AN EVALUATION OF WIND TURBINE TECHNOLOGY AT PETERSON AIR FORCE BASE

THESIS

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Abstract

Wind energy and other renewable energy sources have been around since the dawn of time. But our culture has only recently begun to realize the vast benefits possible from using wind energy for electricity generation. Wind energy technology is a viable source for attaining the emission reduction and renewable energy use goals set forth by the executive office. In accordance with Executive Orders, the Air Force must reduce greenhouse emissions and energy consumption, and expand the use of renewable energy sources within its facilities nation-wide by year 2010. This mandate requires that the Air Force look at alternative electrical production and rely more on such renewable energy resources as wind power. The specific problem addressed by this research is whether on-site wind energy generation can be more economically and environmentally feasible than the conventional energy consumption at Peterson AFB. The hypothesis of this research is that wind energy will not be economically effective as an energy alternative without the inclusion of quantified environmental benefits.

The life cycle cost comparisons derived from generating on-site wind energy proved not to be strictly economically feasible for Peterson AFB when compared to fossil fuel generated electricity. However, with the inclusion of the valuation of environmental benefits, it was determined that wind energy is a worthwhile project if the U.S. Air Force is willing to pay the extra costs for the global socioeconomic benefits.

Acknowledgments

I first want to thank God for the knowledge, ability, and perseverance that He gave me.

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Randy C. Combs

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1. Introduction

1.1 Overview

Wind energy and other renewable energy sources have been around since the dawn of time. But our culture has only recently begun to realize the vast benefits possible from using wind energy for electricity generation. Wind turbines now provide more than 31,000 Mega Watts (MW) of power, enough capacity to provide electricity for more than 90 million American households, a total that has swelled by almost 30 percent in scarcely a year's time and that keeps more than 200 million tons of carbon dioxide out of the atmosphere every year (IEEE, 2004).

This research effort compares the life cycle costs of implementing electrical generation by using on-site wind turbines versus the costs of purchasing electricity through the local power grid for Peterson AFB, Colorado Springs, CO. Non-market valuations of environmental benefits are analyzed and security benefits are addressed.

1.2 Background

Executive Order (EO) 13123, Greening the Government Through Efficient Energy Management, signed on June 3, 1999, requires executive agencies such as the Department of Defense (DoD) to reduce greenhouse gas emissions 30% by the year 2010 when compared to the year 1990 emission levels. In addition, each agency is tasked to expand the use of renewable energy sources within its facilities nation-wide by year 2010. EO 13123 also directs each agency to reduce energy consumption even if on-site energy needs increased (Clinton, 1999).

Wind energy technology is a viable source for attaining these emission reduction and renewable energy use goals set forth by the executive office. Wind is a clean source of energy that avoids most of the environmental impacts that are associated with conventional electricity production. Wind power does not create greenhouse gas or acid gas emissions, both of which result from the combustion of traditional fossil fuels such as coal, oil, and natural gas. Wind energy also does not require the transportation of large quantities of fuel – such as the movement of coal across the country.

Wind energy is also becoming more economically feasible as technology improvements have lowered the cost of wind power production, making it a cost competitive source of energy compared to fossil fuels. In addition, wind energy has the lowest production costs of any renewable energy source (AWEA, 2004). Though the initial capital cost of a wind turbine is about 90% of the total life cycle cost of wind energy (BWEA, 2004), the long term savings can potentially pay for the initial costs and the savings could then be passed back to the DoD. On-site excess energy production can also be sold to local utilities, increasing the cost effectiveness of the project with the prospect of generating revenue for the installation (Thal, 2004). Therefore, as the price of non-renewable energy sources continues to steadily rise, military agencies can adapt to the changing energy environment by using alternative energy generation such as wind power.

Economic, environmental, and security benefits are all associated with the use of wind technology. The economics of wind energy has changed considerably over the past 20 years, as the cost of producing wind energy has declined approximately 90% during that period (AWEA, 2002). The benefits are being recognized with wind energy experiencing an average annual growth rate of 40 percent in the last five years, making it the fastest growing energy technology percent wise in the world (AWEA, 2004). Wind energy production could allow Peterson AFB to be energy self-sufficient and free the base from reliance on traditional energy sources or off-site purchases. In addition, terrorist activity has triggered a greater need for military installations to safeguard their energy supplies. Wind energy production could provide energy security for Peterson AFB while reducing potential electricity supply disruptions.

1.3 Problem Statement

In accordance with Executive Orders, the Air Force must reduce greenhouse emissions and energy consumption, and expand the use of renewable energy sources within its facilities nation-wide by year 2010. This mandate requires that the Air Force look at alternative electrical production and rely more on such renewable energy resources as wind power. The specific problem addressed by this research is whether wind energy can be more economically and environmentally feasible than the conventional energy consumption at Peterson AFB. The hypothesis of this research is that wind energy will not be economically effective as an energy alternative without the inclusion of quantified environmental benefits at Peterson AFB.

1.4 Research Objective

The purpose of this thesis is to evaluate wind turbine technology at Peterson AFB to determine if wind sourced energy is a cost effective energy alternative to provide electrical power to the base. Part of the evaluation includes quantifying the reduction of greenhouse gas emissions. In addition, this research effort will provide a consistent methodology for Air Force installations to use when evaluating energy sources for base consumption.

The particular research questions that must be answered include the following:

1. Where has wind energy been used successfully in the past and what are the characteristics, benefits, and problems encountered with it?

2. What is the value of the environmental and economic impacts of reducing greenhouse gas emissions?

3. What are the life cycle costs of wind turbines to be used at Peterson AFB and the costs of the conventional and green energy for current consumption at Peterson AFB?

4. Is wind energy economically effective as an energy alternative without the inclusion of quantified environmental benefits?

5. Is wind energy economically effective as an energy alternative with the inclusion of quantified environmental benefits?

1.5 Scope

This research will evaluate wind energy technology specifically at Peterson AFB. The forthcoming analysis will provide a comparison for energy consumption using wind turbine technology and the traditional energy system being used at Peterson AFB.

The climatic data collected is site specific to Peterson AFB. In addition, wind energy studies and practices at military installations are assessed. However, the methodology used in this research can be drawn on by virtually any organization to determine the feasibility of wind turbine technology at DoD and civilian installations.

1.6 Approach/ Methodology

In general, renewable energy technologies are a relatively underexploited source of energy generation in the United States (AWEA, 2004). Wind energy is just a piece of that renewable energy pie. Military installations are just beginning to witness the effects of alternative power as they start to implement renewable energy designs into their facilities in accordance with EO 13123. To accurately perform the feasibility study for Peterson AFB, case studies of wind power use will be reviewed and a life cycle economic analysis will be performed. First, case studies using data collected from four sites using wind energy technology will be examined: Dyess AFB, Fairchild AFB, F.E. Warren AFB, and Vandenberg AFB. The data collected from these facilities includes the cost or savings to the government for implementing wind energy resources at Air Force installations. Furthermore, the case studies were used to determine what the U.S. Air Force is currently doing in the wind energy arena and if wind energy use is economical for Peterson AFB to pursue.

The information gathered in the case studies, in addition to expert opinion, was used to determine what type of wind turbine is most practical and economical for application at Peterson AFB. Once the best turbine design for Peterson AFB was determined and a cost estimate was developed, an economic analysis was performed to compare this type of wind turbine and the traditional system that is being used. This allowed for a comparison of economic value to include environmental benefits while evaluating wind turbine technology and the traditional energy consumption at Peterson AFB. A literature review was also conducted to determine environmental costs and benefits, and to determine how and where wind power can be used effectively.

1.7 Significance

This thesis will provide Peterson AFB with the required information to determine if wind energy is more economically effective than conventional electrical energy with or without the inclusion of quantified environmental benefits. In addition, this thesis will present Air Force leaders with a better understanding of wind turbine technology and the possibilities of wind energy waiting to be exploited by the Air Force. This appreciation and subsequent adoption of renewable energy technologies would also further reduce the governmental dependence on outside energy sources and ensure a cleaner environment for future generations.

1.8 Chapter Preview

Chapter 2 contains a literature review of wind energy sources and discusses both limitations and benefits. This chapter also details wind energy project costs. Chapter 3 provides a basic overview of life cycle costing and the supplemental techniques for calculating economic effectiveness as the methodology for this research. Chapter 4 documents the results of the comparative life cycle cost analysis including environmental and security benefits. In addition, chapter 4 includes the case study analysis. Chapter 5 concludes the research endeavor and provides policy recommendations based on comparative analysis. Chapter 5 also includes limitations of the research and potential areas for follow on research.

2. Literature Review

2.1 Overview

This literature review briefly describes wind energy and the economical variations of wind turbines. It reviews the environmental and economic impacts and benefit associated with wind energy generation and then reviews the executive orders that direct federal agencies to implement the use of renewable energy sources and environmental enhancement through clean energy programs. Next, this literature review describes the life cycle costs related to wind energy generation along with the methodologies associated with making alternative comparisons. Finally, current natural resource reserves which hold the fossil fuels that are used for electricity generation are examined.

2.2 Renewable Energy

Wind energy is just one of many types of renewable energies. Other types of renewable energy sources include: hydroelectric, biomass, geothermal, and solar power. Renewable Energy Annual 2002 points out that wind energy produced only 0.12% of the nation's 97.6 quadrillion Btu (British thermal unit) consumed in 2002 (EIA, 2003). Even though wind energy consumption constituted a very small percentage, this represented an increase of 56% from 2001. That increase was due largely to new generation capacity that came on line at the end of 2001 in response to the expiration of the wind Production Tax Credit (DOE, 2004). The Department of Energy estimates that 2% of the 2010 U.S. electricity supply will be provided by wind technology (Nix, 1995). Figure 1 shows the various sources of energy production in the United States.

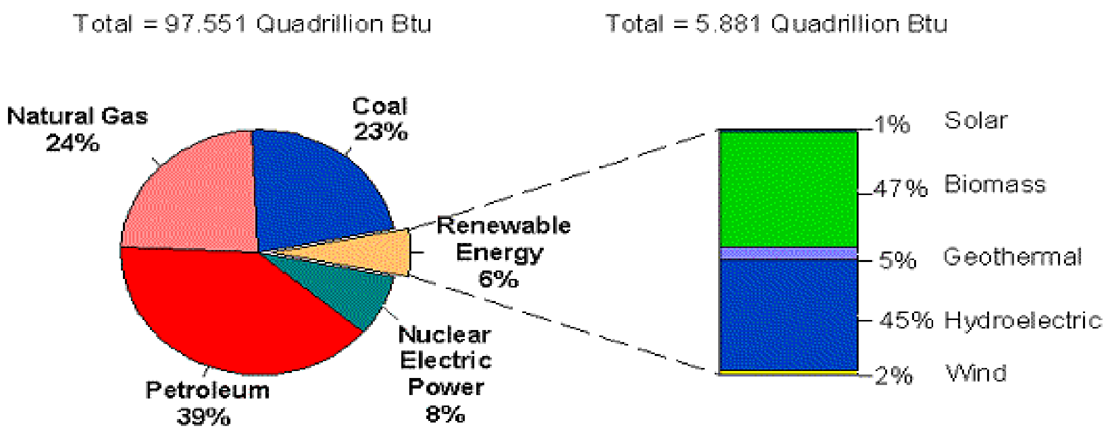


Figure 1. U.S. Energy Production, 2002

Renewable energy technology constitutes only 6% of the nation's energy production (Department of Energy, 2002)

2.3 Wind

Wind is an abundant energy source which is powered by the energy from the sun. The solar radiation heats the earth's surface unevenly creating areas of high and low pressure. Land and water, desert and forest, mountain and valley, the poles and the equator all absorb heat to a different extent. When the earth's surface heats up, it also heats the air above it causing air density and pressure gradients between the different regions (EERE, 2004). The second law of thermodynamics requires these gradients to be minimized. This is accomplished by the movement of air from high pressure areas to low pressure areas, which is wind (Reeves, 2003:5)

2.3.1 Wind Energy

Wind has been a potential source of energy since the beginning of time. Even though the dynamics of wind energy were not understood, mankind was able to corral its power. The first known use of wind as an energy source was with sailboats (CEERT, 2004). The first known windmills were developed sometime between 500 and 900 AD in Persia (Smith, 2003:53). The Ancient Persians predominately used the windmills to mill grain, which is where the name windmill originated. The first recorded wind turbine in Europe dates from 1270 A.D. (Smith, 2003:53). The explosion of turbine use in the United States occurred during the 19th century westward expansion where there was plenty of dry land and water was plentiful underneath the soil (Johnson, 1985:3). Wind turbines provided the energy to move that water to the surface.

More than 8 million mechanical windmills have been installed in the U.S. since the 1860's and some of these units have been operating for more than a hundred years. Back in the 1920's and 1930's, before the Rural Electrification Administration (REA) began subsidizing rural electric coops and electric lines, farm families throughout the Midwest used 200-3,000 Watt wind generators to power lights, radios, and kitchen appliances. The modest wind industry that had built up by the 1930's was literally driven out of business by government policies favoring the construction of utility lines and fossil fuel power plants (Bergey, 2002).

The United States actively began to research and develop sources of wind energy shortly after the Organization of Petroleum Exporting Countries (OPEC) Oil Embargo of 1973 as a possible solution to the energy crisis. Homeowners and farmers looked to reduce their utility bills and small wind turbines emerged as the most cost effective renewable energy technology available. Tax credits and federal regulations fostered the inauguration of more than 4,500 wind systems at individual homes between 1976 and 1985. An additional 1,000 systems were established in numerous remote locations during the same period (Bergey, 2002).

The world's modern wind industry began in California in the early 1980's (CEERT, 2004). Financial incentives and federal regulations aided California in adding over 1,500 MW of wind power to their supply mix. However, large companies were not committed to long term market development, so when the federal tax credits expired in late 1985, and oil prices dropped to $10 a barrel two months later, most of the small wind turbine industry once again disappeared (Bergey, 2002). California's global market share of wind power generation fell from 90% in the early 80's to 10% today.   In 1999, the Department of Energy revealed their plan, "Wind Powering America", which entails providing for 5 percent of our nation's electricity from wind power by the year 2020 (EERE, 2004). Europe is projected to provide half of their region's population with wind generated electricity by 2020 (BWEA, 2004). For comparison, Europe currently has an installed wind generating capacity of over 39,000 MW while the United States has just over 6,700 MW.

The American Wind Energy Association (AWEA) estimates that 3.5 billion kilowatt-hours of electricity was produced in the U.S. from wind energy facilities in 1997. This was enough electricity to meet the needs of more than 353,500 average American households, while displacing 6.65 million barrels of oil or 1.75 million tons of coal (AWEA, 1998). Figure 2 shows the sources of wind energy production (MW) in the United States as of January 2004. Wind energy in the United States could provide as much as 40% of our electricity, yet our nation generates less than 1% of its electricity with the wind (REV, 2004). The U.S. still relies heavily on coal for its electricity production while European nations are replacing coal with wind energy. This is due largely, in fact, to the lapses of the U.S. wind production tax credit of $0.018 per kWh which was implemented in 1992 to offset subsidies to fossil fuels. This essential credit has lapsed three times within the last 5 years and most recently in 2003 when Congress failed to pass a new energy bill (EIA, 2004). President Bush resolved the current situation concerning the wind production tax credit when he signed a tax bill on 4 October 2004 providing a 2 year extension. The extension provides the credit through 31 December 2005 and is retroactive to 31 December 2003, the previous expiration date.

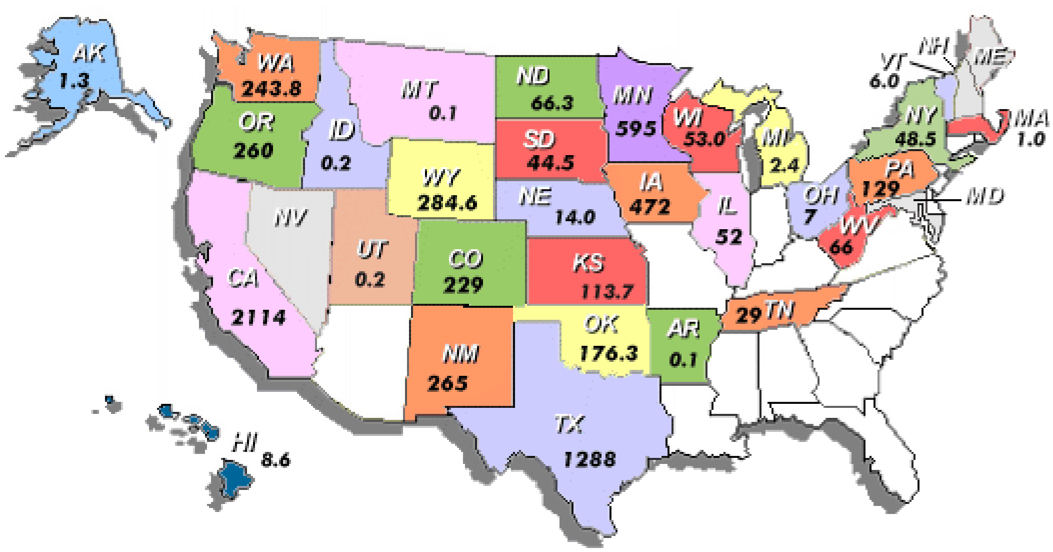


Figure 2. U.S. Wind Energy Capacity, 2002

This map represents the available capacity of wind energy production as of January 2005 (AWEA, 2005)

2.3.2 Wind Power

The power produced by a wind turbine depends on the length of the blades, the speed of the wind, and the power coefficient of the wind generator. Wind varies tremendously across the United States and the evaluation of wind energy is dependent on analyzing the wind speed for a given area. The energy content of the wind is proportional to the cube of its velocity (DWIA, 2003). So if the wind speed is twice as high then it contains $2^3 = 8$ times as much energy. This means that only a slight increase in wind speed can yield significant gains in power production. In addition, the power is proportional to the circular wind area so by doubling the blade length of a horizontal axis turbine, the power increases by a power of 4 (area of a circle = πr^2). The formula for calculating the wind turbine's power is (AWEA, 2004):

$$p = 0.5 \times \rho \times A \times Cp \times V^3 \times Ng \times Nb \qquad (1)$$

where

p = power in watts (W)

ρ = air density (kg m^{-3})

A = rotor swept area (m^2)

Cp = coefficient of performance

V = wind speed (ms^{-1})

Ng = generator efficiency

Nb = gearbox/bearings efficiency

The average velocity of wind affects wind turbine performance and increases with altitude. Average wind velocity determines how often and consistently the wind will create power for a particular turbine. If the instantaneous wind velocity is too low, then electricity cannot be generated and if its velocity is too high, then the turbines can sustain damage from the extreme wind conditions. Generally, wind velocity varies according to elevation above ground and also with surface obstructions. The formula for calculating wind speed for the height of a particular turbine is shown in equation 2 (DWIA, 2004). It is followed by the table corresponding to roughness of the terrain style (DWIA, 2004).

$$v_2 = v_1 \cdot \frac{\ln(h_2 / z_0)}{\ln(h_1 / z_0)} \qquad (2)$$

where

v_2 = wind velocity at height of turbine (ms^{-1})

v_1 = wind velocity at height of 10 m (ms^{-1})

h_1 = the height at which the measurement for site selection is taken, usually corrected to 10 m

h_2 = the height of the hub of the wind turbine

z_0 = roughness corresponding to terrain style

Table 1. Roughness Classes and Roughness Lengths

Roughness Classes and Roughness Length Table			
Rough- ness Class	Roughness Length m	Energy Index (per cent)	Landscape Type
0	0.0002	100	Water surface
0.5	0.0024	73	Completely open terrain with a smooth surface, e.g.concrete runways in airports, mowed grass, etc.
1	0.03	52	Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills
1.5	0.055	45	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 1250 metres
2	0.1	39	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 500 metres
2.5	0.2	31	Agricultural land with many houses, shrubs and plants, or 8 metre tall sheltering hedgerows with a distance of approx. 250 metres
3	0.4	24	Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests and very rough and uneven terrain
3.5	0.8	18	Larger cities with tall buildings
4	1.6	13	Very large cities with tall buildings and skycrapers

(DWIA, 2004)

A variable that has a large impact on the energy potential of wind turbines is the variability of the wind. The probability density function of wind velocity can be closely represented by the Weibull function for a given mean velocity (DWIA, 2004). Figure 3 shows an example of the probability distribution at given mean wind speeds of 7 ms^{-1}. In this case, the median speed is 6.6 ms^{-1}. The probability function tells us that half the time the wind speed will be less than 6.6 ms^{-1} and half the time greater than 6.6 ms^{-1}. Additionally, the probability distribution function shows us that 5.5 ms^{-1} is the mode and has the highest probability of being the wind speed. The Weibull distribution is skewed to the right where extreme wind conditions have a possibility of existing but are not likely. This distribution allows a close approximation of what type of energy output wind can provide.

