ENERGY SECURITY AND RESILIENCY FOR THE TEXAS NATIONAL GUARD

A Thesis

by

SAJJAD HAIDER

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	John Walewski
Committee Members,	Robert Balog
	Ivan Damjanovic
Interdisciplinary Faculty Chair,	Estratos Pistokopolous

August 2018

Major Subject: Energy

ABSTRACT

The Texas Military Department (TMD) faces energy security issues due to the dependency of electricity from the grid that can be disrupted in case of a natural disaster like Hurricane Harvey hitting Texas. This motivates us to generate electricity at the location using locally available renewable sources, reducing TMDs dependency on the grid and giving a sense of energy security. The fall in the price of renewable energy over the last few years makes them a suitable candidate for harnessing greener energy and establishing an independent micro grid. Most of these renewable energy sources are intermittent in nature which takes our focus on storage options, along with greater reliance on more reliable energy sources such as biomass and natural gas.

This study targets the electricity consumption of Camp Swift on an annual basis. From the optimization results we can learn that we can produce over 40% of the energy through renewable sources which is which is higher than the state average of 18%. This results in a total cost of about 2.7 million USD out of which about 62000 USD is kept for running costs while 2.33 million USD is the expected cost of setting up this grid. By using Biomass and Natural Gas, in conjunction with Solar and a Diesel Generator, the system is able to produce 5.5 million kWh of electricity against annual demand of less than 2 million kWh which can be used to sell electricity back to the grid in the event of a grid failure or via net metering enabled smart meters.

ACKNOWLEDGMENTS

First of all, I would like to thank the Lord Almighty, without whom I would never have made it this far in life. I would like to use this opportunity to thank my grandparents, without whose constant support I would be lost in life, and my parents, for putting up with me being absent for days at an end while working on this program and this thesis. I would also like to thank my sister for being my sister and an entertaining character in my life.

A big round of thanks is due to my professors, Dr. John Walewski, Dr. Ivan Damjanovic and Dr. Robert Balog for their constant support and guidance and for being an excellent panel of intellectuals who have given me the space to be intellectually creative in my efforts here while providing me with robust feedback throughout the process.

I would also like to thank the Fulbright foundation, Fulbright Pakistan, the United States Educational Foundation in Pakistan, the US Department of State, the Institute of International Education and Ms. Courtney Castillo for funding and aiding me throughout the course of this thesis. I would also like to thank the College of Engineering and the Texas A&M Energy Institute for allowing me to work here and Dr. Valentini Pappa, for putting up with my late submissions and pushing me through this program.

To Rida, Basim, Ali and Hameed: thank you for letting me stay in your lives while I annoyingly navigated through this thesis period, and to my country: I am what I am as a result of the resilience of my people. No amount of gratitude to the land and the people of Pakistan will ever be enough.

CONTRIBUTORS AND FUNDING SOURCES

Key contributors to this work in terms of guidance and support include the three members of the thesis committee for this project: Dr. John Walewski and Dr. Ivan Damjanovic from the Department of Civil Engineering, and Dr. Robert Balog from the Department of Electrical Engineering and Texas A&M Qatar. The actual work has been compiled and published by Sajjad Haider.

This thesis is made possible by support from the US Department of State, the Fulbright Foundation, the US Education Foundation in Pakistan, the Institute of International Education (IIE) and the entire Fulbright 2017 Cohort for funding this program and this thesis through the Fulbright Master's Program. The contents of this thesis are solely the responsibility of the author and do not necessarily represent the views of any of the above-mentioned organizations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table Page

LIST OF EQUATIONS

CHAPTER I

INTRODUCTION

Background

Texas Military Department

The Texas Military Department is the home office of the Texas Military Forces, which are the three branches of military of the state of Texas. These include the Air National Guard, the State Guard and the Army National Guard. All of these are based physically in the state of Texas and fall under the command of the Governor of Texas. The number of personnel under the TMD account for about a few thousand, most of which are inactive.

When activated by the governor, the TMD is responsible for protection and assistance in times of crisis. Troops based in Texas reside in three major bases, the largest of which is currently Camp Swift, near Austin, Texas. The camp has a population of roughly 6500 people, and currently relies on the neighboring city of Austin to meet their sustainability needs.

The location of Camp Swift played an important role in providing support in terms of logistics and active rescue efforts during and after the advent of Hurricane Harvey in 2017.

Problem Identification

With the advent of renewable energy technologies like solar and wind, and especially since renewable energy prices have plummeted in the last few years, more and more green energy initiatives are coming online on the grid. These renewable options along with geothermal energy are usually unstable and heavily reliant on other factors such as the weather and therefore very volatile. The existing transmission system isn’t designed for this sort of volatility in electricity production. Additionally, natural disasters like Hurricane Harvey hitting Texas, are able to knock out the power to installations, especially military bases that usually lie on the edge of transmission lines driven out of the feeders.

For this purpose, it is important to look at methods of improving the energy resiliency of the TMD, which is what the main purpose of this study. In major environmental catastrophes like Hurricane Harvey in 2017, supply to the electric grid was cut off leading to the closest national guard base (Camp Swift) being activated while large sections of Texas were devoid of electricity for several hours.

The United States EIA estimates that during Hurricane Harvey, as many as 10,000 MW’s of electricity were knocked off the Texas grid, which is over a quarter of the actual demand of the state. This also does not include transmission lines knocked down as a result of the approaching weather and is a number that reflects only generation facilities knocked out as a result of wind and rain. Six 345kV high voltage lines as well has hundreds of smaller lines faced outages, resulting in the state’s electricity demand falling rapidly as well since people were out of power.

The graph below shows the impact of Hurricane Harvey on the average demand seen by ERCOT and shows the significant downward trend in the coastal region of the state.

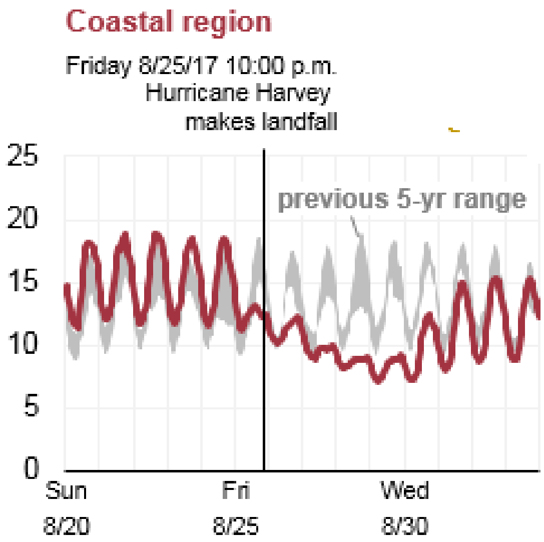


Figure 1: Annual Electricity Demand in Texas – Coastal Region. Reprinted from [1]

As can be seen in the graph above, the Household electricity demand faced record low numbers against predicted values based on data for the last several years. This graph represents the coastal region of ERCOT, shown in purple in the following chart of ERCOT territories

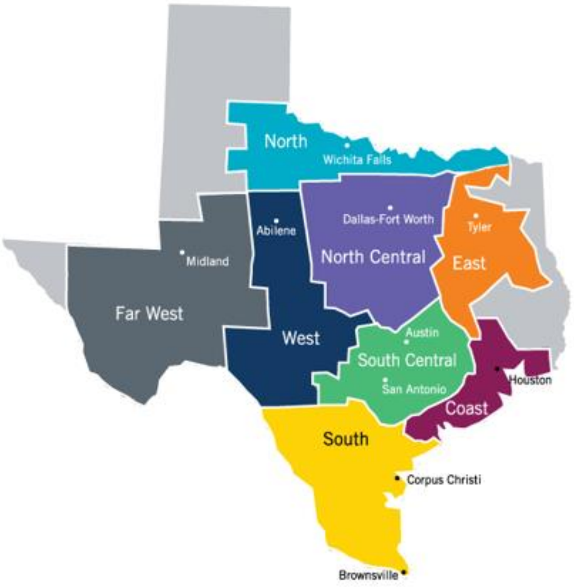


Figure 2: Texas Regions Map. Reprinted from [1]

In other parts of the state, such as the southern region highlighted in yellow, a similar trend occurred in terms of the drop in household electricity demand because of Hurricane Harvey. The graph below shows the predicted trend against actual demand immediately following hurricane Harvey.

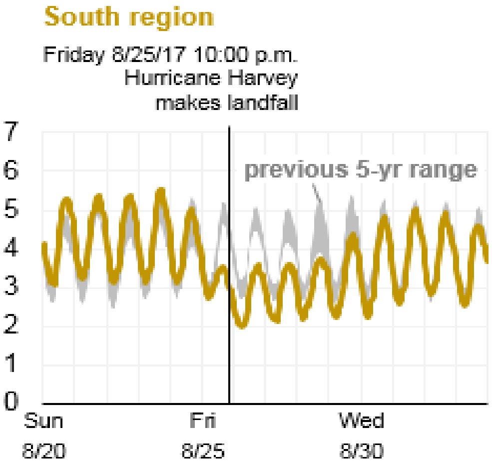


Figure 3: Annual Electricity Demand in Texas – Southern Region. Reprinted from [1].

The hurricane not only flooded combustion generation sources throughout the state, sustained wind speeds of over 130 MPH also meant that thousands of MW of electricity generated by wind turbines had to be turned off in order to ensure safety of the turbine itself. [1]

Researchers at the University of Michigan estimated that in total, about a million users were out of electricity as a result of the hurricane as highlighted in their predicted model shown below:

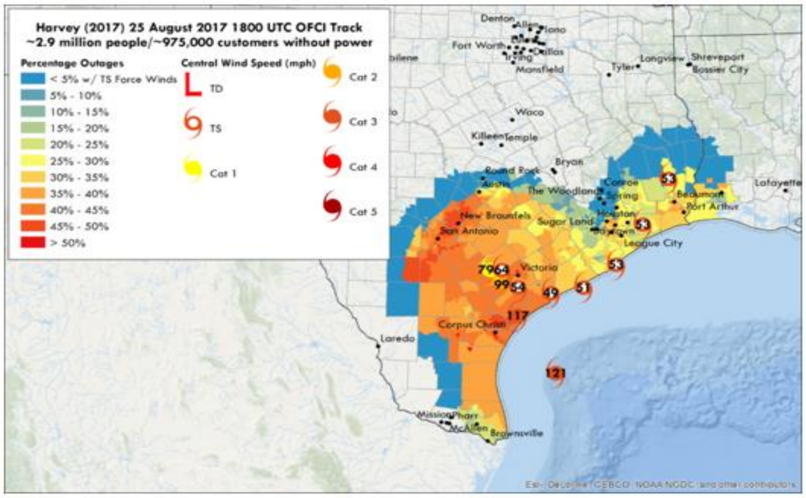


Figure 4: Hurricane Harvey Impact Map. Reprinted from [2].

In the past, similar hurricanes in other States have done more devastation and are worth studying as well. Hurricane Sandy knocked out power to 8.1 million residents over several states.

The chart below shows utility scale power outages attributed to hurricane Sandy where an entire section of customers were without electricity as a result of the utility being knocked out by the hurricane.

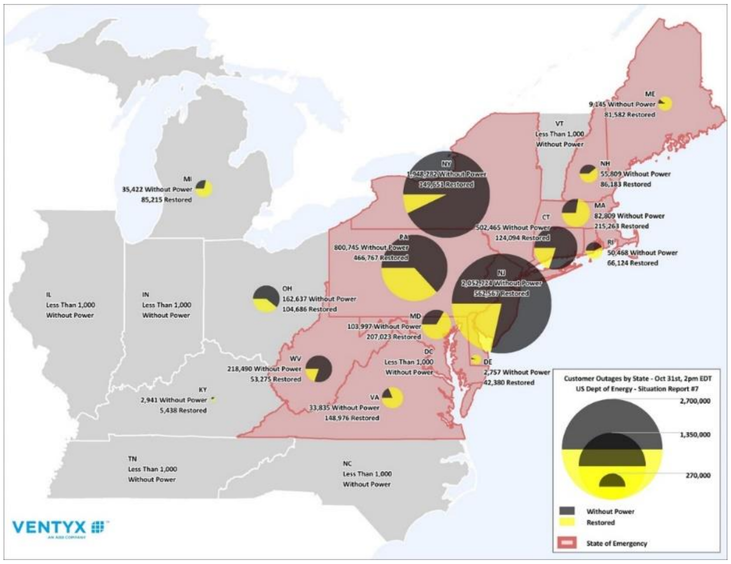


Figure 5: Hurricane Sandy Impact Map. Reprinted from [3].

Such instances were also seen in the recent Hurricane Irma that hit the coasts of Florida with the Florida Disaster organization reporting about 36% of the residents of Florida being without electricity as a result. The graph below shows the affected areas with the orange circles highlighting significant populations:

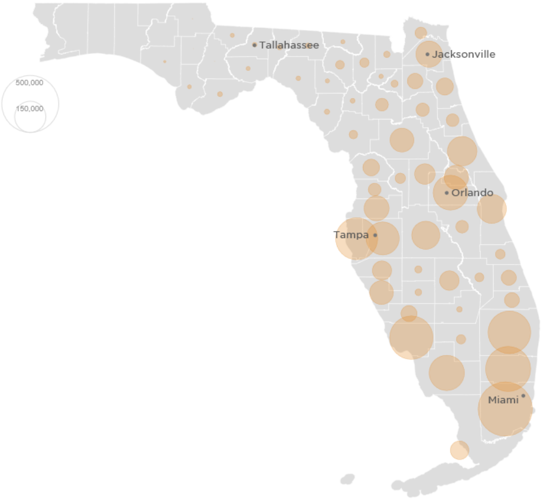


Figure 6: Hurricane Irma Impact Map. Reprinted from [4].

Similarly, Hurricane Mathew in 2016 knocked out double digit percentage of electricity consumers across different states as can be seen in the graph below:

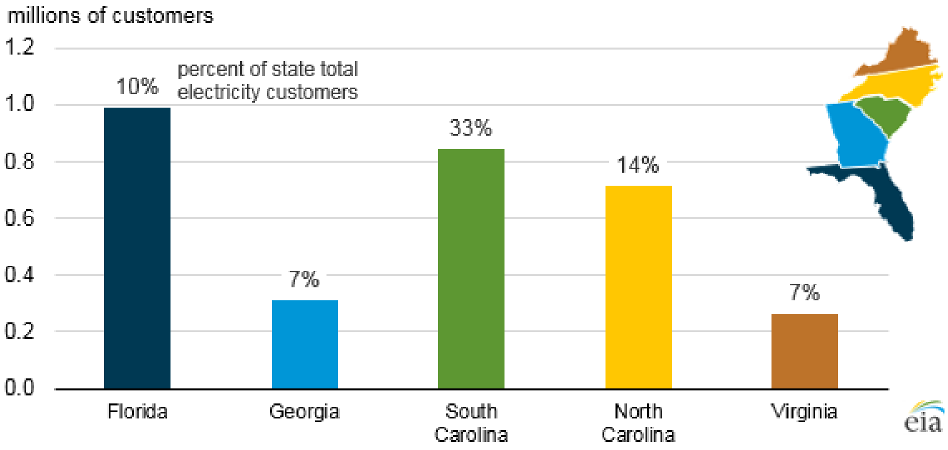


Figure 7: Estimated Outages due to Hurricane Matthew. Reprinted from [5].

Additionally, under existing legal standards, nuclear power plants that supply the grid must shut all operations ahead of an approaching hurricane and can take upwards of 3 days in order to come back online upon the passing of the hurricane in order to ensure safety. Hurricane Mathew also knocked out these nuclear plants and the graph below shows the same. The Harris Nuclear Plant in North Carolina faced closure due to concerns over safety, owing to a steeper drop in the black graph below showing a drop in production in October 2016:

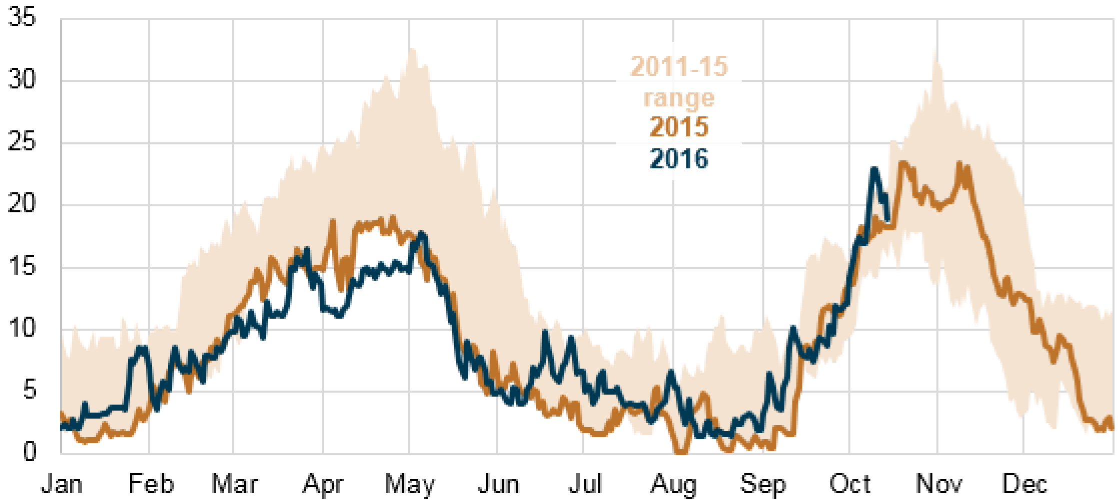


Figure 8: Nuclear Outages. Reprinted from [5].

Furthermore, a study on the biggest power outages in US history until 2017 shows that the top 10 largest, with between 483 and 1248 million consumers without electricity came from hurricanes and storms such as Sandy and Harvey. Such evidence suggests positive correlation between the possibility of being without electricity following a major storm and the need for a more resilient energy grid, especially in campus type installations like Camp Swift and on a larger scale, Puerto Rico and Hawaii. The bar chart below shows some of these statistics:

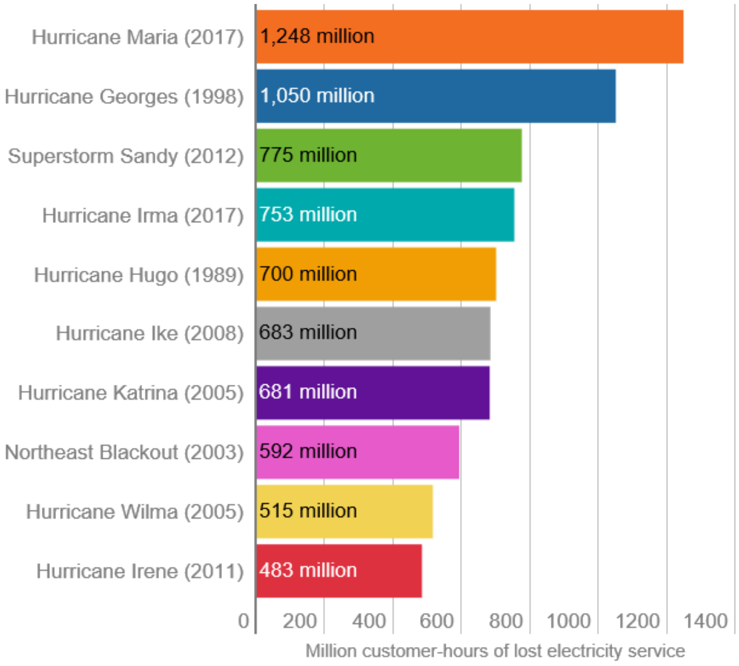


Figure 9: Lost Customer Hours. Reprinted from [6].

It is therefore of paramount importance to look at a mechanism to make grid resilience a part of the supply equation for electricity supply and demand to consumers.

CHAPTER II

SYSTEM IDENTIFICATION

The Texas Army National Guard operates 77 facilities in the state. Some of these facilities are training areas whereas others serve various other purposes. Of these 77 only 60 purchases energy from a utility whereas the other 17 are in rented buildings with existing contracts. Of these 60, an independent study found seven bases used upwards of a million Kilowatt-hours (kWh) of electricity annually. Camp Mabry at Austin used the most at 12 million kWh. An additional 6 facilities used between 0.5 and 1 million kWh. It is important to look at the basic characteristics of electricity and what loads are in order to be able to define the system load. [7]

Currently, the base in question, Camp Swift, operates as a consumer, buying electricity off the ERCOT grid. The first stage of the process of movement away from reliance on the grid is to gauge the specifics of the amount of electricity that area needs to operate at optimal performance. This involves making an estimate of the total load of the base, along with the estimated area of coverage. The final step involved design of a suitable generation capacity at reasonably spaced out areas in order to meet this load.

Load Characterization

Loads can be defined as devices that are connected to and consume electrical power. Electrical power here is referred to as electricity which is governed by three fundamental entities: current, voltage and impedance/conductance. For any electrical system, these need to be taken into account in the planning stage:

For the purposes of this study, we are looking at American standards of electricity transmission, which require electricity to be delivered at 110v, with a frequency of 60Hz. This electricity is derived from the US electric grid by way of transmission lines. The Army's existing method of estimating prime power requirements is unsatisfactory. It is based largely on a single Joint Chiefs of Staff (JCS) electrical planning factor of 0.7 kW per person. Hospital facilities use a factor of 1.6 kW per bed. One shortcoming of the JCS factors is that they ignore other important determinants of power demand: connected load, environmental conditions, and operating profiles. In addition, even when we must ignore the other determinants due to lack of data, for instance - better statistical estimators exist than a simple average of kW per person per installation. While the JCS population factor derives from OCONUS wartime experience, it is based on a severely limited sample, involves questionable adjustments, and is an average value with wide dispersion. [4]

In order to allow for a reasonable estimate of the electricity demand for Camp Swift, multiple non-invasive approaches were followed to their end and the most reasonable one was selected. At any given point, installation of smart meters and data loggers at the site was not an available option, and the electricity consumption of the base had to be estimated using the processes defined below.

Process Restrictions

When coming up with a method to gauge the electricity requirements of Camp Swift, multiple approaches were looked at. The following criteria was set to ensure minimum cost of analysis and to reduce invasiveness of the procedure.

1. The process should be reproducible in other similar areas
2. The process results should be in line with estimates from similar areas across the country
3. The estimation process should be non-invasive
4. The process should allow for flexibility in design and at the formulation stage
5. Estimates should be in line with usage trends in recent years.
6. Installation of hardware is to be avoided due to high complexity and cost, along with the need to secure permission and installation expertise from relevant people

Process 1: Estimation per soldier

The first method that was researched for estimating the electricity demand of Camp Swift was to calculate the overall energy usage of the army and to break it down to its building blocks: individual soldiers. For this purpose, the total energy consumption of the United States army was studied. The annual energy consumption of the Department of Defense is equivalent to roughly 12.6 million gallons of fuel per day. Out of this, it is estimated that the United States Army consumes about approximately 35% of the total energy consumed according to the 2016 DoD Energy Management and Resilience Report, as shown in the following chart:

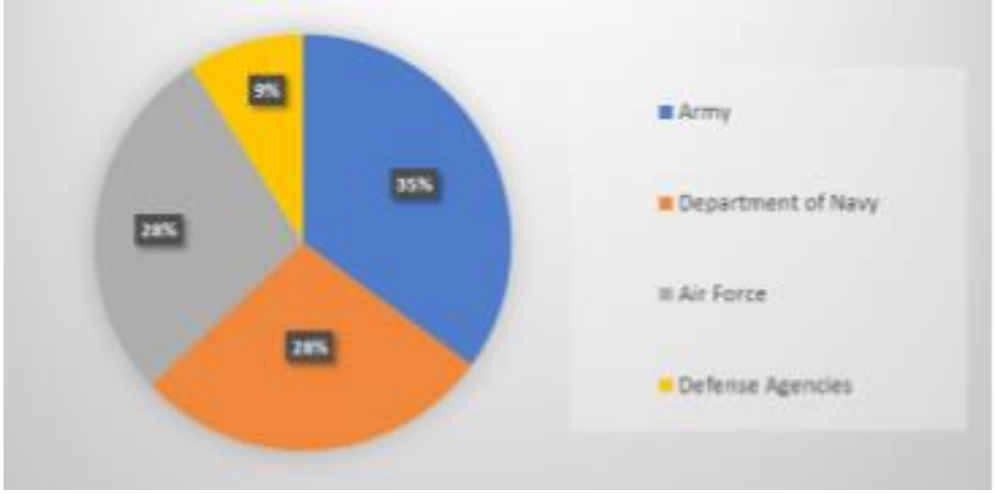


Figure 10: DoD Consumption of Energy. Reprinted from [8].

