ECONOMIC ASSESSMENT OF SMALL-SCALE ELECTRICITY GENERATION FROM WIND

A Thesis

by

KRISTEN DAWN MCALLISTER

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

MASTER OF SCIENCE

May 2007

Major Subject: Agricultural Economics

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Approved By:

Chair of Committee, Joe L. Outlaw
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ABSTRACT

Economic Assessment of Small-Scale Electricity Generation from Wind. (May 2007)

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Chair of Advisory Committee: Dr. Joe L. Outlaw

Analysis was done to determine if small-scale wind energy could be economically feasible on a cotton farm with 1,200 irrigated acres, a house, and a barn. Lubbock and Midland were locations chosen for this model farm and the twenty-year analysis. A 10 kW wind turbine on a 30m tower was installed and five different scenarios were calculated for both locations.

Wind speeds for both locations were collected and analyzed to find the closest fitting distribution to incorporate the appropriate risk. This distribution was the empirical distribution at both locations every month except December in Lubbock, which closely matched the Gamma distribution. Electricity production, usage and costs were analyzed to find the net present value of the investment.

The economic analysis of this system showed that the wind turbine under all situations was much less economical than purchasing electricity solely from the electric company. Small-scale wind energy produced under thesis assumptions was over $10,000 more expensive than traditional electricity in Lubbock and Midland over the twenty year planning horizon.

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CHAPTER I

INTRODUCTION

Wind power, though generating less than one percent of electricity in the United States, is the world's fastest growing source of energy (Mazza and Heitz 2005). The United States is third in global wind production behind Germany and Spain. In 2005, the United States led the way in new installed capacity with a 37% increase from 6,718 MW to 9,149 MW (Global Wind Energy 2006). In addition, incentives included in the Energy Policy Act of 2005 (EPACT) are expected to further stimulate the production of renewable energy.

In 2006 Texas became the leading wind producing state in the United States. Currently, Texas has enough installed wind energy capacity to power over 600,000 average American households (American 2006). There is enough Class 4 wind power in Texas to produce all of the electricity consumed in the state today (SECO 2006a). Along with many other states, Texas has gone even further to support renewable energy by adopting its own renewable energy portfolio standards. Texas is ahead of schedule to meet these goals in part from the strong support of rural communities (SECO 2006b).

Though Texas has been proactive in installing wind generation statewide, there are still a few factors that are impeding the further development of wind energy in the State. First, utility rates in Texas are relatively low which makes it difficult for wind

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energy, often a more expensive alternative, to compete and become successful. Second, the rules and regulations concerning agreements between electric companies and producers with small scale wind energy are different throughout the state, therefore making it difficult for the producer to know what their options are. And lastly, large-scale wind energy has not spread to its potential in Texas in part due to high transmission costs as well as some electric company's policies.

Small-scale wind energy (less than 100kW) production could potentially bypass some of the problems associated with large-scale wind projects, thereby increasing the production of renewable energy from wind in Texas. This study will look at the feasibility of small-scale electric generation from wind so individuals can assess whether an investment in wind energy would be a net economic benefit to them.

Objectives

The primary objective of this study is to analyze the profitability of the use of small-scale wind production for electricity production in Texas. A secondary objective is to incorporate the risk of varying wind speeds to better predict the profitability.

Organization

The remainder of this thesis will be organized as follows. Chapter II discusses the literature on electricity generation from wind and financial models. Chapter III provides a discussion of the analytical methodology used in this research and risk analysis. Chapter IV summarizes the results. The final Chapter provides a summary and conclusion of the research.

CHAPTER II

LITERATURE REVIEW

Previously studies have been done on wind energy and these studies have been analyzed to better conduct the current case study analysis. Simulation literature was also reviewed to more accurately represent wind speed patterns incorporating risk. Policies regarding wind energy were reviewed to better understand issues that could arise. Financial models to determine the feasibility of a project were reviewed to find the best way to determine the economic feasibility of installing a small-scale wind turbine for electricity generation. Previous literature concerning wind energy, simulation, wind energy policies, and financial models are discussed in the subsequent sections.

Wind Energy

Most studies on wind energy deal with the engineering aspects of large scale wind systems. While these are helpful from the standpoint of some of the characteristics and properties of wind and electricity generation from wind, the large size of the systems reduce their applicability to the current problem.

One economic study relevant to smaller scale wind energy was a break-even analysis using wind energy to power an irrigation system in the Texas high plains (Hardin 1981). The analysis used the Rayleigh distribution to estimate wind speeds to power the irrigation system. Hardin’s study only incorporated wind speed data from one location, which limits the usefulness of the results as alternate locations can have different wind speed distributions. The study is applicable, however, because it analyzes using wind energy on a small scale for irrigation. An omission Hardin (1981) is that it did not include the farmer's household energy needs. Households need energy intermittently, while irrigation can be done whenever the wind is available, day or night. Hardin (1981) did not include a backup source of energy; therefore, irrigation could only be done when the wind was blowing hard enough to generate electricity.