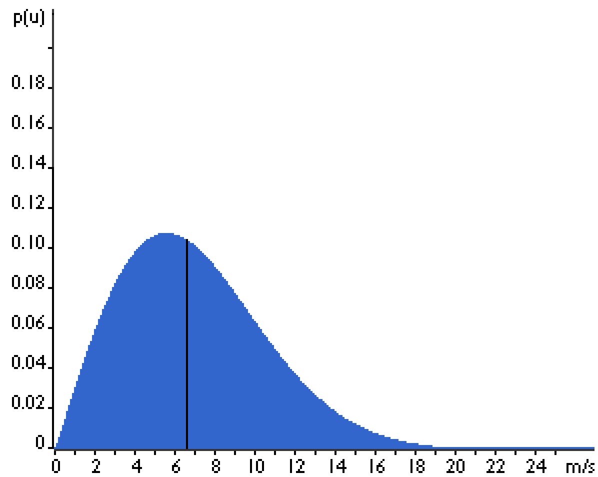


Figure 3. Weibull Distribution of Wind Speed
(DWIA, 2004)

Wind is classified according to wind power classes, which are based on typical wind speeds. These classes range from class 1, the lowest, to class 7, the highest (EERE, 2004). Wind power classes are based on the average wind power density expressed in watts per square meter (W/m^2).   The wind power classifications associated with the particular wind power density and speed are illustrated in Table 2 (NREL, 2004).

Table 2. Classes of Wind Power Densities

Classes of wind power density at 10 m and 50 m[(a)].

Wind Power Class*	10 m (33 ft) Wind Power Density (W/m^2)	10 m (33 ft) Speed[(b)] m/s (mph)	50 m (164 ft) Wind Power Density (W/m^2)	50 m (164 ft) Speed[(b)] m/s (mph)
	0	0	0	0
1				
	100	4.4 (9.8)	200	5.6 (12.5)
2				
	150	5.1 (11.5)	300	6.4 (14.3)
3				
	200	5.6 (12.5)	400	7.0 (15.7)
4				
	250	6.0 (13.4)	500	7.5 (16.8)
5				
	300	6.4 (14.3)	600	8.0 (17.9)
6				
	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) elevation.

* Each wind power class should span two power densities. For example, Wind Power Class = 3 represents the Wind Power Density range between 150 W/m2 and 200 W/m2. The offset cells in the first column attempt to illustrate this concept.

(NREL, 2004)

Class 4 and above are deemed good wind resources where large turbines can be useful in generating wind power. Average seasonal wind power over the upland plains of eastern Colorado range from a maximum of class 4 and 5 in spring to a minimum of class 2 and 3 in the summer (NREL, 1986). The mountainous regions of Colorado produce an enormous amount of wind power, estimated at about a class 6. However, many of these higher mountain ranges may not be suitable for wind turbine applications because of extreme icing, damaging winds, and inaccessibility, especially during the winter (NREL, 1986).

Figure 4 below shows the typical meteorological year (TMY) data pictorially and is known as the Department of Energy's Wind Resource Map (DOE, 2003). This map presents the wind power based on wind speed and wind sensor elevation throughout the United States. A potential site must have a minimum annual average wind speed at a 10 meter height of approximately 9 miles per hour or 4 meters per second (ms^{-1}) to be considered for wind power generation (AWEA, 2004). The National Oceanic and Atmospheric Association (NOAA) indicates that at a 10 m elevation, Colorado Springs has an average annual wind speed of 4.5 ms^{-1} (NOAA, 2004). In addition to NOAA, the Desert Research Institute (DRI) indicates that Colorado Springs has an average annual wind speed of 4.3 ms^{-1} (DRI, 2004). The average annual wind speeds for the Colorado Springs area are based on the location of the Colorado Springs Municipal Airport which is shared with Peterson AFB. More accurate and detailed climatology data was provided by the Air Force Combat Climatology Center (AFCCC) and is summarized in Chapter 4. It is very important to note that these wind speeds are based on one specific site and speeds could vary in either direction depending on the site selection. The map below also suggests that Colorado is located in a high wind area and has wind resources consistent with utility-scale production.

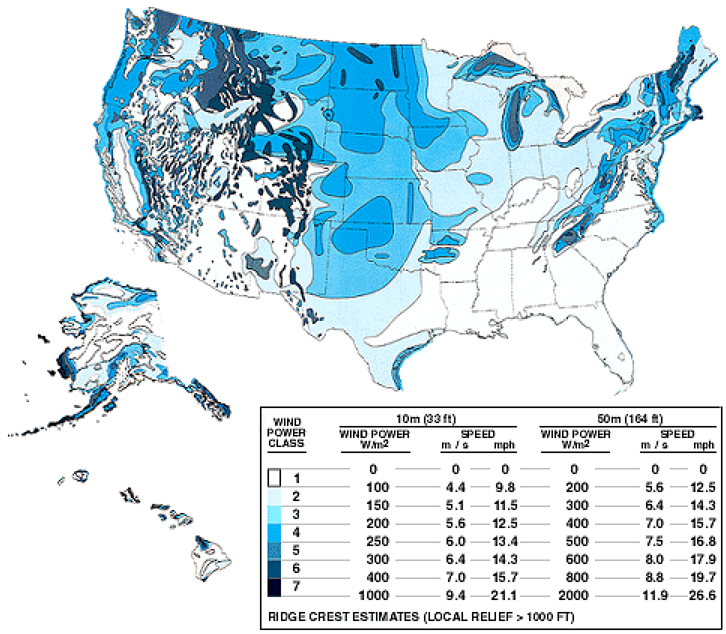


Figure 4. U.S. Wind Resource Map

Much of the wind energy is concentrated in the West and along mountain ranges in both the East and West (NREL, 2003)

2.3.3 Wind Turbines

Wind turbines are currently used around the world for many applications. The scope extends from homeowners using single turbines to produce energy to large wind farms with hundreds of turbines providing electricity to the power grid (EERE, 2004). A wind turbine can harness the energy of the wind by converting the force of the wind into torque acting on the rotor blades turning part of its kinetic energy into mechanical and then to electrical energy. The amount of energy which the wind transfers to the rotor depends on the density of the air, the rotor area, and the wind speed (DWIA, 2003).

The capability of wind turbines to produce electricity is called their capacity factor. If the turbines were to run at a capacity factor of 100%, this would imply that the turbines would run all day, at full power. That would mean that there would be no down time for repairs and that the wind would blow at the rated maximum velocity all the time. This is obviously an impossible target for a wind farm as the turbines operate on the speed of the wind and the availability of the wind. The capacity factor is calculated by taking the wind turbine's actual energy output for the year divided by the energy output if the machine operated at its rated power output for the entire year.

Site selections are one of the most important factors in determining an economically feasible wind project. The power of the wind, the speed of the wind, the wind power density, and the capacity factor all vary with different sites. The goal is to maximize each of these factors by correctly siting the wind turbines. There are also a number of variables which must be taken into account when selecting a site: size of the project and availability of land, zoning codes and ordinances, proximity of power lines, wind turbulence, and wind direction to name a few. A wind rose chart depicts the percent frequency of occurrence of different wind direction and wind speed combinations for a specific location. The wind rose chart for Peterson AFB is shown in Figure 5.

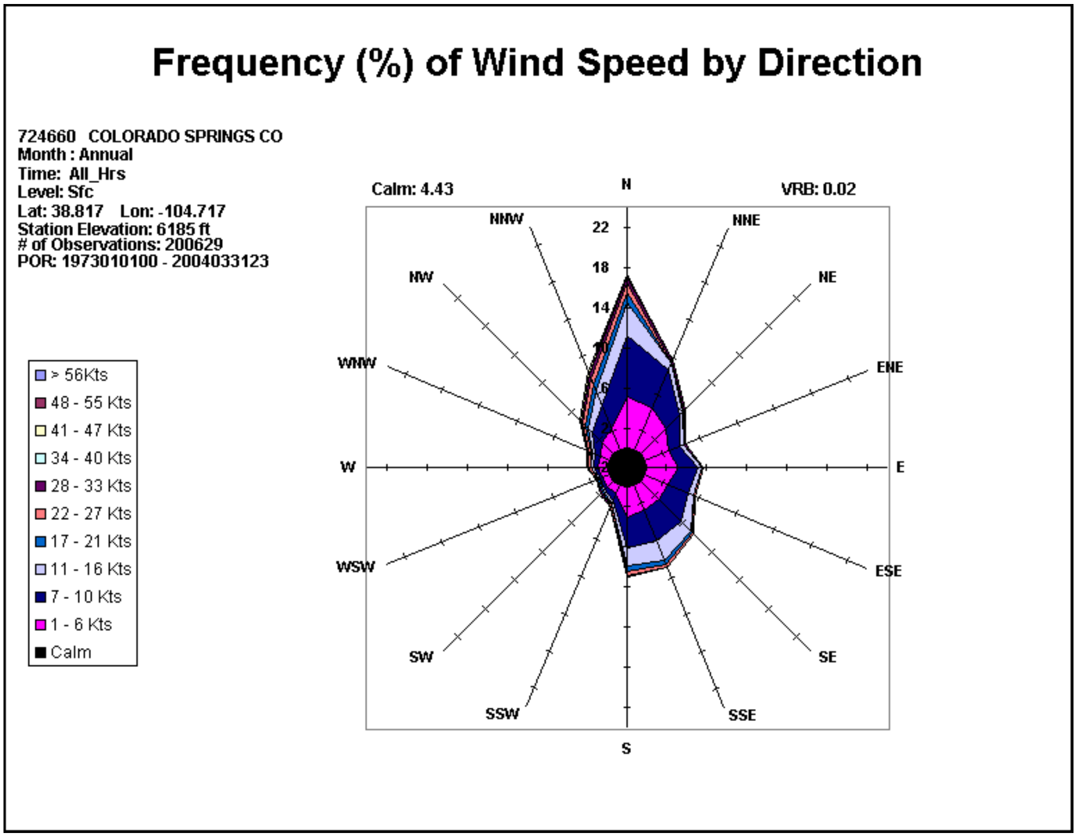


Figure 5. Wind Rose Chart

The data are displayed on a 2-D graph using 16 compass directions. Wind speed is broken out into 10 categories, plus calm. Each wind speed category is color-coded on the graph. 1 knot = 0.514 ms^{-1} (AFCCC, 2004).

All in all, a typical site selection should follow a manner compatible with environmental preservation, sustainable development, and the efficient use of resources. An anemometer, being erected in Figure 6, is a critical tool used to survey a site for selection. The anemometer is used to accurately measure how fast the wind is blowing. It is typically placed on the top of a large pole at a height between 10 m and 60 m. The site survey will typically last one year to provide accurate data.

Figure 6. Anemometer Installation

Workers install an anemometer on a 30 ft pole at
Vandenberg AFB, CA (Vandenberg AFB, 2001)

The economics behind wind energy generation has influenced the design of the massive turbine structures. Wind turbines can be strategically placed to make a project economically and environmentally sound. Areas receiving a combination of strong winds and consistent winds are ideal for wind energy generation. The turbines should be constructed high above the topography so their power supply is not interrupted by turbulence or friction. In addition, the turbines should be sited close to the power lines, batteries, or generators that they supply in order to reduce transmission line loss.

Large wind turbines have emerged as the bulk electricity generator of choice amongst renewable energy technologies worldwide. There are two types of turbines used for large scale utility production: horizontal axis and vertical axis turbines. Their chief virtues are zero emissions, quick payback periods, and a well established track record of reliability (REW, 2004). There are competing technologies in the renewables arena including biomass, biogas, geothermal and hydro electric power generation. While each has its definite merits and abundant niches for applications, only geothermal and utility-scale wind have the capability to pump mass quantities of electrons, greater than 10 MW, into the grid without getting involved in the carbon cycle where the carbon atoms are literally recycled indefinitely. Pricewise, geothermal can no longer keep tempo with utility-scale wind as the price of electricity from a well sited wind farm is now pressing against the $0.04/kWh barrier which is cost competitive with fossil fuels (REW, 2004).

2.3.3.1 Horizontal-Axis

Horizontal-axis turbines are the most common turbine design and are known for their propeller like blades and high reliability. Figure 7 shows a horizontal axis turbine. Prototypes of high-speed horizontal- axis turbines were developed during the oil shortages in the 1970's. The horizontal-axis turbine blade takes on the wind at a 30 to 45-degree angle. Each blade on this type of turbine has no drag on the return into the wind because there is no return into the wind. This approach utilizes high rotations per minute (rpms) and a gear ratio to generate torque to do the work. The majority of horizontal axis turbines can actually rotate upon the vertical axis to face into the wind to consume as much wind energy as possible. Most are computer controlled and can also shut themselves down if wind speeds reach the cut-out speed, or maximum allowable speed, which could potentially cause damage to the rotor and drive train machinery. The average lifetime of a turbine is estimated to be between 20 and 30 years. The military is wary of using horizontal axis turbines on their installations because they present a sizeable obstacle for pilots especially during bad weather and could possibly pose a risk with electromagnetic interference depending on the blade composition (Pugh, 2004).

Figure 7. A Horizontal-Axis Three-Bladed Turbine

The horizontal turbines are the most widely used design (NEG Micon 1500 kW, 2004)

2.3.3.2 Vertical-Axis

The vertical-axis wind turbines work like a revolving door as the blade spins around the shaft of the turbine. This type of turbine is shown in Figure 8. The most popular high-speed vertical-axis turbines are the Darrieus models which were invented in

France in the 1920’s. These turbines have long, thin, and usually 2-3 curved outer blades, which rotate at 3 to 4 times the wind speed. They have a low starting torque and a high tip-speed ratio. The tip-speed ratio measures how much faster the blade tips travel compared to the wind speed. The tip-speed ratio is calculated by taking the blade tip velocity divided by the wind speed.

Darrieus turbines are ordinarily inexpensive and are used for electricity generation and irrigation. One advantage to a Darrieus turbine is its delivery of mechanical power at ground level. The generator, gearbox, and turbine components are on the ground, instead of at the top of a tower as in horizontal-axis turbines. They cost much less to construct, because there is less material, and the pitch of the blades does not have to be adjusted. One disadvantage is that the Darrieus turbine needs a starting motor whenever the turbine blades become idle. In addition, the Savonius model, which originated in Finland in the 1920's, is an S-shaped blade, which rotates and turns a vertical shaft. The benefit of the Savonius turbine is that it has a high starting torque and thus needs no starting motor and can operate in low winds (Johnson, 1985:16). On the down side, the Savonius turbine operates at a slow rotational speed which is not as good for generating electricity but is better for grinding grain or pumping water. Other types of high-speed vertical-axis turbines are the Madaras and Flettner turbines, revolving cylinders which sit on a tracked carriage. The motion of a spinning cylinder causes the carriage to move over a circular track and the carriage wheels to drive an electric generator (Justus, 1978).

Most Vertical axis turbines utilize all of the available power delivered to it by the wind because it takes the wind head on with a blade at a 90-degree angle to the axle. But that same blade must also turn against the wind on the opposite side of the axle, thus creating drag that slows the turbine down. The vertical axis turbines can create a lot of torque at low rpms.

Vertical-axis machines are not managed by the direction of the wind. The vertical blades actually catch the wind. Because the shaft is vertical, the transmission and generator can be mounted at ground level allowing easier servicing and a lighter weight, thus obtaining a lower cost tower. Although vertical axis wind turbines have these advantages, their designs are not as efficient at collecting energy from the wind as are the horizontal machine designs (IEC, 2004).

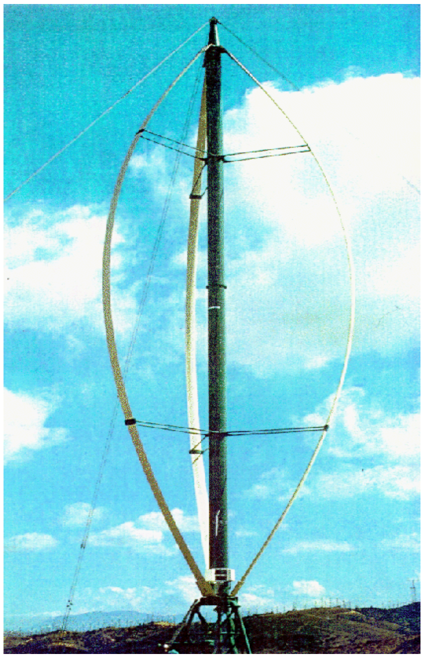


Figure 8. A Vertical-axis Turbine

The vertical axis turbine operates at ground level (Turbomachinery, 2004)

2.3.4 Colorado Wind Energy

The total installed U.S. wind energy capacity has reached an all time high of 6,770 MW as of December 2004 (EERE, 2005). The state of Colorado alone has installed 229 MW as of December 2004. According to Pacific Northwest National Laboratory (PNNL), Colorado is ranked 11th in their projection of use of the available windy land area and wind energy potential in the contiguous United States (PNNL, 1991). Colorado is a state with tremendous, and currently underexploited, wind resources (AWEA, 2004). According to another PNNL study, Colorado's winds could generate 481 billion kilowatt-hours of electricity annually, or enough to serve several times the entire state's population (AWEA, 1998).

Today, 94 percent of Colorado's electricity is produced by the burning of fossil fuels which contributes to acid rain and snow, climate change, urban smog, and regional haze (Cogreenpower, 2004). In a 2003 survey conducted by the Wells Fargo Public Opinion Research Program of the Graduate School of Public Affairs, University of Colorado at Denver, 82 percent of Coloradans said they would like to see renewable sources such as wind, solar or hydropower as the focus for generating new power (Environment Colorado, 2004). Yet, just over 1,000 customers, roughly 0.5%, in the Colorado Springs area are purchasing renewable energy through the Colorado Springs Utilities green power program (Baker, 2004). However, the University of Colorado in Boulder, Colorado took a step towards greening the environment when the student body voted by a 5 to 1 margin to increase student fees by $1 per semester for 4 years to purchase wind power from Xcel Energy's Ponnequin wind farm. The clean, renewable source of energy is projected to lower campus emissions of carbon dioxide by 2.8 million pounds every year (UCSU, 2004). Moreover, in a 2004 ballot initiative, Colorado voters had become the first in the nation to vote on and pass a statewide renewable energy requirement. Amendment 37 will require Colorado's top utility companies to provide a percentage of their retail electricity sales from renewable resources beginning by 2007 (Environment Colorado, 2004). There is considerable support throughout the state of Colorado for renewable energy to be the wave of the future for the state.

2.4 Ponnequin Wind Farm

The Ponnequin wind farm saw its first wind turbine up and running in 1998 and was established as the first wind farm erected in Colorado. The wind farm consists of 44 turbines, 29 of which produce 700 kW and 15 that produce 660 kW. The farm is located on the plains in the north eastern part of Colorado, just south of Cheyenne, Wyoming. Xcel Energy leases the land from local farmers for the turbines for $2,000 - $3,000 annually for each turbine. NEG Micon and Vestas are the two companies who manufactured the turbines. Each 700 kW turbine weighs nearly 100 tons and stands 181 feet to the turbine body, where the blades are attached. The turbine blades have a diameter of 159 feet. Each wind turbine cost about $1 million to build. They begin operating with wind speeds as low as 7 mph and shut themselves down at speeds over 55 mph to prevent over speed damage (FSV, 2004). The farm in total cost roughly $40 million to build, while 99% of the land is still available for other uses; it is currently being used for Buffalo grazing (UCSU, 2001).

A green power program called Windsource, offered by Xcel Energy which is formerly the Public Service Company of Colorado, lets customers elect to purchase a portion of their power from wind energy (FSV, 2004). This is the largest customer-driven wind energy program in the country and is very popular (FSV, 2004). Peterson AFB is currently looking at the prospect of purchasing blocks of green power generated by the Ponnequin wind farm. This research will aid Peterson AFB when considering the purchase of blocks of green power.

2.5 Environmental Impacts

Five environmental concerns are generally examined when considering a wind facility; (i) birds or avian issues, (ii) electromagnetic interference, (iii) visual issues, (iv) noise issues, and (v) flora and fauna issues.

2.5.1 Avian Issues

Bird deaths are one of the most controversial biological issues related to wind turbines. The deaths of federally protected birds and bats at wind farm sites have raised concerns by fish and wildlife agencies and conservation groups. On the other hand, several large wind facilities have operated for years with only minor impacts on these animals (Wind EIS, 2004). A recent report, the Erickson Study, released by the National Wind Coordinating Committee (NWCC) indicates that of the approximately four hundred million (400,000,000) birds killed annually by transportation vehicles, tall buildings, tall communications towers with guide wires, overhead electrical lines and wind turbines, only about eighty thousand (80,000) are killed by flying into wind turbines (Erickson, 2001). A review of studies on avian mortality at more than 15 U. S. wind power facilities reveals relatively few fatalities overall and no ecologically significant mortality at any site, with the possible exception of Golden Eagle fatalities in the Altamont Pass Wind Resource Area of California (Kerlinger, 2001). Outside of California less than ten (10) raptors have been reported killed by wind turbines (NWCC, 2001). Studies by the Royal Society for the Protection for Birds have shown wind turbines to have very little effect on bird populations. The damage to wildlife habitat caused by traditional fossil fuel electricity generation has a much greater impact on wildlife than wind turbines (BWEA, 1999). Provided that candidate sites are properly studied and the turbines sited correctly, there should be minimal impact on birds, if any at all.

2.5.2 Electromagnetic Interference

Depending upon their locations, wind facilities may represent a concern associated with potential interference with radar and telecommunication facilities. And like all electrical generating facilities, wind generators produce electric and magnetic fields (Wind EIS, 2004). The electromagnetic interference is something that has predominately occurred in the past because the turbine blades were made out of steel, rather than the composite or wood laminate which is commonly used today. TV, FM and radar waves are perturbed in line of sight by electrically conducting materials. Therefore, the metallic parts of rotating blades can produce dynamic interference in signals. It is easy, but not necessarily cheap; to install TV and FM repeater stations to provide another direction of signal for receivers. Radar interference is, as yet, a largely undocumented effect, of most concern to the military; however, there are many sites of wind turbines close to airfields, and no significant difficulties have occurred (REW, 2004). Conversely, the U.S. Air Force shut down a $130M wind project at the Shoshone Mountain due to the electromagnetic interference that would disrupt radar signals during training exercises at Nellis AFB in Nevada (Rogers, 2002).

