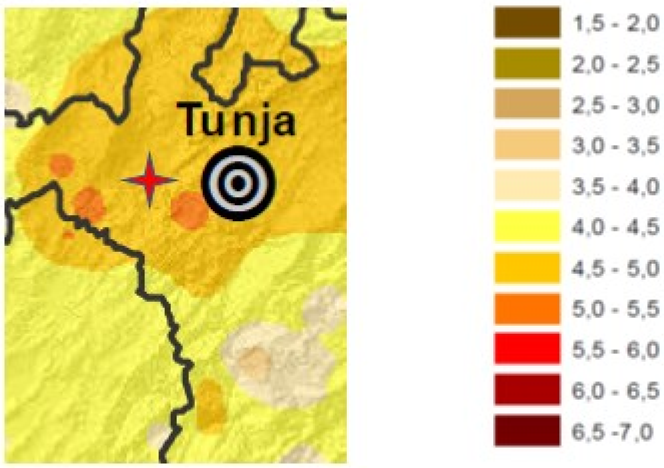


Figure 19 Solar Irradiance Candelaria in (Kwh/m^2/day)

Candelaria Wind average Resource

Candelaria dessert has a Scaled Annual Average wind speed of 2.27 (m/s) Figure 20 data from NASA surface meteorology and Solar Energy Data Base.

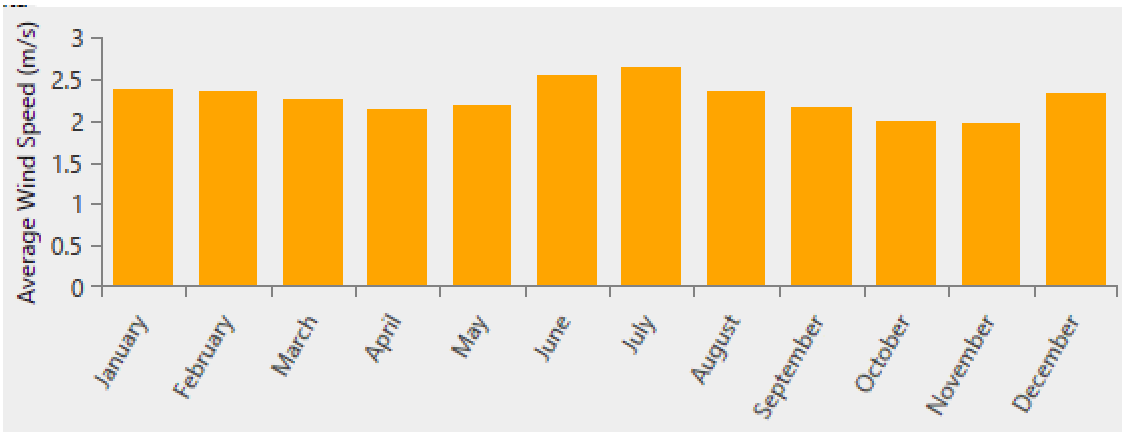


Figure 20 Tatacoa Monthly Average Wind Speed, Graph from Homer Software

Wind speed at 50m above the surface of the air for terrain similar to airports monthly averaged values over a 10-year period (July 1983-June 1993).

Candelaria Temperature Average Resource

Candelaria dessert has a n Annual Average temperature of 18.77 °C Figure 21 data from NASA surface meteorology and Solar Energy Data Base.

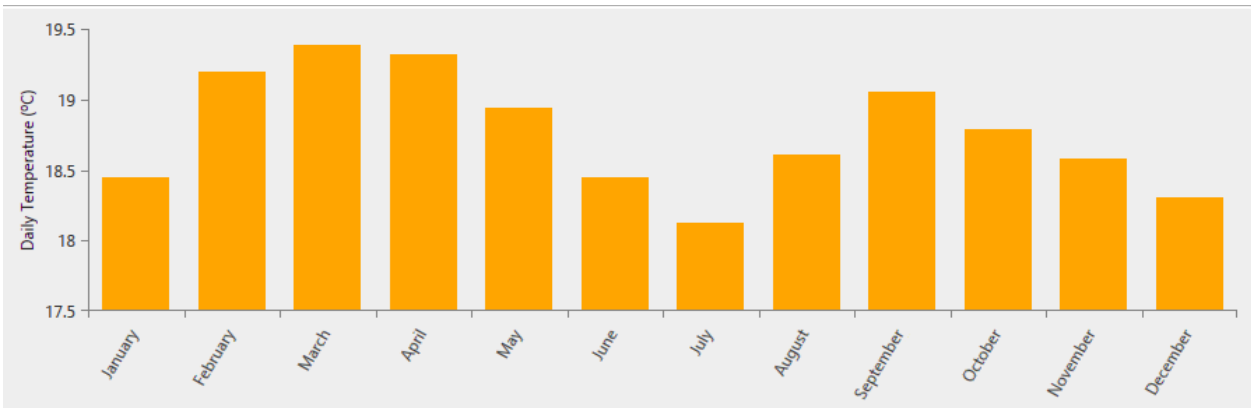


Figure 21 Tatacoa Temperature Monthly Average, graph from Homer Software

Air temperature, monthly averaged values over a 22-year period (July 1983-June 2005)

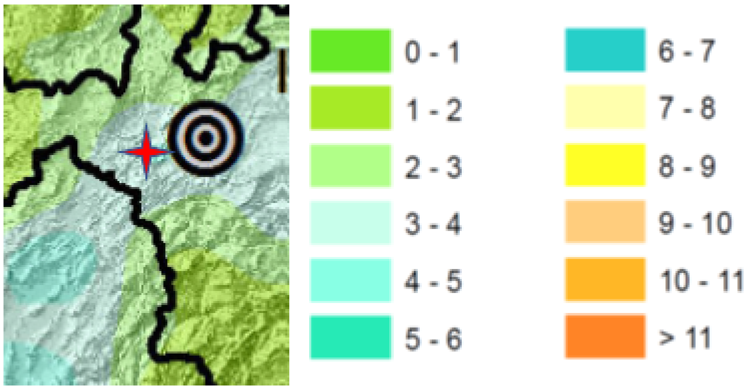


Figure 22 Wind probability Candelaria at 10mts (m/s)

3.4. Solar and wind capacity per year in each dessert

According to the maps of wind probability and solar irradiance the 3 deserts have a daily average solar irradiance of 5-0 to 5.5 kW/m2/day, wind capacity is Guajira desert 4-5 (m/s), Tatacoa desert 3-4 (m/s) and Candelaria desert 3-4 (m/s) with an average of Wind and solar irradiance Maps are from (Ideam, n.d.) general maps from (maps, n.d.).

4. Definition of the electrical demand

It is good to know what is the difference between consumption and demand in order to find the best option to reduce cost.

“Electricity demand is measured in kilowatts (kW) and represents the rate at which electricity is consumed. Electricity consumption, on the other hand, is measured in kilowatt-hours (kWh) and represents the amount of electricity that has been consumed over a certain time period. For example, a 10 W LED will always demand 10 W from the grid when it is on.

However, the LED’s energy consumption will range depending on the number of hours it is on. If the LED is on for 10 hours, it is consumption would be 10 W x 10 hours or 100 Wh.” (Havens, 2017)

The idea of this project is to replace the total capacity of energy produced by Gas and Coal in the year 2016. For this, I used the actual consumption (kWh) of the country that is covered by coal and gas, and I used it to make the yearly load that will be used for calculations in the software HOMER. The total time of the project is 25 years. The following Figures show daily, seasonal and yearly profile

Figure 23, Figure 24, Figure 25.

