RELATIONSHIP BETWEEN WIND AND SOLAR ELECTRICAL ENERGY POTENTIAL IN THE TEXAS HILL COUNTRY: A STUDY AT THE TEXAS STATE FREEMAN RANCH CENTER

by

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DEDICATION

This thesis is dedicated to my mother, Kate Owen. Thank you for always believing in me. Your constant and unconditional love and support has guided me to where I am today. I owe my success to you. Thank you for igniting within me a desire to learn and explore.

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ABSTRACT

Fossil fuel use has led to environmental concerns creating a need for renewable energy sources. The purpose of this study is to analyze metrological data collected at the Freeman Ranch Center to determine if there is the potential for wind energy to supplement solar energy, creating more consistent and reliable energy for the residents of the Texas Hill Country. Hybrid renewable energy systems are an effective way to overcome some of the challenges associates with specific renewable energy sources. A simulation calculator was used to simulate weather conditions of the study area along with potential output of a hybrid wind and solar renewable energy system. A hybrid wind and solar energy system has the ability to significantly contribute to the electricity needs but marginally contribute to the total energy needs of the Texas Hill Country residents. When factoring in cost of the renewable energy theologies it becomes clear that wind energy is not an economically desirable option. The added benefit of supplementing solar energy with wind energy is not significant enough to justify the added cost of wind power at this time for the study area.

CHAPTER 1

INTRODUCTION

I. Problem Statement

The burning of fossil fuel has been linked to global warming for many years. The consequences of global warming are recognized as a significant risk to civilization. The climate change associated with the burning of fossil fuels is occurring much faster than historically estimated by scientists (Leggett and Ball 2012). The finite supply and the environmental costs from fossil fuels have created a need for renewable energy sources. The solution of utilizing renewable energy sources is the most frequently presented solution for minimizing the risk and effects of climate change. Studies report that a complete worldwide transition to renewable energy sources is possible by the year 2050 (Leggett and Ball 2012). Experts believe that wind and solar energy hold the most potential and will be the primary energy sources in the future (Leggett and Ball 2012).

Wind and solar energy are two of the many options for renewable energy sources that are readily available today. The Texas Hill Country is described as an area not suitable for harvesting wind energy, as this area has a low average wind speed (National Renewable Energy Laboratory 2014). The Texas State University Freeman Ranch Center in San Marcos, Texas has collected years of wind and solar data that can be used to assess the viability of generating electricity from wind and solar in the region. This study will look at the relationship between wind and solar electrical generation to see if wind energy could be used to supplement solar energy, to provide a more reliable source of renewable energy.

II. Purpose Statement

The purpose of this study was to analyze the available metrological data and determine the relationship between the levels of available wind and solar energy at the Texas State University Freeman Ranch Center. The results of this research will show if there is the potential for wind energy to supplement solar energy and create a more consistent energy source from these renewable resources at the Freeman Ranch Center and in the Texas Hill Country.

III. Research Questions

This study intends to answer three specific research questions. The research questions for this study are as follows:

For a Texas Hill Country Location:

1. How much energy could a residential sized solar system provide?
2. How much energy could a residential sized wind turbine provide?
3. How much could the two systems provide conjunctively in a hybrid system?

IV. Research Matrix

The study area included the Freeman Ranch Center located approximately five miles west of San Marcos, Texas. Meteorological data from two weather stations at the Freeman Ranch Center were analyzed to assess the wind and solar energy viability for the region. The weather stations record measurements every thirty minutes. Data utilized was wind speed (m/s) and solar radiation (watts/sq_m). Two years of metrological data were analyzed for each of the weather stations. Data from these stations are from January 1, 2008 to December 31, 2009 for the forest site and January 1, 2009 to December 31, 2010 for the transitional site.

V. Objectives

The aim of the described research was to build on the literature of this topic and provide a better understanding of potential contributions wind energy has specifically in areas with low average wind speeds. The objectives of this research include:

1. To compare the relationship between wind and solar energy in the Texas Hill Country;
2. To examine the contribution wind energy can make to solar energy in the study area;
3. To investigate the implications of the found results.

VI. Hypothesis

It was hypothesized that there is enough wind and solar energy potential at the Freeman Ranch Center to demonstrate that the Texas Hill Country can benefit from small hybrid renewable energy systems.

CHAPTER 2

LITERATURE REVIEW

I. Overview

The need for renewable energy sources stems from the recognition of the finite supply of fossil fuels, rising cost of fossil fuels, and the pollution caused by fossil fuels. Despite these issues, fossil fuels still dominate the energy market, accounting for over 80% of energy production globally (Hedberg 2010). Both the physical environment and the social environment are greatly impacted by the consumption and production of energy from fossil fuels. Overwhelming evidence supports the fact that production and use of fossil fuels is unsustainable and has major environmental costs. (Hedberg 2010). Fossil fuels are a limited nonrenewable resource and experts predict that within the next few centuries most will be depleted. In addition to a diminishing supply, fossil fuels face the problem of damage to the environment. A leading cause of climate change is the accumulation of carbon dioxide in the atmosphere from the burning of fossil fuels (Mostafaeipour 2011).

Energy derived from fossil fuel is both limited and non renewable which means that these energy resources are becoming more scarce and expensive (Rahim et al. 2012). Despite the increase in scarcity and expense, the global demand for energy will continue to rise. “It is expected that worldwide primary energy demand will increase by 45%, and demand for electricity will increase by 80% between 2006 and 2030” (Santos-Alamillos et al. 2012). In developed countries there is an expected 1% annual energy growth rate and an expected 5% annual energy growth rate for developing countries (Rahim et al. 2012).

One of the major energy risks that civilization faces is peak fossil fuel. Peak fossil fuel refers to fossil fuel production increasing to a peak and then gradually declining to where it can no longer meet demand. Demand will only be met at prices that are too high to meet the wide spread fossil fuel use that is currently observed today (Leggett and Ball 2012). Researchers discuss the “plausible worst case scenario for peak fossil fuel” which is the earliest predicted peak supported by a substantial amount of peer reviewed literature (Leggett and Ball 2012). Research done by Leggett and Ball (2012) indicate that all fuel types except for coal are expected to peak before 2030 with an average of 2028. Rahim et al explain that “when global energy production is primarily and continuously dominated by fossil fuels, an energy crisis will occur in the future” (Rahim et al. 2012). They claim that in order to avert an energy crisis renewable energy resources will need to be developed in every country.

The potential consequences of climate change have been extensively studied. One of the major goals of researchers is to understand and accurately predict the impending global climate change patterns. Climate change and global warming is expected to intensify as fossil fuel use is continued, resulting in more extreme weather events. Flood and drought are two weather events that are of most concern. It is estimated that in the event that the peak fossil fuel scenario is experienced, that 500 million people will be affected by floods and there will be an increase of 15 to 25 percent to the global land area affected by drought by 2100 (Leggett and Ball 2012).

Fortunately there are solutions that are believed to both prevent the risk of peak fossil fuel and reduce the effects of climate change. Overwhelmingly, researchers support a transition from fossil fuel to renewable energy, with wind and solar as the primary sources. The current figures show that wind and solar have the ability to completely replace fossil fuel use as early as 2024, if the growth trajectory of wind and solar continues to follow the growth rate of the mobile phone/China Expressway system (Leggett and Ball 2012).The pervious statistic is derived from comparing the adoption of renewable energy to the adoption rate of another technology. While this is an important goal and will be a monumental milestone if achieved, there are irreversible and unavoidable climatologic consequences that will still occur. The cessation of fossil fuel related carbon dioxide emissions will not stop global warming, but it will limit future warming. At this point climate recovery is possible, but it is an extremely long process.

The impending energy crisis requires dynamic action in order to be averted. First and foremost there needs to be a global reduction in overall energy consumption. Secondly, there is going to have to be a reduction in the dependence on fossil fuels. Renewable energy sources are going to have to be explored and implemented. Currently renewable energy sources such as biomass, hydro, solar, and wind are the most viable alternative to conventional fossil fuel use (Lovejoy 1996).

Researchers believe that with the established harvest technology and ample domestic availability with renewable energy, complete or near complete energy security is possible (Eke et al. 2005). It is accepted that there is great importance on the development of renewable energy technologies to achieve a more sustainable energy supply. Renewable energy faces many obstacles that limit the growth and development of these technologies. Currently, renewable energy technologies are not able to supply any country with enough energy to meet total energy demand (Eke at al. 2005).

There is substantial literature on renewable energy sources and support for increasing implementation of renewable energy methods. There is a consensus that renewable energy alternatives are the only answer to ensure a long term energy solution. Renewable energy leaves future generations with a non-depleting energy source as well as a healthier environment.

II. Basics of Wind and Solar Energy Generation

a. Wind

Historically, wind machines were used to do work such as pumping water and grinding grain and other materials. It is only recently that wind energy has been used to generate electricity on a larger scale. Although the application has evolved, the modern day wind turbine is similar in principle to its ancestors. Materials such as metal and fiberglass have replaced the old wooden designs and the modern turbines are much larger, sleeker, and quieter (Pasqualetti 2004).

In theory, the Earth holds enough wind potential to meet the energy demands of the world. Almost every country has sites available with wind speeds sufficient for energy production. Various constraints such as funding, environmental concerns, landscape of suitable sites, and available technology make the feasibility of worldwide wind energy development difficult. In addition to these constraints, wind is a variable that is extremely variable and random (Sesto and Casale 1998).

Wind energy has been described as a renewable energy option that offers many advantages. Wind energy is often the more economical choice compared to the other renewable energy options, and it is technologically and environmentally more attractive (Sesto and Casale 1998).

One of the main attributes of wind energy that has lead to its growing popularity is its minimal environmental impact. Wind energy does not contribute to air pollution, require supply trains, mining, pumping, drilling, or pipelines, nor does it generate radioactive waste, and does not use or pollute water (Pasqualetti 2004).