2.5.3 Aesthetic Issues

Wind turbines are often very large structures with an upper height limit of approximately four hundred (400) feet at the blade tip (DISGEN, 2004). These large machines can be a very overwhelming sight. Prior to construction, photo simulations have been successfully used to demonstrate to local communities and permitting officials the expected change in the landscape. Beauty is in the eye of the beholder, but most communities have accepted the wind turbines and their economic benefits without major objection (DISGEN, 2004).

2.5.4 Noise Issues

Modern wind turbines produce noise at approximately forty-five decibels (45db) at the base of the tower. At one thousand feet (1000 ft) from the tower, the noise level is less than thirty decibels (30db), a sound approximating a whisper (DISGEN, 2004). Most turbines are sited far from occupied buildings or residential areas, so noise is rarely a factor. In recent years, engineers have made design changes to reduce the noise from wind turbines. Early model turbines are generally noisier than most new and larger models. As blades have become more efficient, more of the wind is converted into rotational torque and less into acoustic noise (Wind EIS, 2004). Research for quieter rotor blades is ongoing.

2.5.5 Flora and Fauna Issues

Studies to quantify any sensitive species or plants should, depending upon location, be conducted. The scientific evidence to date indicates that there are no significant impacts on surface animals, including migratory animals, except during construction. After construction, the animals resume their normal migratory patterns (DISGEN, 2004). In addition, many turbines are sited on farmland where the farmers will lease a part of their land for the turbines for $2,000 - $3,000 per turbine (WAPA, 2005). As large as these wind turbines are, they do not leave a large footprint on the land. Agricultural operations continue as usual around the base of the turbines, so that income from leases in fact is in addition to customary farming or ranching income. The cement pads that support these heavy machines are buried underground. If the turbine owner ever decides to remove the turbines, the cement pads are buried low enough that they would be covered up and forgotten. Myrna Roman, a cattle rancher in north eastern Colorado welcomes the massive turbines on her property. "There's no pollution and very little noise," said Myrna. "And the cows don't mind it at all." She acknowledged that the lease income is a substantial economic benefit in a cattle industry where profit margins are slight (WAPA, 2005).

2.5.6 Other Environmental Issues

Unlike traditional generating technologies, wind turbines do not use a combustion process to convert fuel into electricity, and therefore do not produce air emissions. The only potentially toxic or hazardous substances are relatively small amounts of lubricating oils and hydraulic and insulating fluids. Therefore, contamination of surface or groundwater or soils is highly unlikely. The primary health and safety considerations are related to blade movement and the presence of industrial equipment in areas potentially accessible to the public (Wind EIS, 2004). Proper location of the wind turbines and wind farms can mitigate the environmental damage.

2.6 Environmental Benefits

Wind is a natural resource that has been and will always be around. Wind is an energy source that produces no pollutants meaning less smog, acid rain, and greenhouse gas emissions. Wind can be constantly exploited without the need to import energy supplies from foreign countries. It can also enhance our nation's security, help protect its beauty, and improve the quality of air we breathe when used to power our homes and businesses. Furthermore, using wind power as a replacement for coal, natural gas, or oil avoids the environmental impacts of mining, drilling, transporting, and burning these fuels.

The Pollution Prevention Act of 1990 states, "The Congress hereby declares it to be the national policy of the United States that pollution should be prevented or reduced at the source whenever feasible…" The U.S. Air Force defines pollution prevention (P2) as, "…the use of processes, practices, materials, or products that avoid, reduce, or control pollution, which may include recycling, treatment, process changes, control mechanisms, efficient use of resources, and material substitution" (Draft AFI 32-7080).

Power plants are the largest stationary source of air pollution in the United States, emitting millions of tons of sulfur dioxide (SO_2), nitrogen oxides (NO_X), methane (CH_4), and carbon dioxide (CO_2) each year which are believed by some to be the cause of global warming and acid rain (REV, 2004). SO_2 causes corrosion, acidification of soil and water, and leads to health damages. NO_X causes smog, acid rain, human respiratory diseases, water quality deterioration, and reacts to form toxic chemicals. CH_4 causes respiratory problems, can reduce the immune system, and is considered the second most frequent cause of greenhouse warming, behind CO_2. Figure 9 shows the life cycle carbon dioxide emissions for the three leading fuels for electricity production in addition to wind energy generation. The life cycle carbon dioxide emissions per unit of power produced from a wind farm are only about 1% of that from coal plants and roughly 2% of that for natural gas facilities (Reeves, 2003:16). The only source of CO_2 emissions for the wind farms stem from the transportation and construction of the wind turbines.

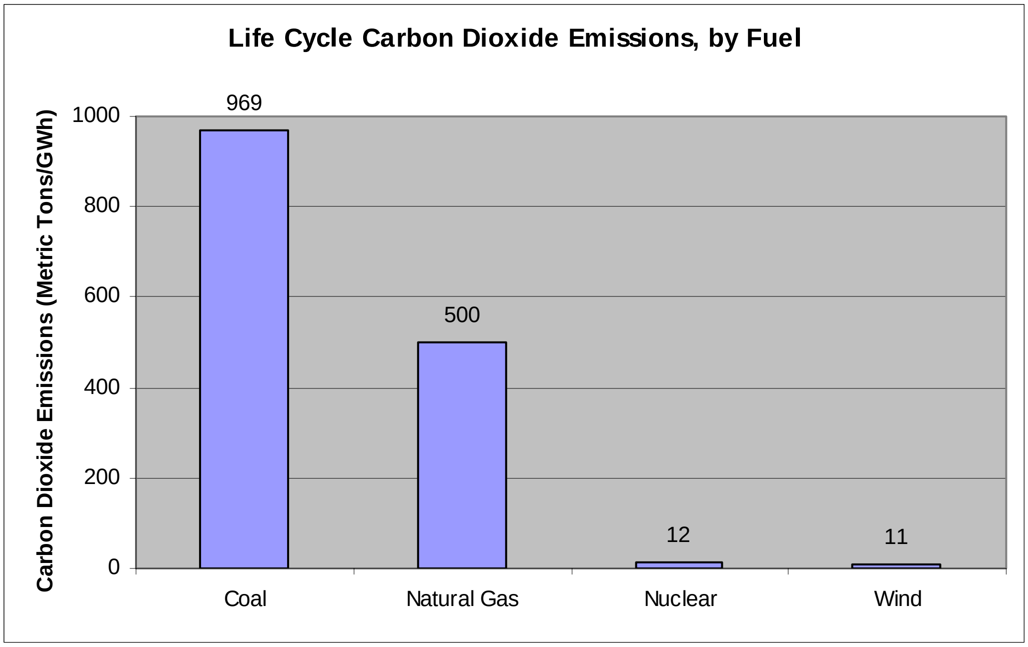


Figure 9. Life Cycle Carbon Dioxide Emissions

Wind energy production dramatically reduces the amount of GHG released into the atmosphere (Reeves, 2003:16)

Every kilowatt hour of wind energy generated offsets emissions of these harmful green house gases (GHG) and other pollutants and reduces the accumulation of toxic materials found in coal. A study conducted by the University of Wisconsin-Madison found that a traditional coal-fueled power plant pollutes 65 times as much CO_2 per gigawatt (GW) hour as a wind powered plant does; this accounts for all the pollutants created in the construction, operation and decommissioning of the power plants (White et. al, 2000). In addition, the study also found that the energy payback ratio (EPR) for a coal plant is 11, while the EPR for a wind plant is 23. This means that 23 times as much energy is produced during the lifetime operation of a wind plant than is required to make that electricity. This study clearly demonstrates that wind power is more than twice as efficient as coal for producing power.

The average household in Colorado uses about 600 kWh of electricity per month (CSU, 2004). Buying one 100 kWh block of wind power each month for a year will produce a positive environmental impact equivalent to eliminating 2,400 pounds of CO_2, not driving a car 2,400 miles, planting a half-acre of trees, or saving 1,200 pounds of coal, assuming that the wind energy displaces electricity produced by coal-fired generating plants (AWEA, 1998). By spending an additional $30 per year on wind power, an average Colorado family could cut its household carbon dioxide production by about 10 percent (Colorado Green Power, 2004).

The average 750 kW wind turbine will produce roughly 2 million kWh of electricity in a year. Based on the U.S. average fuel mix, approximately 1.5 pounds of CO_2 is emitted for every kWh generated. This means that an average 750 kW wind turbine prevents the emission of (AWEA, 1998):

$$2{,}000{,}000\,\text{kWh} \times \frac{1.5\,\text{lb}\,CO_2}{\text{kWh}} = 3{,}000{,}000\,\text{lb}\,CO_2 \qquad (3)$$

Society bears the cost of pollution in terms of poorer health, leading to higher health service costs funded by the taxpayer, and a degraded environment, which increases the cost of food and farm products. Many attempts have been made to put a price on these costs but as yet no universally accepted method has been found (BWEA, 1999).

2.7 Environmental Costs

June 4th 1971, President Richard Nixon delivered a Special Message to Congress on Energy Resources. In this message the President addressed the non-market economic pricing of producing energy. He told Congress, “One reason we use energy so lavishly today is that the price of energy does not include all the social costs of producing it. The costs incurred in protecting the environment and the health and safety of workers, for example, are part of the real costs of producing energy—but they are not now all included in the price of the product” (Nixon, 1971). President Nixon indicates a few of the social costs which are a part of producing energy. Some other external costs include those related to premature mortality and morbidity, infrastructure, agriculture, and the environment.

Environmental benefits are extremely hard to quantify and too open to political interpretation which the federal government carefully avoids. Yet still, there are a handful of studies that try to determine the marginal social damage of producing energy with fossil fuels. Various procedures have been adopted for mortality and morbidity assessments that are based either on contingent valuation (Turner 1993, Bateman and Willis, 1999) or on epidemiological surveys and analyses to determine the years of life lost due to various pulmonary disorders, as well as cardiovascular problems (MMWR 1986). Some studies assume that there is a link between ozone and premature mortality which in turn attributes a higher health cost. Morbidity assessments are typically relating to reduced productivity and the consequent cost increase for health care. Estimated benefits for reducing premature mortality account for roughly 75-85 percent of all benefits represented in economic assessments of improved air quality (Krupnick and Burtraw, 1997). Infrastructure damages are usually accounted for as replacement costs while agriculture damages which stem from air pollution and acid rain are calculated in terms of yield reduction (Gatto et al., 2002). Environmental assessments would include costs such as reducing carbon sequestration, and flora and fauna damages. Air pollutants also impair visibility and damage materials, affecting both aesthetic and property values (Burtraw & Toman, 1997).

Geographic location impacts the resulting monetized value of the social costs related to electricity generation. A city with a much greater concentration of population will have a larger populace affected by emissions (Burtraw & Toman, 1997). Lee et al. estimate that the human health impacts from operation of a new coal plant vary by an order of magnitude between a plant located in New Mexico and one located in Tennessee (Lee et al., 1995).

The European Commission project ExternE was a research project to evaluate the external costs associated with a range of different fuel cycles. The project was developed in lieu of a European requirement which required policy analysts to take environmental aspects into account and use cost-benefit analysis in their decision making (IPTS, 2005). The social damages which ExternE evaluated include damage to the natural and built environment, such as effects of air pollution on health, buildings, crops, forests, and global warming; occupational disease and accidents; and reduced amenity from visual intrusion of plant or emissions of noise (IPTS, 2005). Based on a breakdown of various studies, the European Union estimates that global costs can range from $5 - $183 per ton of CO_2 with an average of $39 (Gatto et al., 2002).

Estimating the social damage costs of electricity generation from utilities examined in Colorado Springs, CO would yield more accurate estimates for the specific area. This research does not estimate the bottom up social damages of Colorado Springs specifically but uses the suggested global cost of GHG emissions.

2.8 Economic Benefits

Wind power generation results in greater fuel diversity and less dependence on fossil fuels, which are subject to price fluctuations. Wind power can also strengthen the local economy by keeping money spent on electricity in the state. It has also helped to create wind industry related jobs. According to the Alternatives Journal, the greater use of renewables promises to create jobs and improve economic competitiveness (Sonneborn, 2000). This is because renewable technologies require direct manufacturing of related technologies (Sonneborn, 2000). The report goes on to state that comparing power plants generating 1,000 GWh per year finds that it takes 100 workers in a nuclear plant, 116 in a coal-fired plant, 248 in a solar-thermal facility, and 542 on a wind farm (Sonneborn, 2000).

2.9 Executive Orders

On June 3 1999, President Clinton issued Executive Order (EO) 13123, <u>Greening the Government Through Efficient Energy Management</u>, requiring executive agencies such as the Department of Defense (DoD) to reduce greenhouse gas emissions 30% by the year 2010, when compared to the year 1990 emission levels (Clinton,1999). EO 13123 also directs each agency to reduce energy consumption even if on-site energy needs increase (Clinton, 1999). In addition, EO 13123 encouraged the Federal Government to promote energy efficiency and the use of renewable energy products, and help foster markets for emerging technologies (Clinton, 1999). The EO also emphasizes the use of LCC analysis in determining the cost effectiveness of energy supply for the government and for reducing source energy. It goes on to say that in an effort to reduce the Federal Government's costs and energy, agencies must use life cycle cost analysis techniques in making decisions about their investments. Agencies are also encouraged to bundle energy efficient projects with renewable energy projects as they consider the life cycle costs. "Agencies that minimize life-cycle costs with efficiency measures will be recognized in their scorecard evaluations" (Clinton, 1999).

Agencies shall use off-grid generation systems, including solar hot water, solar electric, solar outdoor lighting, small wind turbines, fuel cells, and other off-grid alternatives, where such systems are life-cycle cost-effective and offer benefits including energy efficiency, pollution prevention, source energy reductions, avoided infrastructure costs, or expedited service (Clinton, 1999). In addition, the federal government is required to be using 2.5% renewable energy by 2005 (Clinton, 1999). As of 2003, the federal government's renewable energy use was 1.2%. The final figures have not yet been calculated for 2004.

In addition to EO 13123, the 2001 National Energy Policy states, "A primary goal of the National Energy Policy is to add supply from diverse sources. This means domestic oil, gas, and coal. It also means hydropower and nuclear power. And it means making greater use of non-hydro renewable sources now available" (Bush, 2001). In this document President Bush sought to develop a comprehensive and balanced energy policy that could help the private sector and state and local governments "promote dependable, affordable, and environmentally sound production and distribution of energy for the future" (Bush, 2001).

2.10 Cost

Wind power is the most rapidly expanding energy source with an average growth rate of 33% between 1998 and 2002. Wind energy capacity has tripled since 1998 and is projected to increase 15-fold over the next 20 years (PRE, 2004). The American Wind Energy Association estimates that more than $40 billion will be spent worldwide over the next decade to build new wind installations (AWEA, 2004). The opportunities for industries that build, buy, or invest in the wind energy industry are tremendous (NREL, 2003).

The cost of wind power production from wind turbines has declined by 80% since the early 1980's (NREL, 2004). Prices and LCC are now pushing the $0.040/kWh barrier and are projected to drop another 20 to 40 percent over the next ten years (CEERT, 2004). The Department of Energy has created a goal of reaching $0.025/kWh for wind power production (DOE, 2004).

With wind energy as with other renewable energies, the fuel is free, providing for a stable long-term price for power production. The cost of generating electricity from wind turbines includes capital costs and operations and maintenance (O&M). Therefore, once the initial capital costs are paid, the only remaining costs are O&M and other fixed costs such as leasing the land if on-site construction is not an option. Leasing land usually costs between $2,000 and $3,000 annually per turbine. Unlike other power plants, wind energy systems require minimal maintenance and have low operating expenses. Operations and maintenance costs typically run about $0.01/kWh or less for a mainstream wind plant (NWCC, 1997). In comparison, the O&M costs for a conventional coal power plant is at $0.046/kWh and $0.021/kWh for a nuclear plant (REPP, 2004; NEI, 2005). There are options to purchase a maintenance agreement from a manufacturer which will cover the annual maintenance and system inspections for a wind farm. The wind turbine manufacturer, NEG Micon, offers an annual maintenance agreement for about $7,500 per year, per turbine.

The capital cost is high, between 75% and 90% of the total cost for a wind project (BWEA 2004). The capital cost breakdown of a typical 5 MW project is shown below in Figure 10. The cost will vary depending on location and wind resources. Currently, the average cost for a large wind power system is $1,000/kW (DWIA, 2004).

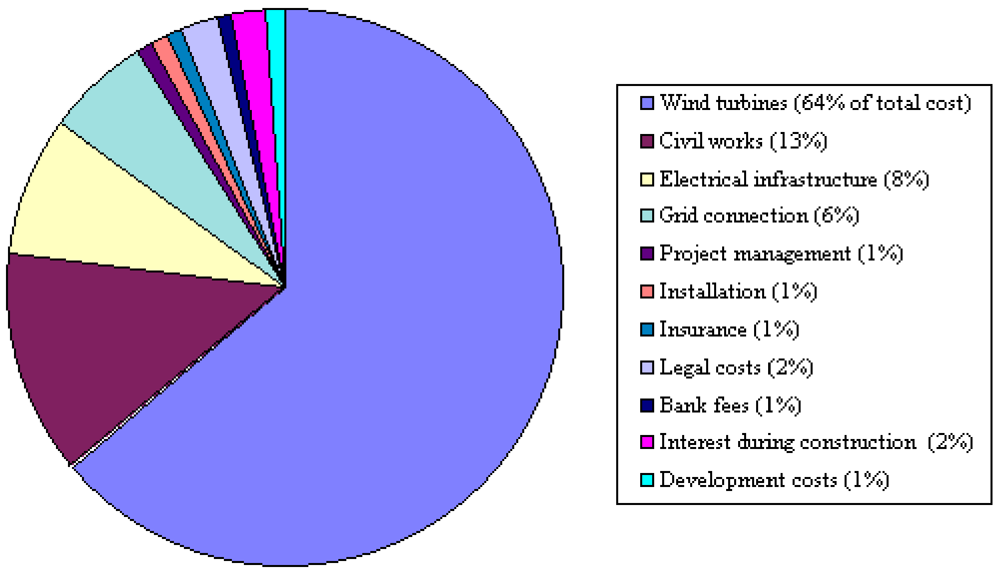


Figure 10. Cost of Capital

The initial capital costs of wind turbines could be as high as 90% of total project costs (BWEA, 2004)

The salvage value of a wind turbine at the end of its useful life depends on several factors. These factors include the extent of design and technology changes in newer models and the attractiveness of wind turbines compared to other alternative technologies at that time (IEC, 2003). According to the Iowa Energy Center, a moderate estimate for salvage value might be a selling price after 20 years that is worth 10% of its cost at today's dollar value (IEC, 2003).

In "Alternative Windpower Ownership Structures: Financing Terms and Project Costs," Ryan Wiser and Edward Kahn of Lawrence Berkeley Laboratory's Energy and Environment Division estimate that a typical 50 MW wind plant, which would deliver power at just under 5 cents/kWh if financed by a wind developer, could generate power at 3.5 cents/kWh--a nearly 30% reduction--if an investor-owned utility (IOU) owned and financed the facility instead (AWEA, 1996). Cost projections for 2005 are as low as 2.5 to 3 cents per kilowatt hour (REV, 2004). Peterson AFB is considered an IOU because they would not need to pay interest to borrow money. The cost is expected to continue to decline as the technology advances and the market for this source develops.

According to the American Wind Energy Association, the most important factors in determining the cost of wind-generated electricity from a wind farm are: (1) the size of the wind farm; (2) the wind speed at the site; and (3) the cost of buying and installing the turbines (AWEA, 2004). Each of these factors can have a major impact. Generally speaking:

- The larger the wind farm, all other factors being equal, the lower the cost of energy;
- The higher the wind speed, the lower the cost of energy;
- The less expensive construction costs are, the lower the cost of energy.

A large wind farm is more economical than a small one. Assuming the same average wind speed of 18 mph and identical wind turbine sizes, a 3 MW wind project delivers electricity at a cost of $0.059 per kWh and a 51-MW project delivers electricity at $0.036 per kWh—a drop in costs of $0.023, or nearly 40% (AWEA, 2002). This cost differential is shown in Figure 11. A larger project will have lower O&M costs per kilowatt-hour because of the efficiencies of managing a larger wind farm (AWEA, 2002). Costs such as administration fees, legal fees, & road maintenance are fixed fees that are not necessarily determined by the quantity of turbines. In addition, a wind farm developer might be inclined to offer a discount on a mass quantity purchase. The optimal size for economies of scale is believed to be 150 – 200 MW for a wind farm (NREL, 2005).