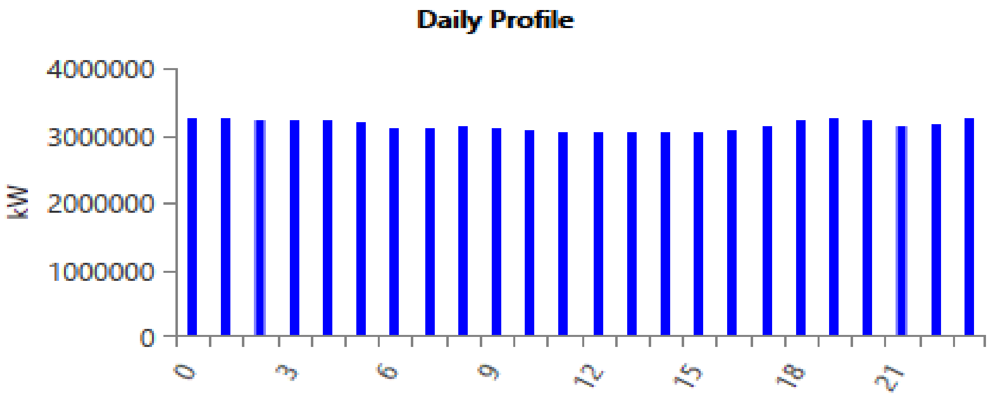


Figure 23 Daily load Profile, Coal and Gas Colombia

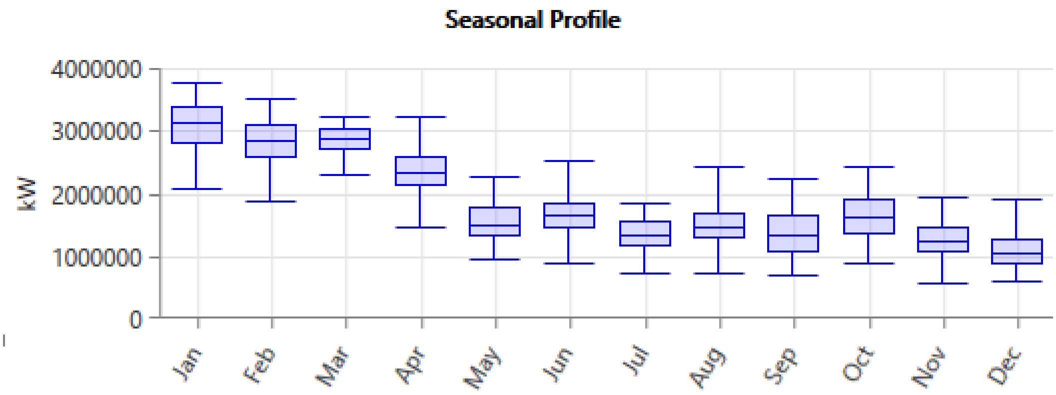


Figure 24 Seasonal Load Profile Coal and Gas

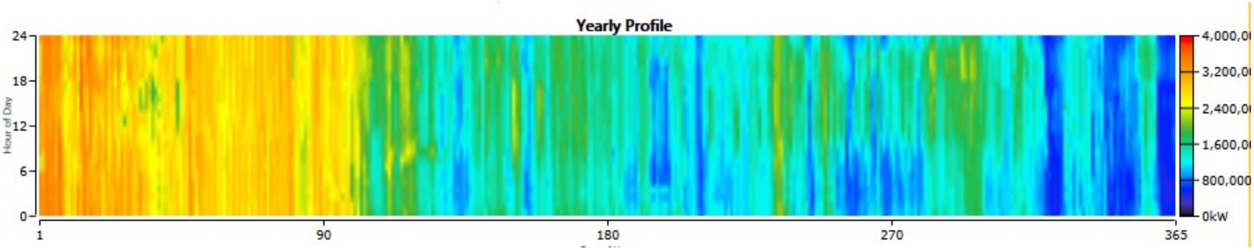


Figure 25 Yearly load profile Coal and Gas

The scaled annual average (KWh/d) is 44,902,41.

Inflation and discount rate

Another fundamental part of our calculation is the inflation and discount rate, these two data they have to be used in the software HOMER in order to improve the results, the inflation rate for 2017 was 4.31% according to (statista, n.d.)

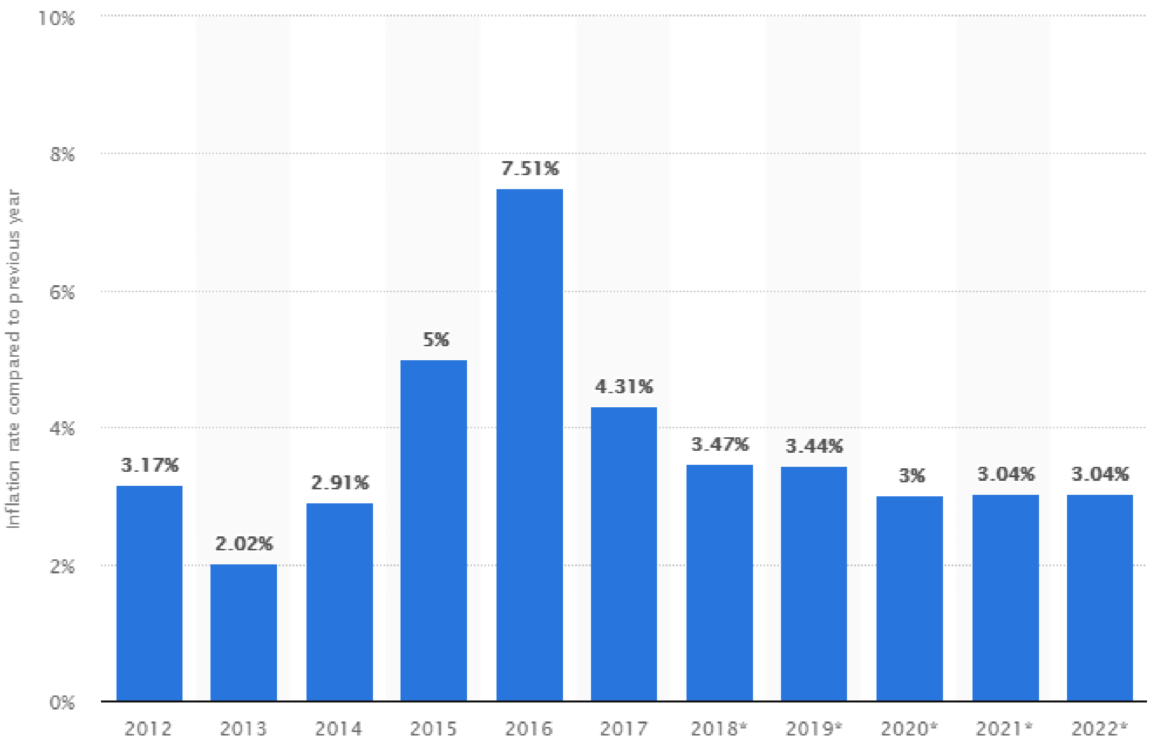


Figure 26 Inflation Rate of Colombia According to STATISTA (statista, n.d.)

The discount rate over 10 years in Colombia has an average of 9.2%. according to CEIC Data, the actual discount rate for 2017 is 6.75 % according to the same source.