A study conducted by Bremnes (2006) discusses different statistical models for making wind power forecasts that incorporate uncertainty. The statistical models discussed in his research are: Local Quantile Regression (LQR), Local Gaussian (LG) Model, and Nadaraya-Watson (NW) Estimator. The results of the study did not indicate a preferred model; therefore additional work in this area needs to be done in this area.

Due to the fact that wind is not a constant source of energy, a turbine system cannot be relied upon as the single source of energy. Wind can sometimes generate more energy than needed and at other times the wind does not produce enough energy. Connecting to a power grid can be a solution to this problem. Research on grid integration of wind farms discusses the problems dealing with voltage fluctuations and solutions to connecting a large wind farm to a power grid (Bousseau, et al. (2006)). Large wind farms must connect to a power grid to sell the wind energy. A small-scale system does not have to connect to a grid system, however to have a constant source of electricity this is often the best solution. A small-scale wind turbine connection to the grid would likely deal with similar issues as the large wind farm. But to properly evaluate whether a small-scale wind project makes economic sense a decision-maker needs to compare the costs incurred due to installing the system relative to the energy cost savings over the life of the investment.

Beenstock (1995) discusses issues involved in a cost-benefit analysis for wind energy when involved in grid integration. One consideration that needs to be taken into account is the volatility of the wind and the cost of the backup electricity, which can be characterized as the price of wind volatility. He discusses how the power curve, which relates wind power to wind velocity, should be incorporated into an analysis as well as the correct statistical distribution for wind velocity. The article used a Rayleigh distribution for wind velocity, but they also suggested that in some areas, a different distribution such as the more general Weibull could be appropriate. According to his research, electricity generation varies directly with the cube of wind velocity, $E=kV^3$, where k represents a technical constant that takes into account the air pressure and size of the turbine. Beenstock (1995) discussed and used Monte Carlo methods for simulation and performed 8000 trials in his analysis.

Molla (1997) found that installing a 10 kW turbine in West Texas for crop irrigation was not economical. He used a Bergey turbine that cost $30,000 at the time; since then, turbine prices have increased slightly, but they are also more efficient. Also, electricity prices have also risen. Greater efficiency and higher priced electricity may make turbines more economical. Molla did not have his turbine connected to the grid for backup power; therefore water was only pumped when there was enough wind. Excess water was stored for later use. In his study, Molla used a double Fourier transformation for the stochastic simulation of wind speeds. The study used historical data as well as a surface map to estimate the parameters for the double Fourier transformation distribution.

Wind Speeds

Since it has a cubic relation with power, wind speed is a crucial aspect in determining if a site has good potential to produce energy. Wind is caused by the sun as well as the seasons; therefore wind patterns tend to have a cycle of one year (Patel (2006)). According to Patel the stochastic manner of wind speed is best described by a Weibull probability distribution. The Weibull distribution is flexible in terms of the shape of the probability distribution curve. When k=1 an exponential distribution will be seen, while a typical wind speed distribution is approximated when k=2. At this level, there are more observations where the wind speed is lower than the average wind speed with a few observations of higher wind speeds. As k increases above three, the distribution will approach a normal distribution. The shape parameter, k, can be changed to closely reflect the historical distribution. Most areas in Texas have wind speeds that closely resemble the Rayleigh distribution where k=2 (The Texas Million 2005).

Wind speed data is often collected at heights lower than the actual hub height for the turbine. Wind speeds at different heights in the exact same location will vary. This is known as wind shear and must be accounted for when analyzing turbine output. Elkinton, Rogers, and McGowan (2006) discussed two different ways of measuring wind shear: the Log Law, and the Power Law.

The Log Law's parameters in (1) are target (z) and reference (z_r) height; the wind speeds at target U(x) and reference U(x_r); and the surface roughness length (z_o).

$$\frac{U(x)}{U(x_r)} = \frac{\ln\left(\frac{z}{z_o}\right)}{\ln\left(\frac{z_r}{z_o}\right)} \quad (1)$$

In equation (1) surface roughness length is the height above ground level where wind speed is theoretically zero. For the smoothest of surfaces, it is very close to zero and increases to three in cities with tall buildings. The major weakness of the Power Law is that it cannot measure wind shear for all locations.

The Power Law uses the target and reference heights along with their wind speeds from above as well as the power law exponent, α (equation 2). This is commonly known as the One-Seventh Power Law due to the fact that α is 1/7 in relatively flat areas. Alpha ranges from .1 in the smoothest of conditions to .4 in areas with tall buildings.

$$\frac{U(x)}{U(x_r)} = \left(\frac{z}{z_r}\right)^{\alpha} \quad (2)$$

In their study it was found that the Power Law worked best in smooth locations that were relatively flat whereas the Log Law worked best in hilly areas.