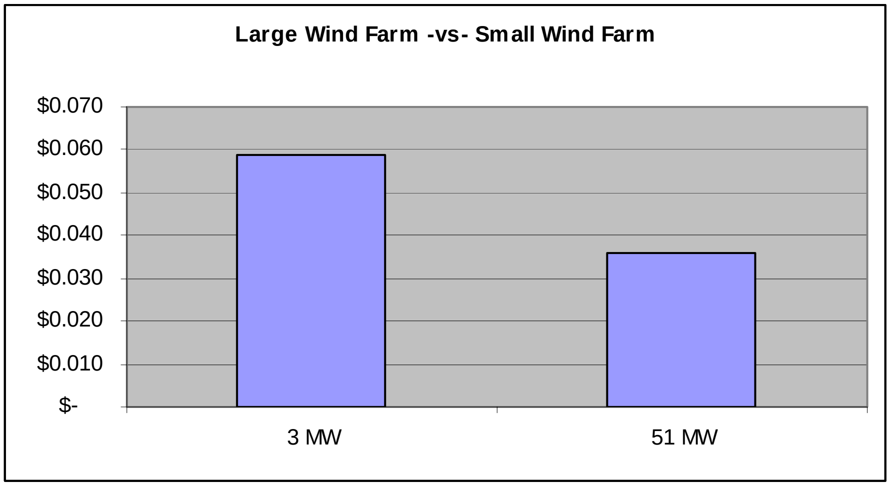


Figure 11. Large Wind Farm –vs- Small Wind Farm

The economies of scale play a large part in the overall cost of wind energy (AWEA, 2002)

Wind speed is a primary determinant of electricity cost; on account of the way it influences the energy yield. The energy that can be drawn from the wind is proportional to the cube of the wind speed, so a slight increase in wind speed results in a large increase in electricity generation. The turbines will run closer to capacity. Consider two sites, one with an average wind speed of 14 mph and the other with average winds of 16 mph. All else being equal, a wind turbine at the second site will generate nearly 50% more electricity than it would at the first location (AWEA, 2002).

In general, the cost of wind follows the law of economies of scale by the fact that the larger the wind farm and the greater the wind speed the greater the power generation and a lower life cycle cost. The three examples in Figure 12 are for costs per kilowatt-hour for a 51 MW wind farm at three different average wind speeds expressed in meters per second (AWEA, 2002).

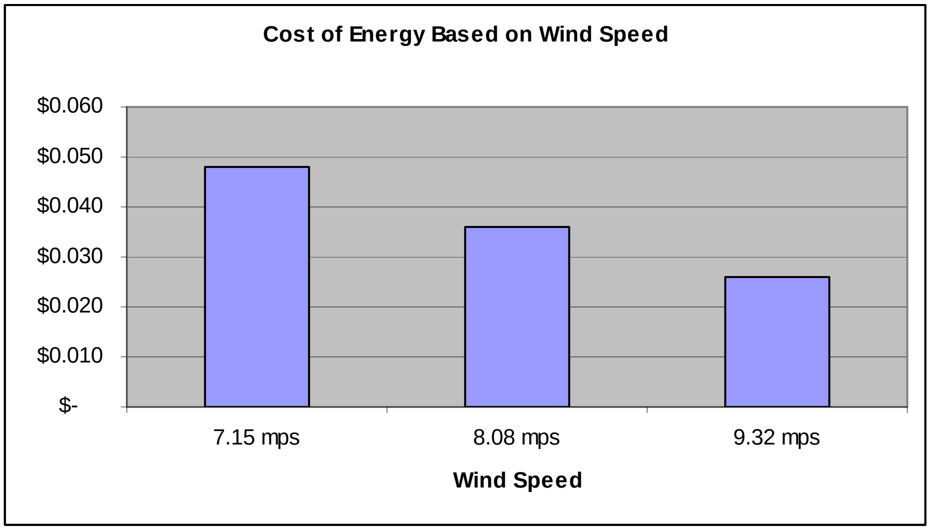


Figure 12. Cost of Energy Based on Wind Speed

The energy content of the wind is proportional to the cube of its velocity, thus reducing the costs per kWh (AWEA, 2002)

The wind turbine construction site is a vital element in determining the final cost per kilowatt-hour. Constructing turbines on ridgelines or mountains can be much more expensive than on flat plains. This in turn will cause the price per kilowatt-hour to increase.

2.11 Financial Support

A small number of financial, legislative, and government policy support structures have evolved to foster the proliferation of large wind capacity worldwide. These include:

- *Feed-in tariffs* - fixed prices for power generated by renewable generators
- *Green energy* - customers pay extra for power from renewable resources
- *Clean energy funds* - states provide capital subsidies and price subsidies using monies gathered from a surcharge on electricity consumed
- *Renewable Portfolio Standards, Renewables Obligation and the EU Renewables Directive* - governments, states and provinces require utilities to derive a set percentage of the electricity they sell from renewable sources
- *Renewables by decree* - governors and mayors require government agencies to buy a specific percentage of the electricity they purchase from renewable sources
- *Attributes separate from energy* - electricity is sold into the grid at market price and a specified value is placed on the fact that the electricity is derived from a renewable resource; this amount is paid by a contracted customer
- *Pollution offsets* - standardized amounts of pollution reduction offsets are assigned to each MWh produced from renewables
- *Carbon markets* - Renewable Energy Certificates (RECs), such as offsets and green tags, are used to satisfy greenhouse gas reduction obligations required by the Kyoto Protocol; the RECs are traded as fungible assets
- *Clean Development Mechanism and Joint Initiative* - countries and companies needing to reduce their greenhouse gas emissions can fund renewable energy projects in participating nations and claim the attributes in the form of RECs at home
- *Production tax credit* - provides a write-off for each kilowatt-hour produced from a renewable source
- *Capacity credit* - an ancillary fee paid by a regional transmission organization on a kilowatt-hour basis for a percentage of the nameplate capacity of a wind farm; in the north-east US, this is about $0.005/kWh.

(REW, 2004)

2.12 Life Cycle Methodologies

Life cycle cost (LCC) analysis is a method of obtaining all costs and benefits related to the wind turbine application including all expenses and revenues over its life. The analysis is applied to a capital investment project which has high upfront costs which are traded for reduced future cost obligations. The LCC analysis can be used to compare different alternatives or determine the most cost effective energy design. There are several supplemental methods that can be used to compare the financial benefits of wind projects to the conventional energy system using life cycle costs. The Code of Federal Regulations (CFR), Title 10, Part 436, Subpart A—"Methodology and Procedures for Life Cycle Cost Analyses" establishes a methodology and procedures for estimating and comparing the LCC of federal buildings, for determining the LCC effectiveness of energy conservation measures, and for ranking identified energy conservation measures (CFR, 2004). The Life Cycle Costing Manual for the Federal Energy Program (FEMP) contains guidelines that Federal agencies can use in performing economic evaluations of energy conservation and renewable energy projects set forth in 10 CFR 436, Subpart A (DOC, 2002). These methods include the simple payback period (SPBP), savings to investment ration (SIR), and the adjusted internal rate of return (AIRR). In addition to the methods set forth in 10 CFR 436, Subpart A, this research compares the LCC using the Net Present Value (NPV). The net present value gives the decision maker a better understanding of the cost or savings of a project. It provides an actual dollar cost or savings rather than a ratio or percentage.

2.12.1 Simple Payback Period

The simple payback period is a common and simplistic way to assess the merit of an investment. The payback period pertaining to this research is the number of years of energy cost savings it takes to recover the investment's initial cost. It is very easy to calculate and measure the time that the project is at risk. The disadvantage to using the simple payback period is that it does not take into account the time value of money over the life of the project and does not account for any cash flows after the payback period has occurred.

The payback period is determined by first estimating the total initial costs, the annual energy cost savings, and the annual operating costs. Dividing total initial cost by the difference between annual energy cost savings and annual operating costs gives the payback period in years as shown in equation 4. The Energy Policy Act of 1992 requires Federal agencies to install to the maximum extent possible, by 1 January 2005, all energy conservation measures with payback periods of less than 10 years (DOC, 2005). The Code of Federal Regulations states that projects with a "significantly lower" payback period compared to the life of the project should be accepted (CFR, 2004). Draft AFI 32-7080 Pollution Prevention states, "The goal of payback analysis is to determine the period of time before the up-front costs of a given P2 project will be recouped through cost savings in subsequent years. The shorter the payback period, the more attractive the P2 project. Simple payback analysis is most appropriate where the payback is anticipated to be no more than three years. For projects with longer payback periods, a complex analysis that accounts for present value is more appropriate" (Draft AFI 32-7080). If the payback period is less than the maximum acceptable payback period, then the project should be accepted.

$$SPBP = \left(\frac{C}{AECS - AOC} \right) \tag{4}$$

where

C = total initial cost

AECS = annual energy cost savings

AOC = annual operating costs

2.12.2 Savings to Investment Ratio

The Code of Federal Regulations states that the savings to investment ratio is the ratio of the total discounted operational savings divided by the total investment of the energy system. The SIR is a benefit-to-cost ratio of the present value of the savings over the economic life to the present value of the investment costs. The numerator of the ratio is the net present value of savings in energy and operation and maintenance costs attributable to the proposed energy measure. The denominator of the ratio is the present value of the net increase in investment and replacement costs less salvage value attributable to the proposed energy measure. The formula is shown below in equation 5. The target for an acceptable SIR is greater than 1.

$$\text{SIR} = \frac{DECS - DOC}{C + DD - DSV} \qquad (5)$$

where

C = total initial cost

DECS = discounted energy cost savings

DOC = discounted operating costs

DD = discounted disposal costs

DSV = discounted salvage value

2.12.3 Adjusted Internal Rate of Return

The adjusted internal rate of return is the annual yield from an alternative over the study period, taking into account reinvestment of interim returns at the discount rate. The AIRR is shown in equation 6. The target for an acceptable AIRR is to be greater than the discount rate. If the AIRR equals the discount rate, then the project's net present value will be zero. The benefit over the internal rate of return (IRR) of using the AIRR is that it correctly assumes the reinvestment at opportunity cost. It also avoids the problem of having multiple internal rates of return. But the AIRR is not as good as the net present value calculation.

$$AIRR = (1+d) \times SIR^{\left(1/N\right)} - 1 \qquad (6)$$

where

d = discount rate

N = total number of years in the life cycle

2.12.4 Net Present Value

The net present value is a tool that allows decision makers to compare two or more alternatives on an economic plane over time (Fabrycky, 1991:39). The NPV is the value of an investment project found by adding the present value of expected future cash flows and the cost of the initial investment. The NPV method of evaluating a project will allow for consideration of the time value of money. The present value of costs or savings will be less than their future value because of the effects of inflation and time preference. In essence, NPV compares the value of a dollar today against the value of that same dollar in the future, taking into account inflation and opportunity costs. One should accept all projects with positive NPV's. When comparing the NPV of mutually exclusive projects, one should accept the projects with the highest positive NPV's. A negative NPV means that the project should be rejected since it is not worth the opportunity cost. The equation for net present value is shown in equation 7.

$$NPV = \sum_{n=0}^{N} \left[\frac{\text{Annual Cash Flow}}{(1+i)^n} \right] \qquad (7)$$

where

i = discount rate

n = single year in a series of N years in the turbine's life cycle

N = total number of years in the life cycle

2.12.5 Summary of Life Cycle Methodologies

10 CFR 436, Subpart A —"Methodology and Procedures for Life Cycle Cost Analyses" establishes a methodology and procedures for estimating and comparing the LCC of federal buildings, for determining the LCC effectiveness of energy conservation measures, and for ranking identified energy conservation measures (CFR, 2004). The SPBP is a common and simplistic measure to determine how long a project will take to recoup its initial investment. The SPBP does not take into account the time value of money or cash flows beyond the payback period. The SIR is a benefit-to-cost ratio of the present value of the savings over the economic life to the present value of the investment costs. The SIR provides a decision maker with the ratio of return on money invested in the project. The AIRR is the annual yield from an alternative over the study period. It provides a decision maker with the rate of return the investment would earn to compare

to the discount rate. The NPV is the value of an investment project found by adding the present value of expected future cash flows and the cost of the initial investment. The net present value gives the decision maker a better understanding of the cost or savings of a project. It provides an actual dollar cost or savings rather than a ratio or percentage.

2.13 Energy Conservation Improvement Program

Energy conservation improvement programs (ECIP) are programs to fund capital improvements that reduce energy consumption and facilitate the reduction of energy costs. These include improvements in the efficiency of furnaces, water heaters, and lighting, conservation of electricity and natural gas, and control systems to manage energy use. The U.S. Air Force allocates a certain portion of total funding towards ECIP projects. Each major command (MAJCOM) competes for funding for ECIP projects based on required funding stemming from the base level.

2.14 Green Power Program

Green power programs have begun to be implemented across the United States. Green power is produced from renewable energy sources such as wind, solar, biomass, geothermal and hydro sources. Green power is sold by utility companies at an additional cost as a supplement to the traditional energy supply. The green power program provides a means of allocating renewable power to customers that do not have a way of producing their own renewable energy, but would like to use it, for business or home energy needs. Green power is a program which supplies clean energy to those people willing to pay a higher marginal price for low-pollution energies (UCSU, 2001).

Colorado Springs Utilities (CSU) provides customers in the Colorado Springs local area with the option to assign a portion of their utility bill to wind generated electricity through their green power program. CSU buys an additional 1 MWh (enough to serve the entire electricity needs of more than 300 households) of wind power from the Ponnequin Wind Farm near the Wyoming border, and offers it to their residential and business customers as a premium service through their Green Power Program (Baker, 2004). Customers pay an additional $3 for one block of green power. One block is equivalent to 100 kilowatt-hours of electricity. For an average Colorado Springs residential home to fully sustain their energy needs from the green power program; based on an average of 500 kilowatt-hours per month, the total additional cost to the consumer will be $180 for an entire year. More than 1,000 customers currently participate in the Green power program (Baker, 2004). By choosing Green Power, customers help influence the type of future electric generation developed in Colorado. They also play a role in building the market for renewable energy within the state (CSU, 2004).

2.15 Natural Reserves

The United States of America is the world's largest energy producer, consumer, and net importer. It also ranks eleventh worldwide in reserves of oil, sixth in natural gas, and first in coal (EIA, 2001). Overall, the United States depends on oil for about 40% of its total primary energy requirements and natural gas and coal for 23% each (EIA, 2004). In 2003, the U.S. average total gross oil imports were estimated at 12.2 million barrels per day (MMBD) representing around 62% of the U.S. oil demand (EIA, 2004). Canada and Saudi Arabia rounded out the top suppliers of oil for the U.S. Natural gas consumption is estimated at 21.9 trillion cubic feet (Tcf), with gross imports of 3.8 Tcf (EIA, 2004). Canada supplies about 87% of U.S. natural gas imports. The United States consumed 1,090 million short tons (Mmst) of coal in 2003 while gross coal imports were estimated at 25.0 Mmst in 2003, up 48% from 16.9 Mmst in 2002 (EIA, 2004). The continued rise in U.S. gross coal imports is partly attributable to heightened demand for low-sulfur coal, and in part to the need to meet stricter sulfur emission requirements of Phase II of the Clean Air Act Amendments (CAAA) (EIA, 2004).

The United States has only 4.6% of the world's population, but consumes 26% of the world's oil annually (DOE, 2003). In the U.S., domestic annual oil production reached a peak in 1971 and has been diminishing since that time. Since then, we have become dependent on foreign sources. About 62% of oil demand in 2003 in the U.S. was imported from foreign counties (EIA, 2004). In addition, the U.S. would have to reduce its oil use to 14% of what it is today in order to have parity with the rest of the world in terms of per-capita consumption.

The Department of Energy estimated the January 2001 global petroleum reserves to be 1,028 billion barrels (DOE, 2002:113). In addition, DOE estimates that global consumption is 75.3 million barrels per day, or 27.5 billion per year (DOE, 2002: 61). This indicates that with current consumption patterns, global oil reserves could be depleted by 2038. As the oil reserves continue to be depleted, society will shift more to natural gas as an energy source, and thus accelerate the depletion of the natural gas reserves.

Natural gas is the fastest growing primary energy source according to the International Energy Outlook 2004 forecast (EIA, 2004). The United States holds only 3.1 percent of the world's natural gas reserves and still consumed more than any other country in 2001 (EIA, 2004). The estimate for world natural gas reserves was 5,504.9 Tcf as of 1 Jan 2003, with world consumption of 89.3 Tcf for that year (EIA, 2004 & PennWell Corp, 2002). If the consumption rate were to hold constant, then we would expect supply to be entirely depleted by the year 2057. But the Energy Information Administration expects consumption of natural gas worldwide to increase by an average of 2.8 percent annually from 2001 to 2025 (EIA, 2004). Assuming that worldwide natural gas consumption levels off after 2025, the world's currently known natural gas reserves could be depleted by 2042.

The major fuel source for electrical production is coal which provides for over 56% of the world fuel needs (DOE, 2002). The Department of Energy estimates that coal will last only another 230 years (DOE, 2003). The world's reliance on coal to compensate for the depletion of the other two energy sources could be devastating to the environment. Coal miners in West Virginia are already applying a contentious strip mining technique called "Mountain Top Mining", where the tops of mountains are blasted off to dig and extract the coal (EMS, 2002). Furthermore, because it is a fossil fuel, the burning of coal contributes to global warming.

2.16 Natural Resources – Soaring Prices

The world's natural resource supply for energy production has been diminishing due to the increase in global population and demand. Global oil and natural gas reserves have a short shelf life remaining and as they continue to be exhausted and threatened by terrorist groups and civil wars, their price will continue to escalate. If supply declines and demand grows, the price of oil and natural gas will then rise. On the other hand, if alternative fuels such as wind power are used for energy production then the forecasted demand for oil and natural gas will begin to decline, causing their prices to rise more slowly or to fall.

2.17 Summary

This chapter reviewed wind energy and the economical variations of wind turbines. It reviewed the environmental and economic impacts and benefit associated with wind energy generation and then described the executive orders that direct federal agencies to implement the use of renewable energy sources and environmental enhancement through clean energy programs. In addition, this literature review described the life cycle costs related to wind energy generation along with the methodologies associated with making alternative comparisons. Finally, fossil fuel energy sources that are currently used in the United States for electricity generation were examined.

3. Methodology

3.1 Overview

This research effort evaluates the economic and environmental effectiveness of the use of wind turbine energy generation as an alternative to conventional energy consumption at Peterson AFB, CO. Case studies incorporating wind energy as a primary or supplemental energy source at particular sites are reviewed in the following chapter. This method allows the investigation of current cases where the technology has been fully or partially implemented and the compilation of data for application to future cases. The case studies are examined to determine common practices of wind power used to generate electricity in the Air Force and the commercial power industry. In addition, the case studies were used to determine a suitable wind turbine design that best utilizes the wind resource in the Colorado Springs area. Expert opinion is also drawn on to determine the proper design of the wind turbines. After evaluation of the various case studies and determination of a feasible wind turbine design, a cost comparison was performed. Life cycle cost (LCC) calculations including non-market valuation techniques were formulated to make the comparisons of the alternatives to determine economic effectiveness. The simple payback period (SPBP), savings to investment ratio (SIR), the adjusted internal rate of return (AIRR), and the net present value (NPV) are used in determining the economic effectiveness of the wind project. Finally, expert opinion and the literature review were employed to determine the level of reduction in green house gases and the value that could be realized with the implementation of wind energy generation.

3.2 Case Studies

There is a great deal of expertise and knowledge to be gained from individual projects. The evaluation and use of case studies is one of many ways to analyze a problem. The knowledge obtained from the following case studies will be summarized for reference and future use by other researchers.

Objective case studies use real world examples to learn from other organizations' successes and failures. The following case studies examine what works best, what fails, and why, to fully understand how to do business better for the Air Force. In addition, these case studies are used to determine best practices that can be applied in the wind technology discipline. The case studies are also useful to disseminate information about the most promising and effective projects in the wind technology field.

The intent of the case studies chosen for this research effort is to evaluate common practices within the Air Force involving electrical power generation from wind energy. Four Air Force sites; Dyess AFB, Fairchild AFB, F.E. Warren AFB, and Vandenberg AFB were chosen for evaluation. These sites were chosen because they are either constructing wind turbines for electricity generation or they purchase wind generated energy from a wind energy site. The data collected from these facilities includes the cost or savings to the government for implementing wind energy resources at the Air Force installations. The case studies were used to determine what the U.S. Air Force is currently doing in the wind energy arena and if wind energy use is economical for Peterson AFB to pursue. This information as well as input from experts in the wind industry was used to determine an optimal wind turbine design for implementation at Peterson AFB, CO.

3.3 Life Cycle Cost

The life cycle cost analysis was used for this research effort to compare the different power options at Peterson AFB. A life cycle cost analysis gives the net present value of the total costs and benefits of the wind turbine project and the total costs of the conventional energy consumption at Peterson AFB including all expenses and revenues incurred over the same lifespan of the system. Life cycle costs include, (1) initial or capital costs, (2) operation and maintenance costs, (3) revenues or savings, (4) salvage and disposal value, (5) environmental costs or benefits. The net present value will be the most critical factor used in determining economic feasibility of wind energy generation at Peterson AFB because comparisons can easily be made to the green power program.

The LCC analysis for alternative systems can be compared by computing annual worth throughout the turbine's estimated life, or by computing total projected net benefits or net costs on a future or present worth basis. To compute the LCC of a project, all items must be assigned a value, even though there are considerations to which a monetary value is not easily attached. For example, the cost of pollution caused by the combustion of fossil fuels requires an educated approximation determined from the literature. To make a good comparison, each project's parameters must be equivalent for an accurate estimation. This research effort uses an estimated life of 20 years for the wind turbines; as a result the life cycle costs for the conventional energy consumption at Peterson AFB are also analyzed for 20 years. A 20 year lifespan is considered a safe estimate for the life of a turbine, considering future technology advances.