Based on the above percentage, and the estimates of electricity consumed by the military specified in the Department of Defense Energy Strategy Manual, an estimate can be made regarding the energy consumption of the Army branch of the US military. The chart below shows statistics from 2006 that specify that of the total amount of energy consumed, about 16% is spent on electricity supply to military installations:

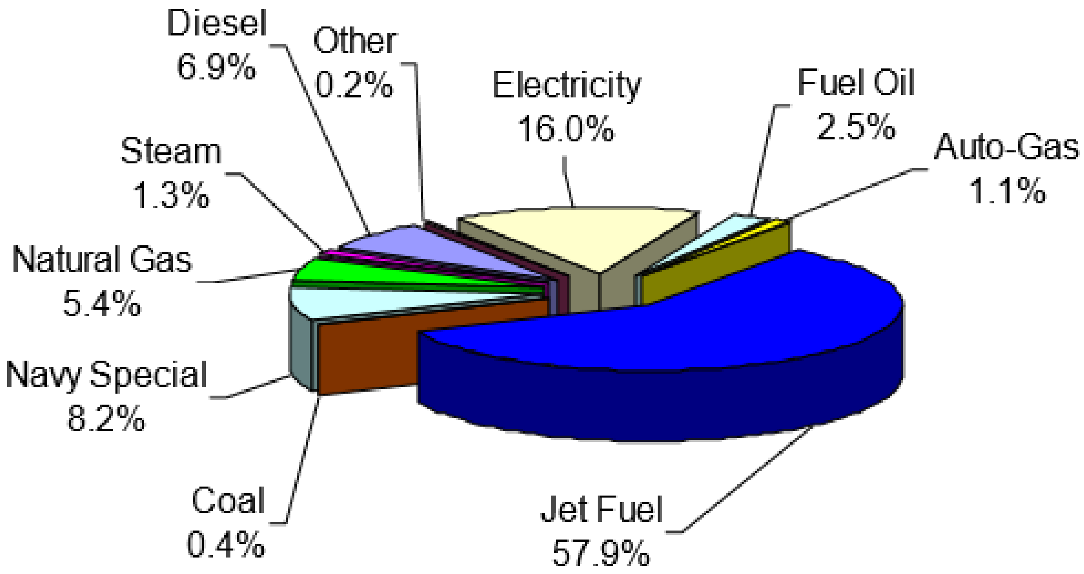


Figure 11: DoD Consumption as a Percentage of Cost. Reprinted from [9].

Using this 16% rating specified above, it can be concluded that the energy consumption of the United States Army is subject to the following standards:

DoD Defense Energy Consumption /US$	Army Percentage	Electricity Percentage	Estimated Total Consumption /US$
18.2 Billion [9]	35%	16%	1.019 Billion

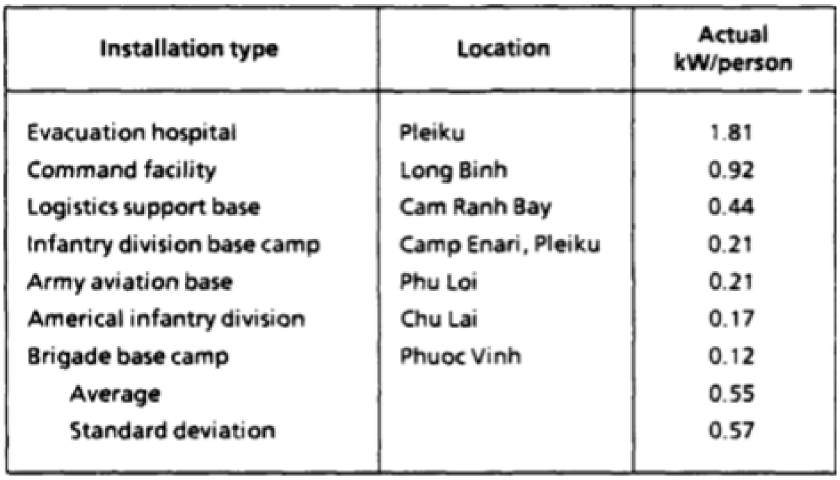
Table 1: DoD Energy Consumption

Based on the above stated expense, 1.019 Billion USD, the total amount of electricity consumed can be calculated looking at market rates. The average cost of a unit of electricity if bought from commercial grids is roughly 12 cents per Kilowatt-Hour [10]. Based on this reading, the total amount of electricity consumed by the Army can be calculated as roughly 8493 Giga-Wh. This number is impossibly large owing to the discrepancies in calculation as consumption is based on total cost paid for both installations in the United States along with overseas and front line establishments that may have to pay more for electricity.

Based on this number, the total energy consumption per soldier can be calculated using the size of the army as a whole. The number of active duty members of the army stands at close to 490,000 since the withdrawal from Iraq [11]. For an army of this size, the total consumption per unit soldier averages out at approximately 17 Mega-Wh. This is another large number that is not reflective of the nature of the soldier’s work and is averaged out over the entire organization.

Such conclusions are inaccurate and difficult to corroborate primarily because of the size of the United States army and the diversity in job descriptions between the soldiers and available equipment. A study from 1989 on the energy consumption in the Vietnam War also discredits this kind of thinking as a result of being an over-generalization. It is argues that instead of using averages to find load based on total population, connected load is a better estimator of the amount of electricity needed. This will account for generation that will cover peak loads as well as averages. It is argued that connected load statistics shown during the Vietnam war concluded that amongst the installations studied, peak load accounted for about 50.6% of the connected load with a standard deviation of only 5%. Furthermore, the differences in the nature of the job description and difference in available equipment caused major variations between the energy consumption with the ratio of peak to connected load ranging from a low of 42 percent at an infantry division camp to a high of 60 percent at an Army aviation base.[4]

Data on domestic peacetime power use at all TRADOC and FORSCOM installations in FY 1987 also show that average power use per person varies widely among installations. The table below is a snapshot of the differences in electricity utilized per person based on the job description and location assigned to the person:



Installation type	Location	Actual kW/person
Evacuation hospital	Pleiku	1.81
Command facility	Long Binh	0.92
Logistics support base	Cam Ranh Bay	0.44
Infantry division base camp	Camp Enari, Pleiku	0.21
Army aviation base	Phu Loi	0.21
Americal infantry division	Chu Lai	0.17
Brigade base camp	Phuoc Vinh	0.12
Average		0.55
Standard deviation		0.57

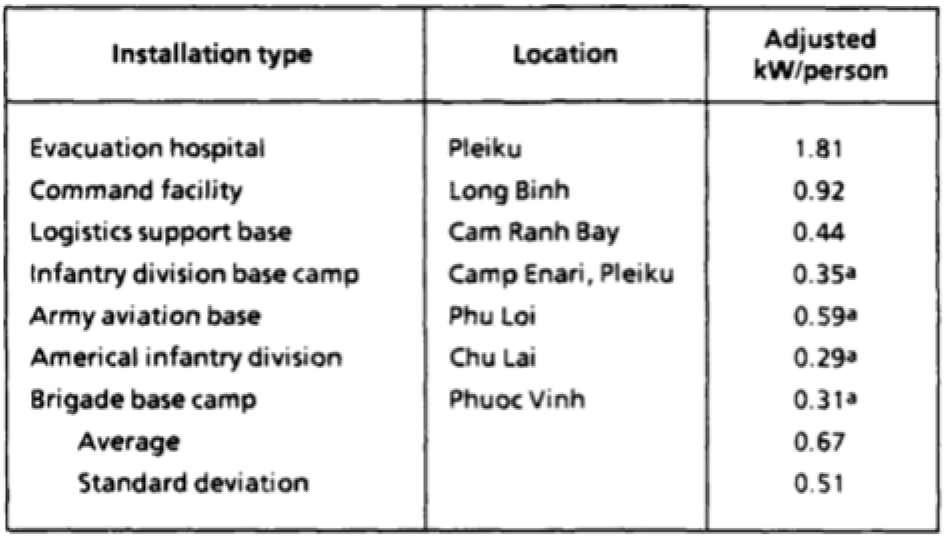
Table 2: Energy Consumption per Unit. Reprinted from [12].

While these values are from 1989 and not reflective of modern day values, the trend in the differences between such diverse consumption facilities exists to this day. The study concluded that when population and power usage are the only data available, the statistical technique of linear regression yields a better estimator than a simple average. The technique calculates a fixed factor and a variable factor; it also provides measures to evaluate the reliability of the estimate. Applying linear regression to our domestic installation data, we find that a typical FORSCOM or TRADOC installation uses a fixed amount of about 1.9 megawatts (MW) plus a variable amount of 0.45 kW per person. That relationship explains about 62 percent of the variation in power usage. [12]

Lastly, with regards to Camp Swift, the nature of this particular military base is another hurdle in this methodology. Camp Swift is primarily a training base and the number of occupants varies seasonally with the number being higher during the training days along with when the National Guard has been activated. For this purpose, per person calculations can be inaccurate due to the vast disparity between the numbers of occupants.

Process 2: Estimation per unit area

The second method of calculating the energy consumption relied on estimating the total covered area that needs to be empowered at the site. This method was formulated based on studies by Keller and Gannon on the military bases in Vietnam and is reflected in the updated chart shown below:



Installation type	Location	Adjusted kW/person
Evacuation hospital	Pleiku	1.81
Command facility	Long Binh	0.92
Logistics support base	Cam Ranh Bay	0.44
Infantry division base camp	Camp Enari, Pleiku	0.35[a]
Army aviation base	Phu Loi	0.59[a]
Americal infantry division	Chu Lai	0.29[a]
Brigade base camp	Phuoc Vinh	0.31[a]
Average		0.67
Standard deviation		0.51

Table 3: Connected Load Energy Consumption. Reprinted from [12].

The adjusted kW/person rating is reflective of consultations with military engineers and takes into account existing standards at that time equal to 1.2vA per square foot for residential lighting and 3.5vA per square foot for base lighting, in addition to other increases for lighting outdoors and special equipment. These numbers are primarily outdated now, with the advent of more advance electrical loads with greater efficiency. For this purpose, the standards used for this study are the commercially applicable ASHRAE 2016 and the amount of energy averaged out was a result of the U.S Energy Information Administration's analysis on average energy consumption throughout the country.

While the numbers vary by geographical location and nature of the building, this researcher has used the energy consumption per square foot readings based on average consumption for buildings of different sizes and shown in the following chart:

	All buildings using electricity		Electricity consumption		
	Number of buildings (thousand)	**Total floorspace (million square feet)**	**Total (billion kWh)**	**per building (thousand kWh)**	**per square foot (kWh)**
All buildings	5,234	84,869	1,243	237	14.6
Building floorspace (square feet)					
1,001 to 5,000	2,556	7,492	130	51	17.4
5,001 to 10,000	1,171	8,489	113	97	13.3
10,001 to 25,000	852	13,565	159	187	11.7
25,001 to 50,000	326	11,672	149	457	12.8
50,001 to 100,000	195	13,604	192	985	14.1
100,001 to 200,000	90	12,362	190	2,115	15.3
200,001 to 500,000	37	10,652	180	4,808	16.9
Over 500,000	8	7,033	130	16,362	18.4

Table 4: Building Energy Usage. Reprinted from [13].

The EIA estimates that these averages are reflective of different requirements for heating and energy use based on size.

The actual nature of the electricity consumption is dependent on energy utilized by the following major functions:

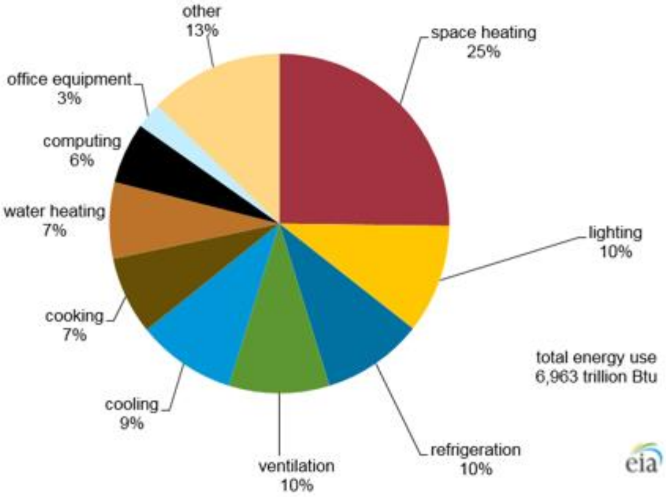


Figure 12: Electricity Consumption Breakdown. Reprinted from [13].

For the purpose of this study however, it was concluded that in order to avoid installation of individual meters and measurement of consumption based on type of usage, the overall average value would be a better fit as it takes into account all of the above. As expected however, lighting and heating accounts for most of the electrical load, which is similar to what was discussed in the previous studies. The area in question for this study is called Camp Swift, and is located in Bastrop County, Texas. It is located in the outskirts of Austin, in Central Texas. The location of the base is highlighted below:

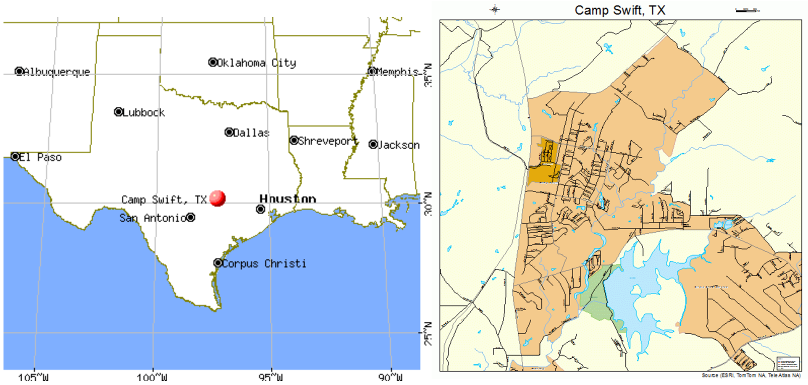


Figure 13: Camp Swift Location. Reprinted from [14].

For this study, the following areas within Camp Swift were placed under consideration:

1. US Army National Guard Office Buildings
2. Texas State National Guard Office Buildings
3. Army National Guard Housing and Maintenance Buildings
4. State National Guard Maintenance Buildings
5. Miscellaneous buildings near above stated buildings

The buildings are shown in the following satellite image:

Figure 14: Camp Swift Building Map

In order to estimate covered area of each of these buildings, a commercial size estimator tool was utilized to draw the edges of the building on a scaled satellite stream. The tool allows for analysis of terrain data as well with a reasonable accuracy and is acceptable as a drafting solution [15].

The resulting covered area for the 25 buildings is summarized below with each of these buildings associated with an individual building in the above image except unit 9, which is a summation of 13 black barracks located near the center of the above image:

Building Number	Area m2	Area ft2
1	1334.03	14359.37
2	1049.19	11293.38
3	385.13	4145.501
4	276.86	2980.093
5	220.01	2368.166
6	161.42	1737.509
7	586.23	6310.121
8	460.61	4957.96
9	2263.04	24359.14
10	460.61	4957.96
11	719.21	7741.505
12	427.17	4598.015
13	719.21	7741.505
14	460.61	4957.96
15	485	5220.492
16	460.61	4957.96
17	195.41	2103.374
18	719.21	7741.505
19	460.61	4957.96
20	485	5220.492
Perimeter Fencing	294772.4	3172901

Table 5: Building Area Calculation

The value for energy required to light and man the perimeter of the base is dependent on military regulations as well as the area of the base. The area was estimated using the same tool as above in order to ensure consistency. The Military Surface Deployment and Distribution Command has in the past, recommended in the Exterior Lighting for Safety and Security Bulletin a base level perimeter fencing setup with at least 0.2-0.4 lumens average vertical illuminance per square foot in order to meet standards [16]. Similar standards have been updated for areas without roofing structures in order to ensure safety. For simple tungsten filament lamps, the wattage output can be calculated from lumens using the formula below where P(w) is the power in watts for a luminance of Φ(lm) and a luminous efficacy of η in lumens per watt:

$$P_{(W)} = \Phi_{V(lm)} / \eta_{(lm/W)}$$

Equation 1: Power Equation

Based on this and taking the lighting requirements to be 0.3 lumens while using the luminous efficacy of tungsten incandescent light bulbs as 0.067 W, the power requirement for perimeter lighting is 0.01858 watts per square foot and the total power required for Camp Swift, with an area of 3172901 sq-ft is 58952.50 kWh annually.

For the remaining buildings, the energy consumed based on the estimates taken form the EIA are as follows:

Building Number	Area ft2	kWh Per sq. ft. [13]	KWh annually
1	14359.37	11.7	168004.5765
2	11293.38	11.7	132132.502
3	4145.501	17.4	72131.71404
4	2980.093	17.4	51853.62436
5	2368.166	17.4	41206.08212
6	1737.509	17.4	30232.65204
7	6310.121	17.4	109796.1071
8	4957.96	17.4	86268.50363
9	24359.14	11.7	285001.8942
10	4957.96	17.4	86268.50363
11	7741.505	13.3	102962.0101
12	4598.015	17.4	80005.46384
13	7741.505	13.3	102962.0101
14	4957.96	17.4	86268.50363
15	5220.492	13.3	69432.53695
16	4957.96	17.4	86268.50363
17	2103.374	17.4	36598.70236
18	7741.505	13.3	102962.0101
19	4957.96	17.4	86268.50363
20	5220.492	13.3	69432.53695
Perimeter Fencing	3172901	0.01858	58952.49259
Total Energy Usage (Annual)			**1945009.434**

Table 6: Per Building Energy Consumption

According to this calculation, the total number of units of electricity needed for Camp Swift are 1945009.434 annually. This translates to 5329 units of electricity on a daily basis. This is the value that the recommended solution will be formulated around.

CHAPTER III

EXISTING SYSTEM

For electricity, the base draws its power from the general electric grid present in Texas called the Electric Reliability Council of Texas (ERCOT). This power is drawn from the nearby transmission lines and is fully dependent on these transmission lines to be functioning. It is purchased at near-commercial rates, which are dependent on the actual demand of the electricity available at that point in time. In the past, the price of electricity has seen close to a 43% increase in year-on-year terms which makes this highly dependent on factors outside military control. Hotter temperatures than expected drove up the demand of wholesale electricity in Texas from around 57000MW in 2016 to about 60000MW at the same time in 2017. This resulted in a day ahead price of about 25.90$/MWh and an average monthly spot price that settled around 18$/MWh. This price has also shown increased sensitivity to natural gas prices which increased about 75% between these two years [17]. In the future, with the temperatures near Austin showing an increase year-on-year, it is expected that the demand will increase further, at a faster rate than the available supply, leading to a possible price increase every year.

The graph below shows the long-term load forecasts published by ERCOT for electricity demand in Texas alone:

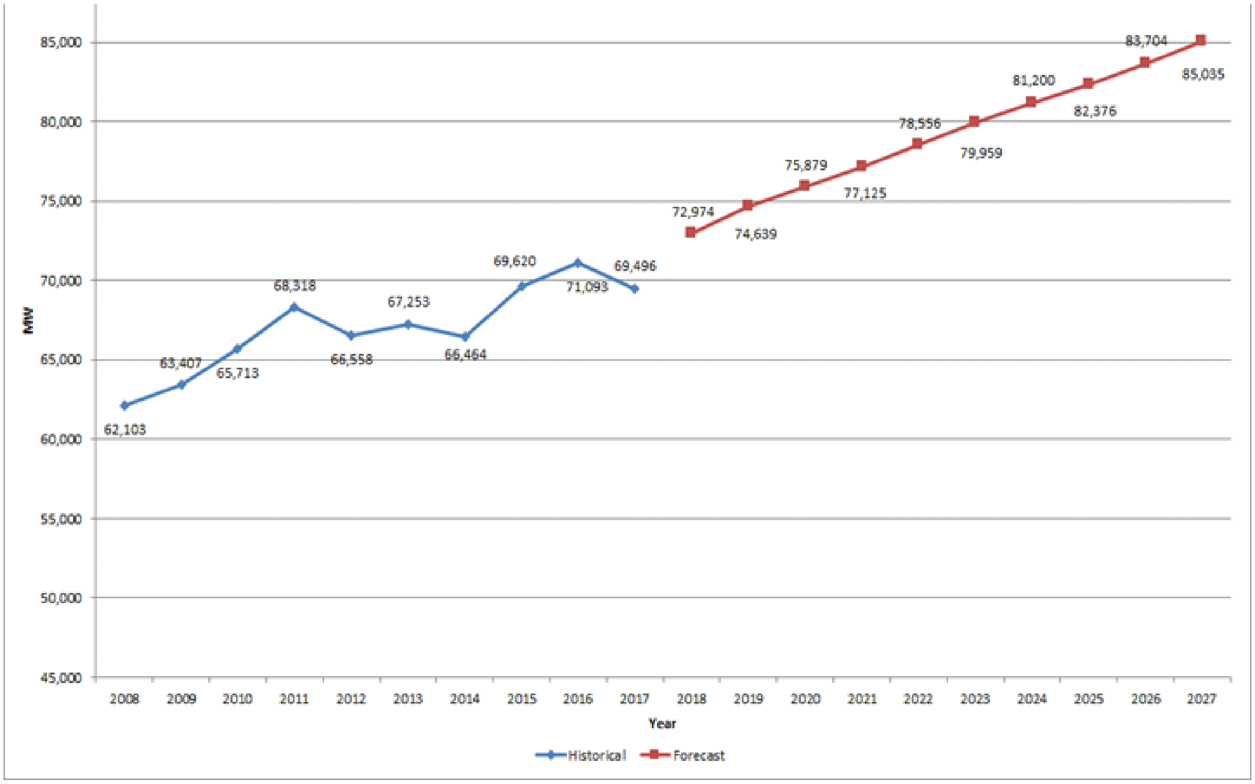


Figure 15: Summer ERCOT Electrical Load. Reprinted from [18].

In addition to an increase in pricing, the electrcity supplied by the grid has been fairly unreliable over the last several years. While the impact of electrcity grid failures on residential areas is significant, the impact on critical military installations such as Camp Swift is immesureable. In 2015, the Energy and Information Administration published the following chart showing the number of major power interruptions and their relevant average length of interruptions.

The chart is important to note that regardless of type of utility chosen to supply electrcity, on average, every consumer in the United States expereinced at least one interruption with atleast 2 hours of downtime:

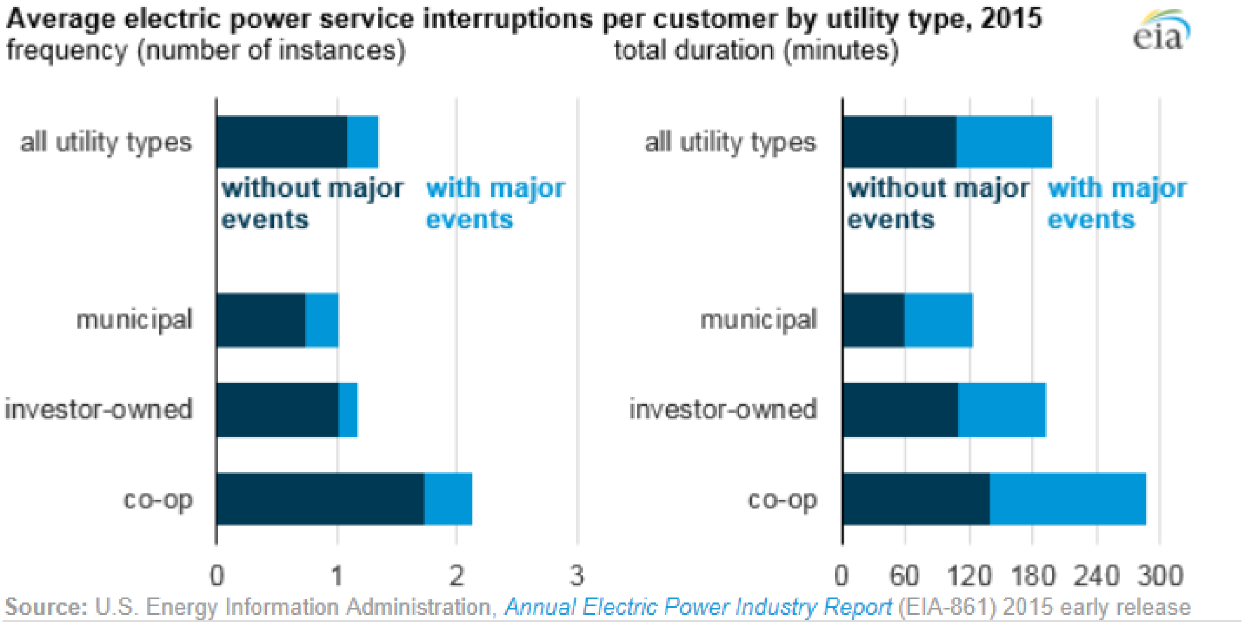


Figure 16: Energy Outage Statistics. Reprinted from [19].