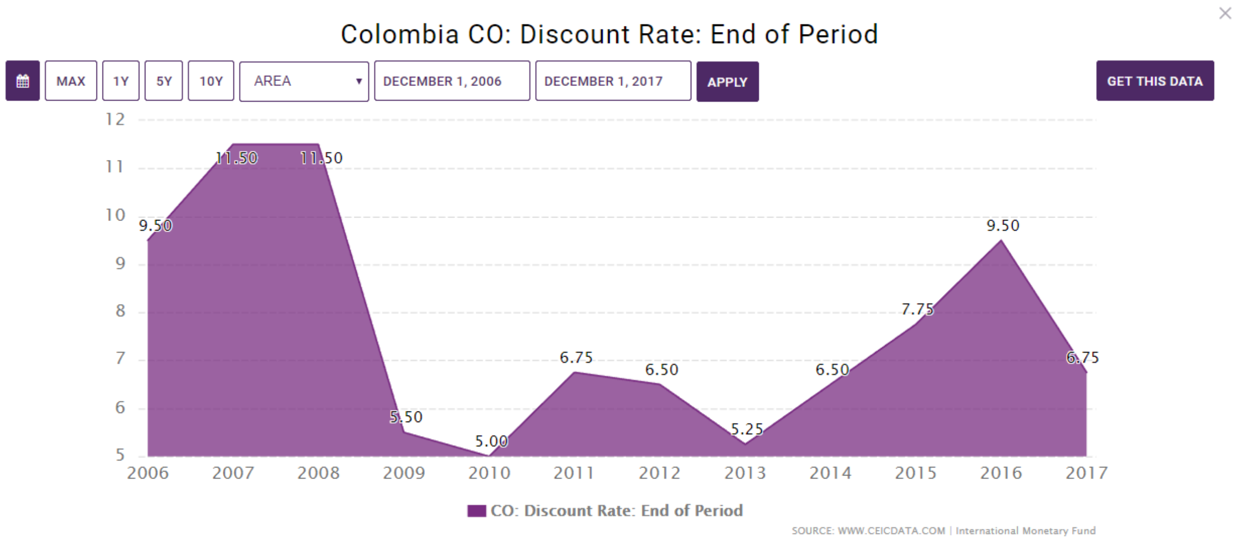


Figure 27 Discount Rate Colombia (Data C. , n.d.)

5. Major Components

The components used for this calculation and cost of each of them are the following:

5.1. Table of components

It is worth mentioning that operation and maintenance cost is assumed after checking different equipment. They could change for different reasons, for example, an unexpected failure but as part of the system calculation, I find important to give a price in order to make more realistic the different scenarios and cost.
All the equipment includes all necessary cables and items for adequate installation and prices are in US dollars.

Table 6 :
Components and prices

Components	Homer Suffix	Capital cost	replacement Cost	Operation and maintenance	Fabricant
PV 350 W	LG 350	$700	$458.48	$30 /year	LG
Converter 7.6 KW	Sol7.616	$1,956.60	$1,956.60	$120/year	Solar Edge
Batteries Rolls S-500EX 6V 517Ah	SurrS-500EX	$445	$430	$120/year	Rollsbattery
Wind turbine Endurance Wind E-3120 50 Kw	End50	$414,633.00	$400,000.00	$4664.63/year	Endurance
Wind turbine Enercon E82 3MW	Ene3020	$4,020,569	$4,000,000	$129,573.12/year	Enercon
Gen 50Kw SD10	Gener50	$16,199.00	$15,000	$0.3/hour	Generac
Generic 2.5 MW Brand Megawatt	GenLarge	$750,000	$700,000	$7/hour	Megawatt

5.1.1. PV Panels

“Solar panels (PV) or solar photovoltaic have not changed that much since around 40 years, even if some materials have improved the whole system continue working in the same way. The whole idea is to convert sunlight to DC using a series of cells, what has improved is the efficiency of the materials with what the cells are made reducing the cost of construction more than 80% since 2008.” (Svarc, Clean energy reviews, 2018).

“When considering Return of Investment (ROI) it is necessary to consider performance and degradation rates over the life of the system. Cheapest solar panels mean fewer upfront costs and its possible they work well for some years but with the past of time (between 4 and 6 years) the best-quality panels will be working near to the maximum power rating which means better energy performance and higher returns. After 20 years is clear that the best panels will continue working better than a low quality on an average of 10% and sometimes more which is an important quantity when is calculated the annual generation.” (Svarc, Clean energy reviews, 2018)

The solar panel system is the LG NeON™ R LG350Q1C-A5 350 w and 25 years warranty, no tracking system is used, the price of each solar panel will be around $700 US dollars and the replacement cost $458 US dollars (CivicSolar, n.d.) Maintenance cost I will assume $40

US dollars year, “Solar panels generally require very little maintenance, they are very durable and should last around 25-30 years with no maintenance. The only maintenance you should need to perform is to wash them clean of dirt and dust two to four times a year, which you can easily do with a garden hose. This basic cleaning routine ensures that the sun can shine brightly on the panel, maximizing the amount of light available to turn into electrical power”. (ecomarksolar, 2016)

Electrical Properties (STC *)

Module	350
Maximum Power (Pmax)	350
MPP Voltage (Vmpp)	36.1
MPP Current (Impp)	9.70
Open Circuit Voltage (Voc)	42.7
Short Circuit Current (Isc)	10.77
Module Efficiency	20.3
Operating Temperature	-40 ~ +90
Maximum System Voltage	1000
Maximum Series Fuse Rating	20
Power Tolerance (%)	0 ~ +3

* STC (Standard Test Condition): Irradiance 1,000 W/m², Ambient Temperature 25 °C, AM 1.5
* The nameplate power output is measured and determined by LG Electronics at its sole and absolute discretion.
* The typical change in module efficiency at 200 W/m² in relation to 1000 W/m² is -2.0%.

Electrical Properties (NOCT*)

Module	350
Maximum Power (Pmax)	263
MPP Voltage (Vmpp)	36.0
MPP Current (Impp)	7.32
Open Circuit Voltage (Voc)	40.1
Short Circuit Current (Isc)	8.67

* NOCT (Nominal Operating Cell Temperature): Irradiance 800 W/m², ambient temperature 20 °C, wind speed 1 m/s

Figure 28 Electrical Data PV LG350Q1C-A5

5.1.2. Wind Turbine

“In a wind turbine, electricity is generated by converting the kinetic energy of wind into electrical energy. Wind turbine farms are becoming important sources of renewable energy and are used to reduce reliance on fossil fuels and consequently pollutant emissions." (Alireza Haghighat, 2016).

According to the National Renewable Energy Labs 2016 report on cost of wind energy, the installed cost per megawatt assuming an installation of 2 megawatt turbines in a 100 megawatt project (200 MW total installed capacity) on a wind farm is approximately $1,690 per kilowatt (Capital expenditure) , the turbine capital cost for the same project would be ($1,209,000 per MW before BOP and finance costs), the information used in the report are in 2015-nominal dollars. ((NREL), 2'017).
Prices decrease on bigger wind turbines, it means if a wind turbine produces more energy the cost of this wind turbine is lower, the same will happen with the diesel generator.

For this analysis, the wind turbines I selected are Enercon E82 82m 3000kw with a price of $4,020,569.00 Dollars and Endurance Wind E-3120 50kw with a price of $414,633.00 the prices according to Open energy Monitor (Monitor, n.d.).

5.1.3. Diesel Generator

Price diesel in Colombia for the year 2016 was 0.64 (US$ per liter) according to the World Bank data (Data T. W., n.d.). After running the software to calculate the generator it will be required 42.000.000 kW choose a power generator Generac protector diesel 50kW SD010 with liquid cooled engine a lifetime assumed to be 15000 hrs. an initial capital of $16,199 US Dollars and also, will assume a Generic 2.5 MW Generator Set with a price of $750,000.00 Us Dollars brand Mega Watt, depending on the size, it is important to say that as in the wind turbines, Generators will decrease the price of kW/w.