The life cycle cost of the wind turbine project was compared to the life cycle cost of the conventional energy consumption at Peterson AFB using the net present value calculation to determine the most cost effective alternative. Other supplemental measures that are used to compare the financial disparity of the wind projects to the conventional energy system will be the simple payback period, savings to investment ratio, and the adjusted internal rate of return as required by the Code of Federal Regulations, Title 10, Part 436, Subpart A. All future costs or savings that are used in the life cycle costing technique are converted to present value by incorporating a discount rate for an accurate comparison. The appropriate real discount rate for these calculations has been obtained from the DOE's Federal Energy Management Program (FEMP) given that energy related projects are exempt from the Office of Management and Budget (OMB) CIRCULAR A-94. Federal agencies are required by 10 CFR 436 to use the DOE discount rates when conducting LCC analyses relating to energy conservation and renewable energy resource projects for federal facilities. The discount rates applicable to non energy or water capital investments are published in the OMB CIRCULAR A-94, Appendix C (DOC, 2004).

3.4 Wind Energy Costs

Life cycle costing goes beyond considering only the initial capital costs of a project; included are all the costs of owning a project over its lifetime. Long term life cycle costing for wind turbines divides costs into four general categories: (1) Installed capital costs, (2) Operations and maintenance costs, (3) Salvage and disposal value, (4) Energy savings or revenues. The following section on wind energy costs provides the detailed costs that are associated with a wind project.

The installed capital cost includes all planning, equipment purchase, construction, and installation costs required to prepare a wind system for operation. Delivery and installation at the site are included in this cost, along with electrical cables and transformers, and any supporting infrastructure as well as foundation costs (NWCC, 1997).

Buildings in support of operations and maintenance (O&M), inventory for spare parts, wind monitoring equipment, and construction insurance are included in the calculation of installed capital costs. There also may be costs of negotiating land use agreements, power purchase contracts, and transmission access agreements (NWCC, 1997).

The operations and maintenance costs include O&M costs over the life of the project, including the cost of major overhauls and subsystem replacements. The majority of O&M costs are incurred for maintenance, including unscheduled but statistically predictable routine maintenance of turbines, preventive maintenance, and major overhauls and component replacement of turbines such as the gearbox and the blades. Unscheduled maintenance visits account for approximately 75 percent of the total maintenance costs, while preventive visits and major overhauls account for 20 percent and 5 percent, respectively (NWCC, 1997).

The O&M measure includes costs for maintenance staff, replacement parts, road maintenance and additional items. Other routine, annually-recurring operating costs include land use payments, insurance, transmission access and wheeling fees, management fees and administrative costs. Operating costs typically are small in comparison to maintenance costs (NWCC, 1997).

The salvage value and disposal costs of wind projects typically occur at the end of the last year of operation. The salvage value is usually between 8% and 10% of the initial turbine cost. Disposal costs would be those costs related to removing any structures and equipment after the terminal life of the wind turbines.

The energy savings or revenues combine the site's wind characteristics and the potential to efficiently capture wind power. An estimate of annual energy production from the wind turbines is calculated using site specific climatic data such as wind speed and air density, along with turbine characteristics such as the hub height, power curve, and rotor diameter. The annual energy production is then multiplied by the utility rate to determine if there are in fact energy savings or revenues.

3.5 Conventional Energy Costs

Peterson AFB purchases all of their electricity supply from the Colorado Springs Utilities (CSU) in Colorado Springs, Colorado. Electricity consumption data was collected from January 1996, to September 2004. This provides 9 years of data and 105 data points which have been examined. The data presents energy consumption in kWh for each month and the associated total cost. Future energy consumption and utility rate increases were forecasted using simple linear regression.

3.6 Wind Energy Project Model

The Wind Energy Project Model Version 3.0 is a software model provided by Renewable Energy Technology Screening (RETScreen®) International and was used for LCC verification and GHG emission factors. The software was developed by Natural Resources Canada (NRCan) in collaboration with the National Aeronautics and Space Administration (NASA), United Nations Environment Program (UNEP), and the UNEP Global Environment Facility (GEF) to be used for evaluating renewable energy projects. The software can be used to evaluate the annual energy production, costs, and financial viability of wind and other renewable energy technologies.

The Wind Energy Project Model can be used world-wide to easily evaluate the energy production, life-cycle costs, and GHG emissions reduction for central-grid, isolated-grid, and off-grid wind energy projects, ranging in size from large scale multi-turbine wind farms to small scale single-turbine wind-diesel hybrid systems. The software includes product and weather databases and an online manual. This version includes a Metric/Imperial unit switch; updated product data; an enhanced GHG model to account for emerging rules under the Kyoto Protocol; a Sensitivity & Risk Analysis worksheet; and the ability to evaluate wind projects using wind power density data, in addition to wind speed data (RETScreen® Intl, 2004).

The inputs that were needed to accurately run the software were the climatic conditions for the site, the turbine model, quantity, height, and rated power, the type of grid connection, the peak load, current utility fuel mix, and LCC data. Using the input data, the software calculated the expected renewable energy delivered from the turbines, a financial summary including net present value, and the GHG emission factor.

3.7 Industry Experts

The life cycle costs are determined, in addition to the Wind Energy Project Model Version 3.0, from reciprocated cost estimates with the Department of Energy's National Renewable Energy Laboratory (NREL) and a Colorado wind project developer. The life cycle cost estimates are independent of each other and provide a range of estimates for the comparative analysis. Sensitivity analysis was also conducted to determine the sensitivity of cost factors against the net present value of the project.

3.8 Environmental Benefits

Environmental benefits associated with supplementing wind generated electricity into the fuel mix for Peterson AFB are determined using the Clean Energy Project Analysis software provided by RETscreen® International. In addition to the software, expert opinion was used to validate the model's results. Data has been collected from the Colorado Springs Utilities presenting the energy mix in terms of capacity for evaluation to determine the accurate amount of reduced GHG emissions. After determining the amount of reduction in GHG, the range of monetary value associated was applied using figures extracted from the literature review.

3.9 Procedures

To effectively compare energy production from an on-site wind turbine with Peterson AFB's energy consumption from the Colorado Springs Utilities, the best type of wind turbine was determined for that area. Case studies featuring four continental U.S. Air Force bases were reviewed to aid in determining a suitable turbine design for Peterson AFB. In addition to the case studies, expert opinion from Mr. Robi Robichaud who works with the Federal Energy Management Program (FEMP) at the National Renewable Energy Laboratory in Golden, Colorado was obtained. Mr. Robichaud's expert opinion was used as the determining factor for a viable wind turbine design at Peterson AFB. Subsequent to determining the proper wind turbine for application, wind velocity was calculated for Peterson AFB using climatology data collected by the Air Force Combat Climatology Center (AFCCC) and sited at the Colorado Springs Municipal Airport.

Once a viable wind turbine design had been determined, the number of turbines needed for wind energy generation at Peterson AFB was ascertained. The quantity of turbines is a function of wind availability, turbine capacity (kWh), and kWh demand at Peterson, AFB. This provided for the quantity of turbine's needed for electricity generation at Peterson AFB. Expert opinion employed from Mr. Robichaud and Mr. Timothy Pugh, electrical engineer at Peterson AFB, was used to determine the demand for energy generation from on-site wind turbines and conventional fuels would be at Peterson AFB.

Once the design and quantity of wind turbines for energy generation had been determined, the life cycle cost estimates were generated. Microsoft Excel ® was used to develop the comprehensive LCC estimates with detailed cost information from NREL as well as the Colorado wind project developer. All figures were converted to present value using the appropriate real discount rate obtained from the Federal Energy Management Program. RETscreen® International's Clean Energy Project Analysis software was used for verification purposes during the LCC estimate.

The reduction in greenhouse gas emissions was also determined using the Clean Energy Project Analysis software. Emission reduction factors of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are quantified based on the fuel mix at Peterson AFB. A range of dollar values associated with the reduction of the greenhouse gas emissions were established by applying GHG studies from the literature review.

A net present value comparison was conducted once all costs and benefits were determined. In addition to the NPV comparison, the SPBP, SIR, and the AIRR were calculated to meet life cycle cost analyses standards set forth in 10 CFR 436, Subpart A . Non-market valuation methods were used to estimate the monetary value of the environmental costs and/or benefits. Qualitative benefits that could not be assigned a specific dollar value are discussed, but are not a formal part of the cost analysis. Green power is also compared to the on-site wind energy generation using NPV for comparison purposes. Subsequent to the comparison of alternatives, the recommendations stemming from this research are provided in the following chapter.

4. Analysis

4.1 Overview

The results of this research are explained and illustrated in this chapter. First, information obtained from case studies, found within the literature, and Air Force base energy managers is summarized. Secondly, assumptions necessary to complete the comparison of the life cycle cost analysis of the alternatives are stated. Thirdly, the range of cost estimates for the turbines are shown and the current energy consumption and life cycle costs calculated showing the optimal alternative for Peterson AFB. This chapter answers the main research questions posed in Chapter 1.

4.2 Case Studies

A case study is defined as, "an examination of a specific phenomenon such as a program, an event, a person, a process, an institution or social group. The bounded system, or case, might be selected because it is an instance of some concern, issue or hypothesis" (Merriam, 1988). This research evaluated case studies from four sites already employing wind turbine technology: Dyess AFB, Fairchild AFB, F.E. Warren AFB, and Vandenberg AFB. The data collected from these facilities includes the cost or savings to the government for implementing wind energy resources at the Air Force installations. The following case studies were used to determine what the U.S. Air Force is currently doing in the wind energy arena and if wind energy use is economical for Peterson AFB to pursue.

4.2.1 Dyess AFB, Texas

Dyess AFB has become the leading consumer of wind energy in the United States according to the DOE (Rosine, 2003). Dyess AFB has signed a 2 year, $1.5M contract with TXU Corporation; a Dallas based Utilities Company, to supply the base with electricity provided by wind turbines throughout the state of Texas (Rosine, 2003). Dyess AFB examined renewable energy following the Texas utility deregulations in 2002. The new deregulation rules mandated that a percentage of power was to come from renewable sources (Denslow, 2004). Before deregulation, Dyess was paying $0.07 per kWh while wind energy was priced at $0.069 per kWh (Rosine, 2003). After deregulation, the price per kWh dropped from $0.07 to $0.051, using a fuel mix of coal, natural gas, and nuclear (Denslow, 2004). The incremental cost for using the wind energy became $0.019/kWh.

Base energy manager Tom Denslow's commented on switching to wind energy generation for the base: "The benefits are far reaching. We have eliminated use of all pollution-making conventional electricity which negates the production of over 100 tons of nitrous oxides, 105 tons of sulphur dioxides, and 58,000 tons of carbon dioxides per year" (Rosine, 2003). While Dyess AFB's energy is generated solely by renewable energy, the likelihood for supply disruptions is unchanged since the electricity generation is not physically on the base. Due to several factors including land, air space for planes, and cost, the Air Force Civil Engineering Support Agency (AFCESA), Air Combat Command (ACC), and Dyess AFB decided that generating their own energy was not the best option, especially since there is an abundance of wind-generated energy available in

West Texas. One of the sources of the wind energy, Trent Mesa, which has 100 - 1.5 MW units is 25 miles west of the base. At an additional site, another company is building up to 80 - 1.5 MW units, just five miles from the base (Denslow, 2004).

Figure 13. Trent Mesa Wind Power Facility

Trent Mesa Wind Power Facility – Sweetwater, TX – 150 MW (GE, 2005)

Denslow's energy team also performed a cost comparison between the use of wind power and conventional energy consumption which is summarized in Table 3 (Denslow, 2004). Several specific items were identified when conducting the comparison:

a) Executive Order 13123, Greening the Government through Efficient Energy Management, requires the government to reduce their Btu ft^{-2} energy consumption using 1985 as a baseline (Denslow, 2004).

b) The Department of Energy has made renewable energy a “non counter” in energy use, thus if Dyess AFB used it, the energy purchased does not count in their reported energy consumption which satisfies EO 13123 (Denslow, 2004).

c) If Dyess AFB were to obtain 100% renewable energy then it could reduce their Btu ft^{-2} energy consumption 19% from the baseline at that time (with a goal of 27% for fiscal year 2003) to over 60%. This also could result in Air Combat Command reducing the entire major command (MAJCOM) reported energy consumption by 2%. ACC estimated that to obtain the same level of improvement would require over $20M of energy conservation improvement program (ECIP) investments. The incremental cost for the wind was $0.019/kWh or approximately $1.5M. Dyess AFB knew that they could get a longer term lower cost for wind generated electricity after their contract was over at the end of calendar year 2004. Most technologies that would be implemented under an ECIP would only last 15 years. ACC did not want to fund a $20M ECIP investment contract, so ACC agreed to fund the additional money for the “Green Energy Program” (Denslow, 2004). A life cycle cost comparison was not prepared to determine the incremental cost or savings of implementing an ECIP project.

Table 3. Dyess AFB Green Tag Program

DYESS AFB GREEN TAG PROGRAM		
Utility	**Utility Rate (kWh)**	
TXU Corporation (Mix of Fossil Fuels)	$	0.051
TXU Corporation (Wind Energy)	$	0.069
Incremental Cost of Green Tags	$	0.019

4.2.2 Fairchild AFB, Washington

Fairchild AFB's electricity generation is also fully sustained by renewable energy. Fairchild purchases its energy from the Bonneville Power Administration (BPA) which uses wind and hydro as their main sources for power generation. The Air Force base requires roughly 7.5 MWh of power annually which is comparable to a community of about 5,000 homes. In FY02, Fairchild received $86K (7,815,980 kWh) in incremental funding from Congress to buy wind power from BPA since they had the lowest surcharge rate of $0.011 per kWh in the area (Boysen, 2004). Fairchild is still purchasing this wind power.

In FY04 after almost a year of work, Fairchild started purchasing green tags from BPA for the remainder of their usage given that BPA had one of the lowest surcharge rates (at the time) of $0.0055 per kWh (Boysen, 2004). Green tags or Renewable Energy Certificates are offered by BPA as a way to offset their cost of renewable energy development and production in the Northwest. Every green tag guarantees that one megawatt hour of wind energy is produced in the Northwest during that year. Fairchild's purchase means that 7.5 annual MWh of renewable energy will be generated in the Northwest, 99 percent of which will come from wind projects under contract to BPA and 1 percent from small hydro-electric sources.

Fairchild's renewable resource mix includes 17 percent actual wind energy and the rest in Green Tags. In FY04, Fairchild's cost of electricity, not including the surcharge for wind power and green tags, averaged out to $0.0408 per kWh. With the surcharges, the cost averages out to $0.0463 per kWh, a difference of 13% (Boysen, 2004).

Fairchild determined that it would be cheaper to buy power than it would be to generate their own, plus they have never had an on-site generating facility. The main reason they are buying green tags is to lower their reported electric usage in accordance with the Energy Policy Act of 1992 and Executive Order 13123. Air Mobility Command (AMC) provides the funding for Fairchild to purchase the green tags which assists the Command because Fairchild is able to reduce their reported energy consumption (Boysen, 2004). The cost for Fairchild's green tag program is summarized below in Table 4 (Boysen, 2004).

Table 4. Fairchild AFB Green Tag Program

FAIRCHILD AFB GREEN TAG PROGRAM		
Utility	**Utility Rate (kWh)**	
Bonneville Power Admin	$	0.0408
Bonneville Power Admin (Wind Energy)	$	0.0463
Incremental Cost of Green Tags	$	0.0055

4.2.3 F.E. Warren AFB, Wyoming

F.E. Warren AFB has been looking into wind generated energy for quite some time. Base personnel even had anemometers in place for several years looking at the opportunities for wind power generation. F.E. Warren's exploration of wind energy potential is what led them to purchase green power from the local utilities. The costs for F.E. Warren's green tag program are summarized in Table 5 (Johnston, 2004). The primary interest in Green Power was to satisfy EO 13123. Because of this, F.E. Warren AFB currently has three wind energy programs.

a) F.E. Warren purchases green tags as part of a Congressional initiative that supported wind energy. Under it they buy green tags from the Rosebud Indian Reservation in South Dakota and Basin Electric Power Cooperative. The additional cost is roughly $0.025 per kilowatt hour.

b) F.E. Warren also purchases green tags for 5% of the energy they receive from Rocky Mountain Generation Corporation at a negotiated fixed price which is good through 2013. The additional cost is roughly $0.025 per kilowatt hour.

Table 5. F.E. Warren AFB Green Tag Program

F.E. WARREN AFB GREEN TAG PROGRAM		
Utility	**Utility Rate (kWh)**	
Rocky Mountain Generation Corp. (Mix of Fossil Fuels)	$	0.0525
Basin Electric Power Cooperative (Wind Energy)	$	0.0775
Rocky Mountain Generation Corp. (Wind Energy)	$	0.0775
Incremental Cost of Green Tags	$	0.0250

c) Beginning FY05, F.E. Warren AFB has a funded ECIP project to build two 660 kW horizontal axis wind turbines on base. The contractor provided F.E. Warren with two wind turbine options. First was to build one 1.8 MW turbine and second was to construct two 660 kW turbines. The total initial cost for the 1.8 MW turbine was $3,503,396 and the cost for the 660 kW turbines came out to be $2,522,090. Based on total initial cost and funds available, F.E. Warren decided to pursue the contract to construct two 660 kW turbines on the base. The initial cost breakout for the turbines was $2.2M for construction costs and $0.3M for supervision, inspection, and overhead (SIOH) costs.

The Idaho National Engineering and Environmental Laboratory (INEEL) provided F.E. Warren AFB with the economic analysis for the two 660 kW wind turbines. F.E. Warren conducted two different site surveys yielding average wind speeds of 7.2 ms^{-1} and 7.6 ms^{-1}. The site that was chosen yielded the lesser wind speed but had less infrastructure costs (Johnston, 2004). Table 6 shows the cost estimate for the wind project (Johnston, 2004). The project passed all the required economic life cycle cost requirements for approval. It is to be noted that the salvage value and disposal costs at the end of the turbine's useful life were not used in the LCC analysis since the payback period was shorter than the study period (Johnston, 2004). The O&M expense per kWh was estimated to be $0.006 and the investment cost per kWh of capacity was estimated to be $1,911.

Table 6. F.E. Warren AFB Wind Project Cost Analysis

F.E. WARREN AFB WIND FARM SUMMARY REPORT			
2004 LCC Analysis			
FEMP Discount Rate			3.0%
2 Wind Turbines			660 kWh each
Economic Life			20 yrs
Construction Cost		$	2,203,308
SIOH		$	318,782
Design Cost		$	-
Total Cost		$	2,522,090
Salvage Value of Existing Equip.		$	-
Public Utility Company Rebate		$	-
Total Investment		$	2,522,090
Utility Rate (kWh)			0.0525
Usage Savings (kWh)		$	4,404,600
Annual Savings		$	231,242
Discounted Savings	14.39	$	3,327,466
Annual Maintenance		$	(25,000)
Blade Replacement Yr 10		$	(25,000)
Discounted Maintenance	12.41	$	(310,271)
Discounted Blade Replace	0.744	$	(18,600)
Total Discounted Maintenance		$	(328,871)
First year savings (annual savings - warranty)		$	208,738
Simple Payback Period (yrs)			12.08
Total Discounted Operational Savings		$	2,998,595
Savings to Investment Ratio			1.19
Adjusted Internal Rate of Return			3.90%
Net Present Value		$	476,505

4.2.4 Vandenberg AFB, California

Vandenberg AFB (VAFB) is working to implement wind energy conversion. In addition to wind energy, Vandenberg also looked at solar energy and wave energy. Solar energy is not as cost effective as wind energy, and wave energy is still a technology under development and is not considered a viable renewable resource at this time. As of yet, Vandenberg has not implemented any renewable resources.

Currently, Vandenberg AFB gets their electric power service from Pacific Gas and Electric Company (PG&E). PG&E obtains its electric power production from nuclear power plants, natural gas fired power plants, and hydroelectric dams. Neither coal nor fuel oil is used for power production in the state of California. Providing electrical power for Vandenberg AFB does not create the GHG emissions as one might envision from other bases around the country. Nevertheless, Vandenberg had other influential reasons to pursue wind energy; (1) compliance with EO 13123, (2) California Electric Utility Industry crisis of 2000-2001 (where power reserves dropped, rolling blackouts occurred, and utilities went bankrupt), and (3) the availability of renewable resources on Vandenberg AFB's 99,000 acres of property.

Vandenberg's initial life cycle cost analysis for a wind farm was first conducted in April 2001. The LCC was based on recorded Weather Squadron wind data for VAFB. This followed on the heals of Air Force Space Command's (AFSPC) success with the installation of a wind farm at Ascension Island in the South Atlantic. VAFB is noted for its windy environment and they felt confident, even in the preliminary stages, that a wind farm was cost effective. Subsequently, Vandenberg developed a project based on preliminary data in order to compete for ECIP funding. Specific data-logging of wind resources began in November 2001 at four different sites on the base. An LCC analysis was then recalculated in December 2001 based on the most preferable, productive site. The savings to investment ratio value was 1.93 with an estimated simple payback of 5.82 years. The Vandenberg AFB wind farm was then awarded the ECIP funding to proceed with the project.