While wind energy is praised as being superior to fossil fuels from an environmental perspective, it does not come without some concerns and limitations. Despite the widespread popularity of the wind energy industry, there are some hurdles that still need to be overcome. Noise from the turbines, risk to wildlife, television interference, dangers to aircraft, and landscape aesthetic degradation are some of the factors that influence the public opinion of wind energy development. Additionally, wind energy from a single region cannot be relied upon to supply base load power, because wind velocities vary throughout the day and as well as seasonally.

Feasibility of wind energy production depends on the energy needs of a specific area and the availability of wind. The size of the wind turbine used determines the necessary wind to produce electricity. While small wind turbines produce less electricity compared to the larger systems but in some cases, smaller wind turbines require lower wind speeds to operate. The lower required operating speed can make small wind turbine systems a good option for energy production in areas with less than desirable average wind speeds, but low energy demands.

When researching wind energy potential it is imperative for the energy needs of the specific location to be clearly defined. The energy demand of a site is one of the most important factors when choosing a wind turbine and calculating feasibility of wind energy production. When determining energy demand, it is important for a consumer to consider all potential energy needs as well and the possible changes in future energy demand. Failing to accurately assess energy demand could result in installing systems that are either too large or too small. Installing a renewable energy system that is not optimized for the specific needs of the consumer, can lead to wasting money on unnecessary equipment or investing in a renewable energy resource and not being able to meet energy demands. There are many factors that influence the performance and success of wind energy production (Pasqualetti 2004). It is apparent by the continued growth of the wind energy industry that these concerns, while important, do not seem to be having a major affect on the growth of the industry. There is extensive research on all of these concerns, and in most cases there are simple and manageable solutions that can be implemented. It is important for the wind industry to closely monitor these concerns, as they have the power to influence public opinion towards wind energy development (Pasqualetti 2004).

The popularity of wind power is wide spread and increasing due to its growing profitability and the environmental benefits it provides (Pasqualetti 2004). Additionally, contrary to fossil fuels, wind is widely available across the globe. The first step to developing wind energy is identifying locations with the best potential. More than just finding the wind, it is essential that there is an understanding of the wind characteristics of the proposed wind energy sites.

Previously, not as much consideration went into turbine placement, it was simply a matter of convenience and necessity. Now that turbines are being used for energy generation rather than pumping and grinding, much more thought and planning goes into the placement. There needs to be an understanding of physics, meteorology, and aerodynamics, to be able to determine the optimal placement of wind turbines, as all play a role in the efficiency of the units. In addition, there are factors that can potentially limit the adoption of wind energy, and those are land ownership, zoning, land use planning, and public opinion (Pasqualetti 2004).

By January 2011, Texas was a leader of the nation in terms of installed wind capacity, boasting 10,085 MW of installed capacity (Alexander 2011). Texas has continued to hold the lead and currently leads the nation with over 14,200 MW of installed capacity (American Wind Energy Association 2015). Texas is a major frontrunner in the wind energy industry and some describe the growth of the wind energy industry in Texas as reminiscent of the early 20th century oil and gas boom (Alexander 2011). As seen in the first Texas oil fields, there is a great demand for wind energy along with minimal regulation of the development of the industry. History warns that unregulated rapid growth could lead to a waste of wind energy resources as seen in the early oil and gas industry. Given that wind is a renewable resource the term "waste" does not have the same meaning as with oil and gas. When wasted, oil and gas is lost for good but wind is replenishable. Wasting wind refers to the opportunity cost of not harnessing the wind for electric power or doing it in an inefficient manner (Alexander 2011).

Although Texas is the leader in terms of installed wind capacity for the nation, most of the wind potential for the state is located in the northern and western regions of the state, where demand is the least (Pasqualetti 2004).

Even though wind energy is named one of the leading alternatives to fossil fuel use, there are still problems that limit the development of the resource. The intermittency of wind poses a challenge to providing a reliable renewable energy source. One of the ways that this problem is being overcome, is by coupling solar with wind energy systems.

b. Solar

Solar energy is claimed to be one of the most important alternatives for viable sustainable energy in the future (Hedberg 2010). Given the clean nature of solar and its wide spread availability, solar is an attractive alternative energy source. The technology for solar is already advanced and continues to develop. There is an unlimited resource base available for solar energy. The amount of energy that the Sun emits is astronomical. In just a single second the Sun radiates more energy than people have used since the beginning of time (Solangi et al. 2011).

Researchers are optimistic that complete reliance on renewable energy is an achievable goal. Solar energy is a leading candidate as a resource capable of transitioning completely away from fossil fuel. With a global energy consumption that is less than 0.01% of the energy that reaches the Earth from the Sun, total dependence on solar energy is a realizable goal (Lovejoy 1996). There has been rapid growth in recent years for photovoltaic facilities. In the United States alone the annual growth rate for photovoltaic and concentrating solar power was 22% in 2010 (Rahim et al. 2012). Similar figures can be seen worldwide. In Europe, total installed capacity went from 4,600 MW in 2008 to 16,000 MW in 2010. In the Asia-Pacific regions, total installed cumulative capacity rose from 333 MW in 2006 to 2,036 MW in 2010 (Rahim et al. 2012). Researchers estimate that only 0.1% of the surface of the Earth would need to be covered by solar collectors to provide a global solar powered energy supply. Solar collectors would include biomass and wind generators (Lovejoy 1996). A large majority of the land area used would be in the desert region terrains, not suitable for agriculture.

There are a variety of ways that sunlight can be used to generate power. Concentrating solar power, solar heating, photovoltaic, and solar fuel synthesis are the most common solar technologies utilized. Solar energy does not contribute as much electricity as wind in the U.S., because it is not yet cost competitive in most locations and situations (Langniss and Wiser 2003).

Similar to wind, solar power faces the challenge of the inherent inconsistent nature of the resource. This is one of the largest hurdles that the wind and solar renewable sources face, and a major issue which researchers are addressing (Garrison and Webber 2011).

In the literature on solar energy, it is stressed that there is going to be a need for political support for a transition to take place to renewable energy sources. This is true for both wind and solar energy. There is a great deal of urgency on this matter, as historically transition times related to energy sources are long (Lovejoy 1996). Texas has had success in political support for renewable energy. The use of the renewables portfolio standard, which is a policy instrument aimed at ensuring a minimum amount of renewable energy contributes to the portfolio of energy resources (Langniss and Wiser 2003). This approach has been quite successful and can be beneficial to other states as well as other countries. It is important that the policies that are designed to support renewable energy development, encourage the diversification of renewable energy sources (Langniss and Wiser 2003). One of the major pitfalls Texas has seen with the renewables portfolio standard is that it is heavily supportive of the development of wind. While Texas has some of the best wind potential in the country, it would be beneficial to develop the solar energy potential in the state. When looking at renewable resource availability for the state, resource availability where populations and energy demand is highest, should be considered. While there is a great wind resource in the state of Texas, solar tends to be the more available resource in the populated areas. Wind development in the panhandle at the commercial level will be important in achieving the coal of zero dependence on fossil fuel. Contributions of residential renewable energy systems must also be considered. At the residential level in Texas, solar has the potential to significantly contribute to energy needs. It is important for policies to also encourage the development of solar energy.

One of the major problems with solar energy is the difficulty of meeting supply with demand over long term periods. The availability of solar energy varies as a result of factors, such as time of day, local weather conditions, geographical position, season, and other environmental characteristics (Rahim et al. 2012). Over time, there will be a change in weather conditions which will affect solar radiation availability. It may increase for some areas, but it may also decrease for others. Energy demand will continue to grow with the constant rise in population in Texas, in absolute terms, the fastest growing state in the U.S. It is going to be necessary for new technologies to determine “the balance between demand and supply in developing solar energy to its full efficient scale” (Rahim et al. 2012).

III. Hybrid Systems that Utilize Wind and Solar

Wind and solar energy are two of the most viable renewable energy options available today. Although these are the frontrunners for renewable energy technologies today, there are drawbacks associated with these methods. Solar energy has the potential to be unpredictable because of its dependence on weather and varying climatic conditions (Hongxing et al. 2009). Wind energy is very intermittent in nature which decreases its reliability as a dependable energy source (Hedberg et al. 2010).

Research finds that in a standalone design, neither wind nor solar are effective in providing continuous power. Periodical and seasonal variations in weather patterns create times where electrical load demand needs cannot be met by one renewable energy source (Zhou 2010). Research has found that an effective way to provide more reliable and consistent energy is to create a system that uses two or more renewable energy sources. These systems are known as hybrid power generation systems. These hybrid systems are designed so that the strengths of one source overcome the weaknesses of the other (Hongxing et al. 2009) (Zhou 2010). Many renewable energy systems are designed to incorporate a backup power system. These backup power systems are usually either a generator or the utility grid. The backup power systems are designed to provide power when too much energy has been consumed or there has not been enough renewable energy captured by the system. Hybrid systems can minimize or eliminate the need of backup power for users who struggle with single source systems that are not receiving enough renewable energy (Subrahmanyam et al. 2012).

While it may seem advantageous to always utilize hybrid system, not all locations are suitable for hybrid renewable energy systems. In order for a hybrid power generation system to be effective there needs to be complementary characteristics between the energy sources used. For example, when conditions are favorable for one source, they are unfavorable for the other.

The use of hybrid energy systems in rural and remote areas has been described as one of the most promising applications for renewable energy (Nema et al. 2009). There is growing popularity for hybrid systems in remote areas, mainly due to the increases in renewable energy technologies and the growing cost of petroleum and petroleum products.

Existing research warns some of the challenges that hybrid systems have faced. A Chinese study by Jun et al. describes the Xcalak systems, which perform well for about the first two years, and by the seventh year is a complete failure.