Current System

The infrastructure is ageing in terms of both the materials used and the general reliability of the system. This has led to multiple power outages every year. Climate Central has concluded that over the last 28 years (until 2012) there has been a tenfold increase in power outages which are larger than 50,000 consumers each. Of these, over 80% are directly related to weather. Texas ranked second with 57 power outages at an average of 800,000 consumers affected per outage. The total number of buildings affected between 2003 and 2012 as a result of power outages stands at an average of 15 million a year. The complete statistics showing this upward trend are shown in the following graph:

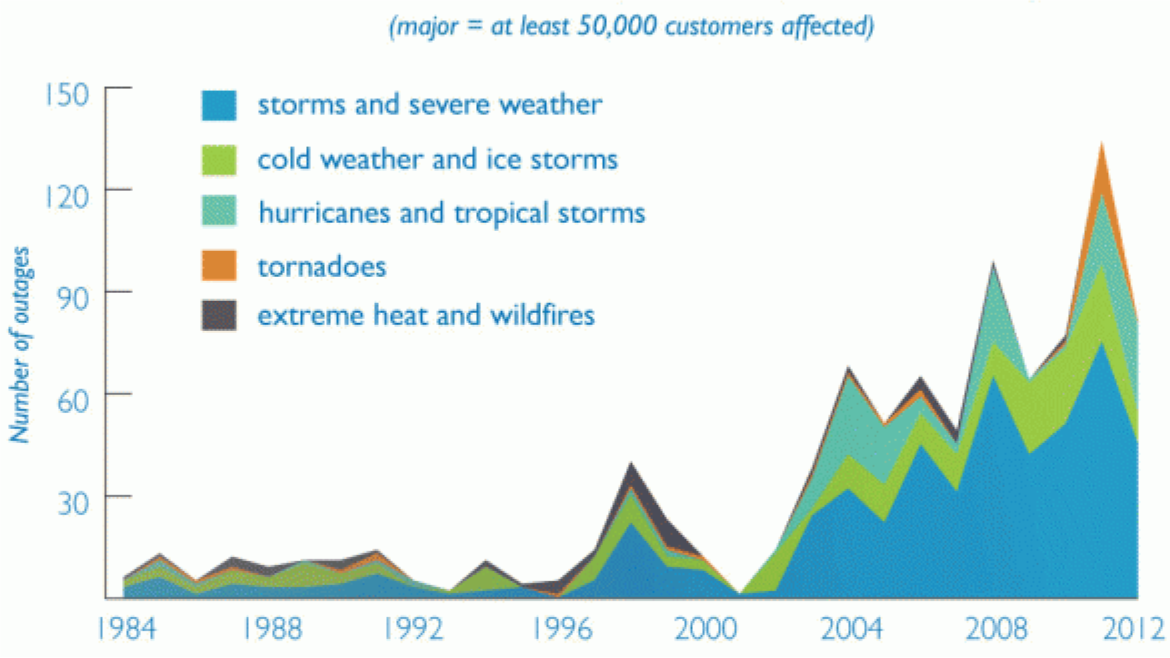


Figure 17: Weather Related Outages. Reprinted from [20].

Current military documents recommend installation of backup diesel generators to allow for some form of backup power supply. These are traditional diesel burning generators in various shapes and sizes based on utility. In addition to these generators, some military establishments have allowed for installation of fuel cells and uninterrupted power supplies (UPS) in order to allow for flexibility in electricity supply. These are discussed in the following sections.

Generators

A standby generator is a back-up electrical system that operates automatically. Within seconds of a utility outage an automatic transfer switch senses the power loss, commands the generator to start and then transfers the electrical load to the generator. The standby generator begins supplying power to the circuits. After utility power returns, the automatic transfer switch transfers the electrical load back to the utility and signals the standby generator to shut off. It then returns to standby mode where it awaits the next outage. To ensure a proper response to an outage, a standby generator runs weekly self-tests. Most units run on diesel, natural gas or liquid propane gas. Automatic standby generator systems may be required by building codes for critical safety systems such as elevators in high-rise buildings, fire protection systems, standby lighting, or medical and life support equipment. Residential standby generators are increasingly common, providing backup electrical power to HVAC systems, security systems, and household appliances such as refrigerators, stoves, and water heaters.

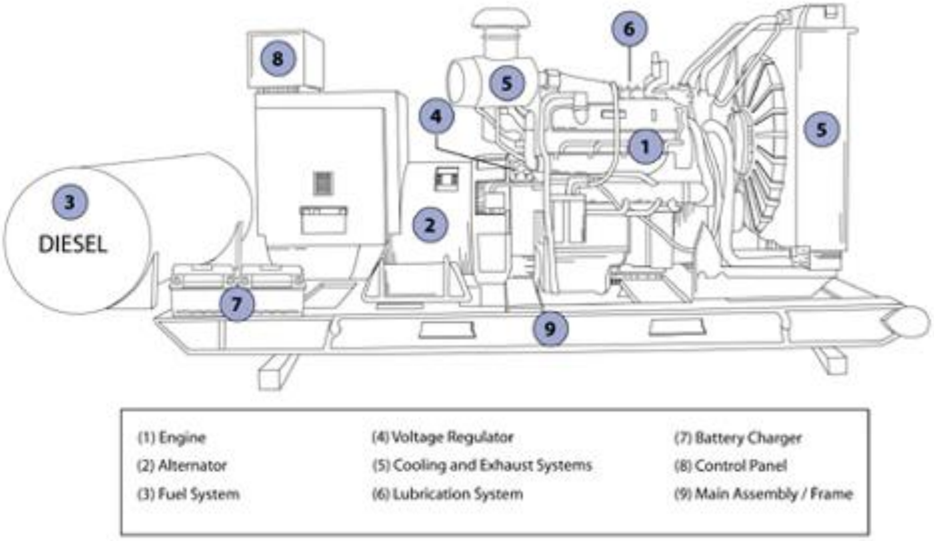


Figure 18: Design of a Diesel Generator. Reprinted from [21]**.**

The basic premise upon which a diesel generator works is the energy stored in fuels. A generator is able to combust said fuel, releasing energy in the form of heat which is used to heat water (or another similar liquid) up until it reaches gaseous state. This gas is then decompressed in order for it to escape at high speed by turning the prime mover / turbine of the generator. This turbine is connected via gears in order to increase speed of rotation. At the other end of this shaft is a set of magnets that rotate within an electrical coil. The variable magnetic field intersecting these coils is able to induce an electric current on the coil, as a result of the Len’s law. This electric current can then be output from the generator. Most generators that are used to supply household loads are 3-phase, and have multiple poles in its magnetic field, details of which are outside the scope of this study.

Standalone generators have been the backbone of electric power supply for the US Military for a while. They are required by regulation to be able to power the critical load of a building and are often hard-wired directly into the building. In addition to the generator, typical bases have fuel stores that can allow the generators to run between 2 and 7 days if necessary. A typical military building requires 20MW of critical load which can peak as high as 50MW, requiring upwards of 200 generators to power. They are also diverse in size and manufacturer, with one study finding 42 diesel generators on one military base, with manufacturing dates between 1968 and the present and sizes ranging from 10kW to 1035kW [22]. Running these generators is also cost ineffective as the cost of constructing and running a generator is much higher than equivalent power sources as shown in the figures below:

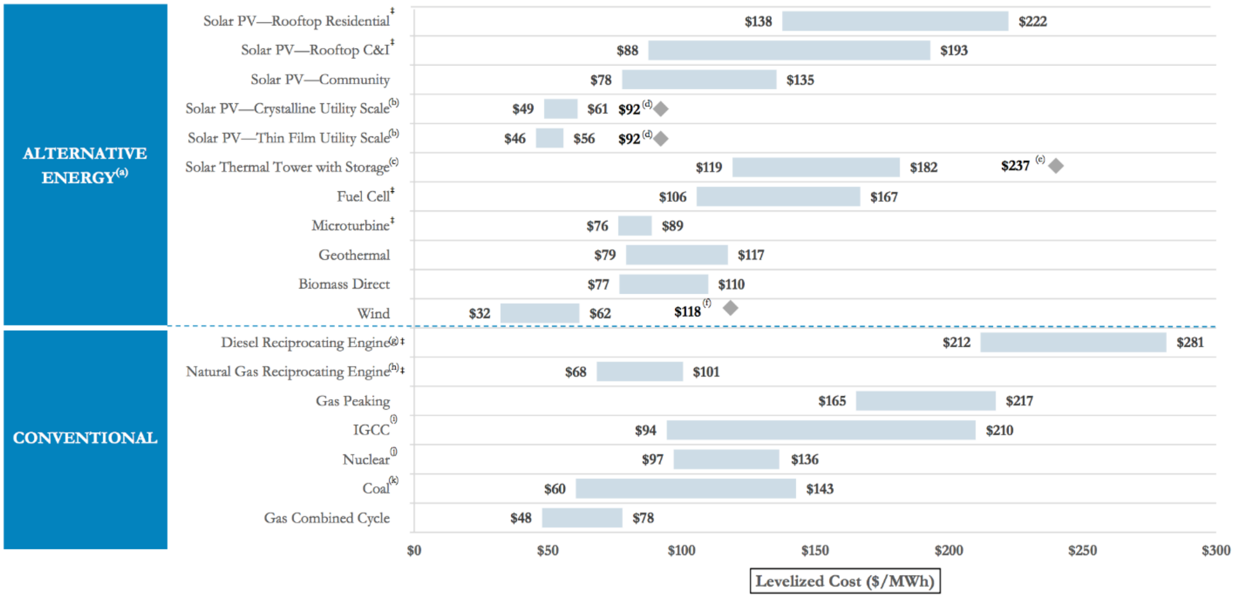


Figure 19: Energy Cost by Type. Reprinted from [23].

As can be seen in the above graph, the cost of running a diesel generator over its lifetime averages out at between 212 and 281 dollars per MWh. This is significantly higher than the solar PV values of between 49 and 92 dollars per MWh. These values also do not take into account the environmental impact of running diesel generators. The world nuclear association has previously estimated that running a generator on oil produces about 700 tonnes of carbon dioxide equivalent in greenhouse gases compared to less than 50 tonnes for equivalent amount of energy utilized from solar PV or biomass. This trend is shown in the following curve of average emissions intensity versus GHG Emissions:

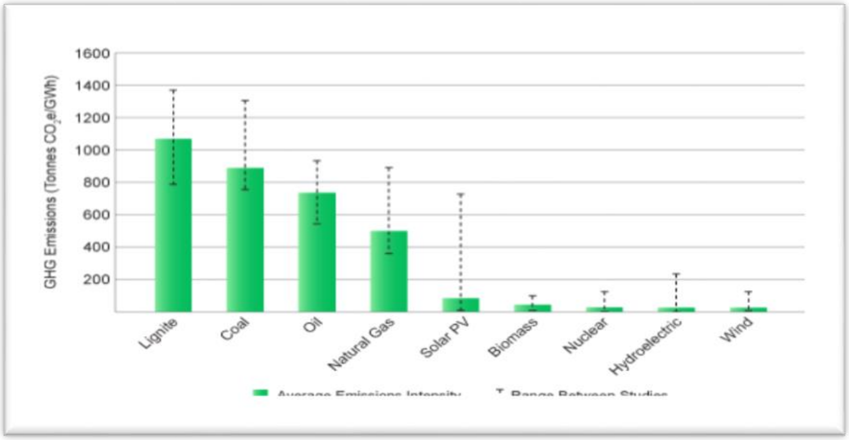


Figure 20: Greenhouse Gas Emissions. Reprinted from [24].

Also associated with using diesel generators are lagging maintenance and replacement costs. Diesel generators often have “failure to startup” issues associated with them, with one study placing the number of repair hours for a generator installed in 1998 at about 5500 by 2001. Since generator technology at existing military bases hasn’t changed much over the last few years, the same can be extrapolated to this day. The actual trend is shown in the graph below:

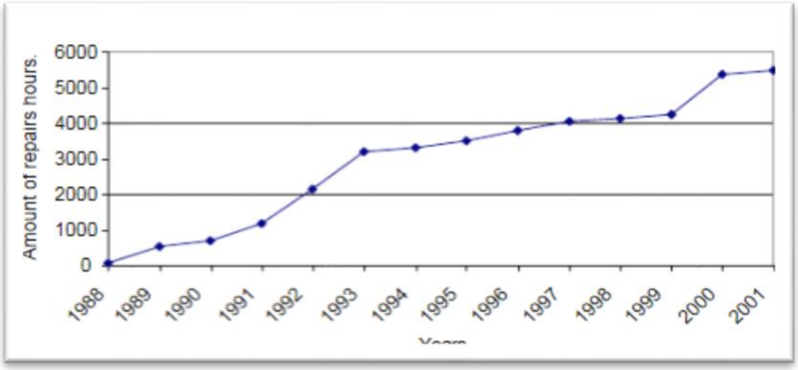


Figure 21: Accumulated Number of Repair Hours. Reprinted from [25].

Additionally, reliance on just diesel generators for backup electricity can lead to a lack of resilience as well since there is only one source of energy to fall back on in case of a major storm like Hurricane Harvey. Diesel generators are relatively cheaper to set up than other alternative sources of electricity. The major cost components of a diesel generator relevant to this study are as follows:

1. Hardware and Installation Costs: these are primarily composed of the price of the diesel generator and the installation costs. Diesel generators have been around for a long time therefore are relatively cheaper to set up than equivalent systems. Additionally, they are highly repairable making replacement costs negligible.
2. Running Costs: For a diesel generator, the major running costs are the cost of fuel along with the operating and maintenance costs of the generator. The cost of fuel for this study is taken as an even \$3 per gallon and the operating costs are estimated at approximately \$0.001 per kWh [26]. A typical diesel generator has an efficiency of 40%, with a gallon of diesel containing enough energy in itself to produce 14.44 kWh of electricity at this efficiency. This brings the expenditure per unit at approximately \$0.23/kWh.

3. Emissions Costs: a typical diesel generator is slated to contribute about 157lbs of CO2 equivalent per million BTU of energy. This translates to about $0.00049376/kWh in emissions cost [27].

Costs associated with a diesel generator are summarized below: [28]

Fixed Costs: $1100/kW

Running Costs: $0.23/kWh

Emissions Costs: $0.00049376/kWh

CHAPTER IV

MICRO-GRIDS

Definitions

The Department of Defense (DoD) has highlighted three goals towards which the general military energy profile is to head:

1. Improve energy security
2. Reduce energy usage
3. Increase renewable energy generation

[29]

For this purpose, a microgrid structure is to be designed. A microgrid can be defined as a small-area network of facilities responsible for distributed generation of electricity, primarily renewable energy technologies, along with storage facilities.

Key Concepts

Microgrids also traditionally include load-side management where the demand is adjusted in accordance with the supply as opposed to traditional grid structures where supply mimics demand. Such systems can operate in parallel with the grid during normal conditions but in the case of an emergency where the grid is unavailable, these can operate as a fully capable grid of its own. Such emergency solutions increase the overall energy resiliency and security of the said campus by making energy available to critical loads, and pushing the overall trend towards renewables as well.

Comparable Examples

The federal government has, in recent years, pushed towards the adoption of microgrid technologies. Examples of these include:

1. The Renewable and Distributed Systems Integration (RDSI) Program:

   The RDSI program seeks to develop alternative distribution systems that allow for integration of distributed resources. The primary purpose is to allocate Department of Energy (DoE) funding to merit based projects that allow for smart-grid implementation using newer technologies for generation, demand response, better sensors and overall energy efficiency. The designed capacity has to be upwards of 15% of the capacity of one substation. Funding can also be derived from the American Recovery and Reinvestment Act. [30]

2. Consortium for Electric Reliability Technology Solutions (CERTS)

   The Consortium for Electric Reliability Technology Solutions (CERTS) was formed in 1999 to answer requirements stated by the US Congress in response to recommendations by the Secretary of Energy Advisory Board Task Force on Electric System Reliability to restart research and development towards reliability of national electricity transmission facilities in order to stop gaps in technology and prevent major blackouts. [31]

3. Sandia's Energy Surety Microgrid (ESM)

   Sandia National Laboratories have used Federal funding and applied it to develop methodology that allows them to directly link energy reliability with identification and fulfillment of loads having critical importance. This type of implementation shifts the focus away from large power generation to distributed systems with room to grow since all implementations are scalable. ESM also incorporates the usage of reversible meters that allow distributed generation facilities to sell electricity back to the grid. [32]

4. Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) The SPIDERS Report came out as a result of the Federal Energy Management Program that summarized the result of the SPIDERS Joint Capabilities Technology Demonstration (JCTD), prepared by representatives of the Naval Engineering Command. The report simulated and demonstrated a cybersecure smart grid that allowed for distributed generation and energy storage specifically for use in military facilities. The SPIDERS report highlighted smart grids as a solution to secure energy for critical defense infrastructure while encouraging adoption of renewables and driving down reliance on oil. [33]

5. Energy Independence and Security Act (EISA)
   Signed by President Bush in 2007, the EIS Act aims to push the United States towards greater energy security and resilience by adopting consumption of renewables and increasing efficiencies of consumption systems. Other side objectives include adopting carbon capture and storage options and moving towards renewable fuel production. the federal government leads the move towards cleaner fuels by example as well. [34]

6. Grid Project Impact Qualification (Grid PIQ)

In order to improve available tools to aid in decision support in the power industry, the Department of Energy (DoE) used its Office of Electricity Delivery and Energy Reliability's Advanced Grid Research and Development Division to bring onboard the Pacific Northwest National Laboratory (PNNL) to develop a tool that can clearly quantify the pros and cons of deployments of smart grids. This collaboration led to the creation of the Grid Project Impact Quantification (Grid PIQ) Screening Tool that provides a clear view into the effects of smart grid implementations.

7. Power Over Energy Program

Power Over Energy is a program jointly funded by the government as well as non-governmental agencies that allows for greater access to knowledge in an attempt to educate the general populous regarding the impacts of their energy consumption in order to allow them to make smarter decisions regarding energy use. The program has a large audience, reaching 100 million people several years ago. This is an example of using technology to change consumer trends and can be classified under demand side management as part of a greater move towards smart grids. [35]

8. Electricity Advisory Committee

The Electricity Advisory Committee (EAC) is a specialists committee established with the purpose of giving advice to the Department of Energy (DoE) in implementing the energy Policy Act of 2005 and executing the Energy Independence and Security Act of 2007. The major goals of this committee are to help lawmakers with issues pertaining to energy generation and transmission and to bring all stakeholders onboard in an attempt to reduce energy related emergencies. [36]

9. The Smart Grid Investment Grant (SGIG) program allowed the federal government to use the Energy Independence and Security Act (EISA) of 2007 to finance several projects pertaining to smart-grids to further guide the United States towards an era of more flexible, functional and cyber secure energy with greater efficiency and overall reliability. [37]

10. Furthermore, in order to reduce reliance on foreign sources and externalities, the Army has recently established the Net-Zero initiative at 17 establishments across the country to reduce the consumption of resources to zero by 2020. Within the scope of this program, the army has looked for innovative ways to reduce consumption of electricity at installations, along with diversifying the sources of generation available to the bases in question. While the Net-Zero initiative takes into account usage of fuel and water as well, this study focuses only on electricity supply to select military installations. [38]

CHAPTER V

GENERATION

Solar Photovoltaics

Description

Solar cells, also called photovoltaic (PV) cells by scientists, convert sunlight directly into electricity. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the PV effect. The PV effect was discovered in 1954, when scientists at Bell Telephone discovered that silicon (an element found in sand) created an electric charge when exposed to sunlight. Traditional solar cells are made from silicon, are usually flat-plate, and generally are the most efficient. The Photovoltaic effect is achieved by joining adjacent semiconductors which are doped with positively or negatively charged atoms. This allows for the formation of a p-type semiconductor and an n-type semiconductor coming into contact to form a P-N junction. The n-type semiconductor is a silicon atom composed of 4 traditionally joined silicon atoms and an extra electron. When a packet of energy such as the photon in incident light hits this atom, it allows the electron to move freely within the silicon structure. N-type semiconductors are created by having a silicon structure doped with a phosphorous based material. The free electron is attracted by the p-type atoms (with one less electron than stable silicon) and this allows for the flow of charges in the circuit. Solar panels take into account this effect in individual solar cells and compound them into multiple rows and columns to amplify the current and electromotive forces produced across the cells. Typical first generation solar panels are encased in hard glass in order to protect against drops and breakages, while ensuring ample amount of light passes through. Second-generation solar cells are known as thin-film solar cells made from amorphous silicon or non-silicon materials such as cadmium telluride. Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Because of their flexibility, thin film solar cells can double as rooftop tiles, building facades, or the glazing for skylights. [39]

Key Concepts

In order to utilize the output electricity of a solar panel, different circuit components are needed to interface the panel with existing requirements. The major components of a solar electric system are as follows:

1. Solar Panel(s): As mentioned previously, solar cells are often connected in strings to form a solar panel. Between these cells, there are special diodes installed called bypass diodes that prevent the flow of current in the opposite direction to the intended flow as a result of solar panels facing partial shading from light. The diagram below shows a typical arrangement of solar cells to form a solar panel:

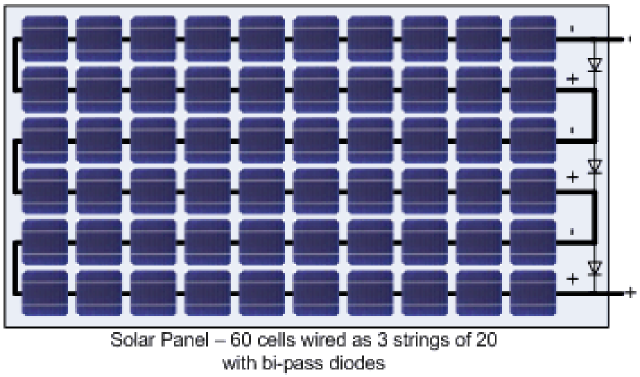


Figure 22: Solar Panel Diagram. Reprinted from [40].

The diagram above shows the formation of a solar panel using 60 individual solar cells, each producing 0.6 volts when placed in sunlight. The panel as a whole is able to produce 36v potential difference across its terminals. In most power-related applications, multiple solar panels are installed in systems that are connected via special cables in strings to add to the voltage and current output of the entire system. Typical solar panels are available with outputs between 110 watts per sq metre (Wp) and 310 Wp which is a reading of the amount of power produced if perfect sunshine falls on one meter square of that solar panel's surface area. Since power is added in series, the diagram below shows a typical arrangement with eight solar panels connected together to increase the output from the system:

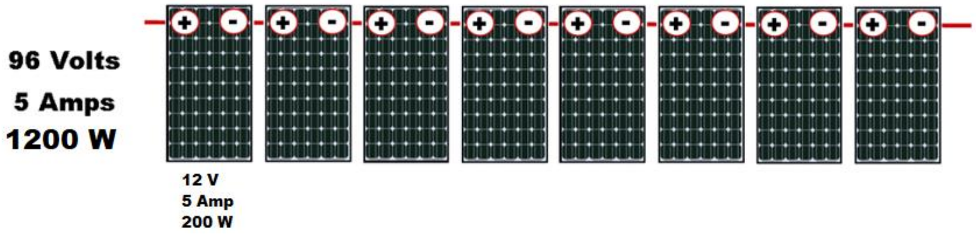


Figure 23 Solar Panel String. Reprinted from [41].

The eight panels are all 200 W rated and have output voltages of 12 V compounded to form a 96-volt system. In some cases, solar panels are connected in parallel to add the current output of the panels together. The same panels are shown here, connected in parallel while keeping the voltage output the same:

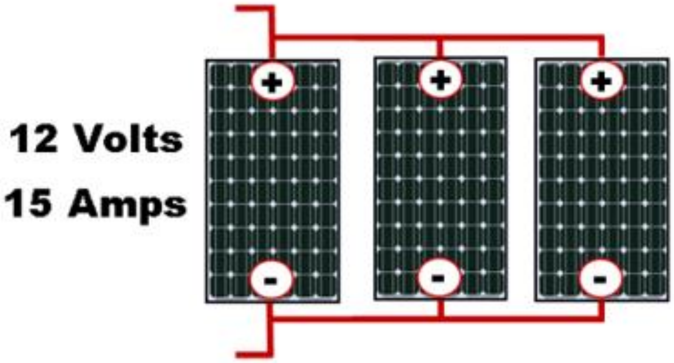


Figure 24: Solar Panels in Parallel. Reprinted from [41].

2. Inverter:

A critical component of a solar system is an inverter, which is an electronic circuit that allows the DC output of a solar panel to be converted into AC (varying with time) which is commercially available across the United States to household consumers. The inner workings of the inverter are outside the scope of this study; however, it is important to calculate the recommended size of the inverter based on electricity demand and available solar panels. Typically, inverters are rated in watts corresponding to the peak wattage required by the consumer. In traditional applications, multiple solar panels are divided into strings that feed into a single large inverter. In newer applications however, small micro-inverters allow small numbers of solar panels (sometimes just one) to be fed into an inverter, allowing more flexibility with solar systems in the face of shading, weather or electrical breakdowns.