Until recently, Vandenberg AFB had pinned its hopes for a wind site at one of two highly productive sites. They have since had to fall back to a less desirable site. VAFB has faced countless obstacles and concerns that have necessitated the need to shift the targeted fiscal year funding dates on several occasions. The reason VAFB now had to fall back to a less desirable site is because of mission constraints and cultural issues. According to Ken Padilla, 30th Civil Engineer Squadron energy manager and utility engineer, these could have probably been surmounted, but it would have been a lengthy, costly, and arduous process (Padilla, 2004). It was determined that success simply would not justify the battle that would have ensued should they have chosen to challenge the issues; hence the opting for a fall-back site. VAFB has now surveyed eight different sites on the installation with calculated capacity factors ranging from 2% up to 43%. The LCC data is now being recalculated at the new site as VAFB is presently working the coordination issues with environmental and mission operations. Ideally, VAFB would like to install a wind farm with an output capacity of three to four megawatts. The size of the turbines installed will depend on the final site selected. If possible, VAFB would like to install three to four 1.0 MW wind turbines.

At the time of the initial LCC analysis, the average cost for electricity was $0.065 per kWh as shown in Table 7. That cost has nearly doubled to $0.100 per kWh following the deregulation of California's utility rate structure in 2001. During the 2001 deregulation of California's electric utility industry, VAFB attempted to purchase green power. But with the onset of the California electric power crisis, a moratorium was placed on direct access. This has prevented VAFB from contracting for green power and still does.

Table 7. Vandenberg AFB Wind Project Cost Analysis

VANDENBERG AFB WIND FARM SUMMARY REPORT		
2001 LCC Analysis		
Utility Rate (kWh)	$	0.0650
Simple Payback Period (yrs)		5.82
Savings to Investment Ratio		1.93
Adjusted Internal Rate of Return		Not Determined
Net Present Value		Not Determined

4.2.5 Summary of Case Studies

The four aforementioned case studies offer unique insights into what advancements and processes are being used in the wind industry and specifically in the U.S. Air Force. Political influence and executive mandates are the driving forces behind the increase use of wind energy as a supplement to traditional electricity generation in the Air Force. The foremost motivation is to reduce reported on-site energy consumption as a result of using renewable energy. EO 13123 requires federal agencies to reduce energy consumption even if on-site energy needs increase. And the Department of Energy has made renewable energy a “non counter” in energy use; therefore the Air Force is reducing their reported energy consumption by using wind energy.

Green power and green tags are used predominately in the Air Force to meet the requirements set forth by the executive orders. The marginal cost of green tags varies from base to base, but does represent an increase in cost when compared to traditional fossil fuel generated electricity. In addition to green tags, Air Force bases are beginning to express some interest in on-site wind turbine technology for electricity generation. The additional funding for wind turbine installation is acquired through ECIP contracts. Site surveys are being conducted at certain Air Force bases where there is the promise of an abundance of wind energy. Cost analyses determining the payback period, savings to investment ratio, and adjusted internal rate of return are calculated to determine economic feasibility of wind turbines for the bases. Life cycle cost analyses involving all bona fide life cycle costs such as salvage value and disposal costs are not a part of the current analysis process. Initial costs tend to be the determining factor for the Air Force when funding a project, rather than taking into account all life cycle costs and savings.

4.3 Assumptions and Calculations

To effectively calculate the life cycle costs for the energy systems being compared, several assumptions and calculations were made. Those assumptions and calculations are presented subsequently with information used in the life cycle calculations. Two independent cost estimates were used for this research. The first cost estimate was a government estimate from Mr. Robi Robichaud, Federal Energy Management Program (FEMP), who works at the National Renewable Energy Laboratory (NREL). The second estimate was provided by a Colorado wind project developer. Cost estimates used for the life cycle comparison are provided in real dollars and the real discount rate of 3% is for discounting purposes. The 3% real discount rate is provided by the FEMP and published by the Department of Commerce.

4.3.1 Wind Energy Supplement

The first step in determining the feasibility of a wind project at Peterson AFB was to determine the proper amount of wind energy to be supplemented into the current fuel mix and whether to be connected to the local utility grid or to be independent from the grid. Whenever more electricity is generated from the wind turbines than consumed, an interconnection agreement with the utility would need to be established to be able to back feed excess electricity onto the grid. This is a nontrivial matter; some utilities will fight extensively to avoid doing this (Robichaud, 2005). To become completely independent of the grid is a very tall order. Energy storage is not inexpensive, and for large loads is not trivial, and can raise the overall cost of energy significantly.

When attempting to meet the entire facility load, Peterson AFB would need to be connected to the local utility grid to avoid energy storage issues. Any excess energy would flow onto the grid and the grid would be the storage which is the simplest, most cost effective storage available. Unfortunately, the time, dollars, and equipment costs can be considerable for a grid connected system, so it was determined to be more desirable to size the total turbine output to be a little less than minimum demand, so the base can never back feed onto the grid.

The far more realistic, economic, and prudent course is to try to stay below the minimum load. All wind turbine electricity gets consumed and there are no storage costs or extra equipment purchases. Peterson AFB will benefit by getting some experience with wind and at a later date could increase the percentage of energy from wind. The phased-in approach also allows for getting some turbines now, and then acquiring some more 3-6 years later as technology has improved, and even more 6-12 years later, etc. Wind technology has changed enough in the last 10 years to merit this approach.

The minimum load at any one point during an average day is first determined by calculating the average monthly load variation of kWh consumption for years 1996-2004. Simple linear regression was then used to forecast the average monthly kWh consumption for 2005. It is determined that the average monthly kWh consumption would be 7,615,880 kWh. Microsoft Excel® was used for the calculations and the regression statistics are shown in Appendix A. The average number of hours in a month is 730. So the demand at any point during an average day in 2005 would be:

$$\frac{7,615,880kWh}{730hours} = 10,433kW \tag{8}$$

Based on a wind project developer and other active systems in the field, it is assumed that the minimum load is 30% of the average load, which gives a minimum load of 3,130 kW at the AFB (Gordon, 2005).

4.3.2 Climatic Data

General climatic data for Colorado Springs is located at the National Oceanic and Atmospheric Association (NOAA) website. This research went a step further and collected detailed data from the U.S. Air Force Combat Climatology Center (AFCCC). The data is specific to the Colorado Springs Municipal Airport which shares its aircraft runways with Peterson AFB. The specific data collected from the AFCCC was the monthly average air density and the daily average wind speed since 1973 for the particular location. The average air density at the Colorado Springs Municipal Airport elevation of 1,881 m is reported to be 1.001 kg m^{-3}. The average wind speed at a 10 m height from 1973 – 2004 is calculated to be 4.3 ms^{-1} and the average wind speed for 2004 in particular is also calculated to be 4.3 ms^{-1}. This wind speed categorizes Peterson AFB as a marginal class 2 wind site. The climatic data is used to calculate the wind energy factors. A customized table of the climatic data is located in Appendix C.

4.3.3 Wind Turbine Design

The basic design for the wind turbines was recommended and confirmed by the National Renewable Energy Laboratory and the Colorado wind project developer from analogous wind projects from commercial wind farms. Below are the characteristics of each proposed turbine:

Manufacturer: NEG Micon
Rated Power: 1.5 MW
Hub Height: 62 m
Rotor Diameter: 72 m
Cut in Speed: 4 ms^{-1}
Cut out Speed: 25 ms^{-1}
Power Coefficient: 40%
Energy Curve Data Source: Weibull
Shape Factor: 2

4.3.4 Wind Energy Factors

The average velocity of the wind speed was adjusted to 62 m which is the hub height of the proposed wind turbine. The roughness class for the terrain was determined to be 1.5 with a roughness length of 0.055 m. The average wind speed at the height of the proposed turbines is 5.8 ms^{-1} as shown in equation 9. The monthly variation in average wind speed for years 2000 – 2004 at a 10 m and 62 m height, and the daily average wind speed variation for 2004 at a 62 m height are shown in Appendix B. The average monthly wind speed at Peterson AFB is noticeably greater during the spring months between March and June and is at its lowest points in December and January. The average wind speed at Peterson AFB noticeably varies with each day. Variations for a 62 m height range from 1.7 ms^{-1} to 15.7 ms^{-1} throughout 2004. The wind turbines energy output is based on the average wind speed which is represented by the Weibull function for 4.3 ms^{-1}. The recorded average daily wind speed at Peterson AFB is at or above the cut-in speed of 4 ms^{-1} 85% of the time for the 1.5 MW, 62 m NEG Micon turbines.

$$4.3\,\text{ms}^{-1} \times \frac{\ln\left(62\,\text{m}/0.055\right)}{\ln\left(10\,\text{m}/0.055\right)} = 5.8\,\text{ms}^{-1} \qquad (9)$$

The table for the wind turbine power data is shown in Table 8. The results of this data come from the Danish Wind Industry Association’s wind turbine power calculator. The wind turbine power calculator uses inputs from the turbine design and the climatic data to produce the turbine’s power input and output results.

The important feature to note is the capacity factor. The capacity factor is calculated to be 17.66%, which results in a yearly energy output of 2,319,902 kWh per year for each wind turbine. The max capacity output for each turbine is 13,140,000 kWh per year which is calculated by multiplying the rated power (1,500 kW) by the total hours in a year (8,760 hrs). The capacity factor for the Colorado Springs area usually runs between 21% - 25% (Gordon, 2005). With that noted, the capacity factor of 17.66% is considered a conservative factor based solely upon the specific site climatic conditions. Sensitivity analysis for changes in the capacity factor is shown in Appendix D.

The power input, 187 W/m^2 rotor area shows the amount of energy in the wind which theoretically would flow through the circle containing the rotor area, if the rotor were not present. The maximum power input at 9.3 ms^{-1} shows at what wind speed we achieve the highest contribution to total power output. This is the wind speed that the turbine operates the most efficiently (DWIA, 2005)

The power output, 65 W/m^2 of rotor area tells us how much of the power input per m^2 the machine will convert to electricity. The energy output, 570 $kWh/m^2/yr$ is simply the mean power output multiplied by 8,760, the number of hours in a year (DWIA, 2005).

Table 8. Table for Wind Turbine Power

Wind Distribution Data			
Weibull Shape Parameter	2.0		
Weibull Scale Parameter	4.852		
Site Power Input Results		**Turbine Power Output Results**	
Power Input	187 W/m2 rotor area	Power Output	65 W/m2 rotor area
Max Power Input	9.3 m/s	Energy output	570 kWh/m2/yr
Mean Hub Height Wind Speed	5.8 m/s	Energy output	2,319,902 kWh/yr
		Capacity Factor	17.66%

4.3.5 Energy Cost Savings

The energy cost savings are those costs avoided by reducing the energy consumption from the Colorado Springs Utilities (CSU). The savings are calculated by multiplying the kWh rate by the projected kWh per year produced from the wind turbines. This is calculated for the 20 year estimated life span of the turbines.

The utilities rate per kWh for years 1 though 20 is first determined by calculating the average yearly rate variation of kWh consumption for the years 1996-2004 for Peterson AFB. Simple linear regression was used to forecast point estimates for the kWh rate for years 2005-2024. Microsoft Excel ® was used for the calculations and the regression statistics are shown in Appendix A. The total energy output from the two wind turbines is expected to be 4,639,804 kWh per year. The average energy cost savings in 2005 would then be:

$$\$0.044 \times 4,639,804 kWh = \$205,956 \tag{10}$$

The total discounted energy cost savings for the 20 year life span of the project is estimated to be $3,880,393. Sensitivity analysis for differences in the utility cost per kWh is shown in Appendix D.

4.3.6 Installation Costs

Installation costs can be broken out into equipment costs which include the cost of the tower, turbine, and shipping. The construction costs include turbine foundations, roads, on-site power collection system, substation, interconnection, maintenance building, and construction management. Some other installation costs include project development, wind resource assessment, permitting, design and engineering, initial spares, project commissioning, and monitoring equipment. Certain installation costs are influenced by the distance the turbines will be sited from access roads and the distance from power lines capable of handling the power output from the turbines. Soil conditions are a factor to consider when laying the foundation for the turbines and building the access roads which must carry 30 ton trucks with considerable turning radiuses. The government estimate of the project investment activities equates to $3,738,000 and is shown in Table 9 (Robichaud, 2005). The cost per kWh of capacity is $1,246. This cost estimate is a rough estimate and a more detailed estimate would be calculated when the project developer is able to conduct a site assessment at the base. An estimated cost per kWh of capacity of $1,000 was provided by the Colorado wind project developer. This cost seems to be an overly optimistic estimate from a contractor. Additional investigation into installation costs yielded a range of $1,200 - $1,400 per kWh according to enXco, a North American wind project developer who installed four turbines at the Ascension Island's in the South Atlantic. Sensitivity analysis for differences in the installation cost is shown in Appendix D.

Table 9. Project Investment Activities

Project Investment Activities			
Equipment Cost		$	(2,307,000)
Construction Cost		$	(930,000)
Other Cost		$	(501,000)
Total Project Investment Activities		**$**	**(3,738,000)**
	per kW of capacity	$	1,246

4.3.7 Maintenance Costs

Maintenance costs for wind projects are relatively minute when compared to other electricity generating facilities. Operations and maintenance costs typically run about $0.01/kWh or less for a mainstream wind plant (NWCC, 1997). In comparison, the

O&M costs for a conventional coal power plant is at $0.046/kWh and $0.021/kWh for a nuclear plant (REPP, 2004; NEI, 2005). The estimated first year annual maintenance costs for the Peterson AFB wind project are shown in Table 10. The component replacement reserve is for replacement parts such as the blades, gearbox, and other mechanical gears. The reserve is spread out from years 6-20 and has a present value of $277K. The total discounted project O&M expenses for the 20 year lifespan are $826,068. The wind project developer estimates total discounted O&M expenses to be $664,158. Sensitivity analysis for differences in the maintenance cost is shown in Appendix D.

Table 10. Project Maintenance Activities

Project O&M Expenses		
Project Administration Fee		$1,000
Insurance		$28,600
Component Replacement Reserve		$0
Operating & Maintenance Contract		$15,000
Road Maintenance		$500
Supervision and Management		$1,000
Legal		$1,500
Total Expenses		**$47,600**
	O&M Expense per kWh	$0.010

4.3.8 Salvage Value and Disposal Costs

The salvage value of the wind project is what the equipment is worth at the end of its useful life. The tower and turbine components will have a minimal salvage value remaining after 20 years due to the foreseen technology advancements in the field. There is also associated decommissioning or disposal costs for teardown at the end of the useful life. Disposal costs could range from 40% to 70% of the total installation cost, depending on the extent of the project decommissioning (Robichaud, 2004). At the 20 year point, PAFB will have the option to leave the wind turbines in place and either extend their useful life or shutdown the operations. This would result in no salvage value or disposal costs. Another option is to leave the tower at its current height and replace the turbine with an advanced and more efficient model. Another option would be to remove the current tower and turbine and rebuild with a higher tower and newer turbine. These two options would not yield salvage value or disposal costs. A new project and economic life would begin and these costs would be associated to the construction cost of the new project. The last option would be to tear down the wind turbine and not rebuild. This would more likely be done if the land was needed for other uses. In this case, there would be associated salvage value and disposal costs. This research will assume that PAFB will replace the tower and turbine with newer and more efficient technological advancements at the 20 year point. Thus no salvage value or disposal cost will be associated to this project. Yet, this research will illustrate LCC comparisons for a project with and without salvage value and disposal costs. The estimated discounted salvage value for the wind project is $206,964 and the estimated discounted disposal costs are $827,856.

4.3.9 Environmental Improvement

Greenhouse gases are gases in the Earth's atmosphere which have an effect on global climate change. Some believe that GHG's enhance the natural greenhouse effect, which leads to an increase in the Earth's average temperature. In addition, greenhouse gases have a damaging affect on the environment and human health. This research was able to capture the reduction in carbon dioxide, methane, and nitrous oxide emissions released from the burning of fossil fuels to produce electricity. In terms of capacity, the fuel mix which is used by the Colorado Springs Utilities to generate electricity was obtained and is shown in Table 11. Fossil fuels make up over 85% of the fuels used to generate electricity and only 0.1% of electricity is from wind generated energy emerging from the Ponnequin wind farm.

Table 11. Colorado Springs Fuel Mix

Fuel	MW	% Mix
Coal	469	53.7%
Natural Gas	275	31.5%
Large Hydro	85	9.7%
Small Hydro	35	4.0%
Nuclear	10	1.1%
Wind	1	0.1%
Total	**874**	**100%**

(CSU, 2004)

The Intergovernmental Panel on Climate Change (IPCC) has established values for calculating the GHG emissions CO_2, CH_4, and N_2O, as well as some other trace gases, from six major emission source categories (IPCC, 1996). The Clean Energy Project Analysis software model was used to determine what the emission factors were, based on the given fuel mix, the fuel conversion efficiency, and the transmission and distribution (T&D) losses.

The model provides the CO_2, CH_4, and N_2O emission factors which represent the mass of greenhouse gas emitted per unit of energy. Emission factors will vary for different types and qualities of fuels, and for different types and sizes of power plants. The default factors provided are those which are representative of large power plants that feed a central electricity grid. On the electricity mix row at the bottom of Table 12, the model calculates the equivalent emission factors for the total electricity mix and per unit of electricity delivered. The electricity mix factors thus account for a weighted average of the fuel conversion efficiencies and transmission and distribution (T&D) losses of the different fuel types (RETScreen®, 2004). For each fuel type selected, units are given in kilograms (kg) of gas emitted per gigajoule (GJ) of heat energy generated. For the total electricity mix shown on the bottom row of Table 12, units are given in kg of gas emitted per GJ of end-use electricity delivered. Since renewable energies produce no GHG emissions, the default value of 100% is inserted as a place holder.

The fuel conversion efficiency is the efficiency of energy conversion from primary heat potential to actual power plant output. This value is used to calculate, for each fuel type, the aggregate GHG emission factor and therefore is only relevant for fuel types which actually produce greenhouse gases. For example, a typical coal-fired power plant has a fuel conversion efficiency of 35%, which indicates that 35% of the heat content of the coal is transformed into electricity fed to the grid (RETScreen®, 2004).

Transmission and Distribution losses are energy losses which occur during the process of supplying electricity to customers. T&D losses vary based on the voltage of transport lines, the distance from the site of energy production to the point of use, peak energy demands, ambient temperature, and electricity theft. The average U.S. T&D losses are estimated to be 8%. The model calculates the weighted average of the T & D losses of the global electricity mix on the bottom row of Table 12 (RETScreen®, 2004).

The software was limited to CO_2, CH_4, and N_2O emissions and does not include criteria pollutants such as sulfur oxides (SO_X), particulate matter (PM_{10}), carbon monoxide (CO), nitrogen oxides (NO_X), ozone (O_3), and lead (Pb). The greenhouse gas emission factor was calculated into metric tons (tonnes) of CO_2 per MWh for valuation purposes. A factor of 0.727 tonnes of CO_2 per MWh was calculated as the GHG emission factor. The equivalent volume reductions based on the global warming potential of these gases as established by the International Panel on Climate Change was converted into CO_2. According to the IPCC, 1 tonne CH_4 = 21 tonnes CO_2 and 1 tonne N_20 = 310 tonnes CO_2.

Table 12. Green House Gas Emission Factors

Fuel type	Fuel mix (%)	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t_{CO2}/MWh)
Coal	53.6%	94.6	0.0020	0.0030	35.0%	8.0%	1.0685
Natural gas	31.4%	56.1	0.0030	0.0010	45.0%	8.0%	0.4911
Nuclear	1.1%	0.0	0.0000	0.0000	30.0%	8.0%	0.0000
Large hydro	9.7%	0.0	0.0000	0.0000	100.0%	8.0%	0.0000
Small hydro	4.0%	0.0	0.0000	0.0000	100.0%	8.0%	0.0000
Wind	0.1%	0.0	0.0000	0.0000	100.0%	8.0%	0.0000
Electricity r	100%	200.1	0.0056	0.0058		8.0%	0.727

(RETSCREEN, 2004)

The GHG emission factor of 0.727 tonnes of CO_2 per MWh was then multiplied by the annual energy delivered from the wind turbines of 4,640 MWh to determine the net annual GHG emission reduction in tonnes of CO_2. The net annual GHG emission reduction from using two 1.5 MW wind turbines at Peterson AFB for energy production is 3,373 tonnes of CO_2. The calculations are shown in Table 13.

Table 13. Net Annual GHG emission reduction

Base case GHG emission factor (tCO2/MWh)	Proposed case GHG emission factor (tCO2/MWh)	End-use annual energy delivered (MWh)	Net annual GHG emission reduction (t_{CO2})
0.727	0.000	4,640	**3,373**

(RETSCREEN, 2004)

The potential cost savings of GHG emission reductions was calculated below in Table 14. The valuation of the reduction of CO_2 was extracted from the literature review where the values range from $5 - $183 per ton of CO_2 with a mean of $39 per ton of CO_2 (Gatto et al., 2002). This research assesses the value of CO_2 reduction by using the mean and applying a sensitivity analysis in increments of 10% and 20%. The reduction in metric tons (tonnes) of CO_2 was converted to short tons (tons) and multiplied by the value of the reduced CO_2. 1.0 tonne is equivalent to 1.1023 tons, therefore 3,373 tonnes is equivalent to 3,719 tons. The average global socio-economic value of the reduction of GHG emissions at Peterson AFB is estimated to be $145,023 per year.