System optimization is another challenge of hybrid renewable energy systems. It is difficult to find the best mix and systems between the multiple energy sources. Proper optimization can lead to an increase of 50% in energy production (Jun et al. 2011).

a. Previous Studies on Hybrid Wind and Solar Systems

i. Examples that worked

There are many studies that have looked at a similar research question and had findings supportive of the hypothesis proposed. These other research projects are important and provide valuable insight into how the research in the Texas Hill Country should be conducted. A study of southwestern Minnesota found that a model wind solar thermal electric power plant produced better electric load matching characteristics than a wind only power plant (Reichling and Kulacki 2008). Another study in Cardiff, United Kingdom found that not only did a hybrid wind and solar supply more autonomy than single source systems, but also a lower unit cost (Celik 2002). One hybrid wind and solar feasibility study discussed the current global energy crisis and brought up how around 1.5 billion people worldwide still do not have access to electricity. This study focused on remote populations and the potential impact hybrid wind and solar energy systems can have for these people. This segment of the population often live in areas where their only source of electricity comes from expensive and pollution producing diesel generators, despite the wide local availability of renewable energy resources. This study analyzed the effectiveness of potential wind and solar systems that utilize a battery storage device. The results showed that for the particular remote island studied, a hybrid renewable energy system could not only replace the current diesel generator but it was also cost effective and would supply continuous power (Ma et al. 2014).

ii. Examples that did not work

While the majority of research projects conducted in this area found it beneficial to utilize a hybrid renewable energy system, some of the findings did not support this conclusion. Research that found results not supporting a benefit of hybrid wind and solar energy systems were anomalies among the research. Thoroughly studying these research cases will allow future research projects to plan for and overcome the challenges faced in previous studies.

None of the literature reviewed presented a study that found a hybrid wind and solar energy system that preformed worse than a single source system. Studies that did not support hybrid wind and solar systems did so because of cost rather than production. In some cases, the additional benefits of the hybrid system, was not worth the added cost of the system. One study located conducted by Kershman et al. (2005) in Libya researched various small scale energy generation systems designed to power a desalination plant. The energy systems studied include national grid connected solar, wind, hybrid wind and solar, and power from the local grid connected diesel generator, hybrid generator and solar and hybrid generator and wind. The study found that there was an increase in energy production from the hybrid wind and solar system, but the individual wind and solar components of the hybrid system did not perform as well as their counterparts in the wind only and solar only systems. Additionally, this study found that compared to most of the other systems analyzed the significantly higher investment rate of the hybrid system lead to a higher cost of energy from this system (Kershman et al. 2005).

Another study located in the Peruvian city of Paita, focused on the potential for hybrid wind and solar systems to power residential homes. This study supported the hybrid systems productivity and found that it would be more than enough to meet the average annual demand with a surplus of 609.64 kWh per year. Despite the promising projected production researches couldn't support the system economically. It was found in this case that the cost of energy from a hybrid wind and solar energy system would be $0.361/kWh, which is over twice Peru's current energy price of $0.174/kWh. Until energy costs are above $0.361/kWh this hybrid system will not be financially viable energy option (Sócola and Aldana 2015).

It was clear that the hybrid systems are successful in producing more reliable energy. Researchers found that the optimization of the systems was crucial in the success of the systems. There needs to be preliminary research done to ensure that the wind and solar components chosen for the hybrid system are suitable for the specific site. Using the wrong mix of renewable sources will result in the cost of the hybrid system not justifying the added electrical output.

b. Lack of Data for this and Similar Areas

There are many studies that have analyzed hybrid power generation systems. Of these studies there are many that examine the feasibility and the efficiency of systems utilizing wind and solar energy. One of the main uses of these hybrid systems is electrification for rural and remote areas. While these hybrid systems are more complex, when placed in the right location they are the ideal option for energy production.

Although, there are many studies analyzing wind and solar hybrid power generation systems, few to none have been conducted in or in an area comparable to the Texas Hill Country. Hong Kong, China, Minnesota, Corsica Island, Izmir, Turkey, Poland, Cardiff, United Kingdom, and Patras, Greece are all locations that have been used for research of hybrid wind and solar power generation systems (Hongxing et al. 2009) (Notten et al. 2011)(Reichling and Kulacki 2007) (Eke et al. 2005) (Paska et al. 2009) (Celic 2001) (Tripanagnostopoulos et al. 2009). It is important for research to be done globally in order to effectively assess the energy potential of various landscapes and terrain.

IV. Methods for Analyzing Wind and Solar Potential

The accepted unit of measure used to describe wind velocity is meters per second (m/s). For solar insolation, the preferred unit of measure watts per square meter (W/m^2). When referring to the amount of solar and wind energy available at each site, a conversion to kilowatt hours (kWh) is preformed.

There are two different methods that are used to model hybrid energy generation potential. The first method is to analyze metrological data of a site and then convert it to energy potential based on hypothetical systems to predict performance. The other method that is commonly used is to actually build a hybrid system pilot project and measure the energy output for the system.

When using the method of analyzing metrological data, typically a simple anemometer is used to record wind speeds. It is not uncommon for researchers to collect additional data such as wind direction, which requires the use of a propeller anemometer. When collecting solar insolation an actinometer is used. For the method of building a hybrid system, photovoltaic solar panels and a wind turbine are used to evaluate the production potential of the system.

a. Frequency of Data Collection

In the analysis of other studies it is clear that larger data sets are preferred. To be able to effectively study weather patterns and assess seasonal changes, a minimum of 10 years of data is the industry standard. While 10 years or more is ideal, short to medium periods ranging from 1 to 5 years are accepted (Coste and Serban 2011). Some researchers take samples as frequently as every ten seconds and use averages of thirty minute periods. Other researchers take samples once or twice an hour for their data measurements, which is most common in the research of meteorological conditions (Tina and Gagliano 2010).

The Internet is another resource that is used for the data collection. In some areas there is simply not enough data or weather stations in place to provide the specific measurements needed. In these situations it is appropriate to turn to global weather data that can be found on the internet. These sources of data are not preferred (Tina and Gagliano 2010).

Site specific wind data is important to have, as small variations in wind speed can cause large differences in wind turbine electrical output. When evaluating potential wind energy it is always preferred to have wind energy data for the specific site.

b. Weibull Analysis

Wind speed is a highly random variable that should not be analyzed in its raw form. A probability density function is commonly used to translate the wind data into a usable variable when measuring wind energy potential (Mostafaeipour 2011) (Coste 2011, 7). The most common and widely accepted probability density function used on wind speed data is the Weibull continuous probability distribution. This specific function is the most acceptable of the distributions and is the basis for the commercial wind energy industry applications and software (Odo et al. 2012). The Weibull distribution describes the percentage of time that that wind speeds are at a certain level (Bivona 2003). Statistical analysis is very important in the analysis of wind power potential of a site as it can provide data on the reliability of the amount and timing of electricity production.

In order to develop the optimal design for a wind energy converter, there needs to be an understanding of the frequency distribution of the wind speed (Odo et al. 2012). Knowing the frequency distribution of wind speeds allows engineers to develop systems that perform best in certain conditions. Additionally, the Weibull analysis is a valuable tool in evaluating the expected performance of wind generating systems in different areas.

The Weibull distribution function is expressed as;

$$f(\mathrm{v}) = \left(\frac{\mathrm{k}}{\mathrm{c}}\right)\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right]$$

Where *f*(v) is the frequency the wind speed (*v*) occurs, *c* is the scale parameter in the unit of m/s, and *k* is the shape parameter which is dimensionless.

The Weibull function is not always the best choice for studies analyzing wind data. Data sets that are bimodal or have many observation of calm no wind times are not ideal candidates for the Weibull function (Cabello and Orza, 2010). The Weibull function is unable to identify the probability of calms when the wind speed is zero. The inability to account for zero is one of the biggest limitations of the Weibull function (Islam et al. 2011). While there was a significant amount of observations that had relatively low wind speeds, there was not one occurrence of zero in the wind speed data, it was determined that the Weibull function was the appropriate function to use when analyzing the wind data for this research.

c. Electrical Demand

i. Peaks in Electrical Demand

Studies show that there are diurnal variations in electrical demands. A study on west Texas found that energy demand was lowest in the morning and steadily increased until peaking in late afternoon (Garrison and Webber, 2011). Accounting for 18 percent of household energy use, Texas' energy consumption for air conditioning is three times higher than the national average. The U.S. Energy Information Administration explains that the warmer weather of Texas is responsible for increased energy consumption for cooling. Obviously, the warm weather increases, highlight the importance of seasonal variations in demand and potential productivity of hybrid renewable energy systems.

In Texas the average household consumes 77.1 million Btu or 22,595 kWh of energy annually with southern rural household energy consumption higher than average at 81.8 million Btu which is 23,973 kWh annually (U.S. Energy Information Administration 2014). According to 2009 data, Texas household energy consumption is 14% below the national average, while Texas household electricity consumption is 26% above the national average. The average Texas household consumes 14,283 kWh of electricity annually with rural residents having a slightly higher than average consumption at 16,835 kWh annually (U.S. Energy Information Administration 2014).

d. Texas Wind and Solar Resources

i. Maps of Wind and Solar Energy Potential for the Area

Given the large size of the state of Texas, there are varying geographic landscapes across the state. Just as the landscape changes across the state, the wind availability also changes. Figure 1. illustrates the average annual wind speed for the entire state of Texas, and Figure 2. illustrates the daily solar Kwh/m^2 for Texas. The counties that comprise the Texas Hill Country are outlined in bold. Figure 1. also indicates the location of the Freeman Ranch Center.

The Texas Hill Country is the eastern, fluvially dissected portion of the Edwards Plateau with a highly variable semi-arid to sub-humid climate (Lai and Lyons 2011). The Balcones Escarpment defines the eastern boundary of the Hill Country (Fenneman 1931). It is immediately west of the rapidly growing Austin-San Antonio Corridor along Interstate Highway 35.