5.1.4. Batteries

Because solar and wind are not constant, it was selected batteries as a storage in order to keep a constant supply. Being a different kind of batteries in the market I decided a lead acid battery, "Lead-acid batteries represent a tried and true technology is one of the most used for off-grid system and has been used for years. Flooded lead-acid batteries have the lowest upfront cost, but the tradeoff comes in the form of maintenance -- every month you'll need to check the water level, adding distilled water to keep them topped off. These batteries expel built-up hydrogen gas, so they need to be installed in a vented enclosure. They also need periodic equalize charges. " (wholesalesolar, n.d.) The battery selected is Surrette / Rolls S-500EX Flooded Battery with a warranty of 7 years, a lifespan of 12 years, a price of $445 US dollars and assume a maintenance of $130 US dollars/year approx.

5.1.5. Inverter

The inverter will transform DC electricity to AC so this is an essential part of the system. Wind turbines are not considered because they already have the inverter, and the diesel generator produces Ac voltage.
The inverter selected is the SolarEdge HD-Wave 7.6kW 240V Inverter SE7600H-US000NNU2 lifetime 15 years and efficiency of 99 % the price of this inverter is $1,956.60 (CivicSolar, n.d.).

6. Software Tool HOMER

The software tool used for this analysis and optimization was HOMER (Hybrid Optimization Model for Electric Renewables) the software has been used to perform the techno-economic feasibility of possible configurations.
The software has the capabilities to work with a variety of technologies like PV, wind, hydro, fuel cells, and boilers and evaluate design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation applications. "HOMER models each individual system configuration by performing an hourly time-step simulation using inputs such as different technology options, component costs, and resource availability." (Alireza Haghighat, 2016)

6.1. Simulation

HOMER software is able to simulate the different operation a system could have by calculating in each time step (intervals) of a year. For each interval, the software compares the electric and thermal demand in that time step with energy that the system can supply in the same interval, as well can calculate the flow of energy from and to every single component of the system. “For systems that include batteries or fuel-powered generators, also decides in each time step how to operate the generators and whether to charge or discharge the batteries.” (Homer, n.d.)

6.2. Optimization

The optimization is performed by HOMER using two optimization algorithms. “The original grid search algorithm simulates all of the feasible system configurations defined by the Search Space. The optimizer uses a proprietary derivative-free algorithm to search for the least-costly system, then displays a list of configurations, sorted by net present cost (sometimes called life-cycle cost), that you can use to compare system design options.” (Homer, n.d.)

Using Homer Pro software for optimization, allows me to run multiple simulations by the total cost of ownership also called Net Present cost or NPC. In that regard, the meaning of optimization can be seen as a set of simulations, and after running a combination of different renewable systems. PV, wind, and wind-diesel give me the possibility to find the design with the lowest cost.

6.3. Sensitivity Analysis

In the case sensitivity variables are defined as inputs, the software Homer will repeat the optimization process for each sensitivity variable that was specified. “For example, if you define wind speed as a sensitivity variable, simulates system configurations for the range of wind speeds that you specify.” (Homer, n.d.)
In other words, is a set of optimizations when I perform a sensitivity analysis in Homer pro software, I can explore how the optimal design, could perform when I change variables, for example, what if the cost of fuel goes up, this would change the optimal design or does it affect what choices me or a designer might take.

6.4. Scenarios

Homer software was used to calculate different configurations for each of the desserts Guajira, Tatacoa and Candelaria.
The ultimate purpose is to find the technical and economic viability and compare the best option with the cost of energy produced by thermal technology in Colombia and in this way be able to know if it is feasible or not.
Will include all the possible configurations of photovoltaic cells, wind turbines, diesel generators, and batteries and to determine the best configuration for electrical power production in each location using the equipment from Table 6 : Components and **prices**.
The possible configurations are:

- Diesel generator
- Photovoltaic
- Wind turbine
- Solar-Wind hybrid
- Solar-Diesel hybrid
- Wind-Diesel hybrid
- Solar-Wind-Diesel hybrid

The optimal result will be the one with the lowest net present cost and cost of operation for each location.

7. Methodology

For this Project, I found the load using the consumption of coal and gas per day and per hour for every single day require to cover the consumption in the country during 2016 the source was XM and in the next table we can see that results

Table 7:
Consumption covered by coal and gas each month 2016

Row Labels	Sum of Demand of Energy kWh	Total offer kWh	Coal kWh	Gas kWh
January	5583627225	2337666468	713935940.4	1623730528
February	5464923954	1979881809	637255892.4	1342625916
March	5567053866	2164630609	739072016.4	1425558592
April	5396940514	1656464496	579088404.8	1077376092
May	5549491425	1129884502	327007941	802876560.8
June	5400642943	1190549191	372654601.4	817894589.7
July	5488292707	986194368.8	379411931.5	606782437.3
August	5761769706	1116577385	426824083.7	689753300.9
September	5541867548	976946135.1	238168310.3	738777824.8
October	5587353321	1198970568	473903870.7	725066697.3
November	5428488358	905005683.3	297076755.2	607928928.1
December	5547980992	762334519.7	215718884.8	546615634.9
Grand Total	66318432559	16405105735	5400118633	11004987102
GWh	**66318.43256**	**16405.10573**	**5400.118633**	**11004.9871**
	Cover by another technology	49913326824	60918313926	55313445457
	% of the demand covered by coal and gas	**24.73%**	**8.14%**	**16.59%**

After having this information we insert the data into Homer software so we can have the load required to start each simulation for the different scenarios, with this process we produce one year of hourly load data.

To insert the data, we use the option that Homer software has to import a time series, it is possible to import data to step down to any time down to one minute, for this case our data comes from every 60 minutes from the year 2016 as shown in Figure 31

On the Electrical, Thermal, or Hydrogen Set Up page from Homer we follow the next steps:

•Click the Import... button to quickly import a simple time series file.

•Click the Import and Edit... button

Using this procedure import data files with gaps (spaces) in the data or an incorrect number of rows. This function includes basic gap-filling tools to fill in missing data points." (Homer, n.d.)