Texas Policy

Recently the electric industry in Texas has undergone some restructuring giving consumers regulated by the Public Utility Commission of Texas (PUCT), which accounts for roughly 75% of the state, "the power to choose." Unfortunately, this restructuring has hurt some aspects of renewable energy. In 1999 the Texas Legislature de-integrated the largest investor-owned electric utilities into three separate entities:

retail electric providers, transmission and distribution companies, and generation companies. This made it difficult to apply the existing net metering rules concerning renewable energy. This restructuring did strengthen the rules concerning the right to interconnect small generating systems to the grid for utility companies still under the PUCT. Unfortunately, there were changes to the current net metering rule that exempt the state's largest utilities from having to pay for energy supplied to the grid from small generators. The restructuring also affected rural cooperatives by exempting them from PUCT jurisdiction. This means that these co-ops are not required to follow the existing net metering rules as well as the newly strengthened interconnection rules. In short, various electric companies service Texas and different rules regarding transmission and net metering can apply (The Texas Million 2005).

Federal Policy

Wind energy supporters including the American Wind Energy Association (AWEA) support the Federal production tax credit of (PTC) 1.5 cents/kilowatt hour for production of electricity from large scale wind energy projects. This PCT was created under the Energy Policy Act of 1992 and has since been periodically renewed. The current expiration date is 2007. This tax credit benefits large-scale wind energy projects, but not small scale. Currently AWEA is attempting to persuade congress to enact legislation giving the owners of small wind systems a 30% investment tax credit. They believe that the tax credit would stimulate growth of the small-scale wind energy industry.

Approaches to Wind Project Investment Analysis

Mathew (2006) discusses the economics of wind energy including different ways to analyze wind turbine projects. One such approach he discusses is 'present worth.' Since wind energy projects are expected to last for at least twenty years and there are costs and benefits each year, Mathew believes that the model must account for the time value of money. The total worth of the project will be a function of future cash flows discounted back to today.

Harsh (2006) discusses the use of partial budgeting methods for evaluating investments. He looks at revenues and expenses that will change as a result of the investment for each year of the life of the investment and discusses several aspects that need to be considered in the partial budget. These aspects include tax impacts, risk, inflation, and the non-cash expense of depreciation. Harsh believes that fast depreciation methods are preferred when analyzing wind turbines.

Net Metering

The Executive Director of Texas Renewable Energy Industries Association (TREIA) provided a discussion of the amount electric companies pay to purchase wind energy from wind farmers (Smith 2006). He indicated that the best possible net metering scenario is one where there is only one meter that turns forward when the consumer is purchasing electricity and backward when the consumer is producing excess electricity. This one-meter system is beneficial to the consumer because the excess electricity produced can be credited to the following months electricity consumption, therefore the consumer is essentially making the retail price for the excess electricity produced. He said that many electric companies require multiple meters for net metering, thus paying the consumer the avoided cost. Avoided cost is the lowest price that the electric company pays for their electricity and today can range anywhere from two cents for a company that generates their own electricity to four or five cents per kWh for a small cooperative that buys electricity from the outside (Smith 2006). Even though these electric companies pay less for electricity, they incur extra bookkeeping costs when they require multiple meters to net meter.

Turbine Maintenance Costs

Redlinger, Andersen, and Morthorst (2002) discuss the operation and maintenance costs associated with wind turbines. They suggest that these costs will increase over the lifetime of the turbine. For a newer turbine, they can range from ten to fifteen percent of the cost per kWh produced. Toward the end of the turbine's life, these costs can increase to twenty to thirty percent. Components included in operation and maintenance costs include: insurance, regular maintenance, repair, spare parts, and administration.

Incorporating Risk in Project Analyses

When risk is ignored during project feasibility analysis, the key output variables (KOVs) are point estimates, which do not show the risks of success or failure (Pouliquen 1970, Reutlinger 1970, and Hardaker, et al. 2004). Pouliquen (1970) identifies benefits of stochastic simulation as providing decision-makers with a range of values for their KOVs and the probability of each occurring. Stochastic simulation gives the decision-makers an idea of the relationships between favorable and unfavorable outcomes.

Richardson (2006) gives the steps to develop a production-based investment feasibility simulation model. First, the probability distribution for each risk variable must be defined, parameterized, simulated, and validated. Next, the simulated stochastic value for each probability distribution is matched with the appropriate accounting relationships needed to calculate production, receipts, costs, cash flows, and balance sheet variables for the project. The resulting variables in the financial statements are stochastic since they are a function of the values sampled from the probability distributions. Richardson finds that when the probability distributions are sampled many times (for example, 500 iterations) the model generates reliable empirical estimates of probability distributions for unobservable KOVs such as net present value (NPV) so decision-makers can evaluate the probability of success of the project.

This analysis will use the information gathered from previous studies to help make improvements in methods used to analyze small-scale wind energy projects. Beenstock (1995) used Monte Carlo methods for simulation; this study will improve upon his research by using the Latin Hypercube procedure for simulation thus requiring fewer iterations. Previous studies have found varying probability distributions to represent wind speed variations; this study will compare several different probability distributions to find the best fit for available wind speed data. In this study the turbine will be connected to the electric grid to have a backup source of energy and to be able to sell excess energy produced. This research will analyze multiple sites in the relatively flat parts of west Texas and will use the power law based on Ray, Rogers, and McGowan's research. The feasibility analysis will use Mathew's suggestion combined with Harsh's prospect to develop a partial net present value (NPV) model to analyze future benefits and costs. This research will incorporate stochastic simulation in several aspects of the NPV model as suggested by previous studies.