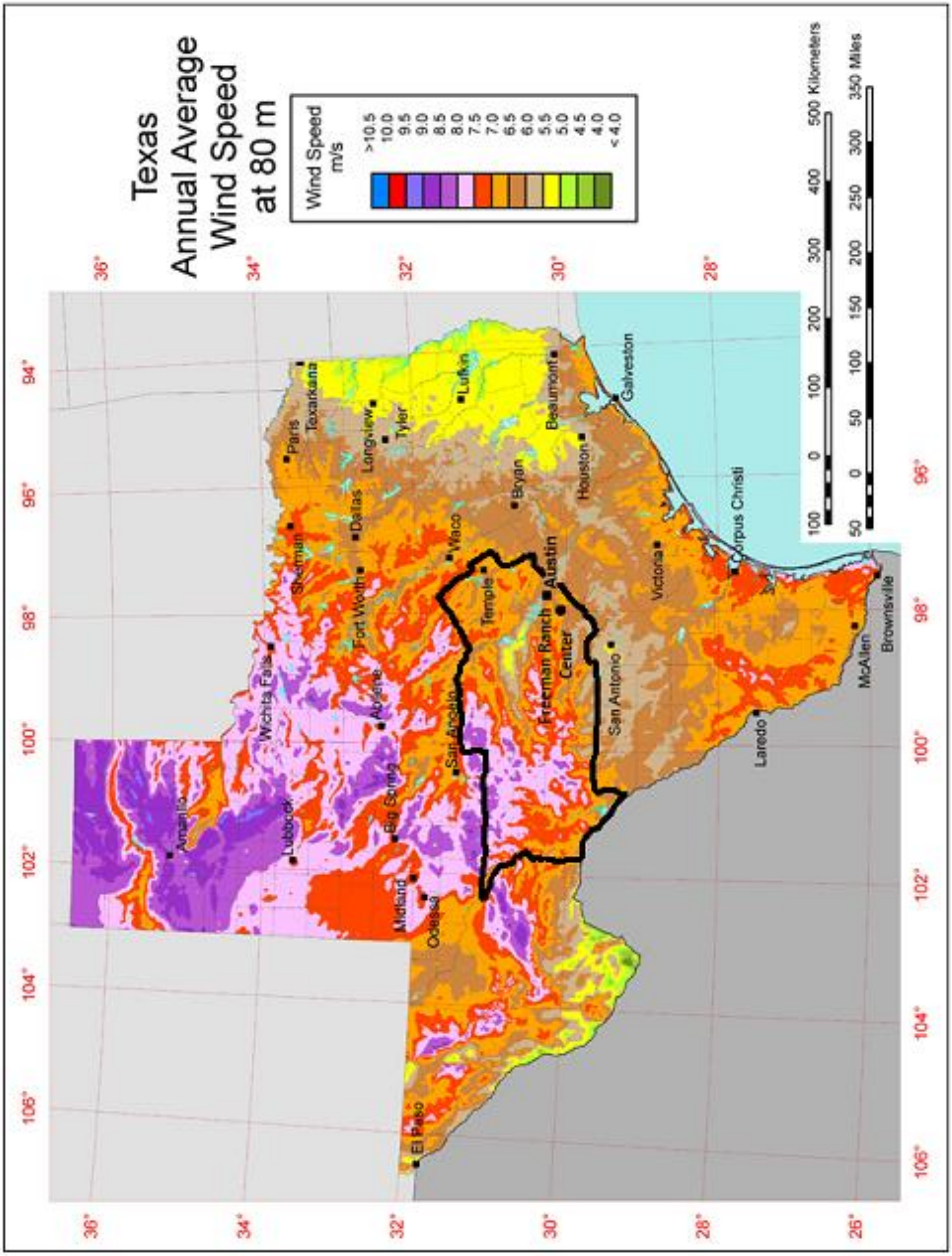

Figure 1. Average Annual Wind Speed in Texas (NREL 2014)

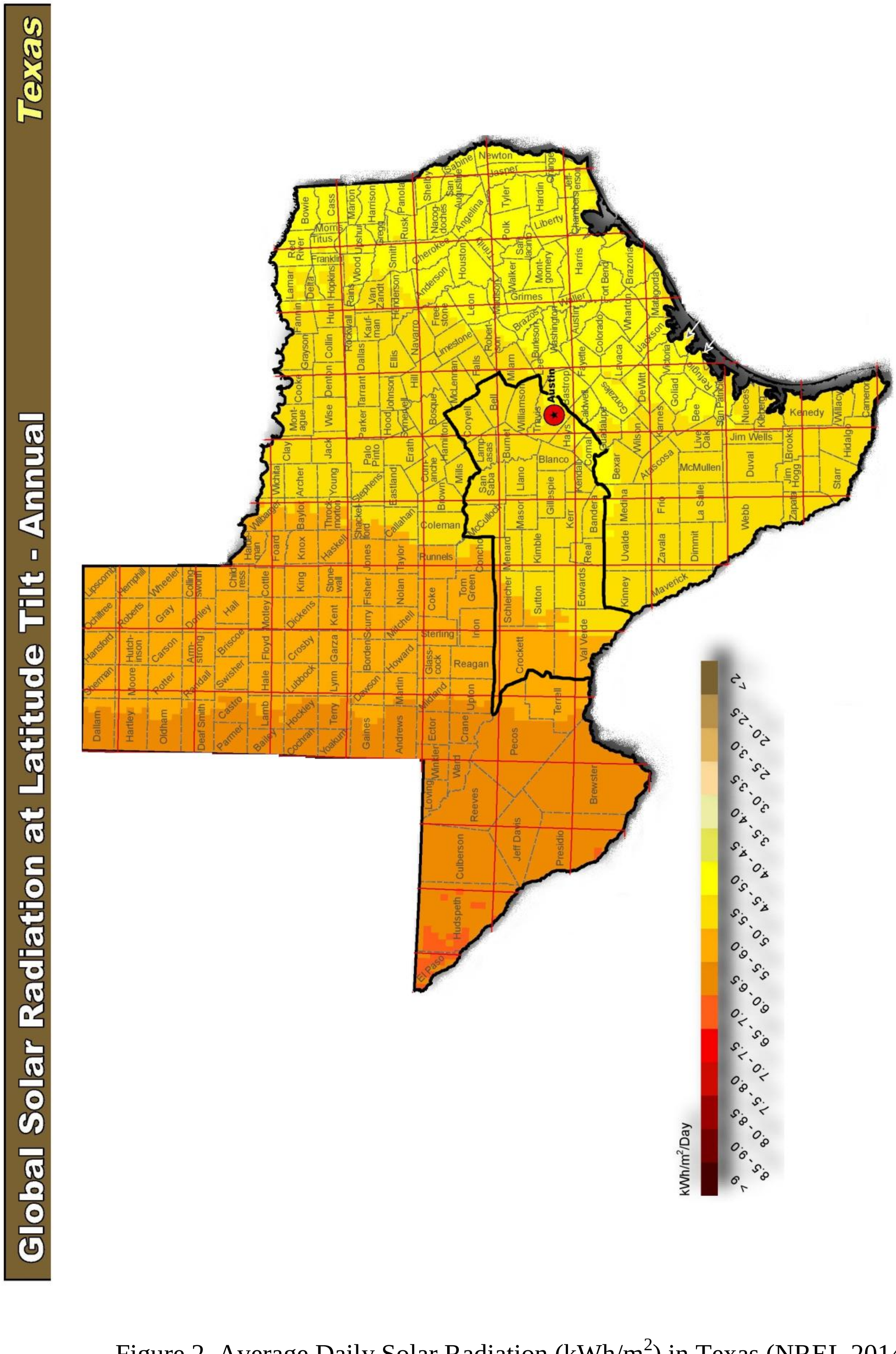

Figure 2. Average Daily Solar Radiation (kWh/m^2) in Texas (NREL 2014)

V. Wind and Solar Electric Generation

There are two main types of wind turbines, large and small. Large turbines are used in industrial wind projects, and on wind farms supplying energy to large populations. Small wind turbines are seen connected to residential homes and supply much less power. Turbines that have a capacity of 100 kilowatts or less and a generator hub height of 120 feet or less are classified as small (Chiras 2010).

Two of the leading small wind turbines are the Polaris P10-20 a 20 kilowatt rated wind turbine and the Bergey Excel 10 killowatt wind turbine. Both units are rated at a speed of 11 m/s. These turbines are on the larger end of what would be utilized in a suburban residential setting and can have trouble receiving permitting in some residential areas. In the rural setting these turbines are popular choices (Polaris 2014) (Bergey 2015).

The cut in speed of a wind turbine is the wind speed at which the blades of the wind turbine are rotating fast enough to begin generating energy. The cut in speed of a turbine is proportional to the size of the turbine itself, smaller turbines have a smaller minimum speed and vice versa. The Polaris turbine has a cut in speed of 2.7m/s and the Bergey unit a cut in speed of 2.5 m/s. The maximum output is 12.6 kW at a wind speed of 12.5 m/s for the Bergey turbine. In the Bergey report it states that with average wind speed of 4.9 m/s the turbine will generate 13,800 kWh of electricity annually (Polaris 2014) (Bergey 2015).

Preliminary analysis of the study location indicates that there is a limited wind potential for the region (National Renewable Energy Laboratory 2014). Having a wind power classification of Class One, the Texas Hill Country is not a candidate at this time for major wind power investment in most of the state (National Renewable Energy Laboratory 2014). It is understood that with current technologies, that large scale wind turbines would not be cost effective or beneficial to residents in the Texas Hill Country. Although there is not enough wind to support large turbines, there may be the potential that smaller to medium sized turbines will have some success in this area.

There are people in the Texas Hill Country who argue that it does not make sense from aesthetic and other perspectives to pursue wind projects in the area because of the relatively low wind potential (Galbraih 2012). This research intends to contribute to the literature on the potential influence wind energy has for the Texas Hill Country.