Such systems therefore allow for increased resilience, which is paramount for Camp Swift. These systems are approximately 25% more expensive than traditional inverter applications.

The diagrams below show these differences in approaches towards conversion form DC to AC:

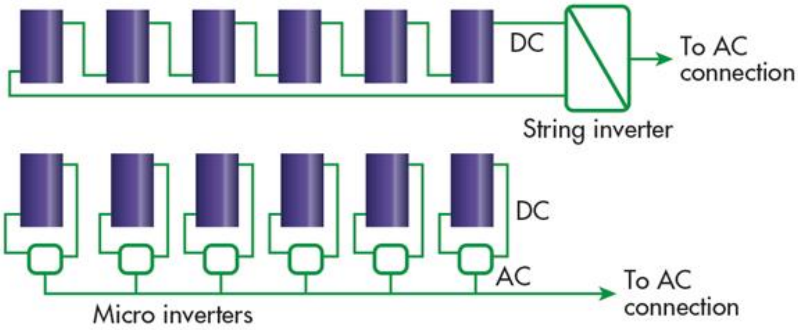


Figure 25: Micro-Inverter vs Inverters. Reprinted from [42].

3. DC- cables:

   These are usually highly weather resistant, well insulated single core wires use to connect solar panels with associated equipment. Since they are mostly uncovered and exposed to the elements, quality insulation is necessary. They also need to be class-II double insulated to ensure a short circuit free application. For the purpose of this study, only UL 4703 certified copper cables are considered.

4. Installation apparatus:

   There are multiple common methods of installing solar panels. This study focuses on installation of solar panels on the ground using a tilt adjustable method that does not involve complex electronics for movement of the solar panels. Studies have concluded that installation of a single axis solar tracking system allows the same panel to achieve greater output power. The graph below shows the result from a single panel:

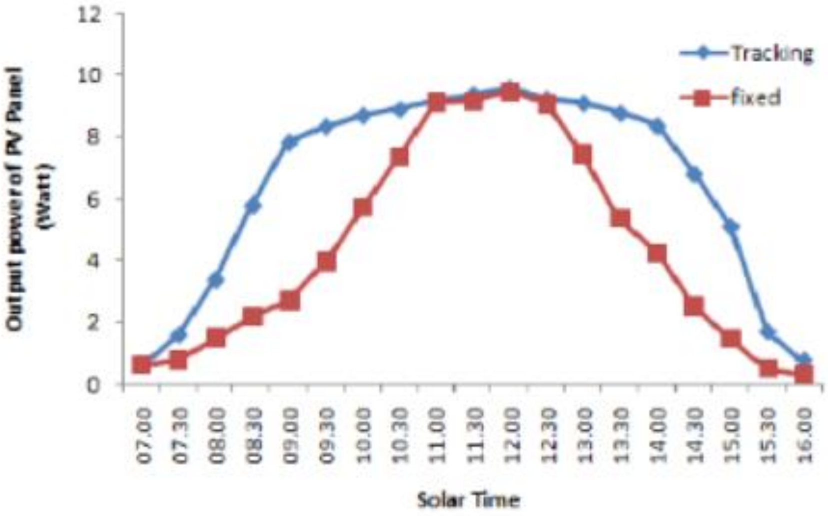


Figure 26: Output Power of PV Panel. Reprinted from [43].

As can be observed from the graph above, a solar tracking system allows for about 40% more energy being absorbed than a similar system. Since this study focuses on standalone solar panels equipped with micro inverters that are independent building blocks for a bigger power plant, it is necessary for each string of solar panels to be connected to a single axis rotary motor. Such apparatus adds approximately an extra 5% to the cost of a panel, if installed in strings instead of individually. In order to minimize complexity of design, the panels will not have a mounted servo motor underneath, but instead will add a simpler rail system allowing the panel to slide out or in as shown in the following diagram:

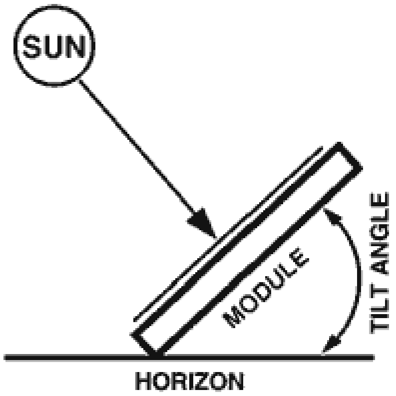


Figure 27: 2-Axis Solar Tracking

5. Storage apparatus

While a solar system that is connected to the grid utilizes the grid as a storage mechanism whereby the power produced by the panels is fed into the grid with no drawback, such a system is not practical for off-grid applications such as during a hurricane or similar. For this purpose, using a storage system to allow for excess energy to be stored and utilized when necessary is very important. Solar panels are highly intermittent, with a typical panel being affected by minor changes in light intensity, shading, ambient temperature as well as other factors. The diagram below shows the time dependent output of a solar panel and the effect of various sky conditions on the panel in one day:

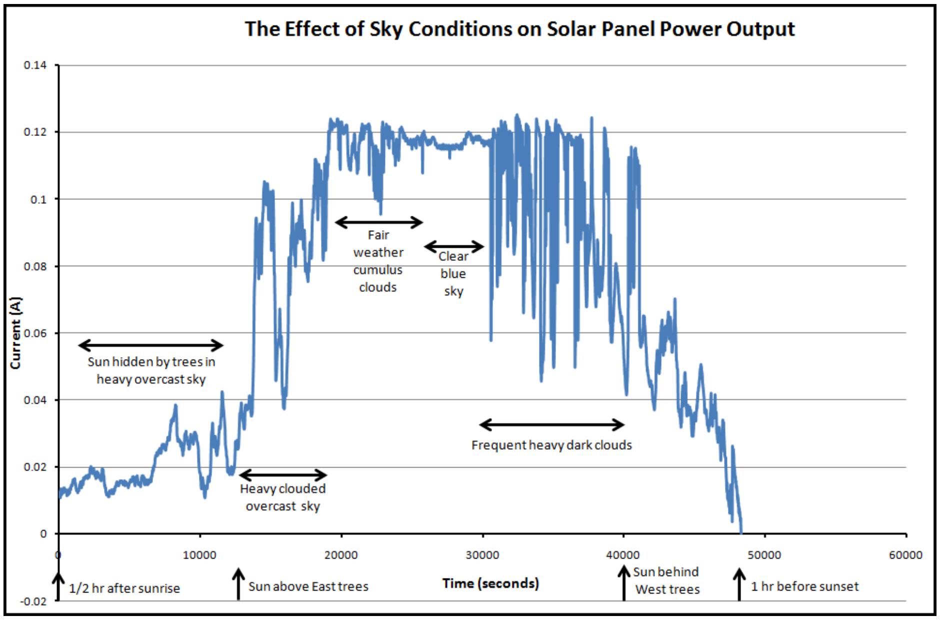


Figure 28: Solar Panel Output. Reprinted from [44].

It is therefore necessary to install a battery (or equivalent) to achieve a smoothing in the output available to the user from these panels, as well as to ensure storage to allow for the system to be used off-grid in the event of a power failure. This ties in with increased resilience of the system that is part of the aims of this study. Additionally, with solar, a major problem is the “duck curve”. The duck curve is a result of the supply from solar energy peaking during the day, whereas the demand from consumers peaking during the late evening when output from solar is low/zero. This is shown in studies done on past data as well as in prediction models shown for the next few years. The graph below shows the duck curve in January along with the risk of over generation during the day and a shortage of energy at night:

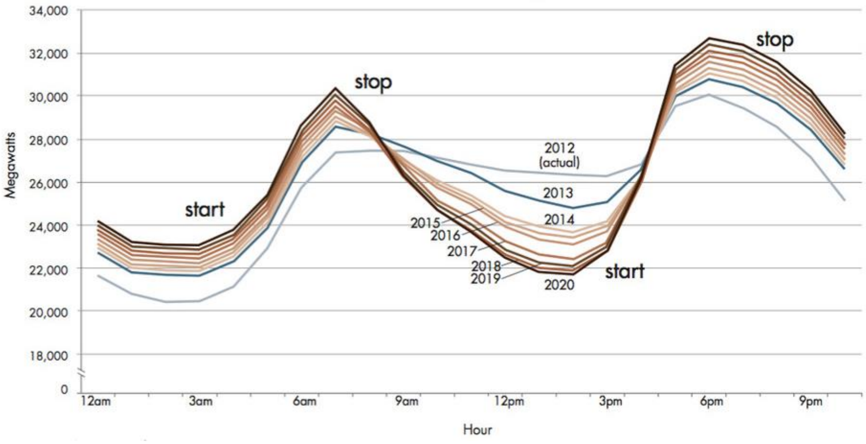


Figure 29: Solar Panel “Duck” Curve. Reprinted from [45].

For this purpose, two major storage options are discussed below:

1. Battery Storage: A typical deep cycle battery allows for a solar system to function with ease. Deep cycle batteries allow for discharges of upto 85-90% of their total capacity. For Camp Swift, the Tesla Powerwall 2 was selected as the battery of choice due to its recent successes in Australia. After a coal power plant had failed, the powerpack allowed for instantaneous delivery of power and has reportedly been highly profitable due to its reliability [46]. It has an estimated payback period of 30 years without taking perceived resilience into account according to recent calculations [47].
2. Flywheel: Flywheels are rapidly rotating machines enclosed within protective shells. In a scenario where there is excess energy, this can be used to increase the momentum of the flywheel against perceived inertia. Upon being cut off from a source of energy, it utilizes the principle of conservation of momentum as a flywheel is able to use its rotational motion to induce electricity in an electromagnet similar to the design of a generator discussed previously. Recent studies have shown that flywheels offer cheaper storage than equivalent battery

storage and are also more environmentally feasible [48]. However, no viable commercially available flywheel manufacturers with equivalent brand value and warranty offerings were available at the time of calculation therefore only battery storage was utilized for this study.

Model Comparison

At camp swift, there is ample space to allow for installation of solar panels. Since Texas is a hot environment during the summer, it is necessary to opt for amorphous silicon solar panels which fare better in terms of efficiency during the summer. The graph below shows the impact of ambient temperature on solar panels composed of different materials. It is evident that the curve for amorphous silicon (a-Si) shows the least drop in efficiency with an increase in the temperature:

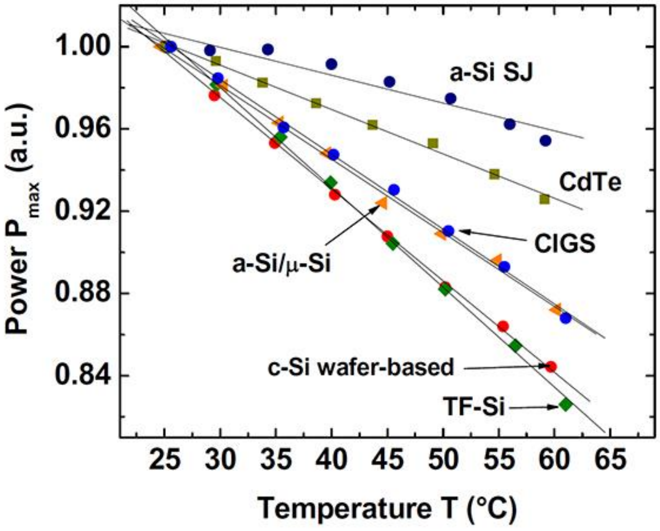


Figure 30: Solar Panel Materials. Reprinted from [49].

At Camp Swift, the following conditions were selected to decide on area which can be utilized for ground installed solar panels:

1. The ground must have no immediate uses at present or in near future
2. The area must be devoid of any possible shading related problems
3. The area must have easy access for repair and maintenance

Based on satellite images, the following area was selected as the best site to install solar panels:

Figure 31: Solar Panel Area Allocation

Financial Breakdown

Globally, the cost of utility scale solar power generation has fallen greatly in the last few years. The following chart shows that trend. As of 2018, the cost of solar power system is estimated in the United States at roughly $1/Watt.

Figure 32: USD per Watt Solar Panel Output. Reprinted from [50].

Costs associated with a typical utility scale standalone solar plant are shown below:

1. Solar panels typically cost between $10,962 and $13,818 in Texas for a 6kW array [51]. This brings the cost of a typical panel to $1800 per kW. At $2000, the cost of the solar panels include costs associated with micro inverters as well. These are typically approximately $0.40 per Watt-AC [52].
2. Soft Costs: For a utility scale PV, with a single axis tilt system, the soft costs are set at 40 percent of the total cost of the system and include costs such as profit, contingency

planning, overheads, taxes, labor and equipment.

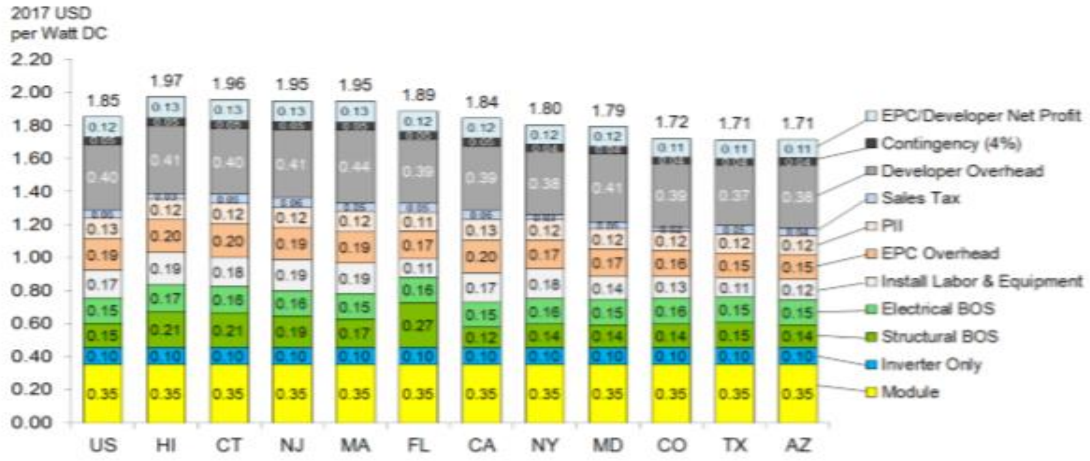


Figure 33: Solar Panel Cost Breakdown. Reprinted from [52].

3. Maintenance and Operation Costs: solar panels have a typical lifespan of 20 years or more. This is however restricted by inverters and batteries that have a typical replacement life of about 10 years. Based on these, the cost of O&M has been estimated at about \$15/kW-yr [52]
4. Carbon Emission Costs: the amount of greenhouse gases released by a solar plant can also be quantified in US Dollars. A typical plant is expected to produce about 6 grams of CO2 equivalent for every kWh produced by solar PV systems [53]. Other sources have put this number at about 49.9g [54]. Additionally, experts estimate the environmental damage done by a ton of CO2 stands at about \$28.80 and that is also taken into account in this study [27].

For this study, the above totals have been summed up as follows:

Fixed Costs: \$3140/kW

Running Costs: \$0.02/kWh

Emissions Costs: \$4.6329E-07/kWh

Wind Turbines

Description

Wind is the flow of air from an area of high pressure to an area of low pressure. These variations in the air pressure are caused due to the effect of the energy of the sun exciting air molecules. These wind patterns are sustained, and affected by further factors such as geographical locations and formation of wind channels due to physical obstructions such as mountains. Wind is a constant flow of kinetic energy however, and can be tapped into for electricity generation in many ways. Primarily, commercial applications tap into wind energy by way of wind turbines. These are giant rotating objects pushed around an axis of rotation by wind. The rotation then drives a magnet within a conductor solenoid in order to induce electricity similar to how generators and flywheels work. There are several problems associated with turbines, primarily due to the size of the turbine and difficulty of both installation and maintenance. Furthermore, since most turbines are over 30 feet high, they may pose a potential hazard for both naturally occurring and manmade flying entities. Additionally, wind turbines operate between certain speed ranges, called the cut-in speed and the cut-off speed. The basic principle governing the creation of electricity from wind is the conservation of energy where kinetic energy in the wind is used to drive the shaft shown in the following diagram:

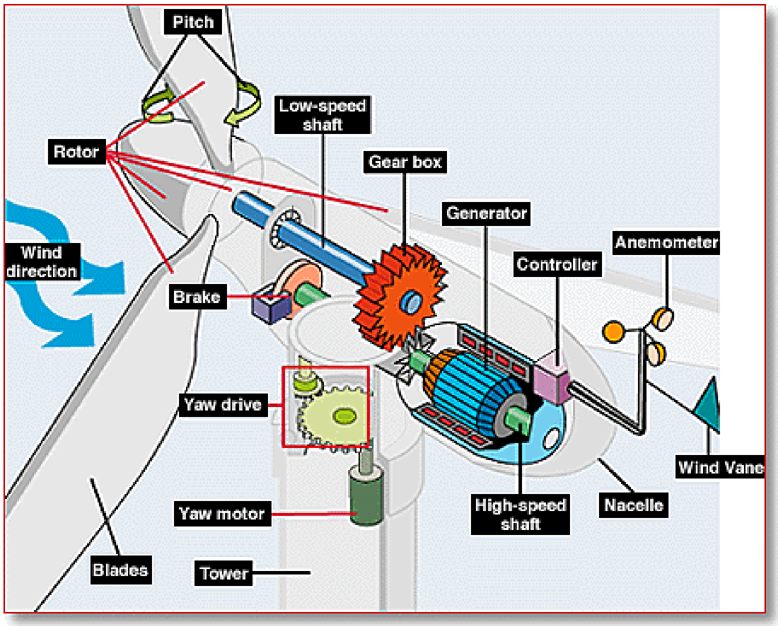


Figure 34: Wind Turbine Breakdown. Reprinted from [55].

Rotation of the turbine works on the aerodynamic principles of lift and drag: forces experienced by an object when in contact with flowing wind. Lift typically points perpendicular to the flow of wind while drag acts in the same direction. Typical wind turbines are of the following two types:

1. Vertical Axis turbines – these turbines typically have blades that are on an axis that is perpendicular to the ground and they rotate around their own axis. These tend to be smaller and more compact than horizontal turbines and can also be stacked on top of each other in the same amount of room. The stress experienced by the turbine is lesser than horizontal axis turbines due to the shorter distance between the blades and the axis of rotation. However, vertical axis turbines experience a backtracking effect as a result of the back of the blades experiencing incoming wind as well, which causes their efficiency to be lower [56].
2. Horizontal Axis turbines – these are turbines that rotate on an axis that is parallel to the ground. They face into the wind and typically have an odd number of blades in order to

reduce stress experienced by the structure. Optimization studies have shown that three blade turbines are generally the most efficient of this kind of turbines. A major drawback of such technology is that the turbines need to be installed with a yaw drive and motor to allow them to turn and face into the wind, increasing maintenance costs.

Research has shown that in similar situations, horizontal turbines allow for output wattages that are 2.5x the output from equivalent vertical turbines. The graph below shows this difference in output performance where consistently, the blue line tracks higher than the orange line:

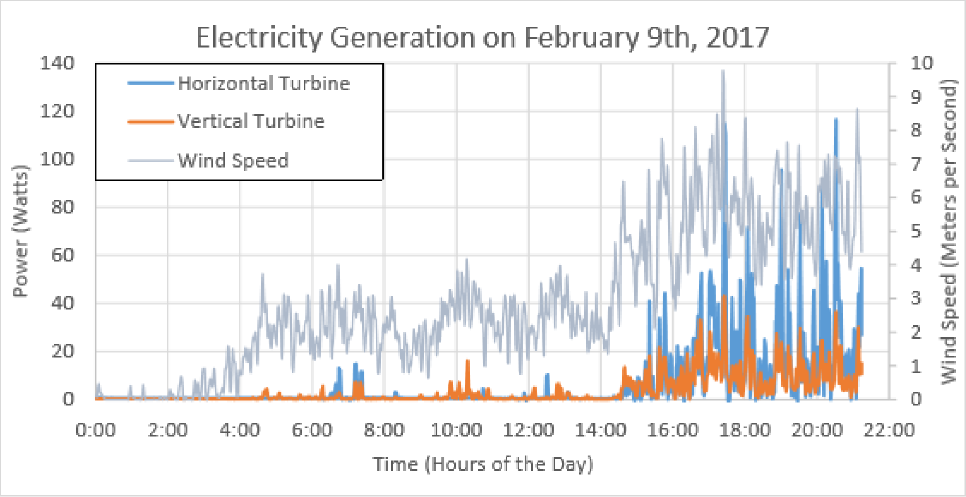


Figure 35: Electricity Generation on Feb 9th, 2017 in Texas. Reprinted from [56].

The average wind speed near Austin, Texas is estimated at over 4m/s at a height of 30m which is based on the estimated height of a wind turbine National Renewable Energy Laboratory, making horizontal axis wind turbines the better choice for Camp Swift. [57]

Model Comparison

For camp swift, with the maximum load being about 5000kWh per day for 100% resilience, it is expected that the size of wind turbines will not be too big. Typical wind turbines that are grid utility scale such as the ones manufactured by Poolaris America are rated at about 50kW per turbine. For Camp Swift, the recommended and chosen model is a 50kW turbine manufactured by Polaris America that stands at over 50feet high and is relatively low noise and high output at wind speeds of over 6m/s. These turbines need to be about 150m away from residential buildings and can be placed 7 blade lengths away from each other in order to maximize energy capture . For this reason, the following areas are selected on Camp Swift as possible wind turbine locations:

Figure 36: Wind Turbine Area Allocation

Financial Breakdown

Wind turbines are costly equipment to set up and interface. They are however, AC units and can be connected directly to consumer's electric supply lines. On average, the cost of wind electricity in Texas has seen a steep decline over the last few years, owing to better access to technology and increasing amount of investment in this area. The overall levelied cost of electricity (LCOE) from wind has fallen by 66% over the last six years to about $45 per MWh, making it one of the cheapest sources of electricity as shown in the following graph:

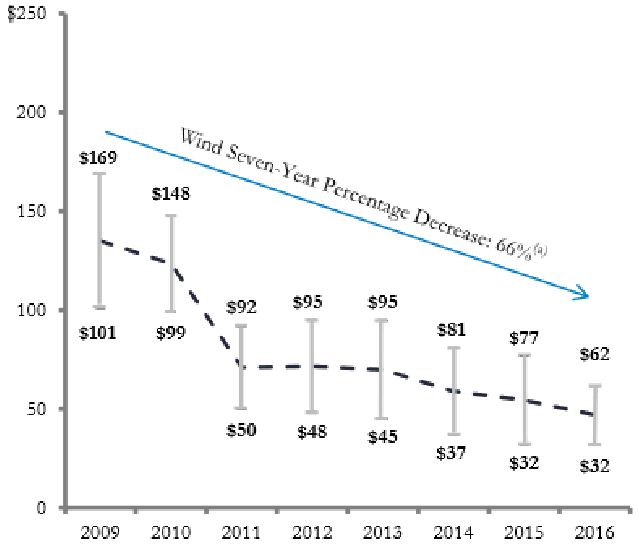


Figure 37: Wind Turbine Costs. Reprinted from [23].

The turbine chosen for Camp Swift is from a class of wind turbines, which cost about $250,000 to purchase. Various associated costs of a wind turbine are broken down below:

1. Cost of Wind Turbines: typical 3 blade, variable axis horizontal turbines cost between 2000 and 2500 US Dollars per kilo-watt [58]. For the purpose of this study, the value chosen is $2500, after adjusting for inflation over the last several years. This includes costs associated with buying individual components such as blades, hubs, gears and the generator. While the value has traditionally been harder to predict, recent trends in

legislation such as imposition of tariffs on import of metal products may cause this price to rise over the next few years.

2. Soft Costs: Soft costs associated with installation and transport of components related to wind turbines are significant at about 20% to 40% of the total project cost. This is estimated at about $1000 per kW installed [58].
3. Maintenance and Operation Costs: Maintenance and operation costs of onshore wind turbines are on average, based on 2010 calculations, 1 cent a kWh for most turbines in the United States [58]. However, owing to these being grid and utility scale installations (typically over 200kW), for Camp Swift, a more accurate estimate utilized for further calculations is $0.05 per kWh produced.
4. Carbon Emission Costs: Studies estimate that the carbon footprint of generating one kWh of electricity at about 34.1g $CO2e/kWh$ [54]. Using the same cost per ton of carbon dioxide as discussed previously, the carbon costs associated with wind energy can be estimated.