CHAPTER III

METHODOLOGY

This study will develop a case study of a small wind project on a representative farm in two locations in Texas. A net present value (NPV) model will be developed for the small-scale wind project to determine the economic feasibility of the project in today's dollars. For ease of programming, the model will be programmed in Excel using Simetar add-in for risk analysis. Two locations will be selected in Texas where farmers typically utilize electric powered irrigation wells to water their crops. Wind speed data will be collected for each location. The data will be analyzed and five NPV models will be developed for each location. These NPV models will evaluate monthly net returns data over a twenty-year period. The results will be used to determine whether a decision to install a small-scale wind energy project would be economically feasible. For the NPV models that include a turbine, this study assumes a $35,000 10kW turbine with a 30-meter (90 foot) tower will be purchased. The turbine and tower are assumed to have a twenty-year life. The turbine will be purchased in December of 2006 and the twenty-year lifetime will conclude December 2026.

To determine the most economically feasible option, net present value will be the key output variable. Net present value for this case study is represented as:

(3) $$NPV = - PT + \sum_{m=1}^{240} \left(\frac{D_m + R_m - OM_m - EB_m}{\left(1 + \left(\frac{DR}{12}\right)\right)^m} \right)$$

The variables are: turbine cost (PT); monthly depreciation tax savings (D_m); monthly revenue from the turbine (R_m); monthly operation and maintenance expenses (OM_m); monthly electricity purchases (EB_m); and the discount rate (DR).

A major factor to consider when deciding to install a wind turbine depends on the local electric company's rules and regulations concerning interconnection and net metering of small-scale wind energy projects. Consumers who live in areas under PUCT jurisdiction have "the power to choose," and therefore can shop for the electric company with the most consumer friendly rules. Consumers who live outside the PUCT must deal with the rules for their electric company. To accurately represent the different situations, this study will look at a case with no net metering, a case with more consumer friendly net metering, and a case with one-meter net metering. The three scenarios will contain different variables; the value of zero will be assigned to the variables that are not in the specific NPV model.

To make the NPV models as realistic as possible, this study will incorporate the risk associated with wind energy production since the wind does not blow at a constant rate. Future electricity prices as well as electricity usage will also be forecasted incorporating risk, which will provide a more accurate distribution of future prices. The Simetar risk analysis software, which is an add-in in Excel will be used to simulate all stochastic variables. This software will also be used to forecast electricity prices and usage over the twenty-year time frame.

First, eight years of daily average wind speed data must be inserted into Excel so stochastic simulation may be done; each month will be included in a separate column. Simetar includes a Univariate Paramater Estimator (UPE), which estimates the parameters for sixteen probability distributions (Richardson 2006). Simetar calculates the parameters of the distribution with the maximum likelihood estimator (MLE). The Empirical distribution is not included in the UPE, therefore must be inserted into the chart. The MLE parameters from the UPE along with the Empirical parameters are then simulated. The simulation is done using Latin Hypercube sampling with 500 iterations. Next, the CDFDEV function in Simetar will be used to find how closely the simulated distribution matches the historical distribution. The closer the CDFDEV value is to zero the more closely the simulated model fits the historical data (Richardson 2006). Once the smallest CDFDEV value is determined the corresponding distribution will be chosen for the month. This process will be done for each month with daily average wind speeds in both Midland and Lubbock. A monthly table for each location will be constructed using the appropriate distribution for the month as well as the MLE parameter for that month's distribution. For this case study the empirical distribution was found the have the smallest CDFDEV for all but one month.

For both locations the monthly average wind speed for each year will then be calculated and inserted into a table. Next, a correlation matrix will be calculated using the monthly average wind speed table to find out if wind speeds in one month affect wind speeds in other months. If correlation exists and is ignored in simulation then the model will either over of under state the variance of the model's NPV (Richardson 2006). Once the correlation matrix is calculated the objective is to make the values on the diagonal equal to one by deleting values in the off-diagonal cells. Next, the correlated uniform standard deviates (CUSDs) are calculated. The CUSDs for each month will then be used with the original daily average wind speeds to find the empirical distribution. Once these values are calculated for each month the formula will then be copied for twenty years so that each monthly value with vary from year to year.

The first NPV model, the base case, will assume the basic energy costs for the model farm. This base cost is assumed to be the same in both locations. First, the retail price of electricity ($\tilde{P}_{by}$) is calculated based on historical electricity prices and forecasted future prices from the Energy Information Administration (EIA). The forecasted monthly prices are in dollars per million British Thermal Units (Btu); they must be converted to dollars per kWh. This is done by dividing by one million to calculate dollars per Btu then divided by 3413 to convert Btu's to kWhs. The forecasted prices are then simulated empirically using deviations from trend on the historical data; the trend forecasted mean prices will remain constant throughout the twenty-year horizon.

Electricity consumed (EC_m), a control variable, will be calculated next. This will remain constant throughout the case study at both sites and is based on an average of three year's data for household (EC_{mh}), barn (EC_{mb}), and irrigation usage (EC_{mi}) (Belk 2006 and Dodd 2006).