VI. Gaps in Literature

While there is a significant amount of literature studying renewable energy sources as well as hybrid wind and solar energy systems, there are some gaps that are found in the literature. First, the literature focuses on sites that are historically known for having a high wind and solar energy potential. It comes as no surprise that when implementing a hybrid wind and solar energy generation system; these locations thrive supporting this technology. The proposed research helps to fill this gap by studying a location that has marginal, at best, wind potential. The idea is that wind energy will complement and supplement solar energy. Solar energy will be the dominant form of energy production and wind will serve as a backup, reducing the number of instances when outside power is needed. Demonstrating that areas unsuitable for large scale wind energy production can benefit from wind energy on a small scale, could be a significant step forward in the widespread adoption of renewable energy sources.

Another gap in the literature is that previous research focuses on the relationship between wind and solar energy throughout the entire year. This is a shortcoming because there will be seasonal fluctuations in the available wind and solar energy potential for any given area. Many research examples acknowledged that there are seasonal fluctuations in the wind and solar energy potential; few studied the magnitude of these fluctuations. This research determines if it is possible for a site such as the Texas Hill Country, with a low average wind speed, has enough wind at precise times of year, to make wind energy a wise investment.

The next gap in the literature is the failure to analyze the potential environmental effect of the batteries that are going to be needed to operate the hybrid systems. Energy storage is a major concern for standalone renewable energy systems that are not tied to the grid. Almost all renewable energy sources are not dependable or reliable enough to provide adequate energy around the clock and storage of surplus energy is a necessity to ensure continuous availability. The environmental consequences of the production and disposal of batteries need to be examined. Wind and solar energy are praised at being environmentally superior to the burning of fossil fuels. While it is true that wind and solar energy have little environmental impacts, there are going to be environmental impacts associated with the batteries. The entire lifecycle of a battery has potential environmental impacts, the production, transportation, and disposal. Currently, the literature and research has failed to recognize the potential consequences from the increased use and dependence on batteries.

CHAPTER 3

METHODS

The research analyzed wind and solar measurements for the Freeman Ranch Center to determine the relationship between the wind and solar electrical potential for the region. The wind and solar data was analyzed to determine annual and seasonal characteristics of potential electrical energy production from those sources. The results identify if there is a complementary nature to the wind and solar resources in the Texas Hill Country region which is beneficial to hybrid wind and solar systems.

I. Background on the Freeman Ranch Center

The Freeman Ranch Center covers 4,204 acres (1700 ha) and is situated in the center of Hays County, Texas. The Freeman Ranch Center is a good representation of the central Texas Hill Country landscape. Topographically the ranch can be described as hilly with an elevation that ranges from 680 feet (200 m) to 1,000 feet (300 m). The Freeman Ranch Center is located in the Balcones Canyonlands landform district of the Edwards Plateau (Fenneman 1931). The Ranch can be divided into various ecozones based on soil composition and topographic features. Approximately 74% of the ranch is made up of upland habitats which are relatively level. Non-sloping lowlands and steep sloping habitats constitute the remaining habitats found on the Ranch (Barnes et al 2000). The upland habitats are made up of savanna woody plant clusters mixed with perennial grasslands. The lower slopes are made up of evergreen woodlands, and the steep slopes are inhabited by deciduous woodland. Overall, the distribution between herbaceous and woody plants on the ranch is almost evenly split (Barnes et al 2000).

General research on the climatology for the area from San Antonio to Austin showed that there is an average wind speed of 9 mph (4.0 m/sec) with a dominant southerly flow. Conditions are typically breezy through the spring. The skies in the summer months are the clearest, resulting in increased incident solar radiation and hours of sunlight, while the winter months are significantly cloudier (Dixon 2000).

a. Renewable Energy Resource Availability at the Freeman Ranch Center

The meteorological data collected at the Freeman Ranch are generally consistent with literature on climate conditions for this area. Table 1. summarizes the wind and solar availability based on the data collected.

Table 1. Average Annual and Seasonal Renewable Resource Availability

Resource	Fall	Winter	Spring	Summer	Annual
Wind (m/s)	2.21	2.74	2.97	2.38	2.58
Solar (W/m^2)	146	140	249	261	199

One of the major discrepancies between the collected data and the literature was the average wind speed. The average annual wind speed for the Freeman Ranch Center was found to be 2.58 m/s, significantly lower than the expected 4.0 m/s. As predicted, the winter and spring are the windiest seasons with an average wind speed of 2.74 m/s and 2.97 m/s respectively. For Table 1. the recorded solar data was averaged seasonally and annually. The solar figures in Table 1. represent the average solar availability at any given time for the respective season as well as annually. Solar availability on average is 199 W/m^2 with spring and summer being the sunniest seasons at 249 W/m^2 and 261 W/m^2 respectively.

Figure 3. illustrates the relationship between the wind and solar resource availability throughout the year. While summer is the second least favorable season at the Freeman Ranch when looking at wind energy but is the most favorable for solar energy. Similarly, winter is the least favorable season for solar energy at the Freeman Ranch Center but the second best season for wind energy.

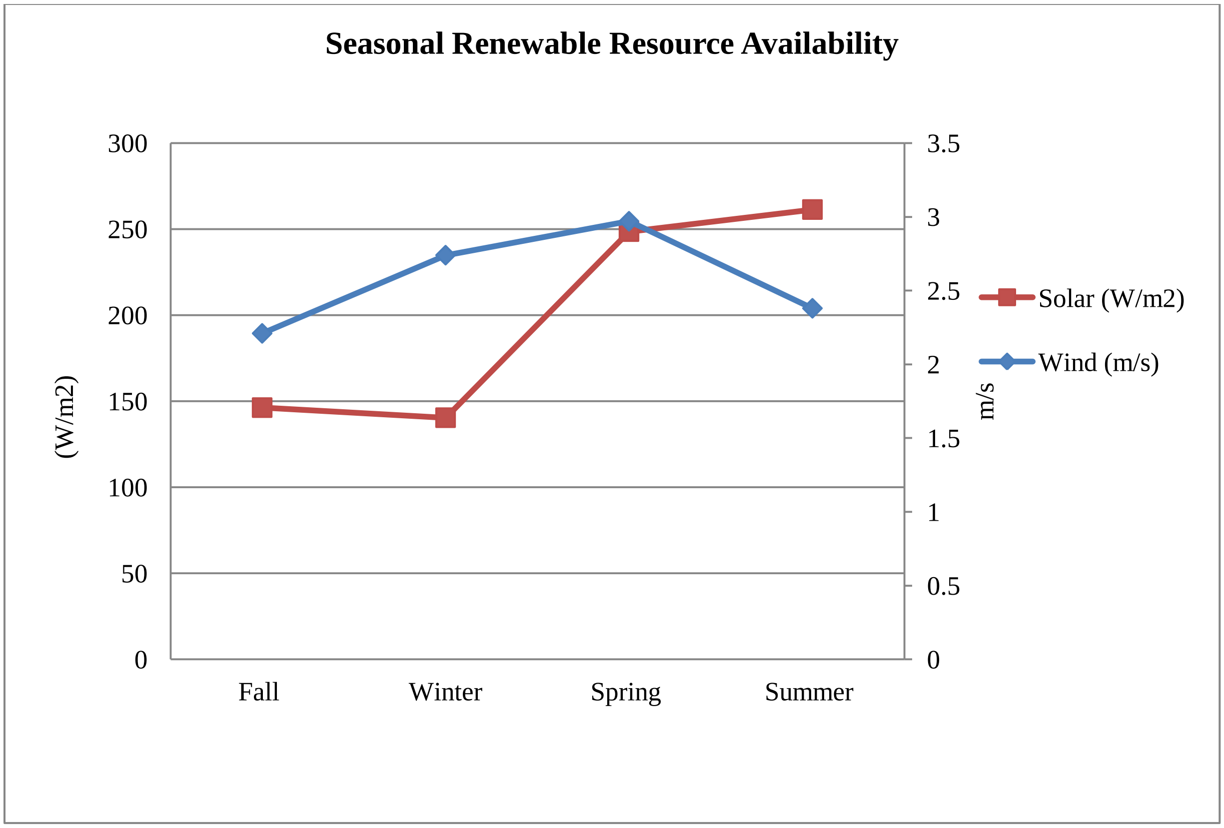

Figure 3. Seasonal Renewable Energy Resource Availability

The landscape characteristics of the Freeman Ranch Center and the preliminary interpretation of the wind and solar data suggest that Freeman Ranch Center is a suitable location, supporting the complementary wind and solar characteristics preferred for an efficient hybrid energy system. The complementary relationship provides a more reliable energy source throughout the year, as the seasons not ideal for one energy source are more favorable for the other.

Understanding the climate data for the study area is important as it is crucial in selecting the right equipment for optimal performance from a hybrid renewable energy system. Choosing the wrong equipment for the system can be the difference between having a successful hybrid renewable energy system and one that fails to meet the needs of the customer.

b. Energy Usage

Presently, residential consumers of Austin Energy use an average of 11,650 KWh of electricity per year but the usage varies seasonally as shown in Table 2.