Table 14. Cost savings of GHG emissions reduction

	Value (t_{CO2})	Reduction ($tonnes_{CO2}$)	Reduction ($tons_{CO2}$)	Cost (t_{CO2})
-20%	$ 31	3,373	3,719	$115,274
-10%	$ 35	3,373	3,719	$130,149
Mean	$ 39	3,373	3,719	$145,023
10%	$ 43	3,373	3,719	$159,897
20%	$ 47	3,373	3,719	$174,771

4.4 Life Cycle Analysis

The project design and life cycle cost estimates were provided by experts in the field to obtain the best possible data for use for the life cycle cost calculations. The methodologies and procedures for estimating and comparing the LCC for 20 years and 25 years are computed in Table 15. Again, 20 years is the typical useful life of a turbine and is a better estimate than 25 years. The focus of comparison is the net present value because it takes into consideration the time value of money and all the other subjective parameters and gives the decision maker a value so he or she can make a legitimate decision. Assuming a 20 year lifespan and using the life cycle cost estimates provided by NREL, the net present value is calculated to be $(683,675). This means that in terms of today's dollars, this wind turbine project has a negative worth of $683,675 to the U.S. Air Force.

The simple payback period is calculated to be 18.15 years which indicates that it will take about 18 years for this project to recoup the initial investment. This payback period is greater than the 10 year maximum required by the National Energy Act of 1992 and only two years shy of the life of the project. The savings to investment ratio is calculated to be 0.82 which is less than the requirement of 1.00. This means that the government will earn $0.82 on every $1.00 invested in the project. The project adjusted internal rate of return is calculated to be 1.96% which is less than the discount rate of 3%. This means that the Air Force will have a shortfall in their rate of return of 1.04% if they construct the proposed wind farm.

$$SPBP = \frac{3,738,000}{205,956} = 18.15\, years \tag{11}$$

$$SIR = \frac{3,880,393 - 826,068}{3,738,000} = 0.82 \tag{12}$$

$$AIRR = (1 + 0.03) \times 0.82^{\left(\frac{1}{20}\right)} - 1 = 1.96\% \tag{13}$$

Table 15. Project Life Cycle Cost Analysis

Without Salvage Value and Disposal Cost

Life Cycle Cost Analysis (20 years)	
Without Environmental Benefits	
AIRR	**1.96%**
Hurdle Rate	**3.00%**
AIRR Shortfall	**1.04%**
Simple Payback Period (years)	**18.15**
SIR	**0.82**
NPV	**-$683,675**

With Salvage Value and Disposal Cost

Life Cycle Cost Analysis (20 years)	
Without Environmental Benefits	
AIRR	**1.18%**
Hurdle Rate	**3.00%**
AIRR Shortfall	**1.82%**
Simple Payback Period (years)	**18.15**
SIR	**0.70**
NPV	**-$1,304,567**

Table 16 illustrates the net present value calculation for the 20 year lifespan. The investment cost, O&M expenses, salvage value, disposal cost, and the energy savings are all discounted using the appropriate 3% real discount rate. The net present value when not calculating salvage value and disposal cost is ($683,675). Table 17 displays the net present value calculation with the inclusion of the non-market valuation of the environmental benefits.

Table 16. Discounted Project Costs w/o Environmental

Discounted Project Costs (20 years)		Discounted Project Costs (20 years)	
Investment	($3,738,000)	Investment	($3,738,000)
O&M	($826,068)	O&M	($826,068)
Salvage Value	$0	Salvage Value	$206,964
Disposal Cost	$0	Disposal Cost	($827,856)
Energy Savings	$3,880,393	Energy Savings	$3,880,393
Environmental Savings	$0	Environmental Savings	$0
Net Present Value	**-$683,675**	**Net Present Value**	**-$1,304,567**

The environmental benefits are attributable to the socio-environmental damages due to electricity generation from CSU's fuel mix. The values are attached to categories such as human mortality and morbidity, ageing and soiling of buildings, yield change in crops, global warming, and acid rain. The average value of $39 per ton of CO_2 was applied to the reduction in CO_2 supplemented from the wind generated electricity at PAFB. The discounted environmental savings for a 20 year lifespan is calculated to be $2,157,576. The assumption that the average value per ton of CO_2 reduced is stated. Yet there are other assumptions that must be attached to the calculated environmental savings. The assumption that the utility fuel mix remains constant and that there will not be an introduction of cleaner burning technologies such as the substitution of low sulfur coal must be considered. With the inclusion of environmental benefits, using wind generated energy at Peterson AFB is an advisable investment for the Air Force based on a positive net present value of $1,473,901 for the 20 year lifespan.

Table 17. Discounted Project Costs w/ Environmental

Discounted Project Costs (20 years)		Discounted Project Costs (20 years)	
Investment	($3,738,000)	Investment	($3,738,000)
O&M	($826,068)	O&M	($826,068)
Salvage Value		Salvage Value	$206,964
Disposal Cost		Disposal Cost	($827,856)
Energy Savings	$3,880,393	Energy Savings	$3,880,393
Environmental Savings	$2,157,576	Environmental Savings	$2,157,576
Net Present Value	**$1,473,901**	**Net Present Value**	**$853,009**

4.5 Green Power Comparison

Peterson AFB is currently looking at the option to purchase green power from the local utility to meet the requirements set forth in EO 13123. Green power is currently being sold by the Colorado Springs Utilities for an additional $0.03 per kWh. This research calculated the life cycle cost for comparison purposes of on-site generated wind energy to the cost of purchasing green energy. The additional discounted total cost to PAFB for purchasing green energy at the same energy demand that would be generated from the wind turbines is $(2,070,857). When comparing the green power program to the on-site wind energy generation, PAFB has a better NPV to construct the on-site wind turbines. However, it must be noted that PAFB can negotiate a long term contract to purchase green energy from the local utility. Green power comparisons at different rates are shown below in Table 18 and sensitivity analysis is shown in Appendix D. It must also be noted that environmental benefits would be a sunk cost in this situation and PAFB would not have the added security of having an on-site electricity generation facility.

Table 18. Green Power Comparison

Without Salvage Value and Disposal Cost

Green Power Comparison (20 years)	
Onsite Generation	($683,675)
Green Power ($0.030)	($2,070,857)
Green Power ($0.025)	($1,725,714)
Green Power ($0.020)	($1,380,571)

With Salvage Value and Disposal Cost

Green Power Comparison (20 years)	
Onsite Generation	($1,304,567)
Green Power ($0.030)	($2,070,857)
Green Power ($0.025)	($1,725,714)
Green Power ($0.020)	($1,380,571)

5. Conclusion

5.1 Overview

Chapter 5 provides a brief review of this research while answering the initial questions presented in Chapter 1. This examination is followed by the main conclusion and recommendations stemming from this study. Then, the limitations of the analysis are addressed. Finally, suggested follow-on research areas are included for continuation of this topic for future endeavors.

5.2 Review

Wind is a natural resource that has been and will always be around. Wind is an energy source that produces no pollutants which means less smog, less acid rain, and fewer greenhouse gas emissions. Wind can be constantly exploited without the need to import energy supplies from foreign countries. It can also enhance our nation's security, help protect its beauty, and improve the quality of air we breathe when used to power our homes and businesses. Furthermore, using wind power as a replacement for coal, natural gas, or oil avoids the environmental impacts of mining, drilling, transporting, and burning these fuels. There are also environmental concerns which are addressed with wind systems. These issues include avian mortality, noise concerns, aesthetics, and electromagnetic interference.

Wind energy is used around the world to generate electricity. Europe has installed over 39,000 MW of wind energy and the U.S. has installed just over 6,700 MW

(BWEA, 2004). The U.S. government has published executive orders requiring federal agencies to begin to implement renewable energy technologies, reduce on-site energy consumption, and reduce GHG emissions. The U.S. Air Force has implemented the use of wind generated electricity at some of their bases in order to meet the executive orders. Green power programs are fairly common and on-site wind energy generation is being assessed at certain Air Force bases.

The environmental benefits are significant as the proposed 3 MW wind system for Peterson AFB can displace 3,719 tons of CO_2 each year based on the current local utility fuel mix. In addition it is estimated that global costs can range from $5 - $183 per ton of CO_2 with an average of $39 (Gatto et al., 2002).

Wind energy systems involve a significant investment and can be competitive with conventional energy sources when accounting for a lifetime of avoided or reduced utility costs. The capital costs of the wind turbines recommended in this research make up 75% of the total present value cost of the project. This research estimates the net present value of the proposed wind system to be $(683,675) for the 20 year life span without the inclusion of the value of environmental benefits. With environmental benefits included, the net present value of the wind system is $1,473,901. When comparing on-site wind energy generation with purchasing green power at PAFB, on-site generation can be valuable to the Air Force if new sites with attractive wind speeds prove to be present.

Technology advancements within the wind industry are essential to providing a cost effective energy source when compared to fossil fuels. Turbine rotor diameters must be larger to collect the lower energy winds from a larger circumference without increasing the cost of the rotor. The towers need to be constructed higher to take advantage of the escalating wind speed at elevated heights. And generation equipment and power electronics must be more efficient to accommodate sustained light wind operation at lower power levels without increasing electrical system costs (NREL, 2003).

5.3 Conclusions/Recommendations

The purpose of this effort was to determine if using on-site wind generated energy was an economically feasible alternative to traditional electricity consumption at Peterson AFB. In addition, the environmental benefits of reduced GHG emissions was quantified and given a dollar value. The life cycle cost estimates were provided by a Colorado wind project developer and developed concurrently with the National Renewable Energy Laboratory. The life cycle cost comparisons derived from generating on-site wind energy with and without salvage value and disposal costs proved not to be strictly economically feasible for Peterson AFB when compared to fossil fuel generated electricity. However, with the inclusion of the valuation of environmental benefits, it was determined that wind energy is a worthwhile project if the U.S. Air Force is willing to pay the extra costs for the global socioeconomic benefits. In regards to whether PAFB should generate energy with on-site wind turbines or purchase green power through the local utility, it is recommended that PAFB conduct site surveys at multiple areas of the base in attempt to harness the most power from the wind. An increase in wind speed from 4.3 ms^{-1} to 4.6 ms^{-1} would increase the turbine capacity factor, to 20.78%, enough to change the NPV of the project from $(683,675) to $3,155. Appendix E shows the break even analysis for wind speed and capacity factors. In addition, on-site wind energy could provide PAFB with a security blanket if conventional fuel availability fell short of meeting demands as well as hedge against fossil fuel price increases. Additionally the on-site wind energy generation can turn PAFB into a small, distributed power station, possibly shaving peak demands to the local utility that overload power lines and drive the need for new power plants.

The U.S. government has revealed preference to pay for the environmental benefits since they are currently providing the production tax credit to wind producers during the first ten years of a project. The government pays a credit for wind energy production of $0.018 per kWh for the first ten years of a project. This is equivalent to $84K per year or a $700K net present value for the Peterson AFB project. This would change the NPV of the project without environmental benefits to a positive value representing an investment greater than the government's opportunity cost.

This research has provided decision makers at Peterson AFB with a comparison of alternatives for on-site wind generation and purchasing of green power from the Colorado Springs Utilities. The on-site wind generation will provide less than 3% of all electricity consumption at Peterson AFB. It is recommended that Peterson AFB negotiate a green power contract with the local utilities that would be comparable to generating their own energy.

The differences in counting salvage value and disposal cost could potentially turn a project from a negative net worth for the government to a positive net worth. It is recommended that salvage value and disposal costs are not to be calculated in government life cycle estimates. If a project is initiated at an area with good wind resources, then the wind resources will more than likely still be present 20 years into the future. In this case, the turbine, and or the tower will be replaced at the 20 year point and a new project will be started. The associated salvage value and disposal costs would become a part of the construction costs of the new project.

5.4 Limitations

The biggest limitation in this research is the constraint of the site data and the use of data averages rather than precise site specific and continuous data. The wind speed, temperature, and air density for this research are all averages based on weather instruments sited at the Colorado Springs Municipal Airport. Variations in climatic data will alter the capacity factor of the wind turbines. A negative temperature change of 10 degrees or a 0.5 ms^{-1} decrease in wind speed could cause the capacity factor to decrease by 5% or 6%. This would reduce the total kWh output of the turbines causing a reduction in energy cost savings and potentially impacting the economic feasibility of the project. Alternatively, a site with more favorable climatic conditions will yield a greater capacity factor for the wind turbines and in the end have the potential to save the government more money while having a greater impact on displacing the release of harmful emissions into the atmosphere. F.E. Warren AFB is a great example for the potential variation in wind speeds for an area. The NOAA reports that Cheyenne, WY has an average yearly wind speed of 5.8 ms^{-1}. The site surveys that the engineers at F.E. Warren conducted yielded annual wind speeds of 7.2 ms^{-1} and 7.6 ms^{-1}.

This research set a value for the reduction of CO_2, CH_4, and N_2O using the European Unions recommended value obtained from various GHG studies. The U.S. federal government avoids the non market valuation of environmental benefits as they are extremely hard to quantify and open to political interpretation (Robichaud, 2004). Environmental benefits depend heavily on geographical location and estimating the social damage costs of electricity generation from utilities examined in Colorado Springs, CO would yield more accurate estimates. In addition, the non-market valuation of the environmental benefits is estimated for 20 years, but it is almost impossible to speculate the changes to the fuel mix for electricity generation. This research assumed that the fuel mix would stay constant for the full 20 year study period.

In addition, this research is limited to quantifying the three main green house gasses linked to global warming; CO_2, CH_4, and N_2O. Other harmful emissions are released during the combustion of fossil fuels which are not quantified in this research. These criteria pollutants include sulfur oxides (SO_X), particulate matter (PM_{10}) and ($PM_{2.5}$), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), and lead (Pb). The standards for these pollutants are established in the National Ambient Air Quality Standards set forth by the Environmental Protection Agency (EPA, 2004).

5.5 Future Research

This research quantifies and values the reduction in greenhouse gases from generating electricity for a specified fuel mix at a specific location. This research also identifies potential security benefits of using wind turbine technology at military installations. Follow-on research can include quantifying and valuing the security benefits of having on-site renewable energy generation.

A potentially greater benefit may be to use the analysis from this research and apply it to military installations worldwide based on site specific climatic data, there by ranking the installations based on net present value for potential ECIP funding.

Another potential area for follow-on research would be to do a comparative analysis taking into account multiple renewable energy systems such as wind turbines, photovoltaic cells, geothermal plants, and the use of biomass for on-site electricity generation. As well as applying non market valuation techniques to place a dollar value to the qualitative costs and or benefits.

An excellent follow on research topic would be to quantify the criteria pollutants emitted during fossil fuel combustion and assessing a value to the socioeconomic benefits. This could increase the value of renewable energies to society.

Finally, goal programming might be an effective way of choosing an energy alternative. By setting constraints and optimizing return, the user could determine which energy alternative is optimal for his or her situation.

5.6 Final Thoughts

The Department of Defense is the leading consumer of energy in the United States. Our nation relies heavily on coal and natural gas to provide the majority of that energy for electricity generation. The supply of worldwide fossil fuel resources is being depleted and the cost for that fuel is steadily increasing. Wind energy is available, plentiful, and free and will not deplete our world's natural resources. The methodology in this research can be utilized by base energy managers throughout the military to determine economic feasibility of wind projects prior to an intensive life cycle assessment. The analysis here can be applied throughout the department of defense for military installations, to not only meet requirements set forth in the executive orders, but also to provide an accurate means of cost comparisons for wind projects. By taking this initial step to meet and encourage the growing demand for wind energy, the Air Force can help reduce the reliance on limited resources while improving and preserving the environment for future generations.

Appendix A. Regression Statistics

This appendix provides the regression statistics performed to predict the average monthly kWh demand for Peterson AFB as well as the yearly utility rate for the life of the project.

Table 19. Regression Statistics for kWh Demand

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.911379924
R Square	0.830613366
Adjusted R Square	0.806415276
Standard Error	231273.8272
Observations	9

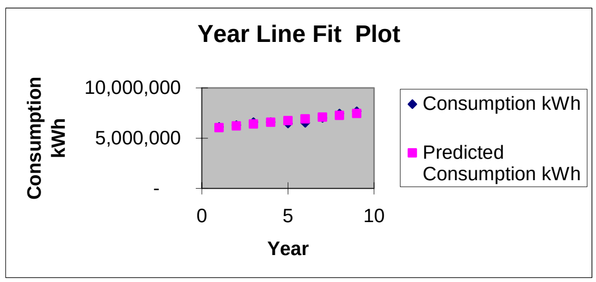
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.83599E+12	1.83599E+12	34.32557	0.000624993
Residual	7	3.74413E+11	53487583160		
Total	8	2.21041E+12			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	5866598.294	168016.5402	34.91679026	4.1E-09	5469302.308	6263894.28	5469302.308	6263894.28
Year	174928.1776	29857.32271	5.858803192	0.000625	104326.8282	245529.5269	104326.8282	245529.5269

RESIDUAL OUTPUT

Observation	*Predicted Consumption kWh*	*Residuals*
1	6041526.472	63739.49423
2	6216454.649	69920.85085
3	6391382.827	201476.5899
4	6566311.004	16255.32903
5	6741239.182	-278346.8485
6	6916167.359	-393257.0261
7	7091095.537	-88496.7037
8	7266023.715	180653.7854
9	7440951.892	228054.5289



Year	Consumption kWh
1	6,105,266
2	6,286,376
3	6,592,859
4	6,582,566
5	6,462,892
6	6,522,910
7	7,002,599
8	7,446,678
9	7,669,006
10	7,615,880

Table 20. Regression Statistics for kWh Utility Rate

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.834621694
R Square	0.696593373
Adjusted R Square	0.653249569
Standard Error	0.002680835
Observations	9

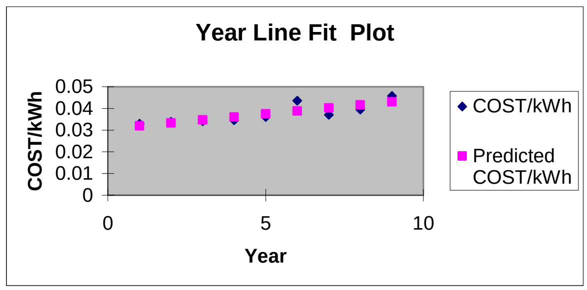
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.000115503	0.000115503	16.07134837	0.005131423
Residual	7	5.03081E-05	7.18687E-06		
Total	8	0.000165811			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.030514567	0.001947581	15.66793083	1.04398E-06	0.025909269	0.035119864	0.025909269	0.035119864
Year	0.00138746	0.000346094	4.008908626	0.005131423	0.000569077	0.002205843	0.000569077	0.002205843

RESIDUAL OUTPUT

Observation	*Predicted COST/kWh*	*Residuals*
1	0.031902027	0.000996718
2	0.033289487	0.000491433
3	0.034676948	-0.000570203
4	0.036064408	-0.001545536
5	0.037451868	-0.001439835
6	0.038839328	0.004681404
7	0.040226788	-0.00319677
8	0.041614249	-0.00215621
9	0.043001709	0.002738998



Year	COST/kWh		
1	0.032899	19	0.056876
2	0.033781	20	0.058264
3	0.034107	21	0.059651
4	0.034519	22	0.061039
5	0.036012	23	0.062426
6	0.043521	24	0.063814
7	0.03703	25	0.065201
8	0.039458	26	0.066589
9	0.045741	27	0.067976
10	0.044389	28	0.069363
11	0.045777	29	0.070751
12	0.047164	30	0.072138
13	0.048552	31	0.073526
14	0.049939	32	0.074913
15	0.051326	33	0.076301
16	0.052714	34	0.077688
17	0.054101		
18	0.055489		

Appendix B. Peterson AFB Wind Speed Variations

The average monthly wind speed at Peterson AFB is noticeably greater during the spring months between March and June and is at its lowest points in December and January.