(4) $$EC_m = EC_{mh} + EC_{mb} + EC_{mi}$$

Household electricity use is based on a 2,000 square foot house; barn usage is based on a barn and a well; and irrigation usage is based on 1,200 acres of irrigated cotton farmland in the two study areas. Table 1 shows the average usage for the house, barn and irrigation in kW hours for the case study. These usage patterns are assumed to be the same each year of the analysis.

Table 1. Monthly Electricity Usage for Model Farm (Belk 2006 and Dodd 2006)

MONTH	HOUSEHOLD USAGE	BARN USAGE	IRRIGATION USAGE
JAN	1322	202	40
FEB	808	137	320
MAR	610	139	113
APR	563	229	40690
MAY	674	259	123200
JUN	1333	248	71470
JUL	1356	396	40783
AUG	1339	302	180250
SEP	1135	193	172877
OCT	674	150	7247
NOV	664	239	113
DEC	1156	358	103

Monthly net returns (EB_m) will be calculated by multiplying the electricity usage (EC_m) by the appropriate year's price of electricity ($\widetilde{P}_{by}$) as seen in equation (5).

$$EB_m = EC_m * \widetilde{P}_{by} \quad (5)$$

Finally, the cash outflows for each month will be used to calculate NPV assuming a 7.5% discount rate. If a different discount rate is desired this number can be inserted into the model and be updated. This NPV model will be the simplest of the four considering electric consumption since wind speeds and electricity production is not included. The information and equations will be used throughout the case study.

The wind turbine without the net metering scenario will have a 10kW turbine installed today at a cost of $35,000. This alternative is more complex since the revenue associated with the electricity generated by the turbine will now be included in the NPV. Equations and assumptions from the base case will continue to be used. First, wind speed data for Lubbock and Midland will be collected, analyzed, and simulated. Electricity produced is stochastic because it is based upon monthly wind speed (WS) data for the particular site. Wind speed data used in this study was attained from the United States Department of Commerce's National Climatic Data Center. The data was collected in both Midland and Lubbock at 10 meters elevation. This data must be converted to 90 meters using the Log Law as described by Elkinton, Rogers, and McGowan in equation (2). For both Midland and Lubbock an alpha level of .14 will be used. The wind speed data was also measured in miles per hour. For the study, wind speed data must be converted into meters per second to work properly with Bergey's specifications. Miles per hour can be multiplied by 0.447 to convert to meters per second.

Wind speed data will be converted into power produced by the 10kw turbine using turbine specifications supplied by Bergey. Since Lubbock ($W\widetilde{S}_{mL}$) and Midland ($W\widetilde{S}_{mM}$) have different elevations, the electricity output for the 10 kW Bergey turbine will vary slightly as seen in the wind speed to power equations (6) and (7):

$$(6) \qquad E\widetilde{P}_{mL} = (0.492629 * W\widetilde{S}_{mL} - 0.73288 + 1.38993 * Norm()) * 24 * \text{Days in Month}$$

$$(7) \qquad E\widetilde{P}_{mM} = (0.498569 * W\widetilde{S}_{mM} - 0.74174 + 1.406747 * Norm()) * 24 * \text{Days in Month}$$

$E\widetilde{P}_{mL}$ and $E\widetilde{P}_{mM}$ represent the monthly stochastic electricity produced for Lubbock and Midland respectively. The first number in equations 6 and 7 is the slope, which is multiplied by the wind speed; the second is the intercept; the third is the standard deviation multiplied by a standard normal deviate (N(0,1)) multiplied by the number of hours in a day multiplied by the number of days in the month.

Electricity bought ($E\widetilde{B}_m$) each month can then be determined by the electricity consumed (EC_m), the stochastic electricity produced ($E\widetilde{P}_m$), and the stochastic price of retail electricity ($\widetilde{P}_{by}$).

$$(8) \qquad \text{if } EC_m > E\widetilde{P}_m \quad \text{then } E\widetilde{B}_m = \left(EC_m - E\widetilde{P}_m\right) * \widetilde{P}_{by}$$

$$(9) \qquad \text{if } EC_m < E\widetilde{P}_m \quad \text{then } E\widetilde{B}_m = 0$$

As seen in equations (8) and (9) if electricity bought is positive, the resulting number will be multiplied by the retail cost of electricity to find the cash outflow for electricity consumption. If the number is negative, the cash outflow for electricity consumption will be zero for that month as excess electricity was produced. Monthly operation and maintenance costs ($O\widetilde{M}_m$) will be treated as a cash outflow and be the same at both sites. Maintenance cost is based on electricity production for the month ($E\widetilde{P}_m$), price of selling electricity ($\widetilde{P}_{sy}$) and a given percentage for operation and maintenance expenses

(OMP). $\widetilde{P}_{sy}$ is arbitrarily set at 40% of $\widetilde{P}_{by}$ due to Smith's 2006 estimate that it currently ranges from two to five cents. OMP is assumed to start at 10% and increase by 5% every four years to be 30% in the last year.