Table 2. Residential Monthly, Annual, and Seasonal Electricity Usage (Austin Energy 2015)

Month	**kWh**	**Season**	**kWh**
January	890	Winter	2397
February	785		
March	723		
April	693	Spring	2646
May	813		
June	1139		
July	1344	Summer	4096
August	1389		
September	1364		
October	1006	Fall	2511
November	742		
December	763		
Monthly average	971		
Annual Total	11,650		

The data used for energy usage was provided from the Austin Energy data library (Austin Energy 2015). Austin energy provided monthly average usage for the residential customers from 2000 to 2012. The data set was used to determine monthly and yearly average residential energy usage. As of 2012, Austin energy had 376,614 residential customers serving the city of Austin and surrounding areas. While the Austin Energy residential customer base is more urban than rural, it was determined that the figures on the previous page will be an appropriate benchmark to analyze performance of a hybrid system in a residential application. Austin falls within the Texas Hill Country and will provide an acceptable representation of fluctuations in energy consumption due to seasonal climate factors. The seasons were divided as follows:

Winter: January, February, March

Spring: April, May, June

Summer: July, August, September

Fall: October, November, December

II. Methods

Data has previously been collected and provided by a research team from Texas A&M University. Data for this research comes from two weather stations found on the Freeman Ranch Center. These stations are referred to as the forest site and the transitional site. The forest site station data ranges from January 1, 2008 to December 31, 2009 and the transitional site data ranges from January 1, 2009 to December 31, 2010. Both weather stations measured half hourly samples of average wind speed, solar radiation, and wind direction. The geographic and instrumentation characteristics for the transitional metrological site and the forest metrological site can be found in Table 3. and Table 4. respectively.

Table 3. Transitional Site Meteorological Station: Geographic and Instrumentation Characteristics

Transitional Site	
Latitude	29° 56’ 58.11” N
Longitude	97° 59’ 46.41 W
Elevation	869 Feet
Height of instruments	10 meters
Anemometer	Campbell Scientific CSAT3
Radiometer	Kipp and Zonen CNR1

Table 4. Forest Site Meteorological Station: Geographic and Instrumentation Characteristics

Forest Site	
Latitude	29° 56’ 29.99” N
Longitude	97° 59’ 36.33” W
Elevation	840 Feet
Height of instruments	14 meters
Anemometer	Propeller
Pyranometer	LiCor LI200

a. Simulation Calculator

The data was analyzed with a simulation calculator developed by Dr. Jesus Jimenez and Dr. Tongdan Jin of Texas State University in the Center for High

Performance Systems in the Ingram School of Engineering. This method is consistent with the procedures of similar research.

The simulation calculator used in this research is operated by the Microsoft Excel computer program. This simulation calculator required the input of various parameters regarding weather conditions, site location, load demand, and wind turbine characteristics in order to properly simulate weather conditions and system output for the hybrid wind and solar energy system. To increase accuracy, 10 repetitions of the simulator were done seasonally and annually, and the results were averaged. Each simulation of the calculator, in theory, is equivalent to one year of data collection.

b. Model of Wind Production

Simulated wind speeds are used for calculations and modeling rather than the recorded data. The simulated wind speeds are used because it provides a better prediction of expected wind than the recorded data. The program used for calculations accounts for the stochastic nature of wind by applying the Weibull distribution in the wind speed simulation. The calculator applies average and standard deviation parameters of the collected wind data and creates a wind speed simulation that follows the Weibull distribution. The probability density function used by the calculator, $f_w(\mathrm{yt})$ is expressed as

$$fw(\mathrm{yt}) = \left(\frac{d}{v}\right)\left(\frac{yt}{v}\right)^{d-1} e\left[-\left(\frac{yt}{v}\right)^{d}\right]$$

yt represents the random wind speed at t time and *v* and *d* are the scale and shape parameters, respectively (Villarreal et al. 2012).

The calculator uses the simulated wind speeds to determine the energy production from the wind turbine system. There are four operating phases of a wind turbine system.

The operating phases are defined by three specific wind speeds: the cut-in speed, v_c; the rated speed, v_r; and the cutoff speed, v_s. The four operating phases of the wind turbine system are the standby phase, the nonlinear production phase, the constant power phase, and the cutoff phase. The standby phase is when the wind speed is greater than or equal to zero and less than the cut-in speed. At this time there is either no wind or not enough wind to rotate the turbine fast enough to produce electricity resulting in a power output of zero. The nonlinear production phase occurs when the wind speed is greater than or equal to the cut-in speed, but less than the rated speed. During the nonlinear production phase, the wind speed is strong enough that there is electricity being produced but not at the rated capacity of the turbine. This phase is called the nonlinear production phase because if the wind speeds and corresponding power outputs of this phase were plotted, a curve rather than a straight line would be observed. The constant power phase occurs when the wind speed is greater than or equal to the rated speed, but less than or equal to the cutoff speed. During the constant power phase the wind speed is high enough that the power output achieved is the rated capacity of the turbine. The cutoff phase is described as the wind speed being greater than the cutoff speed. During the cutoff phase, the wind speed surpasses the maximum speed at which the turbine can safely produce electricity resulting in a power output of zero (Villarreal et al. 2012). The power curve used for the simulation is expressed as

$$Pw(yt) = \begin{cases} 0, & 0 \leq y_t < v_c, y_t > v_s \\ 0.5\eta_w \rho A_w Y_t^3, & v_c \leq y_t < v_r \\ P_{max}, & v_r \leq y_t \leq v_s \end{cases}$$

Where η_w is the wind energy to electric energy conversion rate, ρ is the air density, and A_w is the area of the wind turbine blades. P_{max} is the rated power for the turbine which is the maximum power it is capable of producing.

The simulated wind speeds will be applied to the parameters of a leading residential wind turbine to determine the amount of kWh of electricity that could be produced daily, seasonally, and annually. For this study the parameters for the wind turbine system of the Polaris P10-10 Wind turbine were used. This turbine is one that is commonly used for residential development, agricultural applications, and small businesses. The turbine used in this study is at the larger end of what is commonly used for urban residential application. Given that the study area is largely rural agricultural land, this turbine was seen as an appropriate choice. Also, this turbine was chosen in order to represent the upper limit of wind power production potential available to the residents of the study area. Table 5. highlights the production parameters for this wind turbine system.

Table 5. Wind Turbine Parameters

Polaris P10-20 Wind Turbine	
Type	Horizontal axis, Upwind
Rated Power	20 kW
Cut-in Speed	2.7 m/s
Rated Speed	11 m/s
Cut-out Speed	25 m/s

For the wind data, seasonal and annual averages were gathered. The seasons were broken apart as follows: fall September 22nd through December 20th, winter December 21st through March 19th, spring March 20th through June 20th, and summer June 21st through September 21st.

c. Model of Solar Production

Solar electrical output is not calculated in the same manner as the wind electrical output. The technology for solar power production is relatively consistent. A difference in solar panel manufacture's does not result in drastic differences in the production of solar panels. For this reason, parameters from an actual solar unit are not needed to calculate the mock output. The simulation calculator is able to calculate solar power production based on the panel area size of the system. One attractive feature of the simulation calculator used in the research was that the calculator is able to determine the appropriate sized solar system needed for the study area. The photovoltaic panel area is determined by the energy load demand. For this research, the load was based off the average household energy usage for the study region. The simulator determined that a 2,500 Watt photovoltaic system was appropriate for the study location. Having the calculator compute the size of a solar system needed was helpful with system optimization and ensuring that maximum solar benefit was achieved without choosing a system too large or too small for the study area.

When modeling the solar conditions of the study area, the simulator did not use the recorded solar availability data that was collected at the Freeman Ranch Center. Data was retrieved from the National Oceanic and Atmospheric Administration to determine the average sky conditions for San Marcos, Texas. It was determined on average, there are 191 clear days, 76 partly cloudy days, and 98 cloudy days per year (National Climate Data Center, 2014). These weather characteristics are used to simulate the weather throughout the year and determine solar energy output.

For this research the simulator used the following equation to calculate the PV panel output;

$$P_s(d, \omega, W) = W\eta_s A_s I_t \left(1 - 0.005(T_o - 25)\right)$$

W is the random variable which represents the weather pattern. In this study the W values are as follows: 0.9 for clear days, 0.7 for partly cloudy days and 0.3 for cloudy days (Villarreal et al. 2013). The reason that 0.9 is used for clear days is that even on the clearest days it is unlikely to see maximum output sustained all day. I_t is the solar radiation on the PV panel. η_s is the photovoltaic conversion efficiency. A_s represents the PV panel area. T_o is the PV operating temperature measured in °C. d represents the calendar day and ω represents the solar hour angle.

A major flaw in the method of modeling solar conditions for this study was that the sky condition statistic could only be found as an annual figure. For this reason, the calculator was not able to accurately simulate the seasonal variations in solar radiation availability, resulting in solar production results that had no variation seasonally. It was determined that a correction factor was needed for the solar production results to illustrate variations consistent with the seasonal fluctuations in solar availability.

The correction factor was determined from a latitudinal solar radiation chart (Pidwrirny 2006). The seasonal correction factors used are as follows; fall 1.23, spring 1.46, and summer 1.81. The correction factors were determined by referencing the solar radiation chart and comparing solar availability of the winter season to the other seasons of the year. The simulation calculator used in this study was able to accurately model annual solar production for the system. Using the annual total solar production in kWh and the correction factor values, the following equation was used to calculate the seasonal production of the solar energy resource with *x* representing the solar production for the winter season;

$$1.46x + x + 1.23x + 1.81x = 5990$$

CHAPTER 4

RESULTS

The purpose of this study was to examine the relationship between the wind and solar energy potential at the Freeman Ranch Center. This research used meteorological data to simulate weather conditions and determine potential power output from a hypothetical hybrid wind and solar energy system. The results from the study show that there is potential for a hybrid wind and solar system to have success in the Texas Hill Country. While the proposed hybrid system would not be capable of completely providing for residential homes energy needs it would contribute significantly. Before examining the production potential of the hybrid system, first the production from each of the energy sources will be presented.

I. Contributions from Individual Energy Sources

It is important to examine what each individual component of the hybrid system contributed to production. As expected, solar was the stronger and more productive of the two renewable energy sources. Total seasonal production from solar energy was; 1,340 kWh in the fall, 1,090 kWh in the winter, 1,590 kWh in the spring, and 1,970 kWh in the summer. Table 6. presents the seasonal production for the wind and solar components of the hybrid system and the percentage of the electricity demand for the seasons. Seasonally the solar component of the hybrid system was able to produce nearly half of the electricity demands of the study area throughout the year. With a range from 46% of energy needs met in the winter, to 60% of the energy needs met in the spring.