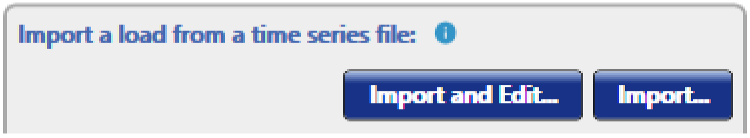


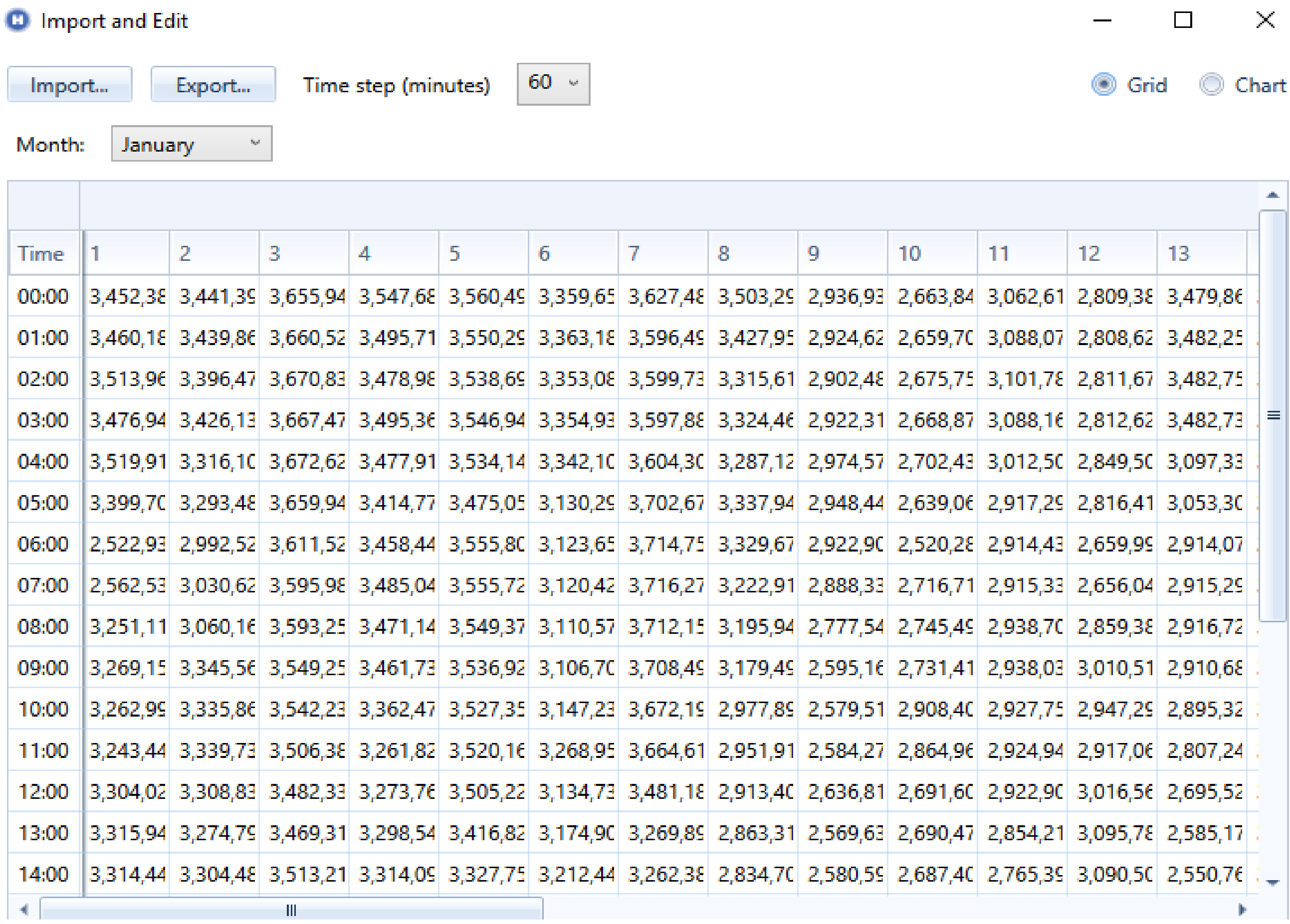
Figure 29 Import a load data from a file

The format used to upload the data so it gets recognized by HOMER software was CSV from excel and organized in the day by row, the following figure shows a small sample of those results.

	A	B	C	D	E	F	G	H	I	J	K	L
1		0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00
2	1/1/2016	3452381	3460181	3513966	3476948	3519916	3399701	2522931	2562537	3251110	3269155	3262992
3	1/2/2016	3441396	3439866	3396478	3426132	3316108	3293487	2992520	3030629	3060168	3345564	3335861
4	1/3/2016	3655944	3660526	3670838	3667472	3672629	3659950	3611522	3595981	3593252	3549255	3542234
5	1/4/2016	3547690	3495718	3478990	3495370	3477919	3414780	3458446	3485048	3471144	3461731	3362477
6	1/5/2016	3560494	3550292	3538690	3546945	3534142	3475058	3555803	3555730	3549374	3536926	3527358
7	1/6/2016	3359656	3363187	3353087	3354933	3342109	3130293	3123652	3120429	3110572	3106707	3147239
8	1/7/2016	3627487	3596493	3599733	3597882	3604309	3702679	3714758	3716278	3712154	3708499	3672192
9	1/8/2016	3503297	3427958	3315619	3324465	3287125	3337949	3329680	3222913	3195950	3179496	2977897
10	1/9/2016	2936934	2924627	2902481	2922316	2974570	2948447	2922910	2888330	2777545	2595162	2579515
11	1/10/2016	2663841	2659700	2675752	2668873	2702440	2639060	2520281	2716712	2745492	2731418	2908404
12	1/11/2016	3062613	3088074	3101790	3088164	3012510	2917297	2914432	2915335	2938703	2938039	2927751
13	1/12/2016	2809386	2808627	2811675	2812623	2849508	2816415	2659994	2656046	2859388	3010514	2947293
14	1/13/2016	3479869	3482251	3482757	3482740	3097332	3053300	2914080	2915291	2916730	2910687	2895323
15	1/14/2016	3035716	2990127	3120271	2991235	3132950	3074787	2907965	3229597	3273421	3308249	3309134
16	1/15/2016	3627970	3592873	3554821	3598878	3458273	3492147	3514112	3523184	3536437	3530729	3510957
17	1/16/2016	3228165	3229662	3272930	3252203	3273440	3240341	3320747	3261441	3340592	2977948	2980275
18	1/17/2016	3528816	3329534	3344020	3340663	3245831	3224406	3152193	3259958	3466094	3511923	3562687

Figure 30 Sample of Day by row format used for upload data

The information gets read by the software and we can see the correct data information on the screen of the software HOMER.



Time	1	2	3	4	5	6	7	8	9	10	11	12	13
00:00	3,452,38	3,441,39	3,655,94	3,547,68	3,560,49	3,359,65	3,627,48	3,503,29	2,936,93	2,663,84	3,062,61	2,809,38	3,479,86
01:00	3,460,18	3,439,86	3,660,52	3,495,71	3,550,29	3,363,18	3,596,49	3,427,95	2,924,62	2,659,70	3,088,07	2,808,62	3,482,25
02:00	3,513,96	3,396,47	3,670,83	3,478,98	3,538,69	3,353,08	3,599,73	3,315,61	2,902,48	2,675,75	3,101,78	2,811,67	3,482,75
03:00	3,476,94	3,426,13	3,667,47	3,495,36	3,546,94	3,354,93	3,597,88	3,324,46	2,922,31	2,668,87	3,088,16	2,812,62	3,482,73
04:00	3,519,91	3,316,10	3,672,62	3,477,91	3,534,14	3,342,10	3,604,30	3,287,12	2,974,57	2,702,43	3,012,50	2,849,50	3,097,33
05:00	3,399,70	3,293,48	3,659,94	3,414,77	3,475,05	3,130,29	3,702,67	3,337,94	2,948,44	2,639,06	2,917,29	2,816,41	3,053,30
06:00	2,522,93	2,992,52	3,611,52	3,458,44	3,555,80	3,123,65	3,714,75	3,329,67	2,922,90	2,520,28	2,914,43	2,659,99	2,914,07
07:00	2,562,53	3,030,62	3,595,98	3,485,04	3,555,72	3,120,42	3,716,27	3,222,91	2,888,33	2,716,71	2,915,33	2,656,04	2,915,29
08:00	3,251,11	3,060,16	3,593,25	3,471,14	3,549,37	3,110,57	3,712,15	3,195,94	2,777,54	2,745,49	2,938,70	2,859,38	2,916,72
09:00	3,269,15	3,345,56	3,549,25	3,461,73	3,536,92	3,106,70	3,708,49	3,179,49	2,595,16	2,731,41	2,938,03	3,010,51	2,910,68
10:00	3,262,99	3,335,86	3,542,23	3,362,47	3,527,35	3,147,23	3,672,19	2,977,89	2,579,51	2,908,40	2,927,75	2,947,29	2,895,32
11:00	3,243,44	3,339,73	3,506,38	3,261,82	3,520,16	3,268,95	3,664,61	2,951,91	2,584,27	2,864,96	2,924,94	2,917,06	2,807,24
12:00	3,304,02	3,308,83	3,482,33	3,273,76	3,505,22	3,134,73	3,481,18	2,913,40	2,636,81	2,691,60	2,922,90	3,016,56	2,695,52
13:00	3,315,94	3,274,79	3,469,31	3,298,54	3,416,82	3,174,90	3,269,89	2,863,31	2,569,63	2,690,47	2,854,21	3,095,78	2,585,17
14:00	3,314,44	3,304,48	3,513,21	3,314,09	3,327,75	3,212,44	3,262,38	2,834,70	2,580,59	2,687,40	2,765,39	3,090,50	2,550,76

Figure 31 Sample of Load data after uploading, grid view

The next Figure 32 presents the same table as a chart.