For this study, the above totals have been summed up as follows:

Fixed Costs: $3500/kW

Running Costs: $0.02/kWh

Emissions Costs: $3.166E-07/kWh

Natural Gas Generator

Description

Natural Gas generators are similar in principle to diesel generators owing to their mode of operation being combustion of fossil fuels in order to heat up a fluid and turn a generator to generate electricity. Other major components of a gas generator include the cooling apparatus along with associated electronics to ensure high voltage transport of electricity. The design of a typical natural gas power plant is shown below:

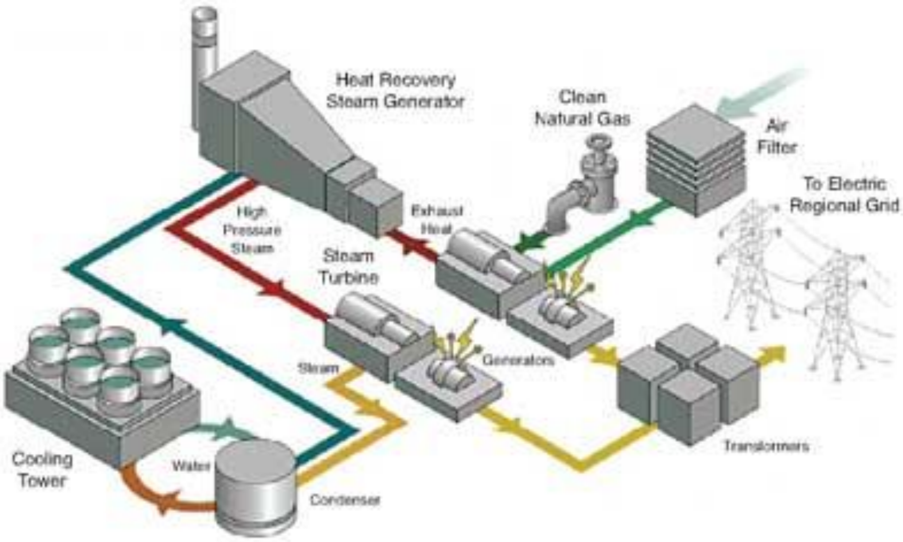


Figure 38: Natural Gas Generator. Reprinted from [59].

Natural gas generators have the added advantage of being combined cycle machines that allow for the semi-cooled steam to condense into warm water that can be used as water supply to residential areas. While this may result in major cost savings, this is outside the scope of this study. Additionally, the natural gas generator designed for Camp Swift is assumed to have access to a direct flow of clean natural gas as well as a storage tank to store enough gas to power the generator for a certain amount of autonomy.

Model Comparison

For this study, typical natural gas generators were catalogued. These include smaller generation units manufactured by Briggs and Stratton with in-built 250-ampere transfer switches, as well as larger models with 20kW ratings manufactured by Kohler. the required generator must have the following further specifications:

- Safety enclosure capsule in order to prevent wear and tear from weather related issues and reduce noise output
- Industrial grade alternator to ensure long life of the power plant.
- High performance controller to allow for greatert control over the plant in order to better plan performance hours in advance
- Long life (preferably greater than 30,000 hours)

The most suitable large scale natural gas power generation plant based on its ability to run for extended periods of time instead of only as a standby source is the SureSource 1500, a 1.4MW plant that runs on natural gas and is manufactured by FuelCell Energy, a subsidary of Exxon Mobil. The plant has an output of 1400kW and can operate contunously in the Texas climate. It has CO2 emissions lower than typical averages and can also serve as a combined heat cycle plant in order to supply hot water to consumers [60]. It has demonstrated its ability to power the University of Bridgeport in the past, which is a similar campus style area as Camp Swift. Additionally, it is quiet and vibration free and therefore can be installed near residential areas. At Camp Swift, the following area was selected as possible location for installation of Natural Gas power plants and generators:

Figure 39: Natural Gas Generator Area Allocation

Financial Breakdown

Cost of Natural Gas Generator: the Energy Information Administration of the Department of Energy estimates that a Natural Gas Combined Cycle (NGCC) plant typically costs close to $1000 per kW in overnight capital costs. This includes the costs associated with purchase and transportation [61]. This also includes costs associated with installation along with necessary surveys of location and site quality done beforehand. Since plants such as these are utility grade, they also include price of flue gas desulfurization equipment and catalytic converters. For the purpose of this study, since the costs associated with carbon emissions are taken into account separately, carbon capture equipment is not counted in the cost of the generator.

1. Soft Costs: Soft costs associated with a natural gas generator are typically the cost of installation along with costs associated with installation of storage tanks in order to store compressed natural gas for autonomous days of use. This is estimated to be about $100, included in the per kW cost mentioned in the above section.
2. Maintenance and Operation Costs: It is estimated that a typical combined cycle plant has relatively low maintenance costs. The EIA estimates that it costs $11 per kW-year in fixed O&M costs along with another $3.5 per MWh in maintenance per unit MWh produced [61]. Furthermore, the cost of Natural Gas fuel is set at $3.00/cubic-ft, which is predicted to be stable over the next few years as shown in the chart below:

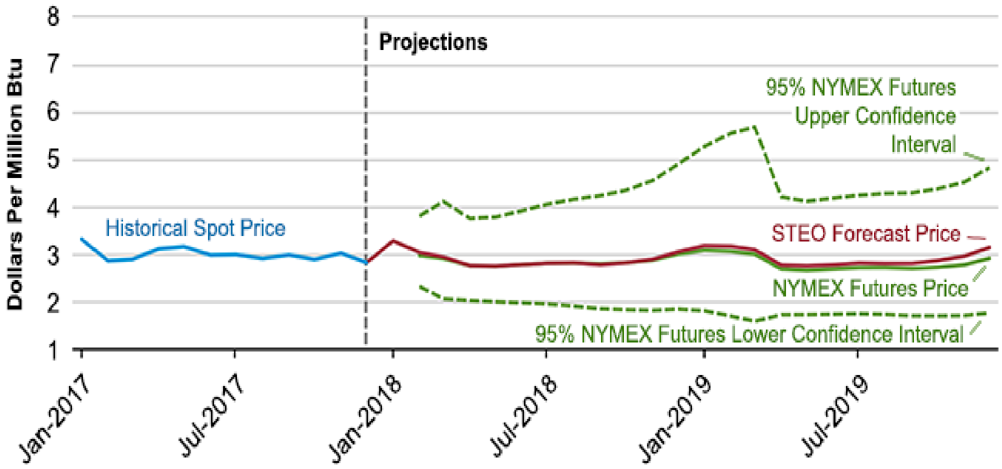
   

   Figure 40: Natural Gas Price Projections. Reprinted from [62].

   Fuel cost for a Natural Gas plant is estimated at $0.025 per kWh based on 2016 averages by the Energy Information Administration [63].

3. Carbon Emission Costs: a typical natural gas combustion plant is slated to contribute 117lbs of CO2 equivalent to the environment for every kWh produced. This is equivalent to $0.00034 in emissions costs for the plant based on previously summarized cost of carbon [64].

For this study, the above totals have been summed up as follows:

Fixed Costs: $1000/kW

Running Costs: $0.026/kWh

Emissions Costs: $0.00034/kWh

Biomass Generator

Description

Biomass generators work in a manner similar to existing combustion based generators where the fuel (in this case, specialized biomass) is burnt to heat water and the resulting steam is used to turn a turbine connected to a generator. Typical biomass generators work on particular types of fuels such as wood chips and terrified biomass. This fuel is stored in available storage tanks and is already when purchased. For the purpose of this study, only gasification of biomass and its subsequent use as a fuel source is considered. Gasification refers to the process by which wood and other similar biomass materials are gasified by reacting it at high temperatures with a controlled and limited amount of oxygen and steam in order to form syngas (synthetic gas) which can be used as a fuel. Biomass has a variable calorific value based on type of plant source and moisture content. This is primarily because of the different composition of carbon and oxygen in the biomass than comparable fuel sources like coal. The graph below shows the difference in calorific value of biomass types:

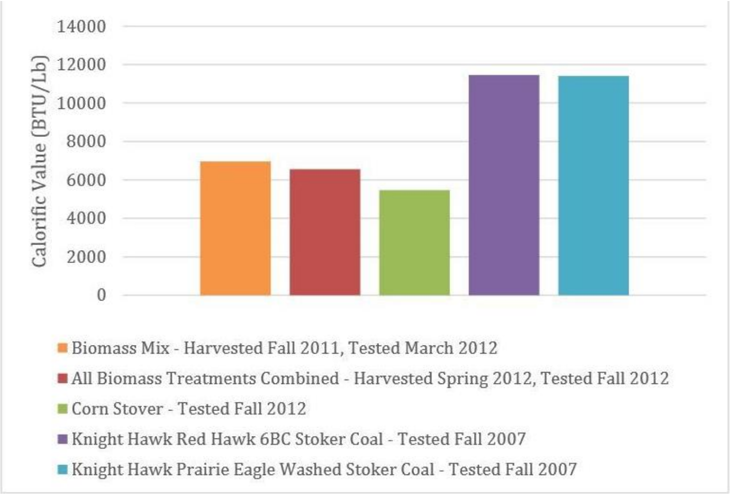


Figure 41: Calorific Content of Fuels. Reprinted from [65].

Of these, biomass mix is the most suitable fuel source as it allows for greater flexibility in type of wood fed into the system. Typical biomass generators are also combined heat and power (CHP) systems which allow for greater efficiency by also producing hot water for consumption. However, this study only looks at the electricity production as a result of biomass burning. For a CHP system, the major components are as follows:

- Fuel storage – this is imperative to a biomass generator as biomass needs to be stored at specific temperature and moisture values in order to enhance life.
- Combustion chamber – this is the enclosed, pressurized chamber that is used to combust gasified biomass at high temperature
- Boiler – heat produced by the combustion chamber is used by the boiler to turn water to steam at high temperature and pressure. This steam is then pumped to the next stage.
- Steam turbine – steam turbines are placed in the path of pumping steam at high temperature and pressure. The steam is able to turn these turbines and a mechanical shaft connected to the turbine turns a magnet within an induced electromagnet in order to allow for the induction of current that is then supplied out.

- Cooling tower/condenser – typically, these are used to release heat from steam into colder water pipes that can be used to supply residential areas

The above stated design of a typical biomass CHP is shown below:

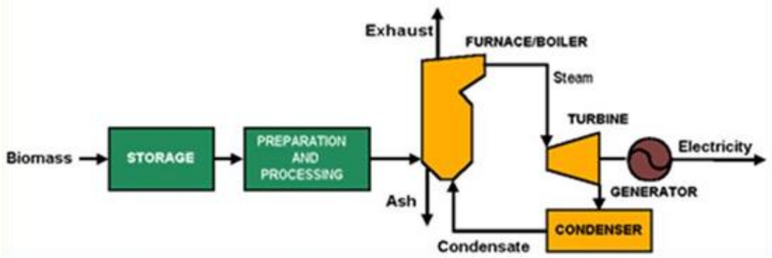


Figure 42: Direct Combustion/ Steam Turbine. Reprinted from [66].

Model Comparison

For the purposes of this study, only biomass generators with smaller than utility scale sizes were looked at. The availability of excess wood from abundant pine trees makes woody biomass the most relevant source of fuel.

Financial Breakdown

1. Cost of Biomass Generator: it is estimated that the cost of a typical biomass generator varies between \$3000 and \$4000 per kW of installed cost. [66].
2. Soft Costs: a major problem with installation of a biomass plant is the availability of a dry fuel source. It is estimated that moisture in biomass varies from 10% to 60% and has a direct impact on the amount of energy receivable from the source. This is converted in net dollars per GJ of energy and plotted below:

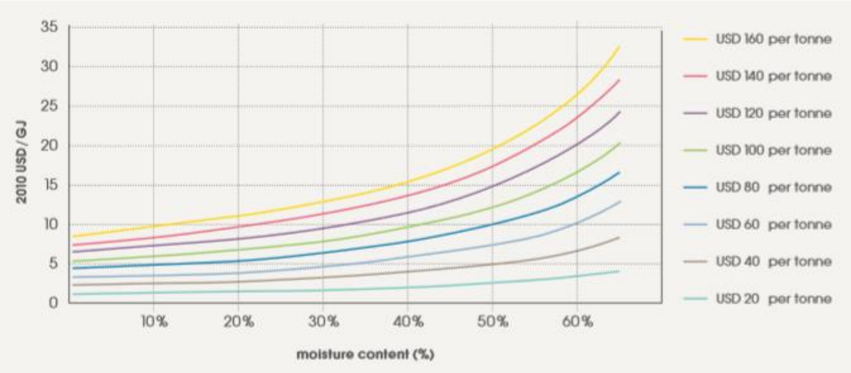


Figure 43: Cost of Biomass Fuel. Reprinted from [58].

In order to keep the costs low, investment is to be done in ensuring moisture free retention of stored biomass for autonomy of the system. This is slated to cost about 20% of the capital cost of the plant stated above. Other soft costs like survey of site and civil engineering associated with it and the consultancy fee for designers of the power plant can be summed up at about 30% of the actual capital required [58].

3. Maintenance and Operation Costs: IRENA estimates that the fixed Operations and Maintenance cost of a biomass boiler and associated equipment stands at about 5% of the capital cost of the plant. Additionally, annual maintenance and repairs along with cleaning of moving parts is slated to cost up to $15 per MWh in total, which translates to about $0.016 per kWh of electricity produced [58]. In addition to this, fuel for this sort of technology costs between $10 and $50 per tonne which translates to an estimated kWh which can be estimated at about $0.025 per unit of electricity produced.
4. Carbon Emission Costs: While it is estimated that burning wood to create electricity will produce about 213 lbs. of CO2 equivalent carbon per kW, this number is different from other fuel sources because of the renewable nature of this fuel source. If carbon accounting is done over a 20-year lifetime, the wood source is expected to

regrow and the amount of carbon released will be sequestered into the soil once again. Given that, the amount of CO2 released per kWh by burning biomass is taken as $0.0008989/kWh in order to keep up consistency with the other fuel sources.

For this study, the above totals have been summed up as follows:

Fixed Costs: $3500/kW

Running Costs: $0.041/kWh

Emissions Costs: $0.0008989/kWh

CHAPTER VI

RESILIENCE

Resilience in energy is defined for the sake of this argument as the ability of the system to adjust to a lack of access to a source of energy without adding another source. The U.S Climate Resilience toolkit mandates that the benefits from building energy resilience by introducing redundancy in the generation facilities is key to securing energy sources in the event of an untoward weather incident. It is therefore recommended that the following steps be taken into account when Energy Resilience (ER) is calculated within the scope of this study:

1. Improve supply chains by diversifying sources to address multiple types of disruptions
2. Increase redundancy into generation facilities in order to ensure continued operation
3. Improve reliability of the system by installing backup power supply, intelligent controls and moving the infrastructure to a smart/micro grid structure.
4. Increase use of low water usage electricity generation facilities like solar and wind
5. Strategically place generation facilities in order to protect against weather related dangers
6. Add peak generation and multiple forms of energy storage
7. Add regional fuel types and sources in order to reduce disruptions in the fuel supply chain
8. Improve demand response capabilities of energy infrastructure by collecting better datasets and using them to improve electricity dispatch

[67]

One of the key parameters hindering accurate implementation of a more resilient energy infrastructure is the lack of key performance measuring parametric to measure and quantify existing infrastructure and its resilience to weather along with the ability to accurately measure any slated improvements. For this reason, this study proposes the following measuring scales to score and quantify energy resilience of a system:

Basic Constraints

The score will be within a 0 to 1 range, with 0 referring to complete reliance off the grid.

All solutions are assumed to be completely off-grid with the grid itself being a backup source.

Scoring mechanism is based on the availability of every marginal kWh of electricity

This study aims to achieve 5 days of standby power for every individual resource in addition to already increased overall system resilience

Scoring Mechanism

Key Variables

Variable	Description
G1	Electricity from Solar
G2	Electricity from Wind
G3	Electricity from Natural Gas
G4	Electricity from Biomass Generator
G5	Electricity from Diesel Generator
G6	Electricity from the Grid
S1	Storage for Solar - Electricity
S2	Storage for Wind - Electricity
S3	Storage for Natural Gas
S4	Storage for Biomass
S5	Storage for Diesel
S6	Storage for Grid - Electricity

RS1	Recommended Storage for Solar - Electricity
RS2	Recommended Storage for Wind - Electricity
RS3	Recommended Storage for Natural Gas
RS4	Recommended Storage for Biomass
RS5	Recommended Storage for Diesel
RS6	Recommended Storage for Grid - Electricity
NGU	Natural Gas Fuel Usage Per kWh
BU	Biomass Fuel Usage per kWh
DU	Diesel Fuel Usage per kWh
RFS	Resilience Factor Solar
RFW	Resilience Factor Wind
RFNG	Resilience Factor Natural Gas
RFB	Resilience Factor Biomass
RFD	Resilience Factor Diesel
RFG	Resilience Factor Grid

Methodology

Step 1: Estimate 5-day Energy Generation

5-Day Usage Solar	$\frac{\text{G1 x 5}}{365}$
5-Day Usage Wind	$\frac{\text{G2 x 5}}{365}$
5-Day Usage Natural Gas	$\frac{\text{G3 x 5}}{365}$
5-Day Usage Biomass	$\frac{\text{G4 x 5}}{365}$
5-Day Usage Diesel Gen	$\frac{\text{G5 x 5}}{365}$
5-Day Usage Grid	$\frac{\text{G6 x 5}}{365}$

Step 2: Calculate Storage for 5 Days

RS1	5-Day Usage Solar	kWh
RS2	5- Day Usage Wind	kWh
RS3	5-Day Usage Natural Gas / NGU	cubic-ft
RS4	5-Day Biomass Usage / BU	lbs.

RS5	5-Day Diesel Usage / DU	Gal
RS6	//	

Step 3: Calculate Resilience Factors

RFS	S1/RS1
RFW	S2/RS2
RFNG	S3/RS3
RFB	S4/RS4
RFD	S5/RS5
RFG	S6/RS6

$$\text{Overall System Resilience} = \\ (\text{RFS x G1}) + (\text{RFW x RS2}) + (RFNG\ x\ RS3) + (RFB\ x\ RS4) + (RFD\ x\ RS5) + (RFG\ x\ RS6)$$

Equation 2: Resilience

CHAPTER VII

OPTIMIZATION METHODS

Methodology 1

In order to calculate the overall cheapest source of electricity based on given values of running and carbon emissions costs, the following optimization problem was formulated:

Generation

G1	Electricity from Solar
G2	Electricity from Wind
G3	Electricity from Natural Gas
G4	Electricity from Biomass Generator
G5	Electricity from Diesel Generator
G6	Electricity from the Grid

Running Cost

RC1	Running Cost - Solar
RC2	Running Cost - Wind

RC3	Running Cost - Natural Gas
RC4	Running Cost - Biomass
RC5	Running Cost - Diesel
RC6	Running Cost - Grid

Emissions Cost

EC1	Emissions Cost - Solar
EC2	Emissions Cost - Wind
EC3	Emissions Cost - Natural Gas
EC4	Emissions Cost - Biomass
EC5	Emissions Cost - Diesel
EC6	Emissions Cost - Grid

Cost (Minimize)

$$\sum_{n=1}^{6} \mathrm{Gn} \text{ x } (\mathrm{RCn} + \mathrm{ECn})$$

Equation 3: Objective Function

Subject to:

$G1 + G2 + G3 + G4 + G5 + G6 \leq 1945009.43$

$G1, G2, G3, G4, G5, G6 \geq 0$

Equation 4: Constraints

Structure

The design of the system is composed of two different power carrying buses. The DC Bus is connected to DC sources of power and storage such as solar panels, while the AC Bus is connected to equivalent AC sources such as generators and turbines. Since the load to be supplied is AC, the AC bus is connected to the load by way of smart meters. Power output from the DC bus is supplied to an inverter in order to be converted into AC and used directly. The entire system is connected together according to the following design:

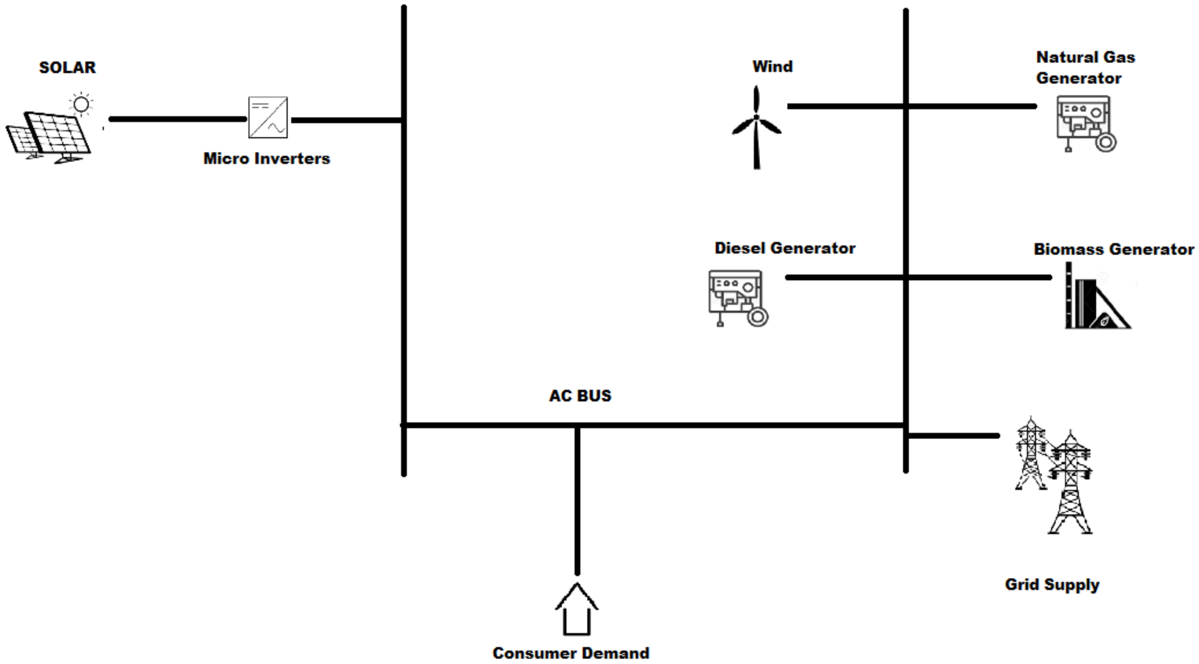


Figure 44: Overall System Design Initial

Simulation and Results

Upon formulation of the optimization problem, the solution was obtained after 24 runs using simplex linear programming algorithm. The results of the runs are presented below:

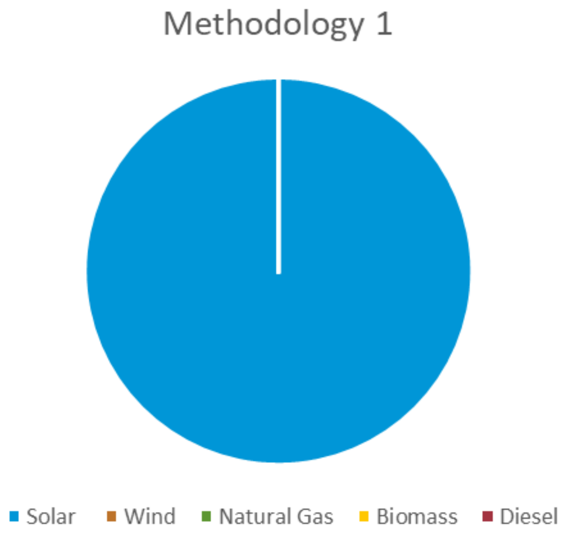


Figure 45: Methodology I

	Annual Generation
Solar	1945009.434
Wind	0
Natural Gas	0
Biomass	0
Diesel	0
Total	1945009.434

Table 7: Electricity Output I

The associated costs of this solution are summarized below

	USD (2018)
Total Cost	38901.09096
Running Cost	38900.18867
Emissions Cost	0.902289876

Table 8: Costs I

In order to enhance energy resilience, the following constraint was added:

G1, G2, G3, G4, G5, G6 $\leq$ 0.25 x 1945009.434

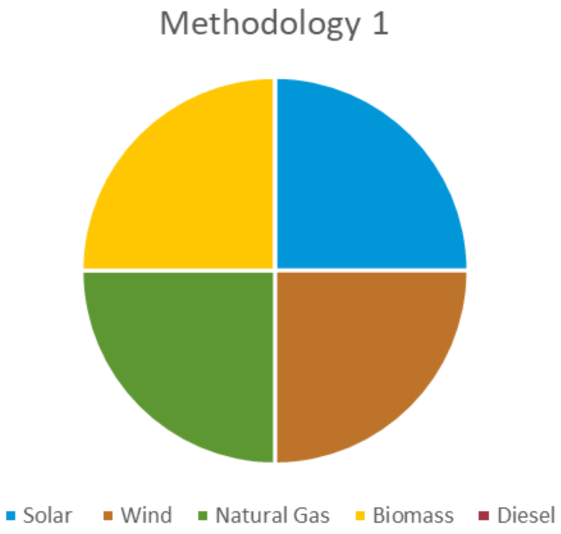


Figure 46: Methodology I Updated Output

The updated cost parameters are summarized below:

	USD (2018)
Total Cost	52631.79992
Running Cost	52029.00235
Emissions Cost	602.7975668