The wind component of the hybrid system produced significantly less than solar, which was to be expected. The total seasonal production for wind energy was; 493 kWh in the fall, 1,130 kWh in the winter, 1,340 kWh in the spring, and 599 kWh in the summer. Seasonally, wind energy was able to provide a much less significant portion of the needs of the study area. In the summer months the wind production could only contribute 15% of electricity needs and in the spring the largest contribution to electricity needs is observed at 50%.

Table 6. Seasonal Production from Solar and Wind Compared to Electricity Demand

	Fall	Winter	Spring	Summer
Electrical Need kWh	2511	2397	2640	4090
Solar Production kWh	1,340	1,090	1,590	1,970
% of Electricity Needs	53%	46%	60%	48%
Wind Production kWh	493	1,130	1,340	599
% of Electricity Needs	20%	47%	50%	15%

Energy demand refers to the total electricity, natural gas, and propane consumption of the residential consumers. When factoring in other energy sources the productivity of the hybrid wind and solar system is much lower. Table 7. identifies how much the wind and solar energy components of the hybrid system can contribute annually to the total energy needs of the residential Texas Hill Country consumer.

The hybrid system can only provide about 40% of the annual energy needs for residents, with solar energy contributing 25% and wind energy providing 15% of those needs.

Table 7. Annual Production from Solar and Wind Compared to Energy Demand

Annual Production	
Solar Production kWh	5,990
% of Energy Needs	25%
Wind Production kWh	3,490
% of Energy Needs	15%

Below, Figure 4. illustrates the seasonal average electric production for the hybrid system. This figure provides a visual representation of the contribution that wind energy makes to solar energy in the hybrid system, as well as the seasonal fluctuations in production. It can be observed in Figure 4. that wind energy supplementing solar energy does provide a more reliable energy source seasonally, despite the seasons with limited production.

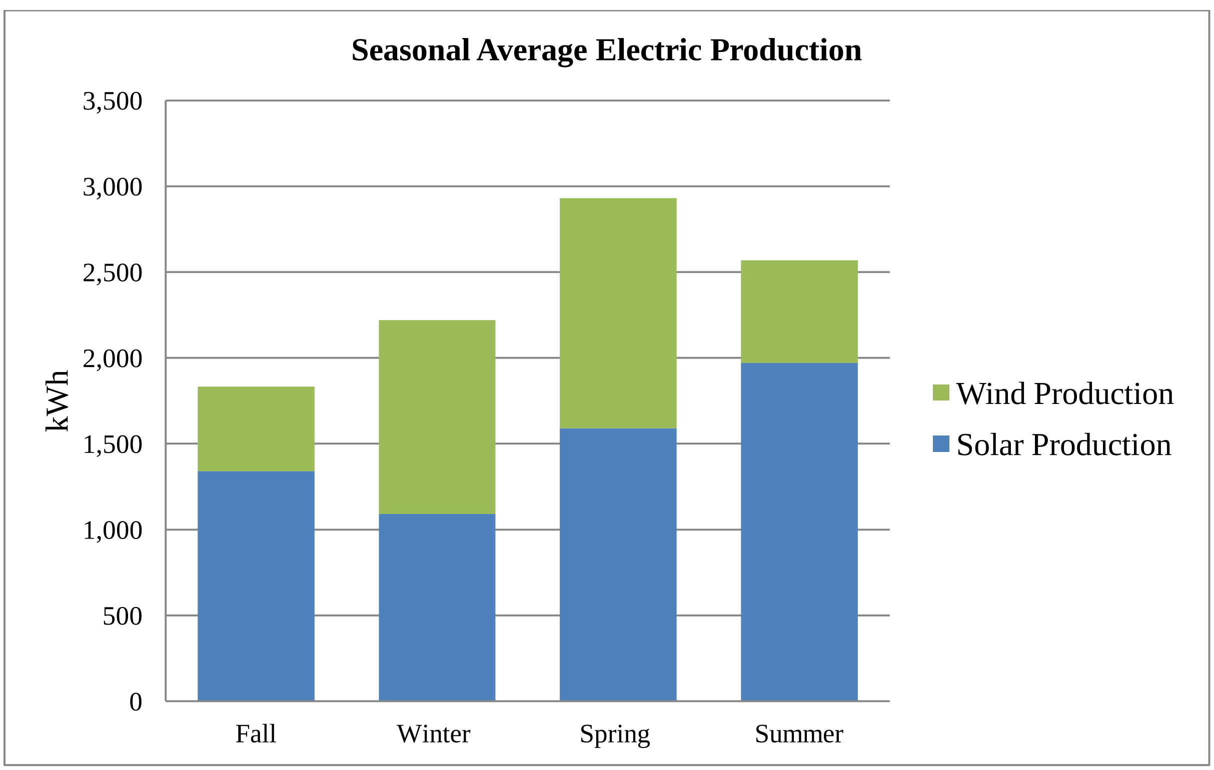

Figure 4. Seasonal Average Electric Production

II. Hybrid System Performance

On average, the hybrid system provided 9,490 kWh of energy annually. Seasonally, the typical resident could expect the following energy production from the hybrid system; fall 1,830 kWh, winter 2,220 kWh, spring 2,930 kWh, and summer 2,570 kWh. Table 8. compares seasonal and average production of the hybrid system as well as how much production could contribute to electricity and energy needs.

Table 8. Annual and Seasonal Production from Hybrid System

Hybrid Wind Solar System	Fall	Winter	Spring	Summer	Annual
Average Production (kWh)	1,830	2,220	2,930	2,570	9,480
Percent of Electricity Needs	73%	93%	110%	63%	81%
Percent of Energy Needs	-	-	-	-	40%

Focusing on only electricity consumption, a rural Hill Country resident could expect for a significant portion of their electricity needs to be met from the hybrid system. In the spring, the most productive season, over 100% of the electricity needs could be met by residents. In summer months, when electricity demand is highest at approximately 4,000 kWh for the season, residents could expect about half of their electricity needs to come from the hybrid wind and solar system. Annually, about 81% of electricity needs for the typical Hill Country Resident would be met.

III. Annual and Seasonal Demand and Production

When looking at electrical demand versus energy production it is important to also consider it in terms of kWh/day. The measure of kWh/Day is a beneficial way to look at the demand compared to the production because it illustrates the expected day to day performance of the system. Throughout the research process it was found that when determining demand of a specific area there are many factors that influence it. Table 9. shows energy demand and energy production of the hybrid system. As seen in Table 9. Energy demand for a single location can vary greatly depending on which factors are considered. For a resident that is unsure of anticipated electrical demand and is looking to install a renewable energy system, it important for a statistic to be used that is representative of all factors for that specific consumer and location. The demand data for Table 9. comes from the U.S. Energy Information Administration and the Austin Energy Online Data Library.

Table 9. Seasonal and Total Energy Annual Demand and Production in kWh/Day

Household Demand	
	kWh/Day
Electrical Demand Austin	
Fall	28
Winter	27
Spring	29
Summer	44
Annual	32
Energy Demand Annual Texas	62
Electricity Demand Annual Texas	39
Energy Consumption Annually in Southern States	
Urban	37
Rural	46
Production	
Hybrid System Wind and Solar	
Fall	20
Winter	25
Spring	32
Summer	28
Annual	26
Solar	
Fall	15
Winter	12
Spring	17
Summer	21
Annual	16
Wind	
Fall	5
Winter	12
Spring	14
Summer	6
Annual	10

Examining the results in terms of kWh/day is beneficial because seasonal and average totals in production vary based on the total number of days. When observing the results in average kWh per day, comparisons between variations in production are more reflective because they are all measured based on the same time period. The results of electrical energy production from the individual renewable energy sources as well as the hybrid system as a whole were promising when examining total production. It becomes clear when looking at production in kWh per day that the contributions of wind in supplementing solar energy are limited. In the windy seasons of winter and spring, an additional 12 and 14 kWh per day can be contributed from wind respectively. During the windy seasons, wind is able to nearly double system output. While daily production of wind is competitive with that of solar in the windy seasons, the rest of the year wind struggles to contribute. In fall and summer, wind is only able to produce 5 kWh per day and 6kWh per day respectively. During half the year, wind production is expected to be less than 10 kWh per day. While the spring and winter seasons for wind production showed great promise, the fall and summer wind production significantly limits what wind is able to contribute as a resource.

IV. Cost

An extensive cost analysis of the hybrid system was not conducted because the results did not support heavy investment in wind energy for the study area.

According to a 2012 study, the cost of wind turbines depends largely on the rated power. The average cost of wind turbines sized 10-20 kW is $2,550 per kW (Ohunakin et al. 2013). For a turbine comparable in rated power to the one used in this study, the cost would be expected to be around $51,000.

Compared to wind energy, solar power is much cheaper when looking at price per installed kW. A California study found that the average purchase cost of small scale photovoltaic systems to be \$6.73/W or \$6730/kW (Liu et al. 2014). The cost information is based on 2012 data, the same as the study referenced for wind costs. For this research, the expected cost of the installed photovoltaic component of the hybrid system is \$16,800. Table 10. identifies how the cost of the wind and solar energy compare to each other when amortized over 20 years.

Table 10. Wind and Solar Production versus Cost

	Solar	Wind
Production kWh/Year	5,990	3,490
20 Years kWh production	119,800	69,800
Resource Cost	\$16,800	\$51,000
Cost/kWh	\$0.14	\$0.73

When examining the cost of the renewable energy resources, the figures in Table 10. represent the cost of the resources before any tax credits or rebates. It is common for renewable energy systems to qualify for incentives that reduce the cost of the systems. For the purpose of this research, the full cost of the resources was considered to in order to compare the differences between the cost and production of the different technologies.