Table 21. Average Monthly Wind Speed 10 m (2000 – 2004)

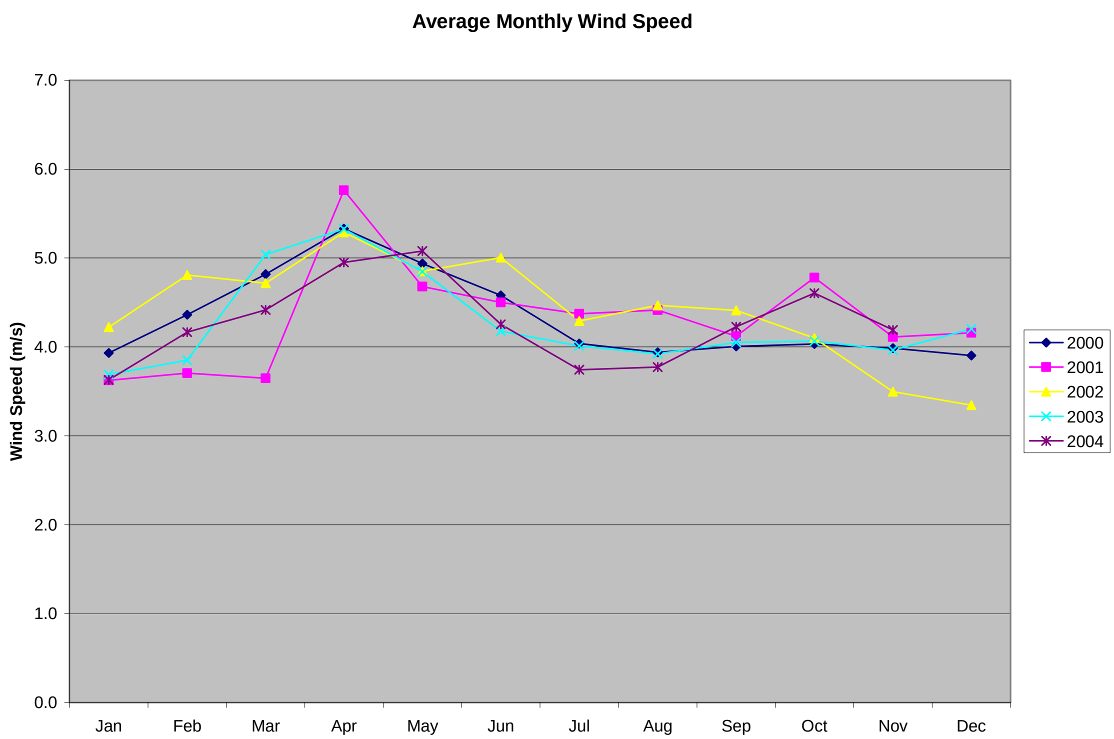
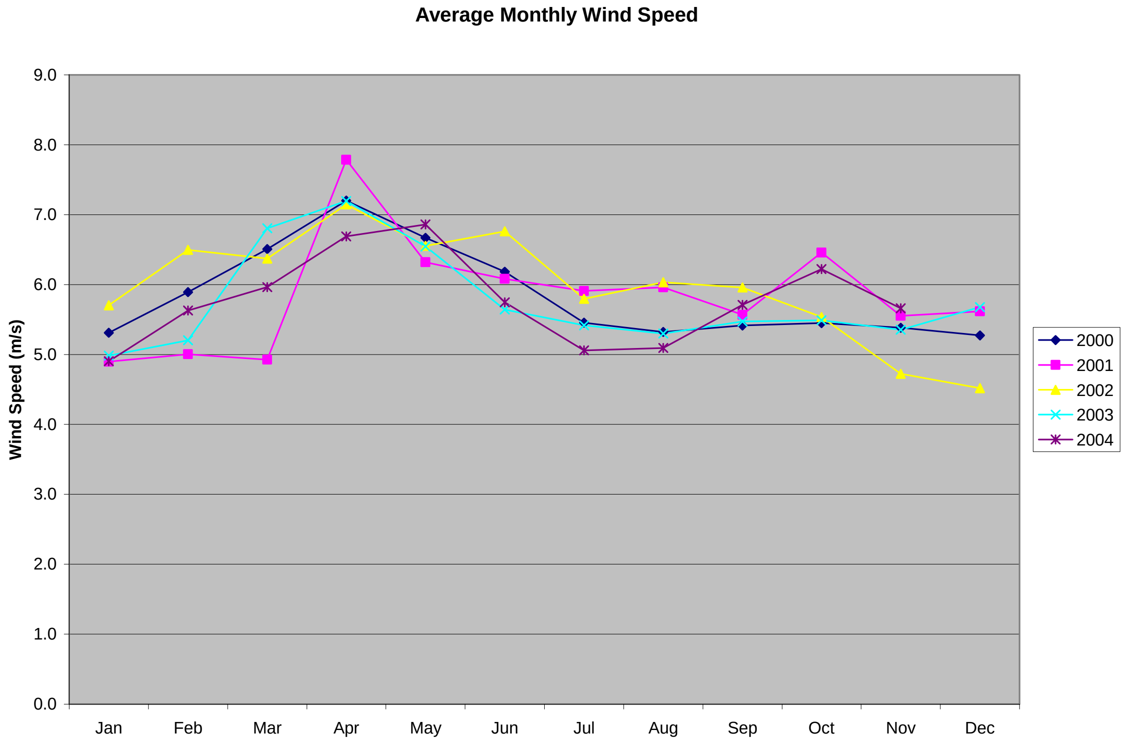
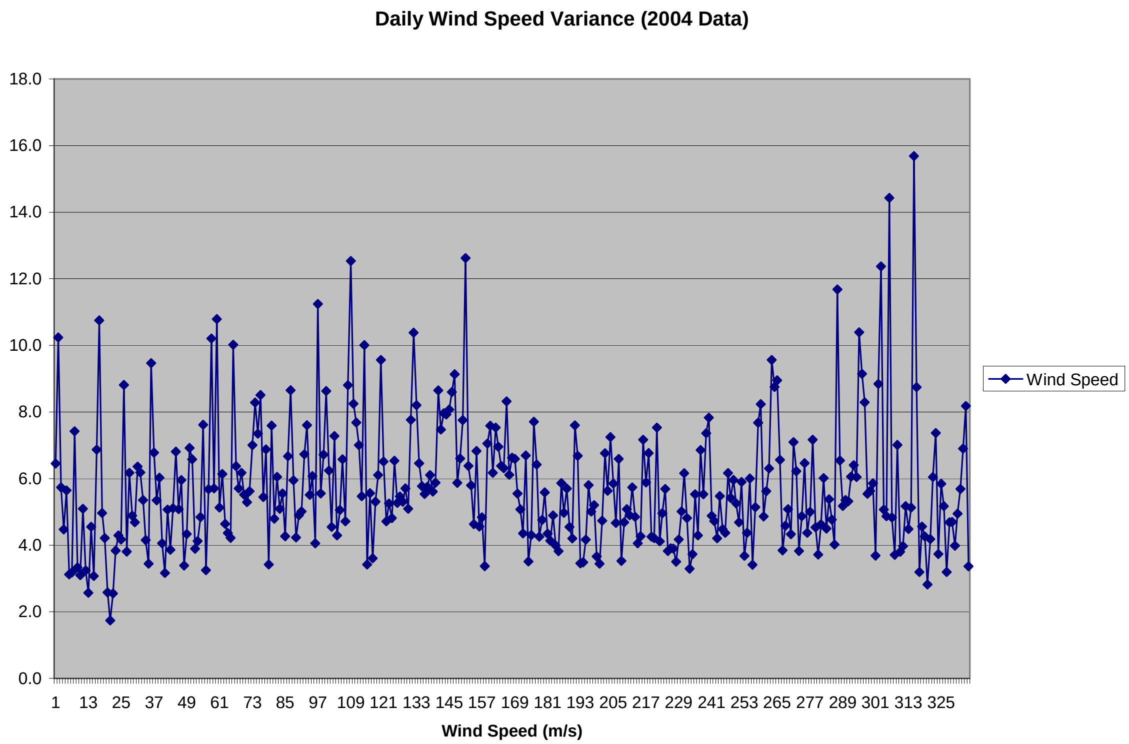


Table 22. Average Monthly Wind Speed 62 m (2000 – 2004)



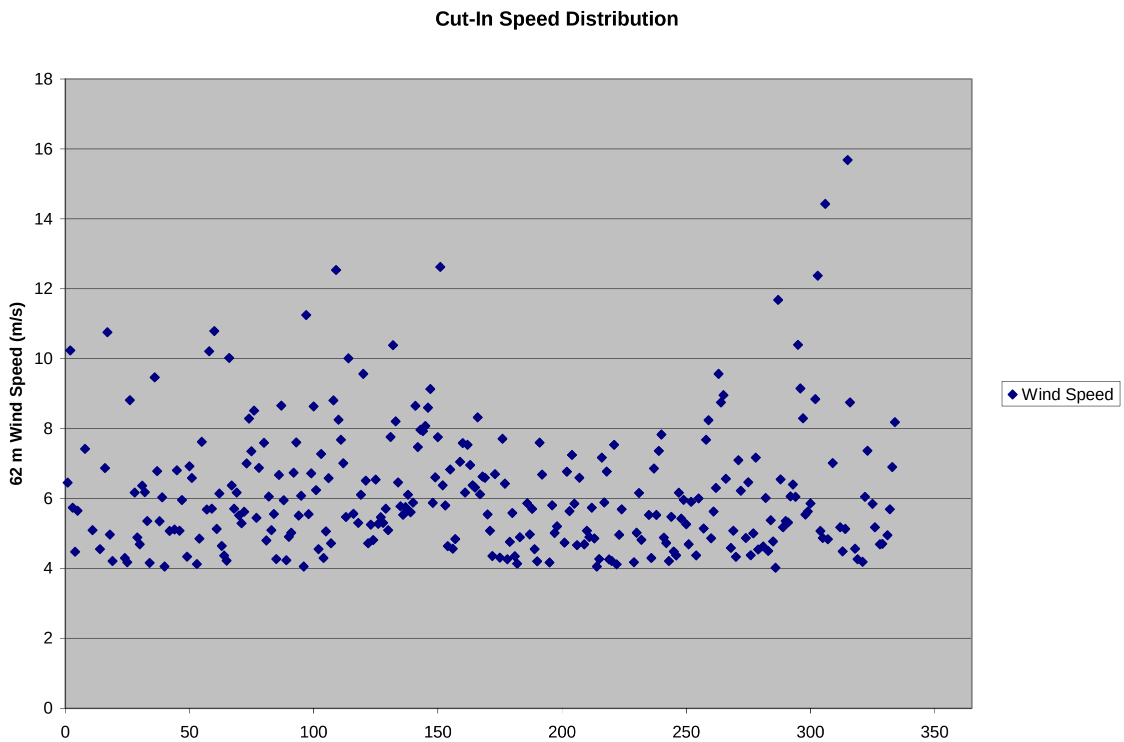
The average wind speed at Peterson AFB noticeably varies with each day. Variations for a 62 m height range from 1.7 ms-1 to 15.7 ms-1 throughout 2004.

Table 23. Daily Wind Speed Variance (2004)



The average daily wind speed at Peterson AFB is at or above the cut-in speed of 4 ms^{-1} 85% of the time for the 1.5 MW, 62 m NEG Micon turbines.

Table 24. Cut-In (4 ms^{-1}) Wind Speed Distribution (2004)



Appendix C. Continuity Tables of Air Density and Wind Speeds

The following tables represent climatic data collected from the Colorado Springs Municipal Airport. The data has been provided by the Air Force Combat Climatology Center. The air density data is represented as monthly averages and the wind speed data is represented as daily averages.

Table 25. Table for Air Densities

Average Colorado Springs Air Density	
Month	Avg (kg/m3)
1	1.0383
2	1.0315
3	1.0168
4	1.0022
5	0.9859
6	0.9707
7	0.9635
8	0.9689
9	0.9811
10	1.0006
11	1.0231
12	1.0361
All	1.0013

Table 26. Table of Wind Speeds (10 m)

	2000	2001	2002	2003	2004	Average
Jan	3.9	3.6	4.2	3.7	3.6	**3.8**
Feb	4.4	3.7	4.8	3.9	4.2	**4.2**
Mar	4.8	3.6	4.7	5.0	4.4	**4.5**
Apr	5.3	5.8	5.3	5.3	5.0	**5.3**
May	4.9	4.7	4.9	4.8	5.1	**4.9**
Jun	4.6	4.5	5.0	4.2	4.3	**4.5**
Jul	4.0	4.4	4.3	4.0	3.7	**4.1**
Aug	3.9	4.4	4.5	3.9	3.8	**4.1**
Sep	4.0	4.1	4.4	4.1	4.2	**4.2**
Oct	4.0	4.8	4.1	4.1	4.6	**4.3**
Nov	4.0	4.1	3.5	4.0	4.2	**4.0**
Dec	3.9	4.2	3.3	4.2		**3.9**
Average	**4.3**	**4.3**	**4.4**	**4.3**	**4.3**	

Table 27. Table of Wind Speeds (62 m)

	2000	2001	2002	2003	2004	Average
Jan	5.3	4.9	5.7	5.0	4.9	**5.2**
Feb	5.9	5.0	6.5	5.2	5.6	**5.6**
Mar	6.5	4.9	6.4	6.8	6.0	**6.1**
Apr	7.2	7.8	7.1	7.2	6.7	**7.2**
May	6.7	6.3	6.6	6.5	6.9	**6.6**
Jun	6.2	6.1	6.8	5.6	5.7	**6.1**
Jul	5.5	5.9	5.8	5.4	5.1	**5.5**
Aug	5.3	6.0	6.0	5.3	5.1	**5.5**
Sep	5.4	5.6	6.0	5.5	5.7	**5.6**
Oct	5.4	6.5	5.5	5.5	6.2	**5.8**
Nov	5.4	5.6	4.7	5.4	5.7	**5.3**
Dec	5.3	5.6	4.5	5.7		**5.3**
Average	**5.8**	**5.8**	**6.0**	**5.8**	**5.8**	

Appendix D. Sensitivity Analysis

This appendix provides the representation of the results of performing sensitivity analysis on each of the cost measures for the proposed wind project based on the amount of renewable energy delivered by each wind turbine and the results of the change in NPV. The energy savings and installation costs are the most sensitive factors towards the change in NPV. Each cell value represents the NPV of the wind project without the inclusion of the value of environmental benefits.

The cells shaded in yellow represent a government savings for pursuing green power rather than constructing the off-grid wind farm. Three versions of sensitivity are provided for comparing the wind project with purchasing green power from the local utility. The first sensitivity table uses a $0.030/kWh surcharge for purchasing green power, the second is for $0.025/kWh, and the third is for $0.020/kWh.

1,856 MWh = 14.2% capacity factor

2,088 MWh = 15.89% capacity factor

2,320 MWh = 17.66% capacity factor

2,552 MWh = 19.42% capacity factor

2,784 MWh = 21.19% capacity factor

Table 28. Sensitivity Analysis ($0.030/kWh Green Power)

Energy Savings ($/kWh)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
0.0355	-20%	-2,701,509	-2,391,077	-2,080,646	-1,770,214	-1,459,783
0.0400	-10%	-2,391,077	-2,041,842	-1,692,606	-1,343,371	-994,136
0.0444	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
0.0488	10%	-1,770,214	-1,343,371	-916,528	-489,684	-62,841
0.0533	20%	-1,459,783	-994,136	-528,488	-62,841	402,806

Initial costs ($)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
2,990,400	-20%	-1,208,867	-820,828	-432,789	-44,749	343,290
3,364,200	-10%	-1,644,756	-1,256,717	-868,678	-480,638	-92,599
3,738,000	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
4,111,800	10%	-2,516,535	-2,128,495	-1,740,456	-1,352,417	-964,378
4,485,600	20%	-2,952,424	-2,564,385	-2,176,345	-1,788,306	-1,400,267

Annual costs ($)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
38,080	-20%	-1,915,432	-1,527,393	-1,139,353	-751,314	-363,275
42,840	-10%	-1,998,039	-1,609,999	-1,221,960	-833,921	-445,882
47,600	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
52,360	10%	-2,163,252	-1,775,213	-1,387,174	-999,134	-611,095
57,120	20%	-2,245,859	-1,857,820	-1,469,781	-1,081,741	-693,702

Disposal Cost ($)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
662,285	-20%	-1,915,075	-1,527,035	-1,138,996	-750,957	-362,917
745,070	-10%	-1,997,860	-1,609,820	-1,221,781	-833,742	-445,702
827,856	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
910,642	10%	-2,163,432	-1,775,392	-1,387,353	-999,314	-611,274
993,427	20%	-2,246,217	-1,858,177	-1,470,138	-1,082,099	-694,059

Table 29. Sensitivity Analysis ($0.025/kWh Green Power)

Energy Savings ($/kWh)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
0.0355	-20%	-2,701,509	-2,391,077	-2,080,646	-1,770,214	-1,459,783
0.0400	-10%	-2,391,077	-2,041,842	-1,692,606	-1,343,371	-994,136
0.0444	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
0.0488	10%	-1,770,214	-1,343,371	-916,528	-489,684	-62,841
0.0533	20%	-1,459,783	-994,136	-528,488	-62,841	402,806

Initial costs ($)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
2,990,400	-20%	-1,208,867	-820,828	-432,789	-44,749	343,290
3,364,200	-10%	-1,644,756	-1,256,717	-868,678	-480,638	-92,599
3,738,000	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
4,111,800	10%	-2,516,535	-2,128,495	-1,740,456	-1,352,417	-964,378
4,485,600	20%	-2,952,424	-2,564,385	-2,176,345	-1,788,306	-1,400,267

Annual costs ($)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
38,080	-20%	-1,915,432	-1,527,393	-1,139,353	-751,314	-363,275
42,840	-10%	-1,998,039	-1,609,999	-1,221,960	-833,921	-445,882
47,600	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
52,360	10%	-2,163,252	-1,775,213	-1,387,174	-999,134	-611,095
57,120	20%	-2,245,859	-1,857,820	-1,469,781	-1,081,741	-693,702

Disposal Cost ($)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
662,285	-20%	-1,915,075	-1,527,035	-1,138,996	-750,957	-362,917
745,070	-10%	-1,997,860	-1,609,820	-1,221,781	-833,742	-445,702
827,856	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
910,642	10%	-2,163,432	-1,775,392	-1,387,353	-999,314	-611,274
993,427	20%	-2,246,217	-1,858,177	-1,470,138	-1,082,099	-694,059

Table 30. Sensitivity Analysis ($0.020/kWh Green Power)

Energy Savings ($/kWh)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
0.0355	-20%	-2,701,509	-2,391,077	-2,080,646	-1,770,214	-1,459,783
0.0400	-10%	-2,391,077	-2,041,842	-1,692,606	-1,343,371	-994,136
0.0444	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
0.0488	10%	-1,770,214	-1,343,371	-916,528	-489,684	-62,841
0.0533	20%	-1,459,783	-994,136	-528,488	-62,841	402,806

Initial costs ($)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
2,990,400	-20%	-1,208,867	-820,828	-432,789	-44,749	343,290
3,364,200	-10%	-1,644,756	-1,256,717	-868,678	-480,638	-92,599
3,738,000	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
4,111,800	10%	-2,516,535	-2,128,495	-1,740,456	-1,352,417	-964,378
4,485,600	20%	-2,952,424	-2,564,385	-2,176,345	-1,788,306	-1,400,267

Annual costs ($)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
38,080	-20%	-1,915,432	-1,527,393	-1,139,353	-751,314	-363,275
42,840	-10%	-1,998,039	-1,609,999	-1,221,960	-833,921	-445,882
47,600	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
52,360	10%	-2,163,252	-1,775,213	-1,387,174	-999,134	-611,095
57,120	20%	-2,245,859	-1,857,820	-1,469,781	-1,081,741	-693,702

Disposal Cost ($)		Renewable Energy Delivered (MWh) 1,856 -20%	2,088 -10%	**2,320** 0%	2,552 10%	2,784 20%
662,285	-20%	-1,915,075	-1,527,035	-1,138,996	-750,957	-362,917
745,070	-10%	-1,997,860	-1,609,820	-1,221,781	-833,742	-445,702
827,856	0%	-2,080,646	-1,692,606	**-1,304,567**	-916,528	-528,488
910,642	10%	-2,163,432	-1,775,392	-1,387,353	-999,314	-611,274
993,427	20%	-2,246,217	-1,858,177	-1,470,138	-1,082,099	-694,059

Appendix E. Break Even Analysis

Table 31 has been created to illustrate the break even point for wind speed at a 10 m height. Capacity factors are calculated specifically for the NEG Micon 1500/72 60 Hz wind turbine with an air density of 1.001 kg m^{-3}. At a wind speed between 4.6 ms^{-1} and 4.7 ms^{-1}, the net present value of the project changes from a negative present value to a positive present value.

Table 31. Break Even Analysis

Wind Speed (m/s) 10 m	Capacity Factor	NPV	
3.5	9.78%	$	(2,414,927)
3.6	10.59%	$	(2,235,833)
3.7	11.41%	$	(2,056,737)
3.8	12.49%	$	(1,817,943)
3.9	13.58%	$	(1,579,150)
4.0	14.40%	$	(1,400,054)
4.1	15.48%	$	(1,161,261)
4.2	16.57%	$	(922,468)
4.3	17.66%	$	(683,675)
4.4	18.47%	$	(504,579)
4.5	19.56%	$	(265,786)
4.6	20.64%	$	(26,993)
4.7	21.73%	$	211,800
4.8	22.82%	$	450,595
4.9	23.90%	$	689,388
5.0	24.72%	$	868,483
5.1	25.80%	$	1,107,276
5.2	26.89%	$	1,346,070
5.3	27.71%	$	1,525,165
5.4	28.79%	$	1,763,958
5.5	29.88%	$	2,002,753

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Captain Randy Charles Combs was born at Barksdale AFB, Louisiana. In 1996, he graduated from Douglas County High School in Colorado. He earned a Bachelor of Science degree in Business Administration from the University of Northern Colorado in Dec 1999 and was commissioned into the U.S. Air Force the day of graduation.

His first assignment was to Peterson AFB, Colorado. While there, he served as the NORAD Chief of Financial Management for the Strategic and Nuclear Deterrence Command and Control Systems Program Office. In August 2003, he entered the Cost Analysis Program, Graduate School of Engineering and Management, Air Force Institute of Technology. Following graduation, Captain Combs will be assigned to the Program Executive Office for Space at Los Angeles AFB, California.

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14. ABSTRACT
Wind energy technology is a viable source for attaining the emission reduction and renewable energy use goals set forth by the executive office. In accordance with Executive Orders, the Air Force must reduce greenhouse emissions and energy consumption, and expand the use of renewable energy sources within its facilities nation-wide by year 2010. This mandate requires that the Air Force look at alternative electrical production and rely more on such renewable energy resources as wind power. The specific problem addressed by this research is whether on-site wind energy generation can be more economically feasible than the conventional energy consumption at Peterson AFB. The hypothesis of this research is that wind energy will not be economically effective as an energy alternative without the inclusion of quantified environmental benefits.

The life cycle cost comparisons derived from generating on-site wind energy proved not to be strictly economically feasible for Peterson AFB when compared to fossil fuel generated electricity. However, with the inclusion of the valuation of environmental benefits, it was determined that wind energy is a worthwhile project if the U.S. Air Force is willing to pay the extra costs for the global socioeconomic benefits.

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