Figure 32 Sample day by row data after uploading chart view

After this, the software is able to give us a seasonal demand as shown in Figure 23 Daily load Profile, Coal and Gas Colombia, Figure 24 Seasonal Load Profile Coal and Gas, Figure 25 Yearly load profile Coal and Gas.

7.1. Scaled Data for Simulation

"HOMER uses scaled data for calculations. To create scaled data, HOMER multiplies each of the baseline data values by a common factor that results in an annual average value equal to the value that you specify in Scaled Annual Average" (Homer, n.d.)

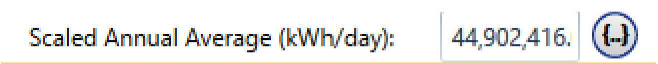


Figure 33 Scaled data for used for this project

"To determine the value of this factor, HOMER divides the scaled annual average by the baseline annual average. The scaled data retains the shape and statistical characteristics of the baseline data but may differ in magnitude. The default value for the scaled annual average is the baseline annual average. When the two values are equal, the scaled data and baseline are identical." (Homer, n.d.). It is important to appoint that the average load is reported in kWh/day but the peak load is reported in kW.

7.2. Components

"A component is a piece of equipment that is part of a power system. Components include a Controller, Generator, PV, WindTurbine, Storage, Converter, Custom, Boiler, Hydro, Refor mer, Electrolyzer, Hydrogen Tank, Hydrokinetic, Grid, and Thermal Load Controller. You can select as many components as you want to consider as part of the power system.

For the wind turbine, generator, PV, and storage components, the software allow adding more than one component, at doing this the software could require more time for calculations but adding more than one component makes it possible to compare different properties for the system. You can compare wind turbines with different power curves, generators with different fuels and efficiency curves, storage systems with different chemistry, and PVs with different orientations" (Homer, n.d.)

To add the different components that are in Table 6, we go to the tab components:

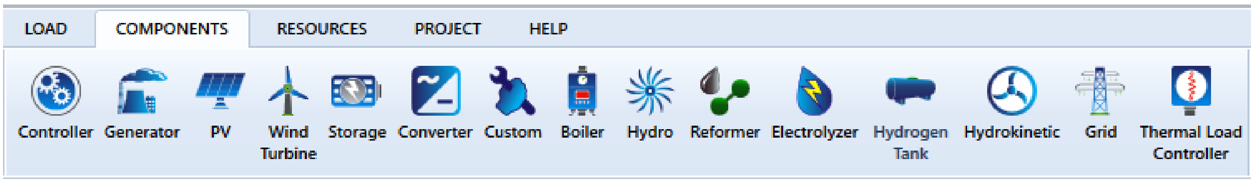


Figure 34 Components Tab Homer

Here we can size our project or allow the software to compare different quantities and sizes of the same component.

For our scenarios I allow the generator to be auto-size so in this way the software finds the optimal solution and after that I found one or more generators able to cover the required load, this size will be the smallest possible that will produce no capacity shortage in all sensitivity cases and future years for this case the required is 42.000.000 kW. it also adjusts the fuel to match the size. (Homer, n.d.)

PV, the wind turbine of 3 MW, and the converter where also optimize using HOMER Software.

7.3. Optimization settings

“The software HOMER uses the simulation time step to simulate the operation of each system configuration. It is possible to choose the value by selecting one of the values between one hour and one minute from the "Minutes per time step:" drop-down menu.” (Homer, n.d.)

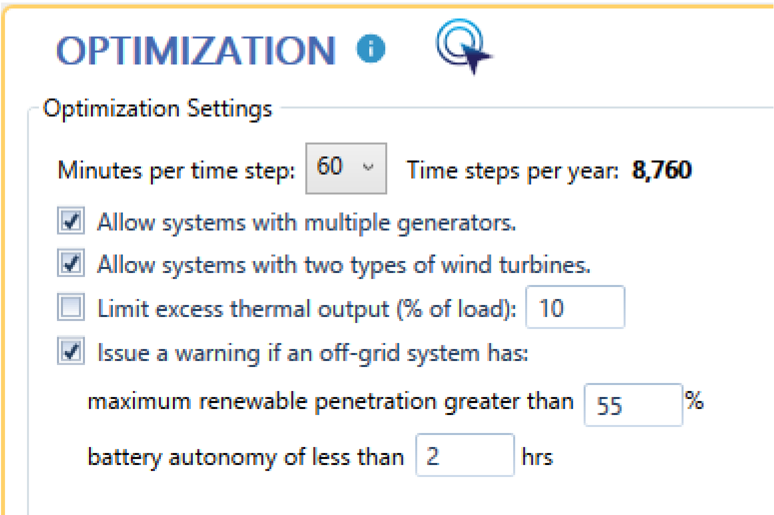


Figure 35 Optimization configuration

Table 8:
Variable and description optimization options.

Variable	Description
Allow systems with multiple generators	If checked, HOMER considers systems that contain more than one generator. It has no effect if you are considering only one generator.
Allow systems with generator capacity less than peak load	If checked, HOMER considers systems whose total generator capacity is less than the annual peak primary load.
Allow systems with two types of wind turbines	If checked, HOMER simulates system configurations that contain more than one type of wind turbine. If you add two types of wind turbines to the schematic and only want to choose between them, leave this check box unchecked. If you want HOMER to simulate systems that contain both types of turbines, check this check box.
Limit excess thermal output	If checked, HOMER prevents the system from producing more than the allowable amount of excess thermal energy.
Issue a warning if an off-grid system has ...	If checked, HOMER issues warnings in the results for systems that meet the criteria you specify here.

Source. (Homer, n.d.)