The economic benefit of solar power can be seen in Table 10. In this hypothetical system, the solar component produced 71% more energy annually than the wind component, while costing 33 % as much. When considering the cost, it is seen as more favorable for a Hill Country resident to invest more money in solar energy generation rather than wind energy generation. Solar energy has experienced a declining trend in cost and it can be expected that it would remain financially competitive option for residents looking to invest in renewable energy (Liu et al. 2014).

CHAPTER 5

DISCUSSION

It was hypothesized that there is enough wind and solar energy potential at the Freeman Ranch Center to demonstrate that the Texas Hill Country can benefit from small hybrid renewable energy systems. In the process of testing the hypothesis, the research questions were answered. It was determined that for a Texas Hill Country Location, a residential sized solar system could provide 16 kWh of electricity per day on average; a residential sized wind turbine could provide 10 kWh of electricity per day on average; and conjunctively in a hybrid system, these renewable resources could provide 26 kWh of electricity per day on average.

When looking at renewable energy potential for the Texas Hill Country, solar is the strongest in terms of availability and potential production. The results for solar production are consistent with what was expected to be found based on the literature. Solar production seasonally and annually showed the potential to significantly contribute to the electricity needs of residents in the study area. Even in the seasons least favorable to solar production, it was still able significantly contribute to demand.

Additionally, with regard to solar production, it was observed that solar production followed the variation in solar availability with summer being the most productive month followed by spring, fall, and winter. Interestingly, household electricity demand seasonally followed the same pattern of solar availability and production. The fact that solar production and electrical demand have the same seasonal fluctuations could be a contributing factor as to why the solar resource was able to contribute so highly to seasonal demands, even in the seasons with the most limited solar availability.

The results for wind power generation at the study area were mixed. The average annual wind speed at the study location was significantly lower than what the literature indicated to expect. Production could have been greater if the observed annual wind speed had been more consistent with what was found in the literature. As expected, wind energy production potential was not overwhelmingly strong. Even in the spring which is the strongest season for wind, the production observed was only 2 kWh per day higher than the production seen in the winter for solar. The theory behind hybrid renewable energy systems is that by coupling different energy sources the strengths in one resource overcome the weakness in the other. Winter would be described as the weakness of solar energy, as it is the season that provides the least solar availability. During this time wind is able to only match the solar production in terms of daily kWh of energy produced. A truly successful hybrid renewable energy system would show the relationship between the seasonal variations in production as being more complementary. Rather than seeing wind energy produce roughly the same amount of energy as solar in the winter, it would have been more desirable to observe wind being able to produce significantly more.

When examining the production potential of these resources combined together as a hybrid system the results were promising. In the Texas Hill Country, the typical resident could expect significant contributions to their electricity needs using a hybrid system similar to the one modeled in this research. The contribution made from wind increased seasonal production to a level where residents could expect no less than half their electricity needs met each season. Despite the high results in terms of how production could contribute to electricity needs, energy needs should be considered. When factoring in total household energy needs, the potential production from the hypothetical hybrid dropped dramatically. The contribution the hybrid system had to energy demand was about half of what was observed with regard to electrical demand.

Once cost was considered when examining the renewable energy resources, it became clear that wind energy development at the residential level for the Texas Hill Country is not economically supported. Wind energy produced significantly less energy while costing significantly more. The purpose of combining the renewable energy resources is to provide more consistent and reliable energy. One implication from the cost of wind is that rather than spending an exorbitant amount of money on a resource with limited production, part of the money that would have been spent on that resource could be invested in energy conservation measures. Rather than focusing on meeting demand with renewable resources, consumers should focus on ways to reduce energy consumption. By reducing consumption the potential benefit of renewable energies increases. A reduction in consumption, would allow for a single renewable energy source to have a greater impact with regard to contributions to energy demands as well as reduce the need for a supplementary energy source.

Another consideration when looking at cost of renewable energy systems for rural residents such as those found in the Texas Hill Country is the instillation cost of connecting properties to the electrical grid. Residents that live a considerable distance from a city or town face the issue of the substantial cost tying into the electric grid. In some cases, the cost of having an electric company extend the grid to their property may be more expensive than installing a renewable energy system large enough to meet energy demands. In cases such as these, it could be beneficial for residents to invest in renewable energy systems, specifically hybrid systems. When there is no backup energy available from the electric grid, diversifying the energy sources would be advisable. In an area such as the Texas Hill Country where the available wind resource is not extremely significant, residents would likely not be advised to choose a wind system comparable to the one used in this study. The size, cost, and production potential of the wind system used in this research make it unlikely that the typical residential user would find it an appropriate choice for their needs. Texas Hill Country residents may find that a smaller residential wind turbine is more affordable and while it would not be able to provide a significant amount toward household energy needs, it could serve as a backup power source when the solar unit fails to meet energy demands.

I. Limitations

While this research does contribute to the literature related to hybrid wind and solar renewable energy systems, there were some limitations to this research.

The first limitation was that the simulation calculator was unable to properly simulate variations in solar availability. This was the major weakness in this specific research. Having had solar data that was collected at the study site, it would have been beneficial if the collected solar data could have been applied to influence the solar portion of the weather pattern simulation. The ability to more accurately represent the variations in solar availability and production would be beneficial in predicting potential output and understanding the full scope of the impacts this resource could have in the study area. Considering that solar energy was the strongest of the renewable resources available at the study area, it would have been beneficial to apply the collected solar data to the simulation calculator.

Another limitation was the amount of data collected at the study site. When working with weather data, the time period in which data is collected is extremely important when making predictions of future weather expectations. It is understood that more years of available data will provide better results when modeling expected weather patterns. The limited years of available data for this study could have had an impact on the results. As mentioned before, the measured average annual wind speed was found to be significantly lower than the literature had predicted. It could be that the data was collected during a period in which there were unusually low wind speeds. Having a data set over a longer period of time may have produced different average annual and seasonal wind speeds, which would affect the production results with regard to wind energy. While the average annual wind speed was just slightly below the cut in speed of the wind turbine, observing an average annual wind speed which was at or above the cut in speed would have resulted in significantly higher wind energy production values.

II. Implications for Future Research

The California study by Liu et al. (2014) discussed the economic differences between purchasing and leasing photovoltaic systems. While the literature for wind did not provide information about potential leasing options, this study raises the question of the potential impact leasing turbines could have on wind energy application in the Texas Hill Country. It would be beneficial to examine if leasing wind turbines versus purchasing them makes them any more affordable in the study area. While a lower cost turbine would not change the production potential of the wind energy resource, it would make it more feasible to diversify renewable energy resource for the residents of the study area.

There are some political implications of this study. Policies made to promote renewable energy sources need to be tailored to the resources that best benefit specific areas. It is clear from this research that central Texas has strong solar resource availability and that should be considered when making policies relating to renewable energy. It is important to continue research on the technology and application of wind energy but political legislation, tax credits, and rebate incentives that encourage wind development in non suitable areas will only perpetuate dependence on fossil fuel. Future research on this topic should include how political factors influence consumers' decisions regarding renewable energy implementation at the residential level.

III. Summary

This research set out to examine the wind and solar energy potential at the Freeman Ranch Center to demonstrate the contributions these energy sources could make to the typical Texas Hill Country resident. Specifically, this study examined the potential for wind energy to supplement solar energy, creating a more reliable and consistent energy source.

A simulation calculator was used to simulate weather conditions for the study area. The simulation calculator also calculated energy production from residential sized wind and solar energy generation systems. Production from these sources was analyzed to determine annual and seasonal variations between the two resources, as well as what these sources could contribute when combined in the form of a hybrid renewable energy system.

It was found that the benefits of a hybrid renewable wind and solar energy system in the Texas Hill Country are not significant enough to justify the application of these systems at this time for this region. This research did find that the Texas Hill Country does, to a degree, demonstrate the complementary characteristics in terms of solar and wind availability that appeals to hybrid systems. When factoring the cost associated with these renewable energy resources, residents of the Texas Hill Country would find that a solar only system would be a more sensible option. This research does not suggest that wind energy should not be applied in the Texas Hill Country but rather that careful consideration must be taken when installing wind systems. Understanding climate data for specific locations will be imperative in seeing these systems perform optimally.

IV. Conclusion

It is understood that the Texas Hill Country is classified as an area that is not suitable for wind energy development. The purpose of this research was to better understand the relationship and fluctuations between wind and solar energy potential for the area. It was hypothesized that there is enough wind and solar energy potential at the Freeman Ranch Center to demonstrate that the Texas Hill Country could benefit from small hybrid renewable energy systems. Having a reliable renewable source of power would be extremely beneficial to the Texas Hill Country residents. In the event of unusually severe weather conditions, stand alone solar could struggle to meet energy needs. Diversifying the energy source is one way to prevent an energy shortage during those times of need.

This project helped fill some of the gaps in the literature. There is relatively little literature on coupling wind and solar energy together for an application suggested by this research. Studies similar to this have been conducted elsewhere but few have been conducted in a comparable setting.

The Freeman Ranch Center, Texas State University, and the residents of the Texas Hill Country have the potential to greatly benefit from this study. This study shows how the renewable energies, wind and solar, can contribute to meet the energy needs at the Freeman Ranch Center. More importantly, this study demonstrated how other landowners in the Hill County can employ similar systems and reduce their energy expenses and it also demonstrated the negative effects of traditionally produced electricity from fossil fuels.

While the results of this study did not support the predicted hypothesis, the implications made from this research are an important contribution. From this research it can be concluded that the added benefit of supplementing solar energy and wind energy is not significant enough to justify the added cost of wind power at this time in the Texas Hill Country. However, the result of this study opens the door for continued research on the renewable energy potential of the study area and brings the residents of the Texas Hill Country one step closer to a fossil fuel free future.

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