(10) $$O\widetilde{M}_m = E\widetilde{P}_m * \widetilde{P}_{sy} * OPM$$

Since there is a large capital investment involved that will lose value over time, the model farm will see tax savings due to the depreciation expenses reducing their taxable income. This case study will assume a monthly double declining depreciation method over twenty years. Double declining depreciation entails selecting the time period which the turbine will depreciate over (n) and calculating straight line depreciation (d_{ySL}) on the turbine's estimated value (PT):

(11) $$d_{ySL} = \frac{PT}{n}$$

In this case (n) will be 20 years. Next, this straight-line depreciation percent will be calculated and doubled to find the double declining depreciation percentage (d_{yDD}).

(12) $$d_{yDD} = \left(\frac{d_{ySL}}{PT}\right) * 2$$

The double declining depreciation percentage will then be applied to the book value (BV) of the turbine each year to find the monthly depreciation until the dollar amount of depreciation for the year (d_y) is less than d_{ySL}.

(13) $$d_y = d_{yDD} * BV_{y-1}$$

Once $d_y < d_{ySL}$, the remaining BV will depreciated using the straight-line method described above. Finally, the depreciation tax savings (D_y) is found by multiplying the year's depreciation (d_y) by the assumed tax rate (t); this will not vary from site to site. Tax savings for depreciation for each year will be accounted for the following January until year 20 where that year's tax savings will be accounted for in December since the model ends there and it has already accrued.

(14) $$D_y = d_y * t$$

This case study assumes a 28% tax rate; for 2006 this rate would be for a married couple filing jointly with a taxable income between \$123,700 and \$188,450. Individuals with different incomes or filing statuses should consult the federal tax brackets to determine their appropriate tax rate. This number can be used in the model and all information would be updated. Finally, the cash outflows ($\widetilde{OM}_m$ and $\widetilde{EB}_m$) and cash inflows (D_y) for each month will be inserted into the NPV equation to find the value of the project today.

The wind turbine with a net metering scenario will use all of the above assumptions. Revenue from the turbine ($\widetilde{R}_m$) is dependant upon the rate the electric company will pay for electricity ($\widetilde{P}_{sy}$); electricity produced ($\widetilde{EP}_m$); and electricity consumed (EC_m) within the month. The rate that the electric company will pay for electricity is calculated at 40% of the retail price of electricity and will remain constant throughout each year. The following equation will be used if production is greater than consumption:

(15) $$\tilde{R}_m = \left(E\tilde{P}_m - EC_m\right) * \tilde{P}_{sy}$$

If consumption is greater than production the electricity bought equation ($E\tilde{B}_m$) from the turbine scenario without net metering will be used to determine the amount of electricity that must be bought from the retail electric provider. This number ($\tilde{R}_m$) is the revenue that the farm will earn from the electric company as a result of the installed turbine. Monthly operation and maintenance expenses are outflows. Depreciation expense will be calculated and multiplied by the tax rate to determine the savings in taxes, or revenue from the turbine. Turbine revenue, electricity bought, operation and maintenance expenses, and depreciation tax savings for each month in Midland and Lubbock will then be inserted into the NPV equation to find the value of the project today.

The NPV for the one-meter, or "rollover" net metering scenario will include operations and maintenance costs, tax saving from depreciation, and the cost of electricity bought. If there is excess production in year one this excess is added to the production in year two to calculate the new excess usage or excess production.

$$\text{if } \tilde{E}_m = 0$$

(16) $$\text{then } \tilde{E}_{m+1} = E\tilde{P}_m - E\tilde{C}_m + E\tilde{P}_{m+1} - E\tilde{C}_{m+1}$$

$$\text{if } \tilde{E}_m > 0$$

(17) $$\text{then } \tilde{E}_{m+1} = E\tilde{P}_{m+1} - E\tilde{C}_{m+1}$$

(18) $$E\tilde{B}_m = \tilde{E}_m * \tilde{P}_{by}$$

In the above equations $\widetilde{E}_m$ is the amount of electricity bought for the month, if this number is zero then the excess production is carried over to the next month, if the number is positive then you calculate next month's electricity bought as we have previously. This is multiplied by $\widetilde{P}_{by}$ to find the price of electricity bought for the month ($E\widetilde{B}_m$). The appropriate outflows ($E\widetilde{B}_m$ and $O\widetilde{M}_m$) and inflow (D_y) for each month in Lubbock and Midland will then be used in the NPV equation to calculate the value of the scenario today.

The final NPV model will assume that all electricity produced by the wind turbine will be sold to the electric company. This is done to find the price of electricity that will make a wind turbine break-even over a twenty year NPV in both locations.

(19) $$R_m = E\widetilde{P}_m * \widetilde{P}_{sy}$$

The revenue for this turbine is strictly the electricity produced each month multiplied by the price the electric company will pay for electricity. Again, operation and maintenance expenses are treated as an outflow and depreciation tax savings will be included as an inflow. This model will not be compared to the other four alternatives in this analysis since they are not comparable.