7.4. Economic Analysis

The main indicators for selecting the proper configuration system are the net present cost (NPC), the levelized cost of energy (COE) and the initial capital cost; the lowest of that cost will be selected at the end of the analysis for each of the locations already explained.
According to the paper of (Alireza Haghighat, 2016).
"Between NPC and COE is more reliable NPC since the value that is given to COE is random in some way while NPC comes from a mathematical concept. The capital initial capital cost (C_{cap}) of a component is the total installed cost of that of that component at the beginning of the project." (Alireza Haghighat, 2016)

For each component, the annualized capital cost is:

$$C_{acap} = C_{cap}\text{*CRF}$$

Equation 1 Annualized Capital Cost

Where CRF is the capital recovery factor that is given by

$$CRF = \frac{i(1+i)^N}{(1+i)^N - 1}$$

Equation 2 Capital Recovery Factor

“Where N and I are the system lifetime and the annual real interest rate.
In addition, the rescue value, a renewable fraction (RF) and operating cost have been reported and evaluated to give a view of the operation of optimal cases in the different areas.
The way to calculate net present cost is as follow:

$$NPC = \frac{TAC}{CRF}$$

Equation 3 Net Present Cost

Where TAC is the Total Annualized Cost (the sum for each component of all annualized cost)

$$TAC = C_{acap} + \sum_{i=1}^{n} C_{O\&M,j} + C_f + \sum_{i=1}^{n} C_{R,i}$$

Equation 4 Total Annualized Cost

Where n is the number of equipment in the full system, the operation annual cost of operation and maintenance ($C_{O\&M,j}$) for every component of the system, the total fuel annual cost is C_f and the replacement cost for each component $C_{R,i}$". (Alireza Haghighat, 2016)
The levelized cost of energy (COE) is determined as the useful electrical energy that is produced by system configuration is given in “kWh”.

The equation for calculating (COE) comes from dividing the annual cost of energy production (total annual cost minus cost of the given thermal load) by the full amount of electricity given for the system.

$$COE = \frac{C_{ann,tot}}{E_{prim,AC} + E_{prim,DC} + E_{def} + E_{grid,sales}}$$

Equation 5 Levelized Cost of Energy

Where $C_{ann,tot}$ is the annual cost of the system ($/year), and $E_{prim,AC}$, $E_{prim,DC,}E_{def}\, and E_{grid,sales}$ are the total AC, DC deferable and the grid sales of the load energy served all are in (KWh/year). The remaining value of the component or salvage value at the end of the lifetime project is assumed as a linear depression, or in other words, means that is directly proportional to the remaining life of the project. It is even based mainly on the cost of replacement rather than the initial cost. And it can be given as follows:

$$S = C_{rep}\frac{R_{rem}}{R_{comp}}$$

Equation 6 Salvage Cost

Where $\boldsymbol{C_{rep}}$ is the cost of replacement and $\boldsymbol{R_{rem}\ and\ R_{comp}}$are the remaining cost of the component ($) and lifetime (Years).

The total operating cost (TOC) is the sum of annual operation cost and maintenance cost (O&M) plus the total fuel cost ($\boldsymbol{C_f}$) plus the annual replacement cost of each component ($\boldsymbol{C_{R,i}}$) minus the annualized salvage cost of each component ($\boldsymbol{C_{s,j}}$).

$$\boldsymbol{TOC = \sum_{i=1}^{n} C_{OM,j} + C_f + \sum_{i=1}^{n} C_{R,i} - \sum_{i=1}^{n} C_{S,i}}$$

Equation 7 Total Operating Cost

Where n is the number of devices in the system. (Alireza Haghighat, 2016)

When the best configuration is found for each case the selected one is the one with the minimum NPC. In order to know if it is feasible or not this is compared with the average cost per kilowatt produced in by thermal technologies vs the renewables that it has been already calculated.

We can find as well the fraction of energy delivered to the load that is originated from renewable power sources, this fraction is calculated with:

$$f_{ren} = 1 - \frac{E_{nonren} + H_{nonren}}{E_{served} + H_{served}}$$

Equation 8 Fraction of Energy delivered

Where : E_{nonren} = nonrenewable electrical production, H_{nonren} = nonrenewable thermal production, E_{served}= total electrical load served, H_{served} = total thermal load served. (Homer, n.d.)

7.5. Possible System Configurations

The different off-grid configuration that is analyzed by Homer Software according to the equipment selected for this study number from S1 to S7.

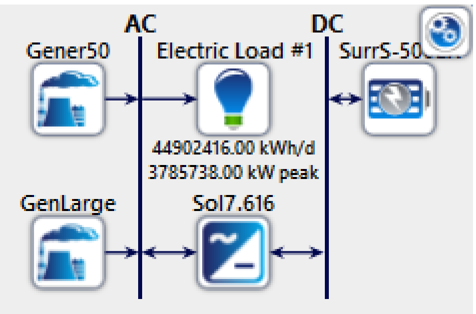


Figure 36 (S1) Solar system (off-grid configuration)

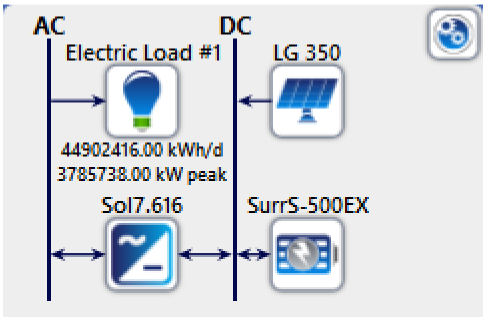


Figure 37 (S2) Diesel System (off-grid configuration)

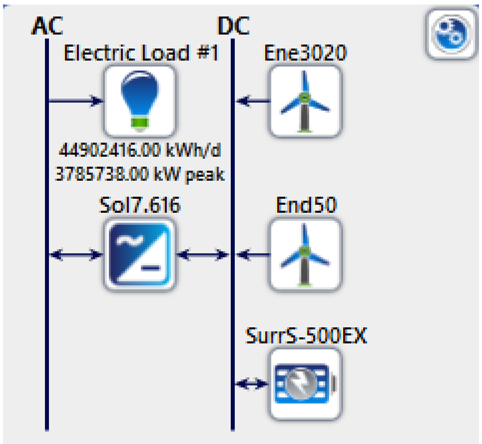


Figure 38 (S3) Wind System (off-grid configuration)

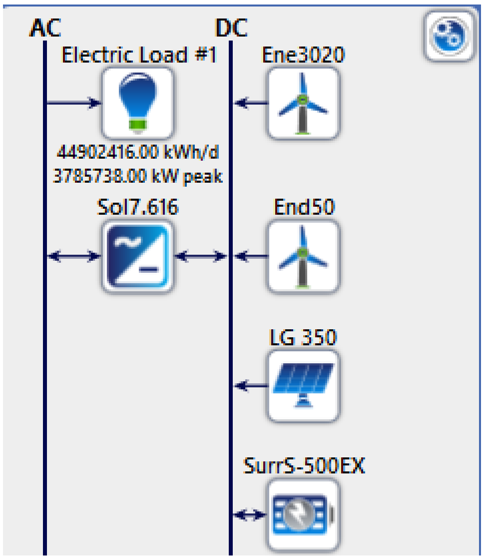


Figure 39 (S4) Wind Solar Hybrid System (off-grid configuration)

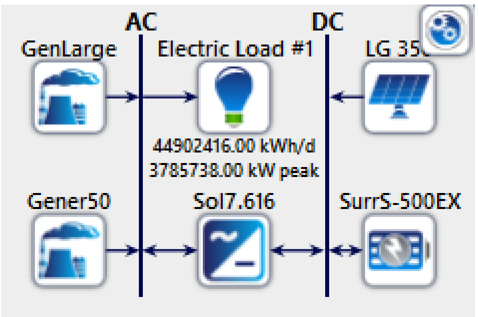


Figure 40 (S5) Diesel Solar Hybrid system (off-grid configuration)

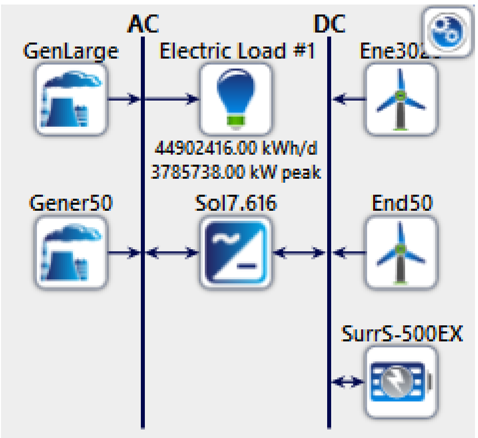


Figure 41 (S6) Diesel Wind Hybrid System (off-grid configuration)