Table 9: Costs Updated

	Annual Generation
Solar	486252.3584
Wind	486252.3584
Natural Gas	486252.3584
Biomass	486252.3584
Diesel	1.16415E-10
Total	1945009.434

Table 10: Output Profiles

Methodology 2

To calculate the cheapest source of electricity based on cost of electricity (COE) after taking into account the equipment costs and maintenance expected, until the end of the 20-year usable life of the equipment, is formulated using the following optimization problem. The optimization problem allows for creation of storage facilities based on real world constraints on equipment costs and purchasing power. Additionally, in order to account for fixed costs associated with installation of relevant equipment, a recommended sizing method was adapted to effectively size generation facilities required. For fuel intensive generation sources, the amount of actual fuel used is calculated based on typical values of fuel used per unit kWh of electricity generated:

Generation

G1	Electricity from Solar
G2	Electricity from Wind
G3	Electricity from Natural Gas

G4	Electricity from Biomass Generator
G5	Electricity from Diesel Generator
G6	Electricity from the Grid

Running Cost

RC1	Running Cost - Solar
RC2	Running Cost - Wind
RC3	Running Cost - Natural Gas
RC4	Running Cost - Biomass
RC5	Running Cost - Diesel
RC6	Running Cost - Grid

Emissions Cost

EC1	Emissions Cost - Solar
EC2	Emissions Cost - Wind
EC3	Emissions Cost - Natural Gas
EC4	Emissions Cost - Biomass

EC5	Emissions Cost - Diesel
EC6	Emissions Cost - Grid

Fixed Costs

FC1	Fixed Cost - Solar
FC2	Fixed Cost - Wind
FC3	Fixed Cost - Natural Gas
FC4	Fixed Cost - Biomass
FC5	Fixed Cost - Diesel
FC6	Fixed Cost - Grid

RS1	Recommended Storage for Solar - Electricity
RS2	Recommended Storage for Wind - Electricity
RS3	Recommended Storage for Natural Gas
RS4	Recommended Storage for Biomass
RS5	Recommended Storage for Diesel

RS6	Recommended Storage for Grid - Electricity
S1	Storage for Solar - Electricity
S2	Storage for Wind - Electricity
S3	Storage for Natural Gas
S4	Storage for Biomass
S5	Storage for Diesel
S6	Storage for Grid - Electricity

In order to apply real world considerations to storage facilities, storage facilities are limited at the following values:

Storage:	Storage Design	
Solar	280	KWh
Wind	280	NA
Natural Gas	5203.981028	Gallons
Biomass	4803.673632	Lbs
Diesel	5000.000005	Gallons

Table 11: Storage Design

To calculate fuel used for natural gas, biomass and diesel generators, the average fuel usages per unit of electricity were utilized. For every generation source, recommended storage was compared with the limits above and the most cost-effective storage option was chosen. The costs associated with the above-mentioned storage sources are as follows:

Storage:		Price		
Solar	P1	392.8571429	/kWh	Tesla
Wind	P2	392.8571429	/kWh	Tesla
Natural Gas	P3	1.636363636	Gallon	Tank
Biomass	P4	0.0034	Lbs	Shed
Diesel	P5	1.636363636	Gallon	Tank
Grid	P6	//	NA	NA

Table 12: Storage Pricing

In order to design the size of the generation facilities required, the availability of resources in Texas is taken into account. Typical availability values used are as follows:

Solar – 5.5 hours daily (Equivalent Peak Sunshine Hours)

Wind – 25% effective availability

Biomass – 100% availability

Natural Gas – 100% availability

Diesel – 100% availability

Grid – 100% availability (not counted in solution)

The above stated values are taken into account to formulate design specifications for generation facilities in kW using the following formulae:

C1	Capacity - Solar	G1/[365 x 24 x (5.5/24)]
C2	Capacity - Wind	G2/[365 x 24 x 0.25]
C3	Capacity - Natural Gas	G3/(365 x 24)
C4	Capacity - Biomass	G4/(365 x 24)
C5	Capacity - Diesel	G5/(365 x 24)
C6	Capacity Grid	99999999

Table 13: Capacity Calculations

The designed capacity is in kWh.

Cost

(Minimize)

$$\sum_{n=1}^{6} [\mathrm{Gn} \times (\mathrm{RCn} + \mathrm{ECn})] + [\mathrm{Cn} \times \mathrm{FCn}] + [\mathrm{Sn} \times \mathrm{Pn}]$$

Equation 5: Cost Function

Subject to:

$G1 + G2 + G3 + G4 + G5 + G6 \leq 1945009.43$

$G1, G2, G3, G4, G5, G6 \geq 0$

Equation 6: Constraints

Structure

The structure is designed according to the following diagram:

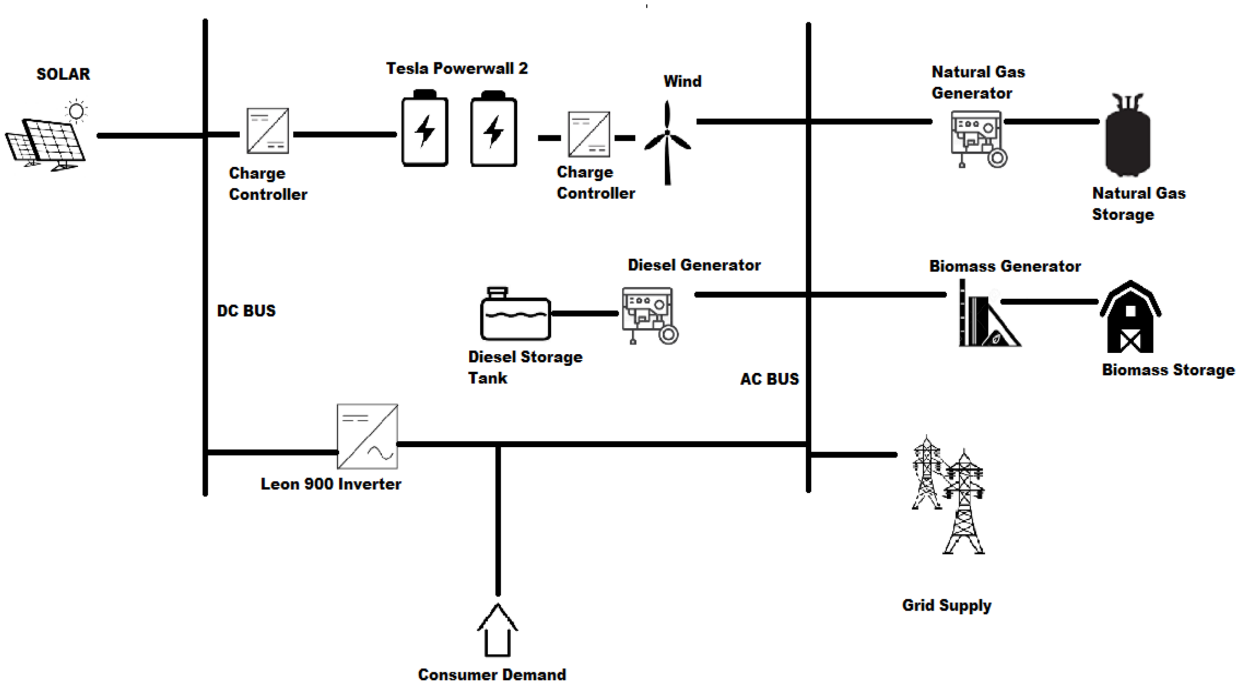


Figure 47: Overall System Design Updated

Simulation and Results

Upon formulation of the optimization problem, the solution was obtained after 24 runs using non-linear programming algorithm. The results of the runs are presented below (in kWh annually):

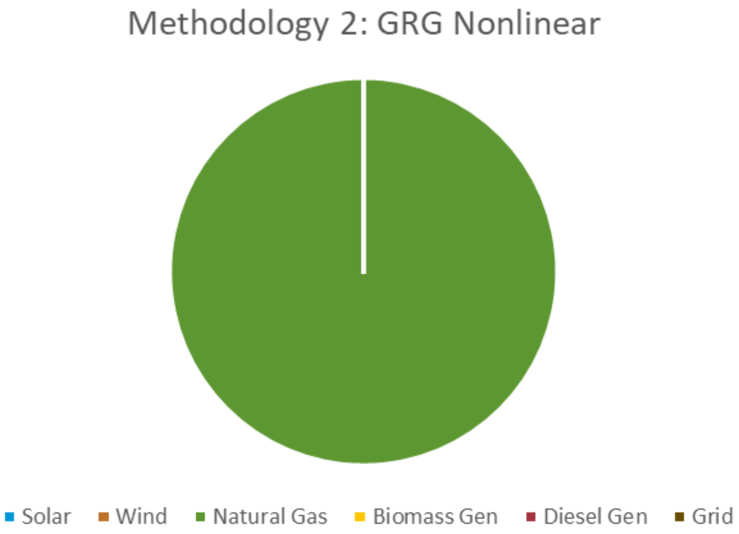


Figure 48: GRG Nonlinear Results

Source	Generation
Solar	**0**
Wind	**3.63798E-12**
Natural Gas	**7812781.2**
Biomass Gen	**0**
Diesel Gen	**0**
Grid	**0**

Table 14: Output Profile II

The associated costs and resiliency factor are shown below:

Total Cost	1185149.9	USD (2018)
Running Cost	78127.812	USD (2018)
Emissions Cost	3468.8749	USD (2018)
Fixed Cost	891870	USD (2018)
Storage Cost	16363.636	USD (2018)
Resiliency Factor	**0.0467183**	
Generation Capacity	891.87	kW
Days of Cover	0.2335916	

Table 15: Overall System Costs and Resilience

Based on the predetermined resilience scoring criteria, the overall system resilience of this system translates to a score of 0.0467 which is equivalent to a storage capacity of 0.23 days for the entire system. This is in addition to the in-built resilience as a result of inbuilt resilience due to reliance on self-generation. The resilience factor is low. To increase the resilience of the system to one day of cover, the following parametric restraint is applicable:

$$(RFS \times G1) + (RFW \times G2) + (RFNG \times G3) + (RFB \times G4) + (RFD \times G5) + (RFG \times G6) > 0.2$$

Equation 7: Resilience Constraint

In 24 simulations using GRG nonlinear optimization algorithm, the following average result was obtained:

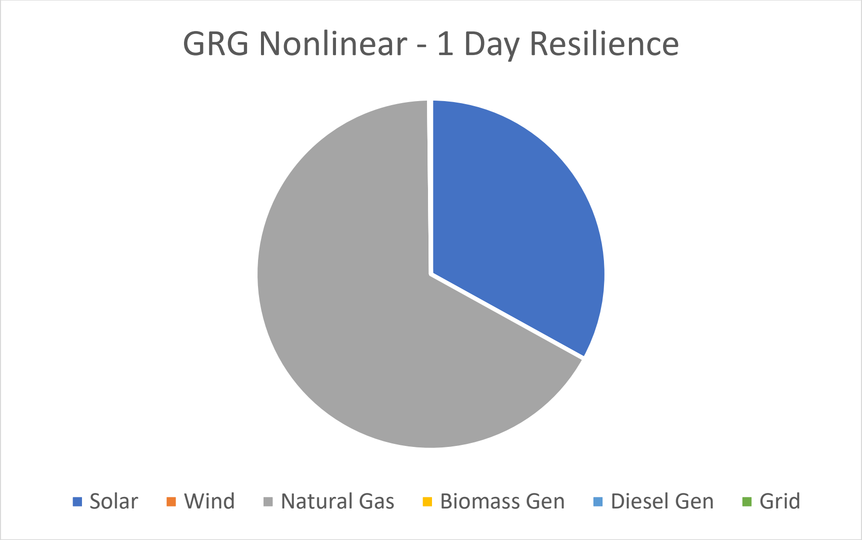


Figure 49: GRG Nonlinear Result – 1 Day Resilience

Solar	**1222392.075**
Wind	**0**
Natural Gas	**2472376.704**
Biomass Gen	**0**
Diesel Gen	**6329.980716**
Grid	**0**
Total	**3701098.76**

Table 16: Output Profile (kWh)

This solution corresponds to over generated electricity equivalent to 1756089.326 kWh annually due to which associated costs are higher than expected, as shown below:

Total Cost	2450086.1	USD (2018)
Running Cost	49234.908	USD (2018)
Emissions Cost	1103.0427	USD (2018)
Fixed Cost	2195015.3	USD (2018)
Storage Cost	142727.27	USD (2018)
Resiliency Factor	0.2000001	
Generation Capacity	891.87	kW
Days of Cover	1.0000003	

Table 17: Overall Output Profile

The required capacity for individual sources based on the above-mentioned methodology is automatically calculated and is shown in the following chart:

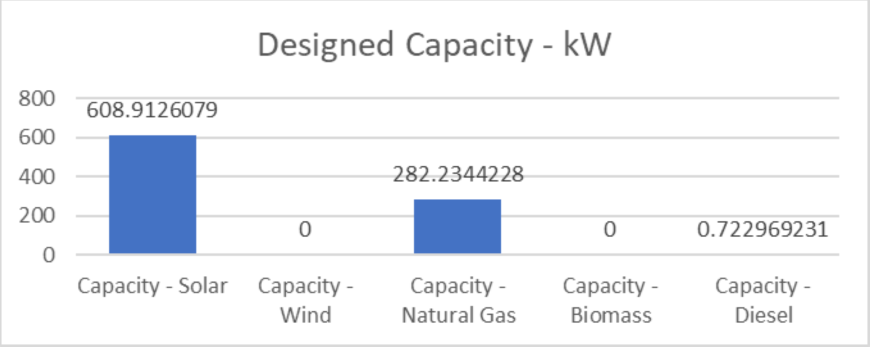


Figure 50: Designed Capacity

The same solution, when optimized for electricity generation taking into account potential sellback to the grid for 12 cents per kWh results in the following design:

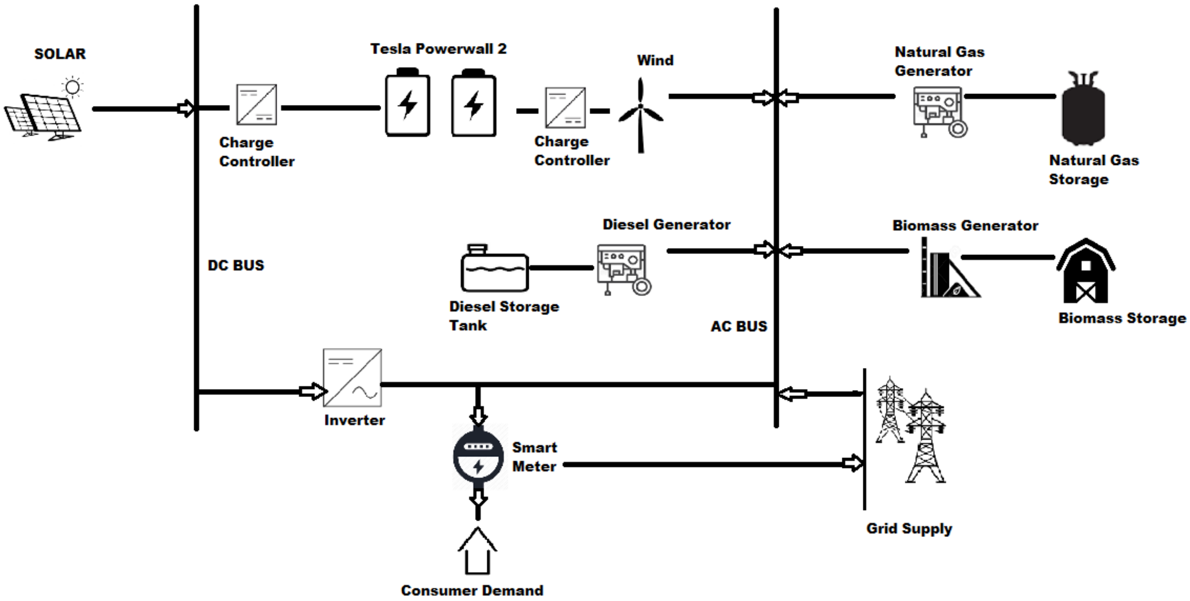


Figure 51: Overall System Structure III

This corresponds to the following solution when optimized based on Non-Linear algorithm:

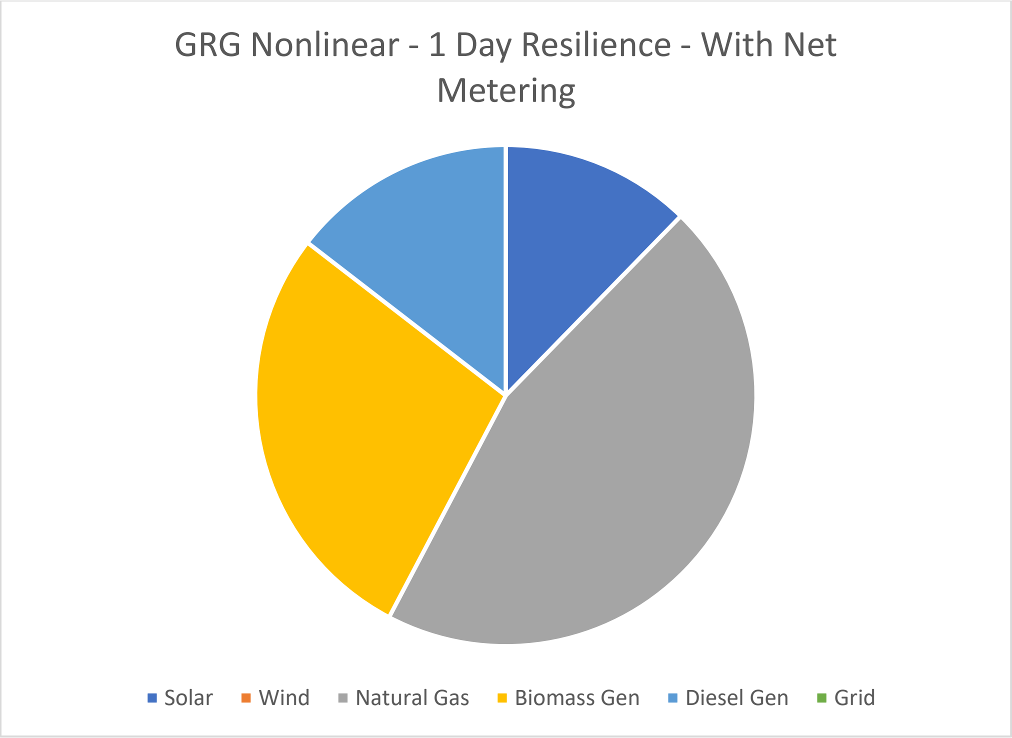


Figure 52: GRG Nonlinear – 1 Day Resilience with Net Metering Output

The corresponding kWh values are shown below:

Solar	**679816.7326**
Wind	**0**
Natural Gas	**2509734.667**
Biomass Gen	**1533002.184**
Diesel Gen	**803571.3337**
Grid	**0**
Total	**5526124.918**

Table 18: Output Profile GRG Nonlinear

This solution minimizes cost of electricity by over-generating electricity by about 3581115.484 kWh annually in order to sell the surplus at a net amount equal to USD 465545.0129. The other associated costs are shown in the following table:

Total Cost	2661879.5	USD (2018)
Running Cost	62059.417	USD (2018)
Emissions Cost	3816.2088	USD (2018)
Fixed Cost	2325730.5	USD (2018)
Storage Cost	142761.27	USD (2018)
Resiliency Factor	0.1999991	
Generation Capacity	891.87	kW
Days of Cover	0.9999955	

Table 19: Overall System Cost and Resilience Output

The associated generation capacities required are as follows:

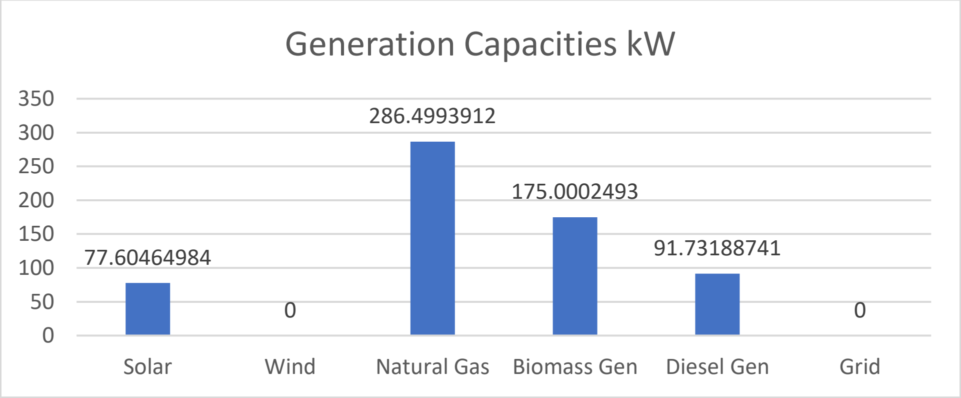


Figure 53: Designed Generation Capacity

In order to increase resiliency further by restricting generation sources from overshadowing other sources, one generation source is forbidden from producing over 25% of the total annual requirement of the base by adding the following constraint:

$$G1, G2, G3, G4, G5, G6 < 0.25 \times (1945009.43)$$

Equation 8: Resilience Constraint II

This results in the following energy generation profile:

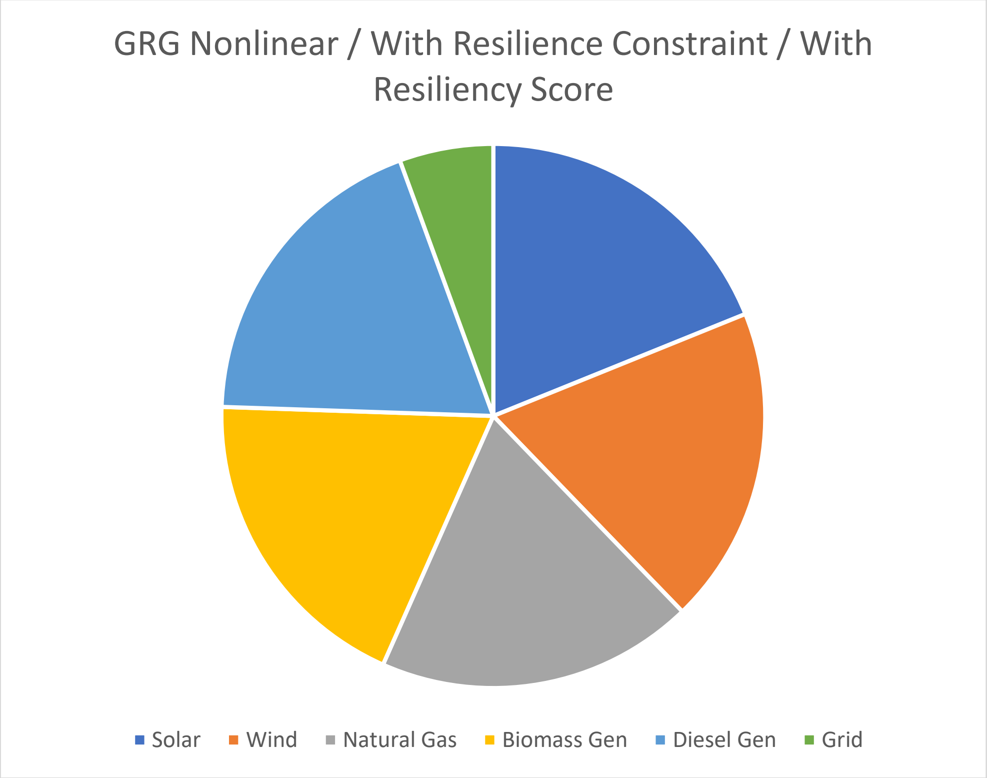


Figure 54: GRG Nonlinear with Resilience Constraint and Resiliency Score

The costs associated with this generation profile are summarized below:

Source	KWh Generation
Solar	**486252.3584**
Wind	**486252.3584**
Natural Gas	**486252.3584**
Biomass Gen	**486252.3584**
Diesel Gen	**486252.3584**
Grid	**143782.8623**
Total	**2575044.654**

Table 20: Output Profile

Total Cost	2278787.8	USD (2018)
Running Cost	34181.448	USD (2018)
Emissions Cost	1515.4373	USD (2018)
Fixed Cost	1931788.4	USD (2018)
Storage Cost	252738.06	USD (2018)
Resiliency Factor	0.3363881	
Generation Capacity	630.77568	kW
Days of Cover	1.6819405	
Net Metering Sellback	-47723.131	USD (2018)

Table 21: Output Profile with Costs and Resiliency Score

The algorithm suggests the following generation capacities in order to achieve this solution:

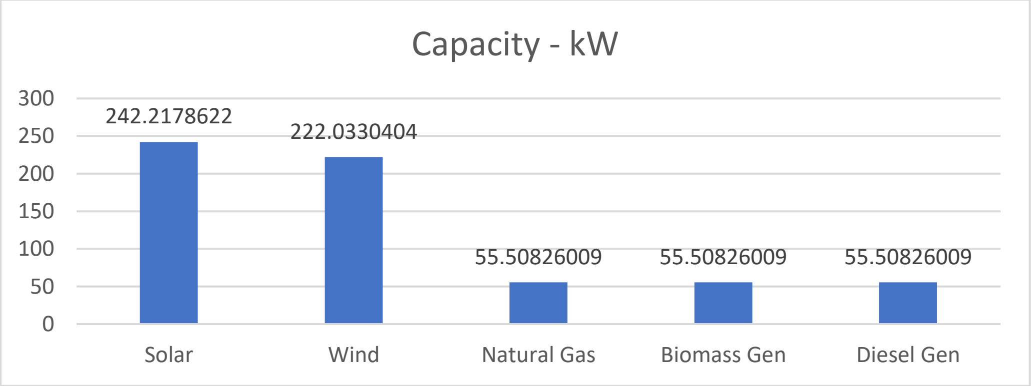


Figure 55: Overall System Capacity

CHAPTER VIII

COST OF ELECTRICITY

The levelized cost of electricity is defined as economic cost of one unit of electricity based on economic predictions and electrical generation values over the lifetime of the generation. This takes into account the cost of maintenance, replacements, equipment and inflation based on existing discount rates. The Levelized Cost of Electricity can be calculated using the following simplified formula:

$$\frac{\sum_{t=1}^{n} \frac{\mathrm{Ft} + \mathrm{Mt} + \mathrm{Rt} + \mathrm{Et}}{(1 + \mathrm{r})^{\mathrm{t}}}}{\sum_{t=1}^{n} \frac{\mathrm{Gt}}{(1 + \mathrm{r})^{\mathrm{t}}}}$$

Equation 9: Lifecycle Cost of Electricity

Ft = Fixed Costs in year t (including financing) (USD)

Mt = Maintenance Costs in year t (USD)

Rt = Running Costs in year t (USD)

Et = Emissions Costs in year t (USD)

Gt = Electricity generated in year t (kWh)

R = Discount rate

N = Life of the system (Years)

[68]

Based on the above mentioned parametric, the cost of electricity associated with each of the above used optimization methods is as follows:

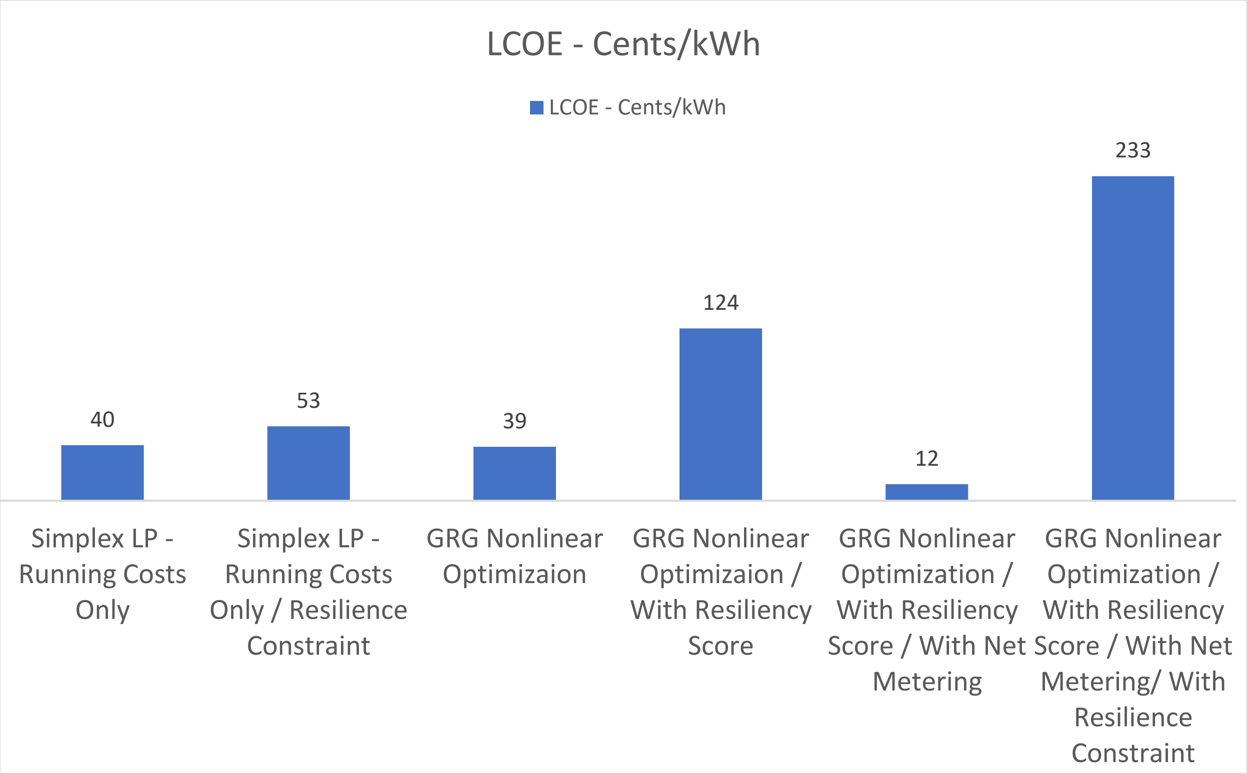


Figure 56: LCOE Comparison

CHAPTER IX

HYBRID OPTIMIZATION SOFTWARE

The above-mentioned optimization problem can be formulated using professional hybrid optimization software HOMER Pro version 3.11.5. The design of the system is kept constant using the following diagram:

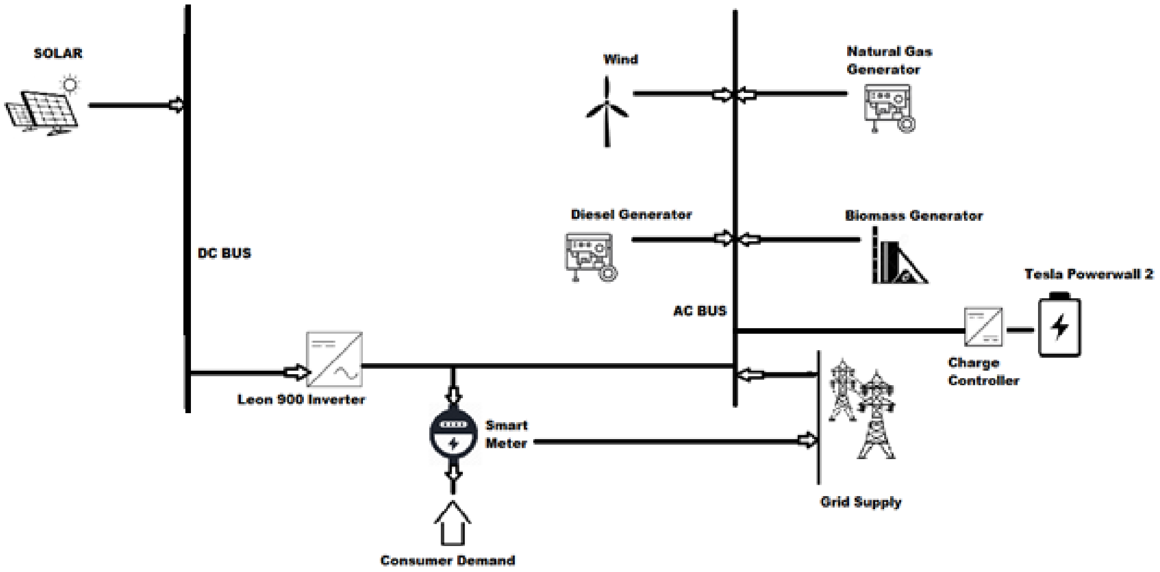


Figure 57: Overall System Design Structure III

For the particular components of the system, the following design parameters were adopted:

1. Solar: Auto-sized based on previously stated values of fixed and maintenance costs. Emissions Costs discounted as HOMER does not allow conversion into dollar amount from lbs. of CO2 equivalent. Solar irradiance based on inbuilt weather maps of Camp Swift.
2. Wind: 13kW Wind turbine model used. Wind Speed based on inbuilt weather maps of Camp Swift. Wind Speed over 5m/s discounted to ensure accuracy of results.

3. Charge Controller: Auto-sized
4. Inverter: Leon 900
5. Diesel Generator: Fixed 830kW standard model inbuilt in HOMER Pro. Diesel price set at $0.80/gal in order to ensure generic pricing compared to earlier models.
6. Natural Gas Generator: 200kW Generic Natural Gas Generator inbuilt in HOMER Pro. Natural Gas fuel price set at $3.00 per cubic-ft to ensure same pricing model.
7. Biomass Generator: 100kW Generic Generator used. Biomass prices kept same as previous methodology.
8. Storage (Tesla Powerwall 2 Only): 187kW (system recommended), pricing kept same as previous methodologies
9. Consumer demand kept constant at 1945009.43kWh/year and 5500kWh/day.
10. Discount rate is kept constant at 2.5% throughout the simulation.

Simulation and Results

Upon optimization in HOMER Pro, 285 feasible solutions were obtained. Of these, solutions with wind speed more than 8m/s are filtered out. The Cost of Electricity (CoE) calculated by HOMER Pro over a 20 year period is shown below for the relevant solutions:

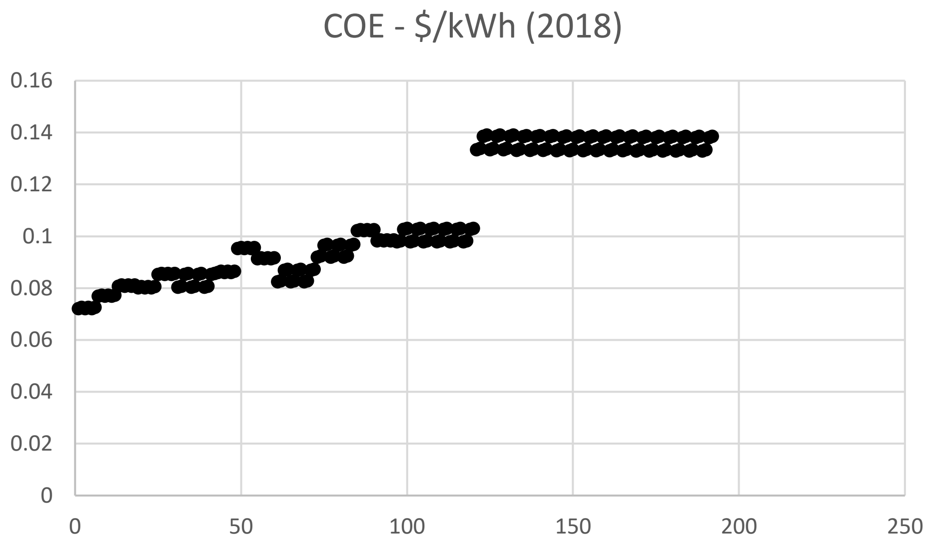


Figure 58: Cost of Electricity - HOMER

The lowest cost of electricity for a solution with the least reliance on the grid turned out to be 7.209 cents per kWh. This solution is most optimal and is therefore utilized here. The total amount of energy produced by the system was calculated to be 2121013.13 kWh. In addition to this, HOMER chose to buy 284771.1 kWh from the grid at 13 cents per kWh, and also sold 189246.2 kWh of energy back to the grid at 12 cents per kWh. The net usage of electricity from the grid stood at 95524 kWh per year. The overall breakdown of energy produced by different generation sources is shown in the diagram below:

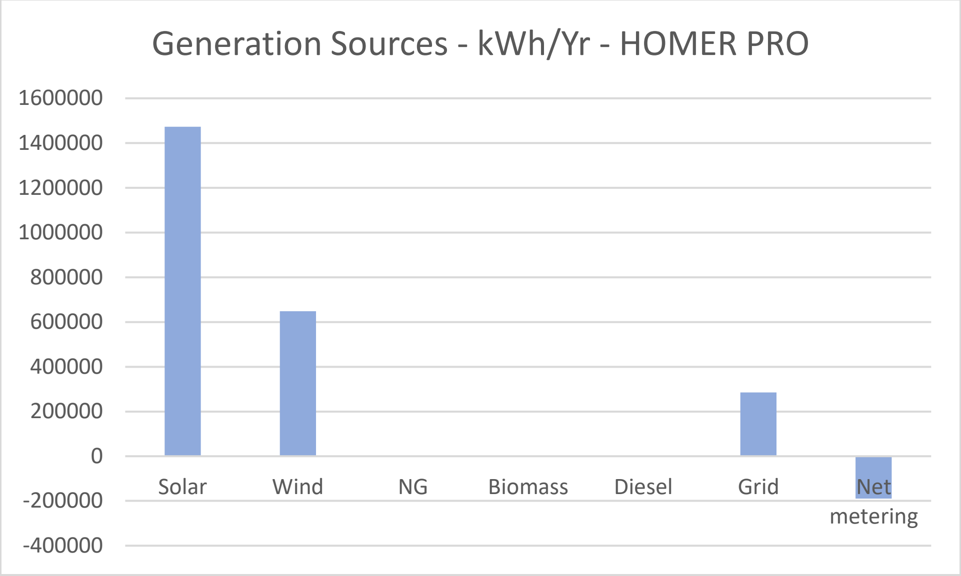


Figure 59: Generation Output Profile – HOMER

HOMER was able to optimize the generation capacity for different sources as well. The optimal solution was provided with the following system sizes:

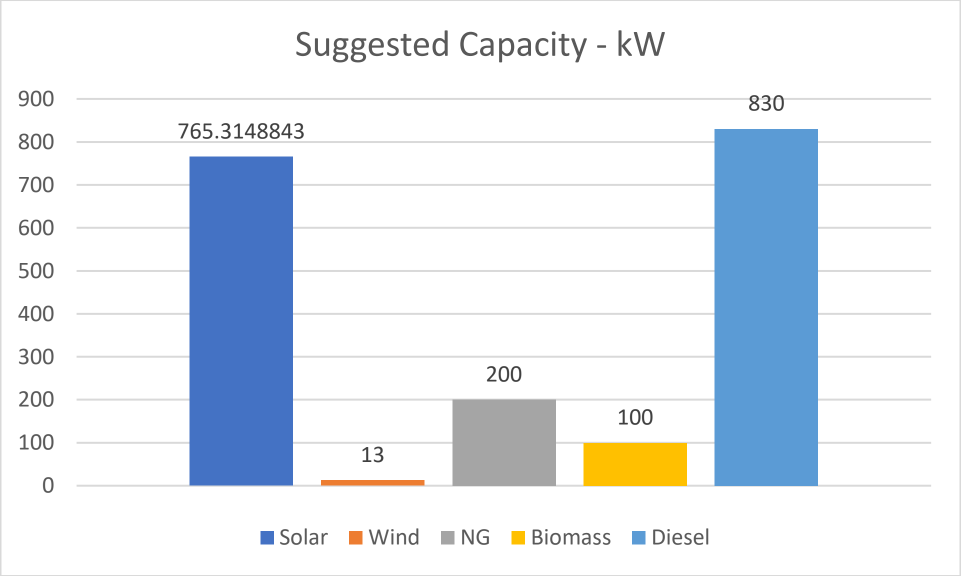


Figure 60: Suggested Capacity – HOMER

However, based on the actual use case scenario, the system calculated the optimal sizes without natural gas, biomass and diesel generators. These are presented below:

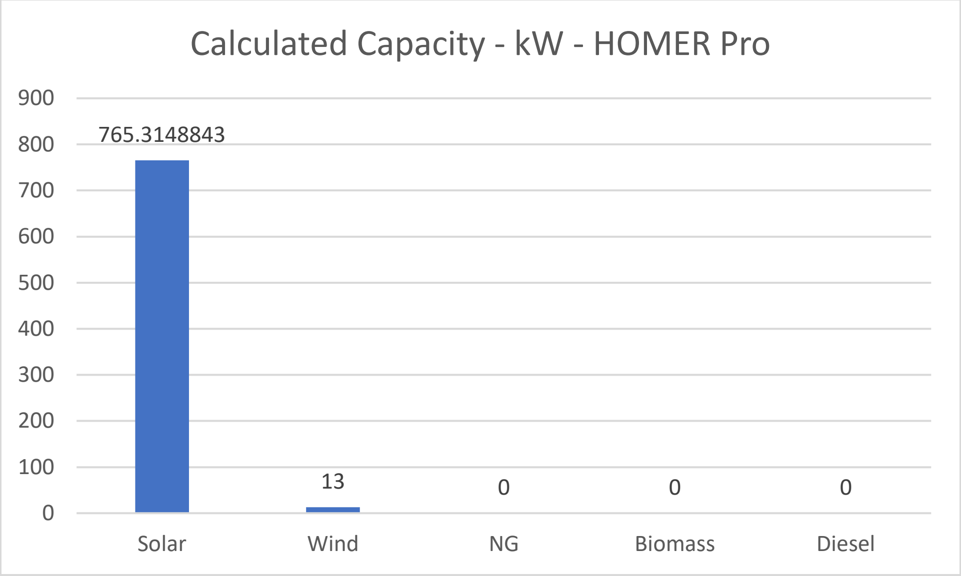


Figure 61: Calculated Capacities – HOMER

While the system capacity was much higher, HOMER did not use any Natural Gas, Biomass or Diesel for electricity generation. This solution presented an overall renewable percentage of 86.65% with the amount of CO2 being emitted standing at less than $1 per year due to solar and wind, and $166 due to the grid. The system uses Tesla Powerwall 2 for storage of upto 187kWh of electricity. This is able to provide only 12 seconds of power (on average) if the entire system is cut off from all generation sources.

CHAPTER X

SCOPE OF FUTURE WORK

In the future, this research will focus on reducing the snapshot time of the optimization problem. By reducing the optimization window, electricity dispatch will be calculated on hourly basis. This opens up the opportunity to use data collected over several months and years to predict electricity demand in the future based on common parameters associated with electricity such as the impact of weather conditions, time of the day / year as well as number of occupants. For this purpose, a test data collection rig needs to be built to allow for accurate measurement and data logging over a long period of time. Additionally, post data collection, more advanced techniques can be applied to predict demand than traditional manual methods. These involve statistical methods such as prediction based on extrapolation of the line of best fit or similar curves, as well as the application of Markovian models to predict data in the future. Another possible alternative is the use of Machine Learning to predict data using both supervised and unsupervised learning against actual data in order to reduce errors along progression. The use of these methods can also predict electricity generation from facilities alongside the above-mentioned demand prediction. By accurately predicting demand and supply, the research can lead to a smart-grid that allows for decent lookup times in order to provide sufficient lead time for starting and stopping various electrical generation (or consumption) points to minimize cost of electricity.

Furthermore, where the current model takes into account costs and availability at the level of generation only, it is also proposed to expand this to the preferred sources of energy. This can be used to allow for sufficient lead time to ensure accurate delivery of fuel sources, thereby reducing reliance on storage options and widening a possible choke point in the supply chain.

Lastly, this researcher proposes a simultaneous optimization study to take into account physical location of the generation and consumption sources to ensure application of shortest path algorithms such as Dijkstra’s which will ensure greater resilience and efficiency for the whole system. This involves dividing the grid into various nodes and assigning accurately predicted values of electricity supply as constrained by demand related factors. This optimization should also take into account the structural integrity of the generation systems as a function of their physical location as well.

CHAPTER XI

CONCLUSION

The problems faced by the Texas Military Department, with regards to energy security warrant diversification of electricity generation sources and increasing the overall system resilience by adding more redundancy in the form of storage, along with the ability of the system to operate reliably when completely detached from the system. The addition of more generation sources needs to be done on-site, so that the military campus can function in the form of a microgrid. The choice of energy resource must depend on overall cost-effectiveness and should also make an attempt at increasing the overall renewable energy percentage of the system in an attempt to reduce greenhouse gases. Owing to these renewable energy sources being intermittent in nature, storage options must be considered, along with greater reliance on more reliable energy sources such as biomass and natural gas. For this, storage methods different from electrical storage must be considered and optimized over time to account for resiliency of the system. The approaches mentioned and discussed in this study are part of multiple possible optimization techniques that can be used to further develop microgrids as possible improvements to existing grid structures. The grid designed in this study targets the electricity consumption of Camp Swift on an annual basis. Of the various methodologies and systems studied above, the nonlinear optimized solution with inbuild resiliency score constraint along with possible net metering options allowing it to sell back to the grid is the cheapest and therefore most cost effective. It affords an overall renewable energy percentage of 40% which is higher than the state average of 18%. By using Biomass and Natural Gas in conjunction with Solar and a Diesel Generator, the system is able to produce 5.5 million kWh of electricity against annual demand of less than 2 million kWh which can be used to sell electricity back to the grid in the event of a grid failure or via net metering enabled smart meters. This results in a total cost of about 2.7 million USD out of which about 62000 USD is kept for running costs while 2.33 million USD is the expected cost of setting up this grid. The system averages out at an emissions cost of 3816 USD in terms of environmental damage caused, which is equal to approximately 132 tons of CO2 equivalent in terms of greenhouse gas emissions. The resiliency score of this solution stands at about 0.2 which is equivalent to one day of overall production cover. The total generation capacity of the system is calculated as 891.87 kW of electricity. The system is designed to function constantly throughout the day, with dispatch being in the form of 24 hourly function instead of fixed hours of the day. In the case of renewables such as solar and wind, the availability factor has already been taken into account while designing the individual capacity of the system.

Additionally, resilience cannot be defined as an abstract phenomenon and warrants a scoring mechanism that allows for comparison between combinations of generation and storage options in order to increase overall resilience. The approaches used in this study with regards to scoring energy resilience are robust and account for measurement in terms of the ability of the system to withstand complete cutoff from the national grid. Resilience has been measured on a scale of 0 to 1 with 0 corresponding to no storage and 1 corresponding to enough overall system electricity and fuel storage to allow for one day of electricity generation. This is in addition to the already 100% off-grid generation structure of this microgrid. At all points, access to the grid is kept available to allow for additional backup options while also ensuring electricity selloff to the grid. While actual figures related to net metering were outside the scope of this study, at all times, sellback price was kept lower than purchase price for electricity from the grid. It is evident that the system relies more on overgeneration from sources of electricity that are cheaper than the market in order to increase profitability in the system overall.