Once all five NPV models are completed for both sites the no turbine; turbine without net metering; turbine with net metering; and turbine with "rollover" net metering scenarios will be compared to see which of the four options would be most economically feasible at each location. The case study will focus on the distribution of NPV for each scenario when ranking the different scenarios. The probability of success or failure can be calculated from the NPV distributions. The study will also find a distribution for turbine prices that would make each turbine scenario an economically sound investment when compared to the base scenario without a turbine. The NPV distributions can also be compared from location to location to choose which location has the better wind speeds to make a 10kW wind turbine economically feasible.

The fifth scenario, selling all electricity produced by the turbine, will then be analyzed to find the price of electricity sold that will allow the turbine to break-even over the twenty-year time frame at each location.

Finally, validation must be done to check the simulation model for completeness, accuracy, and forecasting ability (Richardson 2006). In this process all equations in the model must be analyzed to make sure they correctly calculate what they are designed to calculate; this is known as verification. All random variables must be checked to see if they are correctly simulated and possess the properties of the parent distribution. When validating the stochastic component means, variances, correlation, coefficient of variation as well as minimum and maximum can be analyzed. In a multivariate distribution checking the means is done with Hotelling's T-Squared test. This checks if the simulated vector means of the multivariate probability distribution are statistically equal to the original distribution's vector of means. Box's M test of homogeneity is used to test multivariate variances. It checks if the covariance of the simulated distribution equals the covariance of the historical data. A t-test is used for each of the coefficients in a correlation matrix to see if they are appropriately correlated. The coefficient of variation should equal its historical value or change over time if the model specifies. When checking the historical data against the simulated stochastic variables charts can help in the verification process. These charts include: cumulative distribution functions (CDF); probability distribution functions (PDF); and fan graphs (Richardson 2006).

CHAPTER IV

RESULTS

Wind is classified into Wind Power Classes of light wind (1) to high winds (6). Wind energy can be produced in areas with wind power classes three and above (SECO 2006b). As seen in Figure 1, both Midland and Lubbock have class three wind speeds. These locations were chosen due to their wind speeds as well as being areas with irrigated farmland.

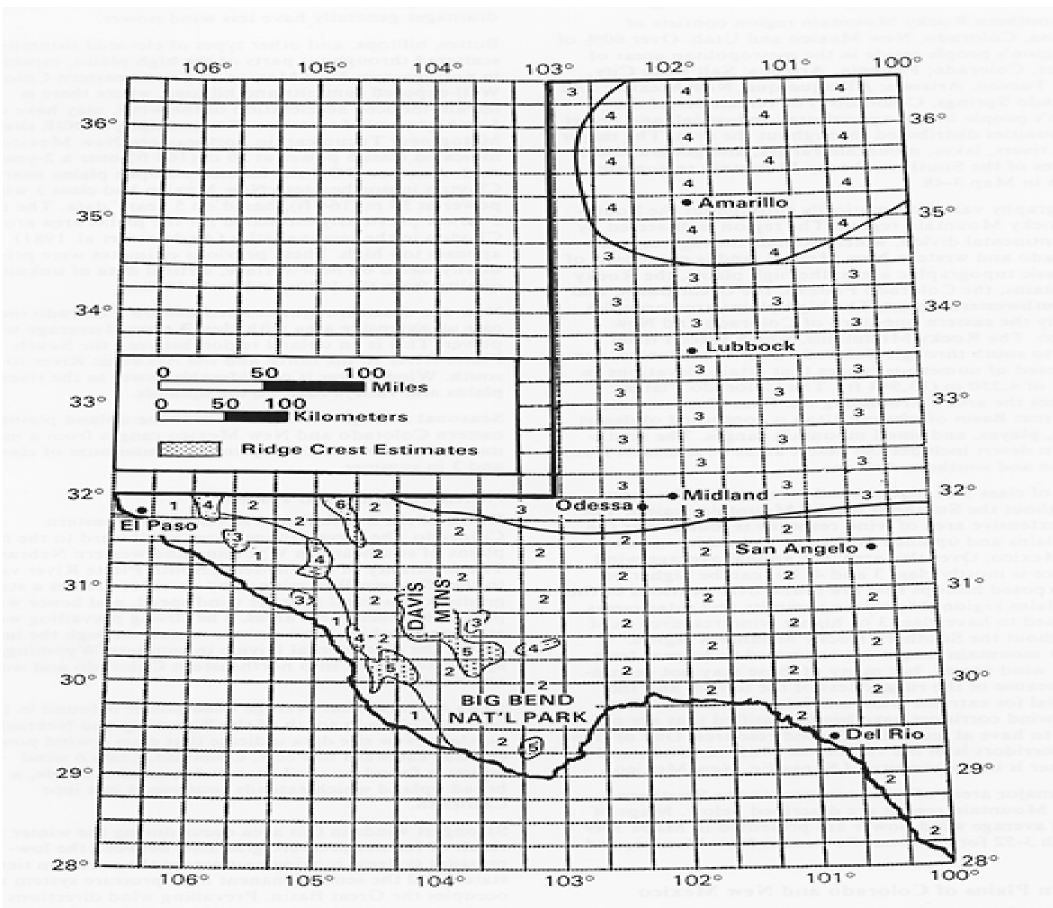

Figure 1. Wind Speed Classes in West Texas

Figure 2 illustrates wind speed patterns in both Midland and Lubbock as well as the electricity usage pattern for the irrigation of cotton in that area of Texas. This study assumed that cotton was the crop being irrigated; in western parts of Texas, the majority of the irrigating is done in August and September. In Lubbock, April appeared to have the highest average wind speed and August saw the lowest average wind speed. More electricity is needed for irrigating than can be supplied during these times of high irrigation due to low average wind speeds. This is a countercyclical relationship between high wind speeds and irrigating months, which hurts the profitability of the wind turbine. If a crop were planted with a different irrigation cycle the study would likely produce different results.