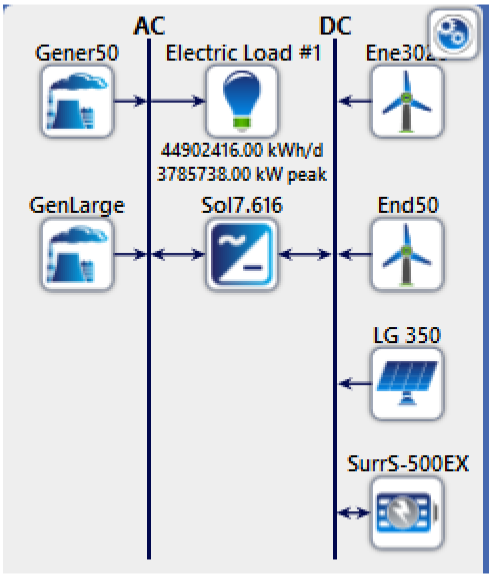


Figure 42 (S7) Solar Wind-Diesel Hybrid System (off-grid configuration)

8. Results

The best design obtained by the simulations with the different configurations Figure 36 to Figure 42 at each location are shown in the following Tables:

Table 9:
Cost winner and system configuration for each region

Winner	***Configuration***	***NPC ($)***	***COE ($)***	***Operating Cost ($/yr.)***	***Initial Capital***
Guajira	S7	1.17E+11	0.3626868	4.17E+09	3.47E+10
Candelaria	S5	2.14E+11	0.6659418	8.40E+0.9	4.94E+10
Tatacoa	S5	2.35+11	0.7315268	9.18E+09	5.52E+10

Table 10 shows the percent of energy delivered by renewable energy and the total annual volume of fuel consumed by the system.

Table 10:
Renewable Fraction in the system

Winner	*Configuration*	*Renewables Fraction (%)*	*Total Fuel (L/yr.)*
Guajira	S7	79.75519	9.95E+08
Candelaria	S5	38.88116	3.01E+09
Tatacoa	S5	31.12919	3.39E+09

Table 11 shows the size of the system in KW for the PV, Large Generator (GenLarge), and inverters, and the number of wind turbines and batteries.

Table 11:
Size system configuration

Winner	***LG 350 (kW)***	***End50***	***Ene3020***	***GenLarge (kW)***	***Gener50 (kW)***	***SurrS-500EX***	***Sol7.616 (kW)***
Guajira	5725790.07	10	3703	4.20E+07	350	13590487	4240607.627
Candelaria	17766294.14			4.20E+07	50	25850175	4193449.833
Tatacoa	20629046.02			4.20E+07	100	26193252	4038593.975

The result that we see on the above tables are the best over the whole simulations and the ones with the lowest net present cost.

8.1. Optimal design la Guajira

The optimal design for la Guajira desert is a Figure 42 (S7) Solar Wind-Diesel Hybrid System (off-grid configuration) with the lowest NPC overall configurations. The optimal size system as shown in Table 11 for this case is 16.360 PV panels from 350 W each, 10 wind turbines of 50 kW Endurance wind E-3120, 3703 wind turbines of 3 MW Enercon E82, 7 generators of 50 kW, 16,800 Generators of 2.5 MW, the number of batteries SurrS-500EX are 13,590,487 with 6V and a capacity of 820AH, the number of inverters is 557. This configuration as shown in Table 11 and Table 9 has an initial capital cost of 34.7 billion ($34,741,070,000), and an operating cost of $4.17 billion each year (4,172,360,000 $/year), a total net present cost $117 billion ($ 116,625,100,000) and a total cost of energy of $ 0.363 kWh ($ 0.3625868), this system has a renewable fraction of energy originated from renewable power sources of 79.8% as seen in Table 10

8.2. Optimal design Candelaria

The optimal design for la Candelaria desert is a Figure 40 (S5) Diesel Solar Hybrid system (off-grid configuration). The optimal size system as shown in Table 11 for this case is 50,761 PV panels from 350 W each, 1 generator of 50 kW, 16,800 Generators of 2.5 MW, the number of batteries SurrS-500EX are 25,850,175 with 6V and a capacity of 820AH, the number of inverters is 551. This configuration as shown in Table 11 and Table 9 has an initial capital cost of 49.4 billion ($49,373,110,000), and an operating cost of $8.40 billion each year (8,398,592,000 $/year), a total net present cost $214 billion ($ 214,198,400,000) and a total cost of energy of $ 0.666 kWh ($ 0.6659418), this system has a renewable fraction of energy originated from renewable power sources of 38.9% as seen in Table 10.

8.3. Optimal design Tatacoa

The optimal design for the Tatacoa desert is a Figure 40 (S5) Diesel Solar Hybrid system (off-grid configuration). The optimal size system as shown in Table 11 for this case is 58,941 PV panels from 350 W each, 2 generators of 50 kW, 16,800 Generators of 2.5 MW, the number of batteries SurrS-500EX are 26,193,252 with 6V and a capacity of 820AH, the number of inverters is 531. This configuration as shown in Table 11 and Table 9 has an initial capital cost of 55.2 billion ($55,211,530,000), and an operating cost of $9.18 billion each year (9,175,996,000 $/year), a total net present cost $235 billion ($ 235,293,700,000) and a total cost of energy of $ 0.732 KWh ($ 0.7315268), this system has a renewable fraction of energy originated from renewable power sources of 31.1% as seen in Table 10.

9. Conclusions

Analyzing the results, I can draw a conclusion that for this analysis the best place to develop a project like this would be la Guajira over the other two locations Candelaria and Tatacoa. Table 11 reflects the average cost per kWh (COE) of $ 0.363 $0.666 and $0.732 respectively. Comparing these results with the prices of Table 5, where the average prices are offered for coal and gas, and selecting the highest price for coal in Nov 2017 of $ 0.058 and the highest for gas in Dec 2017 with an offer price of $ 0.15, we can conclude that replacement of those energies will not be economically feasible as prices are higher in the results of this project in any of the above-mentioned desserts.

Practically speaking, the technologies of this study can provide energy for communities in Colombia where the grid is too far, and the cost to extend is too high. A better option, in this case, is to install a hybrid, solar or wind system which constantly takes care of the community consumption in order to calculate an optimal configuration.

The systems of this project were optimized and tailored apart for Guajira, Tatacoa, and Candelaria location. To meet efficiently the technical specifications with the equipment I selected the natural conditions of the desserts. For this reason, the research helped to provide reliable key information for the design of a similar system.

It is essential to have in mind that even if the entirely renewable and hybrid configurations are apparently the most preferred designs from the environmental point of view, in this project we are considering just cost, and for this reason, the result is not feasible.
Maybe if we consider health issues and if the Colombian government support the installation of renewables with legislation in favor of those technologies as a reduction of taxes and exemptions and tax the use of thermal technologies, the possibility of a project like this could be analyzed (reevaluated) again.
Limitations in this study I can address that does not consider some variables that could affect for better or worse the results, for example, environmental problems and political decisions.
Another problem I found while writing this master thesis was the difficulty to obtain information from companies that produce equipment as they don't provide prices for industrial designs, the answer they gave me is that they just provide this information business to business, at the end some of the equipment used for calculations where equipment that is possible to find in some specialized pages for renewable home energy installation.

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