In the cost analysis over the lifecycle of the project, it has been observed that the system is impacted more by the fixed cost of installing a major generation unit than the running costs and emissions costs. On average, the Lifecycle Cost of Electricity (LCOE) is impacted by fixed costs about 15 times more than the emissions and running costs. Of a single dollar spent towards this electricity, the estimated breakdown is shown in the chart below:

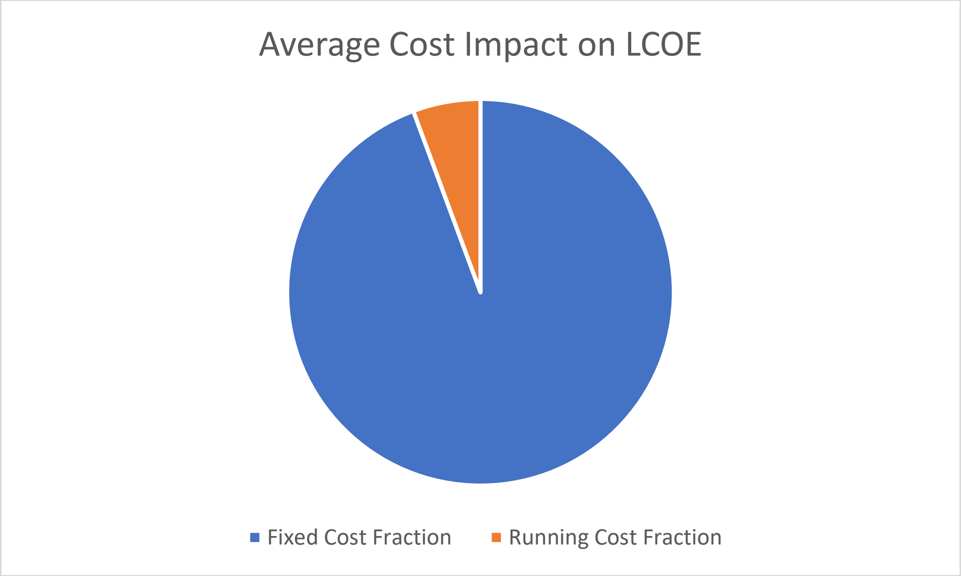


Figure 62: Average Cost Impact on LCOE

Throughout all simulations, Natural Gas turned out to be the cheapest on-site generation source followed by the biomass generator, wind, diesel generators and solar power. When fixed costs were neglected, as in the Simplex LP methods, the system automatically moved towards renewable energy sources which turned out to be cheaper to run and maintain than traditional alternatives. The impact of environmental damage in dollars over the lifecycle of the system has been a minor contributing factor which is overpowered by the larger fixed cost of the system. In terms of USD equivalent damage to the environment, the expected outputs of the simulations are summarized below:

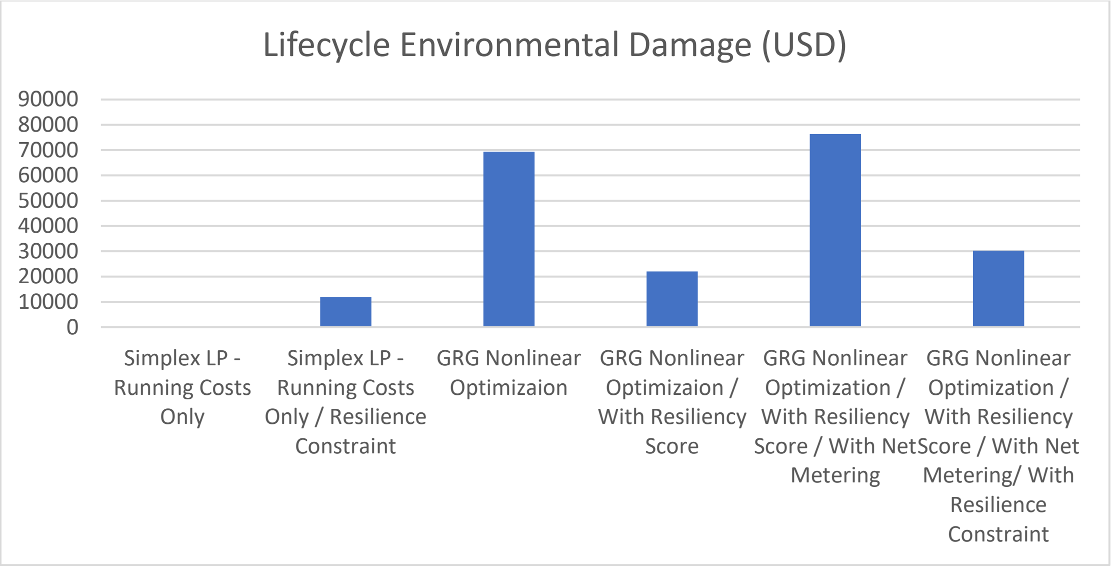


Figure 63: Lifecycle Environmental Damage (USD)

At the same time, taking into account equivalent CO2 concentrations released to the environment as a result of running the system for 20 years, the annual environmental damage predicted by the system is shown in the following trend graphs:

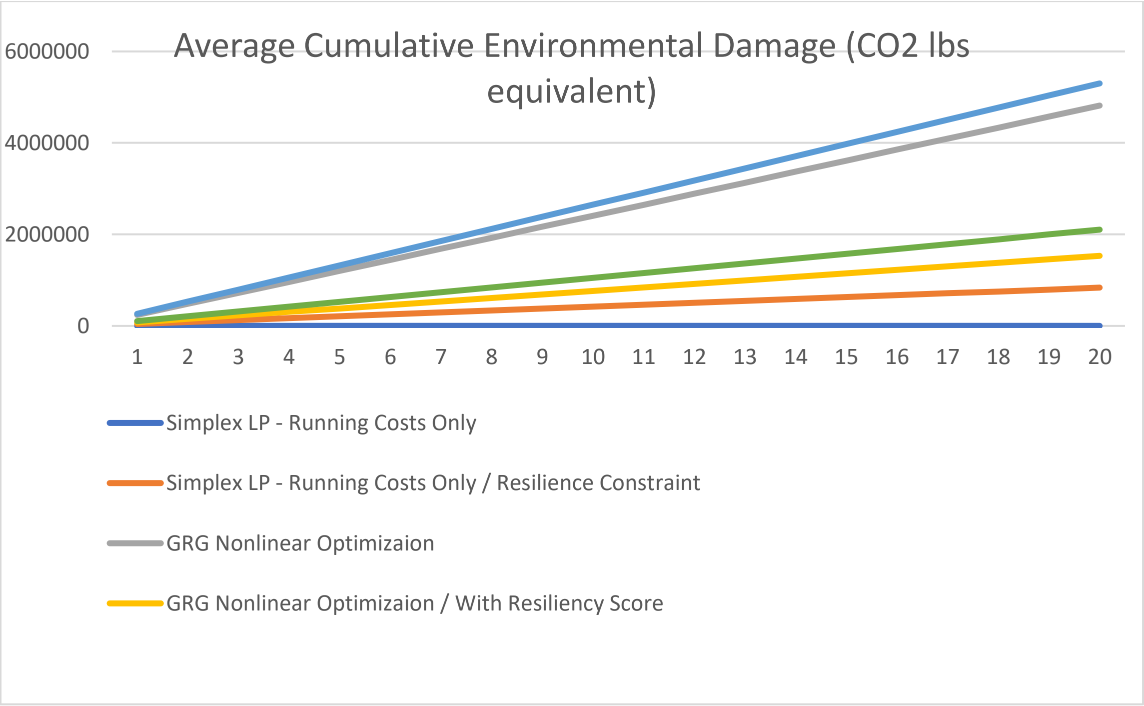


Figure 64: Average Expected CO2 Equivalent Emissions

As seen in the trend graph above, the most renewable options which were deemed most expensive, are predicted to produce the least environmental impact. The cost of electricity predicted by these algorithms is relatively high compared to the national average considered in this study. This is despite the fact that the cost of grid electricity has increased several times over the last decades. The graph below shows that the cost of electricity has risen by about 19% for customers between 2016 and 2017:

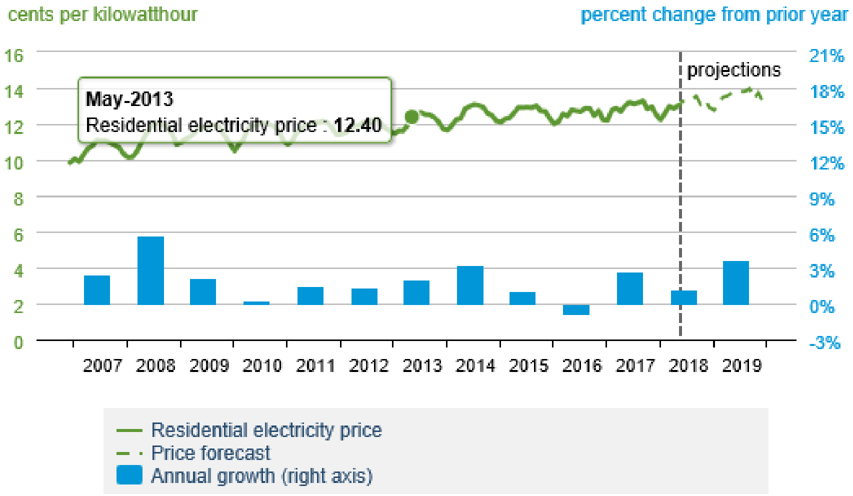


Figure 65: Grid Electricity Costs. Reprinted from [69].

This value itself has seen a rise from an annual increase of 15% between 2005 and 2006. Cost of electricity, if these estimates are extrapolated over the next 20 years, will reach 17 cents per unit of electricity as well. the predicted price of electricity purchased from the grid is shown in the following chart:

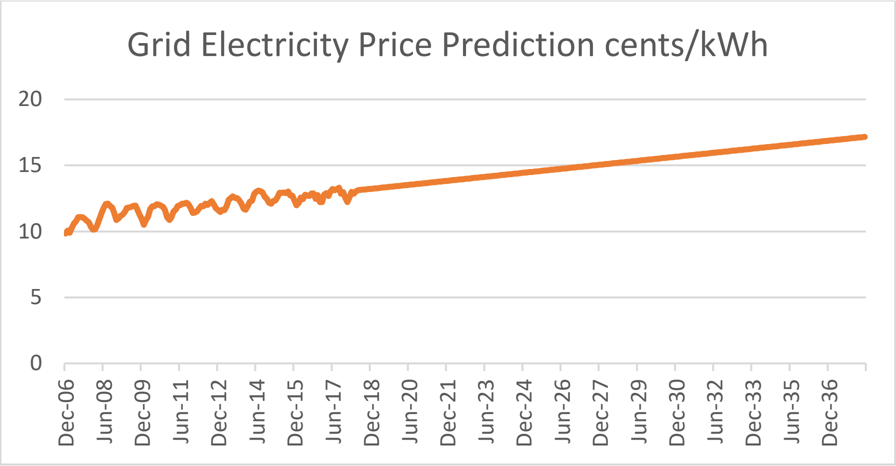


Figure 66: Grid Electricity Price Prediction

While the approaches highlighted in this study have led to comparable costs of electricity to the above stated grid electricity prices, they are nevertheless based on averages.

BIBLIOGRAPHY

[1] US EIA, "Hurricane Harvey caused electric system outages and affected wind generation in Texas," US EIA, 13 9 2017. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=32892. [Accessed 15 05 2018].

[2] J. Samenow, "Model Predicts nearly a million power outages in Texas," The Washington Post, 2017. [Online]. Available: https://www.washingtonpost.com/national/2017/liveupdates/weather/hurricane-harvey-updates-preparation-evacuations-forecast-stormlatest/model-predicts-nearly-a-million-power-outages-in-texas/. [Accessed 15 05 2018].

[3] M. Sledge, "Hurricane Sandy Utility Outages May Be Worsened By Underinvestment, Lack Of Planning," HuffingtonPost, 06 12 2012. [Online]. Available: https://www.huffingtonpost.com/2012/11/01/hurricane-sandy-utilityoutages_n_2053120.html. [Accessed 15 05 2018].

[4] B. Chappell, "Power Outages Persist For Millions In Florida, Georgia And Carolinas After Irma," NPR News, 13 09 2017. [Online]. Available: https://www.npr.org/sections/thetwoway/2017/09/13/550674848/power-outages-persist-for-millions-in-florida-georgia-andcarolinas-after-irma. [Accessed 15 05 2018].

[5] Energy Information Administration, "Hurricane Matthew caused millions of customers to go without power," US EIA, 17 10 2016. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=28372. [Accessed 15 05 2018].

[6] P. Masters, "America’s Biggest Blackout," Rhodium Group, 26 10 2017. [Online]. Available: https://rhg.com/research/americas-biggest-blackout-2/. [Accessed 15 05 2018].

[7] O. o. t. A. S. o. Defense, "Annual Energy Management Repor," Department of Defense, 2015.

[8] S. Hicks, "American Security Project," 09 2017. [Online]. Available: https://www.americansecurityproject.org/wp-content/uploads/2017/09/Ref-0204-Poweringthe-DoD.pdf. [Accessed 16 05 2018].

[9] DoD, "Annual Energy Management Report," D0D, 2014.

[10] J. Jiang, "The Price Of Electricity In Your State," NPR News, 28 10 2011. [Online]. Available: https://www.npr.org/sections/money/2011/10/27/141766341/the-price-of-electricity-in-yourstate. [Accessed 16 05 2018].

[11] D. Goure, "The Measure of a Superpower: A Two Major Regional Contingency Military for the 21st Century," 25 01 2013. [Online]. Available: https://www.heritage.org/defense/report/themeasure-superpower-two-major-regional-contingency-military-the-21st-century. [Accessed 16 05 2018].

[12] J. H. D. M. B. Robert W. Salthouse, "Prime Power: Filling the Army's Electric Power Gap," Logistics Management Institute, Bethesda, Maryland, January 1989.

[13] O. o. E. C. a. E. S. U.S. Energy Information Administration, "Form EIA-871A - 2012 Commercial Buildings Energy Consumption Survey," US EIA, 2012.

[14] Landsat, "Camp Swift, Texas Street Map 4812334," Landsat, 2018. [Online]. Available: www.landsat.com/camp-swift-texas-street-map-4812334.html. [Accessed 2018].

[15] Daftlogic, *Google Maps Area Calculator Tool,* 2018.

[16] D. Kirkpatrick, "Military Surface Deployment and Distribution Command Transportation Engineering Agency (SDDCTEA)," 10 2010. [Online]. Available: https://www.sddc.army.mil/sites/TEA/Functions/SpecialAssistant/TrafficEngineeringBranch/Bull etins/SDDCTEA_Bulletin_Exterior_Lighting_2010-09.pdf. [Accessed 17 05 2018].

[17] ENERNOC, "EnerNOC Insights," Enernoc Insights, Texas, 2017.

[18] ERCOT, "Long-Term Load Forecast," ERCOT, 3028. [Online]. Available: http://www.ercot.com/gridinfo/load/forecast. [Accessed 19 05 2018].

[19] U.S. Energy Information Administration, "Annual Electric Power Industry Report EIA-861," U.S. Energy Information Administration, 2016.

[20] Climate Central, "Weather-Related Blackouts Doubled Since 2003: Report," Climate Central, 10 04 2014. [Online]. Available: http://www.climatecentral.org/news/weather-related-blackoutsdoubled-since-2003-report-17281. [Accessed 17 05 2018].

[21] Hercules Power, "How Does a Generator Create Electricity?," Hercules Power, [Online].

Available: http://hercules-power.com/Diesel-Generator-Philippines-How-Generators-Work/. [Accessed 15 01 2017].

[22] J. Maqusee, "Power Begins at Home: Assured Energy for U.S. Military Bases," The Pew Charitable Trusts, 2017.

[23] Lazard, "Lazard's Levelized Cost of Energy Analysis Version 10.0," Lazard, 2016.

[24] World Nuclear, "Greenhouse gas emissions avoided through use of nuclear energy," World Nuclear Association, 2018. [Online]. Available: http://www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/comparison_of_life cycle.pdf. [Accessed 2018].

[25] R. Alzbutas, "Diesel Generators Reliability Data Analysis And," Lithuanian Energy Institute, 2003.

[26] D. Kozlowski, "Onsite Options," Facilitiesnet, 1 03 2002. [Online]. Available: https://www.facilitiesnet.com/powercommunication/article/Onsite-Options-FacilityManagement-Power-Communication-Feature--1679. [Accessed 21 05 2018].

[27] D. Serchuk, "Calculating The True Cost Of Carbon," Forbes, 03 06 2009. [Online]. Available: https://www.forbes.com/2009/06/03/cap-and-trade-intelligent-investingcarbon.html#3b1c23de1af0. [Accessed 20 05 2018].

[28] Solar Island, "The Cost of Electricity from Burning Fossil Fuel," Solar Island Energy, 08 09 2017. [Online]. Available: https://solarisland.energy/2017/09/cost-electricity-burning-fossil-fuel/. [Accessed 20 05 2018].

[29] Environmental and Energy Study Institute, "DoD’s Energy Efficiency and Renewable Energy Initiatives," EESI, Washington DC, 2011.

[30] SmartGrid.gov, "Renewable and Distributed Systems Integration Program," smartgrid, [Online]. Available: https://www.smartgrid.gov/recovery_act/overview/renewable_and_distributed_systems_integr ation_program.html. [Accessed 14 01 2017].

[31] Consortium for Electricity Reliability Technology Solutions, "Certs," Certs, [Online]. Available: https://certs.lbl.gov/about-certs. [Accessed 15 01 2017].

[32] Sandia National Laboratories, "Energy Surety Microgrid," Sandia National Laboratory, 2015. [Online]. Available: http://energy.sandia.gov/energy/ssrei/gridmod/integrated-research-anddevelopment/esdm/. [Accessed 15 01 2017].

[33] T. Abdallah, "Smart power Infrastructure Demonstration for Energy Reliability and Security," Joint Capability Technology Demonstrator, 2015.

[34] United States Environmental Protection Agency, "Laws and Regulations - Summary of the Energy Independence and Security Act," EPA, 2007. [Online]. Available: https://www.epa.gov/lawsregulations/summary-energy-independence-and-security-act. [Accessed 15 01 2018].

[35] poweroverenergy, "Poweroverenergy," Poweroverenrgy, [Online]. Available: poweroverenergy.org. [Accessed 15 01 2017].

[36] Office of Electricity Delivery and Energy Reliability, "Electricity Advisory Committee (EAC)," Energy.gov, [Online]. Available: https://energy.gov/oe/oe-information-center/electricityadvisory-committee-eac. [Accessed 15 01 2018].

[37] SMARTGRID, "Smart Grid Investment Grant Program," smartgrid.gov, [Online]. Available: https://www.smartgrid.gov/recovery_act/overview/smart_grid_investment_grant_program.ht ml. [Accessed 15 01 2018].

[38] K. Kingery, "The Net Zero Initiative," The Military Engineer, [Online]. Available: http://themilitaryengineer.com/index.php/tme-articles/tme-magazine-online/item/396-the-netzero-initiative. [Accessed 19 05 2018].

[39] Science Heathen, "Solar Photovoltaic Energy Systems Explained," Science Heathen, 05 06 2016. [Online]. Available: scienceheathen.com/2016/06/05/solar-photovoltaic-energy-systemsexplained-solar-pv-panels-cells-modules-science-of-the-photovoltaic-effect/. [Accessed 15 01 2018].

[40] B. Miller, "Information on Grid Connect Solar Photovoltaic systems," BarryMiller.com.au, [Online]. Available: http://www.barrymiller.com.au/solar/. [Accessed 19 05 2018].

[41] PVeducation, "Series and Parallel Wiring," PVeducation, [Online]. Available: https://pveducation.com/solar-concepts/series-and-parallel-wiring/. [Accessed 2018].

[42] M. Guerra, "Electronic Design," Electronic Design, 21 03 2016. [Online]. Available:

http://www.electronicdesign.com/power/electrical-grid-keeping-smart-solar-inverters. [Accessed 19 05 2018].

[43] I. Abadi, "Design Of Single Axis Solar Tracking System At Photovoltaic Panel Using Fuzzy Logic Controller," *Brunei International Conference on Engineering and Technology,* 2014.

[44] R. G. Born, "The Effect of Sky Conditions on Solar Panel Power Output," Vernier, 16 05 2011. [Online]. Available: https://www.vernier.com/innovate/the-effect-of-sky-conditions-on-solarpanel-power-output/. [Accessed 20 05 2018].

[45] D. Roberts, "Solar power's greatest challenge was discovered 10 years ago. It looks like a duck.," Vox, 31 03 2018. [Online]. Available: https://www.vox.com/energy-andenvironment/2018/3/20/17128478/solar-duck-curve-nrel-researcher. [Accessed 20 05 2018].

[46] F. Lambert, "Tesla's giant battery in Australia made around $1 million in just a few days," Electrek, 23 01 2018. [Online]. Available: https://electrek.co/2018/01/23/tesla-giant-batteryaustralia-1-million/. [Accessed 20 05 2018].

[47] Institute for Energy Research, "How Long Does It Take to Pay Off a Tesla Powerwall?," 05 01 2016. [Online]. Available: https://instituteforenergyresearch.org/analysis/payback-on-teslaspowerwall-battery/. [Accessed 20 05 2018].

[48] A. Buchroithner, "Decentralized low-cost flywheel energy storage for photovoltaic systems," in *2016 International Conference on Sustainable Energy Engineering and Application (ICSEEA)* , Indonesia, 2017.

[49] V. Pavanello, "Overview of Temperature Coefficient of Different Thin Film Photovoltaic Technologies," in *25th European Photovoltaic Solar Energy Conference and Exhibition,* Spain, 2010.

[50] E. Wesoff, "Solar Costs Are Hitting Jaw-Dropping Lows in Every Region of the World," Green Tech Media, 27 07 2017. [Online]. Available: https://www.greentechmedia.com/articles/read/solarcosts-are-hitting-jaw-dropping-lows-in-every-region-of-the-world#gs.Yl10kU8. [Accessed 15 01 2018].

[51] EnergySage, "How Much Do Solar Panels Cost in the U.S. in 2018?," EnergySage, 2018. [Online]. Available: https://news.energysage.com/how-much-does-the-average-solar-panel-installationcost-in-the-u-s/. [Accessed 20 05 2018].

[52] R. Fu, "U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017," NREL, Golden, CO, 2017.

[53] S. Evans, "Solar, wind and nuclear have ‘amazingly low’ carbon footprints, study finds," CarbonBrief, 08 12 2017. [Online]. Available: https://www.carbonbrief.org/solar-wind-nuclearamazingly-low-carbon-footprints. [Accessed 20 05 2018].

[54] D. Nugent, "Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: A critical meta-survey," *Energy Policy,* vol. 65, pp. 229-244, 2014.

[55] Energy.Gov, "Components of a Wind Turbine," US DOE. [Online]. [Accessed 20 05 2018].

[56] A. Winslow, "Urban Wind Generation: Comparing Horizontal and Vertical Axis Wind Turbines at Clark University in Worcester, Massachusetts," Clark University, Worcester, 2017.

[57] AWS Truepower, "Wind Resource Estimates," NREL.

[58] IRENA, "Renewable Energy Technologies: Cost Analysis Series," IRENA, 2012.

[59] A. O'Brien, *Natural Gas Plant Proposal Pulls Rockland into Contentious Energy Debate,* Rockland:
freepressonlne, 2015.

[60] FuelCell Energy, "SureSource 150," 02 2017. [Online]. Available:
https://www.fuelcellenergy.com/wp-content/uploads/2017/02/Product-Spec-SureSource1500.pdf. [Accessed 21 05 2018].

[61] U.S. Energy Information Administration - Independent Statistics & Analysis, "Capital Cost Estimates for Utility Scale Electricity Generating Plants," US Department of Energy, Washington DC, 2016.

[62] US EIA, "Henry Hub Natural Gas Price," US EIA , Washington DC, 2018.

[63] US EIA, "Average Power Plant Operating Expenses for Major U.S. Investor-Owned Electric Utilities, 2006 through 2016 (Mills per Kilowatthour)," US EIA, 2016. [Online]. Available: https://www.eia.gov/electricity/annual/html/epa_08_04.html. [Accessed 21 05 2018].

[64] US EIA, "How much carbon dioxide is produced when different fuels are burned?," US EIA, 2018. [Online]. Available: https://www.eia.gov/tools/faqs/faq.php?id=73&t=11. [Accessed 21 05 2018].

[65] K. Fletcher, *University of Northern Iowa releases study of biomass feedstocks,* Iowa: Biomass Magazine - http://biomassmagazine.com/articles/12726/university-of-northern-iowa-releasesstudy-of-biomass-feedstocks, 2015.

[66] U.S. Department of Energy Federal Energy Management Program (FEMP), "Biomass for Electricity Generation," WBDG, 15 09 2016. [Online]. Available: https://www.wbdg.org/resources/biomass-electricity-generation. [Accessed 21 05 2018].

[67] G. F. Jan Dell, "Explore impacts to energy supply and use.," National Climate Assessment, 2014. [Online]. Available: https://nca2014.globalchange.gov/report/sectors/energy. [Accessed 24 05 2018].

[68] D. O. o. I. Energy, "Leelized Cost of Energy (LCOE)," US DOE, 2015.

[69] U. EIA, "Short Term Energy Outlook," 06 2018. [Online]. Available: https://www.eia.gov/outlooks/steo/report/electricity.php. [Accessed 20 06 2018].

[70] University of Oregon, "Electricity Fundamentals," uoregon, [Online]. Available: http://zebu.uoregon.edu/disted/ph162/lec04.html. [Accessed 15 01 2017].

[71] :. Leiva-Gomez, "Brighth Hub Engineering," Brighth Hub Engineering, 29 08 2009. [Online]. Available: http://www.brighthubengineering.com/commercial-electrical-applications/47374electrical-impedance-explained/. [Accessed 14 01 2017].

[72] J. D. Sujit Kumar, "Application And Use Of Flywheel In Engineering: Overview," *International Journal of Advances in Science Engineering and Technology, ISSN: 2321-9009* , vol. 1, no. 2, 2013.

[73] T. H. John Gardner, "Sustainability Research - Overview of Compressed Air Energy Storage," Boise State University, Boise, 2007.

[74] Houses of Parliment (UK), "Carbon Footprint of Electricity Generation," Houses of Parliment (UK), London, 2011.

[75] A. Wade, "Carbon footprint of solar panels under microscope," Euractiv, 07 11 2016. [Online]. Available: https://www.euractiv.com/section/energy/opinion/mondaycop22-lower-co2emissions-with-lower-carbon-solar-energy/. [Accessed 15 01 2018].

[76] Forbes, "Calculating The True Cost Of Carbon," Forbes, 03 06 2009. [Online]. Available:

https://www.forbes.com/2009/06/03/cap-and-trade-intelligent-investingcarbon.html#2e5df78c1af0. [Accessed 15 01 2018].

[77] Department of Energy, "Concentrating Solar Power," DoE, [Online]. Available: https://energy.gov/eere/solar/concentrating-solar-power. [Accessed 15 01 2018].

[78] J. Cuttica, "Combined Heat and Power (CHP) Is It Right For Your Facility," Midwest CHP Application Center, UIUC, Oak Ridge National Laboratory, Chicago, 2009.