In Midland, April had the highest average wind speeds and August had the lowest as seen in figure 2. When comparing Midland to Lubbock, both have similar yearly wind speed patterns that are counter-cyclical to the cotton irrigation pattern. Lubbock had higher average wind speeds that produce more electricity each month, thus making a wind turbine more feasible. Crops with different irrigation patterns than cotton could also be analyzed to see if they would be more economically feasible. In both Midland and Lubbock an ideal crop that could be planted to take full advantage of the wind would be one that needs the majority of its irrigation in April.

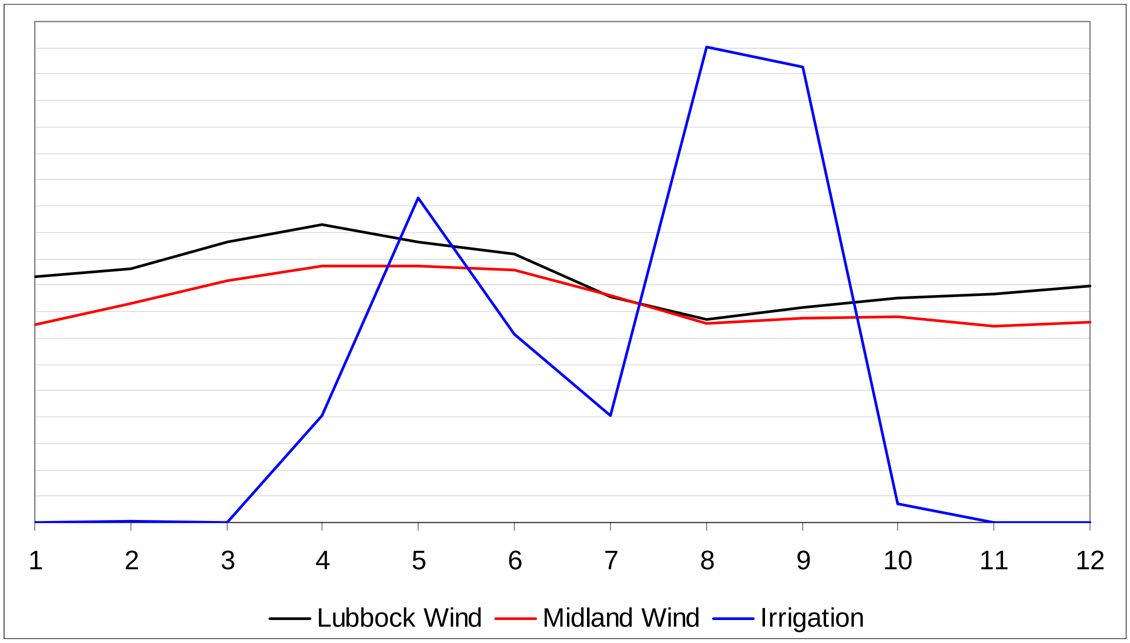

Figure 2. Monthly Wind Speed and Irrigation Patterns

The wind speed data utilized in this study for both Lubbock and Midland would be most accurately represented using the empirical distribution. There was one exception to this; the wind speed data for December in Lubbock was most accurately represented by the gamma probability distribution. The best fitting distributions were found by comparing the historical data to simulated data for each distribution. This procedure was done for each month at both locations. Wind speed in certain months can affect the wind speed in other months, therefore making the distribution of wind speeds a multivariate distribution.

To simulate wind speeds, first, the monthly average wind speeds were recorded and a correlation matrix of monthly average wind speed was calculated. According to Richardson (2006) if correlation is ignored in the simulation process, the mean and variance for the KOVs will either be overstated or understated. Richardson states that if positive correlation was ignored the variance would be understated and if negative correlation was ignored the variance would be overstated. Once all values in the correlation matrix that were not strongly correlated were deleted, the monthly correlated uniform standard deviates (CUSD's) were calculated for twenty years. The CUSD's were then used with the parameters for the appropriate month to simulate the stochastic wind speeds for the month.

When looking at all four scenarios at both locations under the assumptions of the case study each scenario has a negative NPV using a twenty-year planning horizon. The option to sell all electricity will be ignored in this part of the analysis since the objective of this study is to look at profitability for the model farm. Figures 3 and 4 are probability distribution function graphs that show the means and variability for the four different NPV scenarios for Midland and Lubbock.

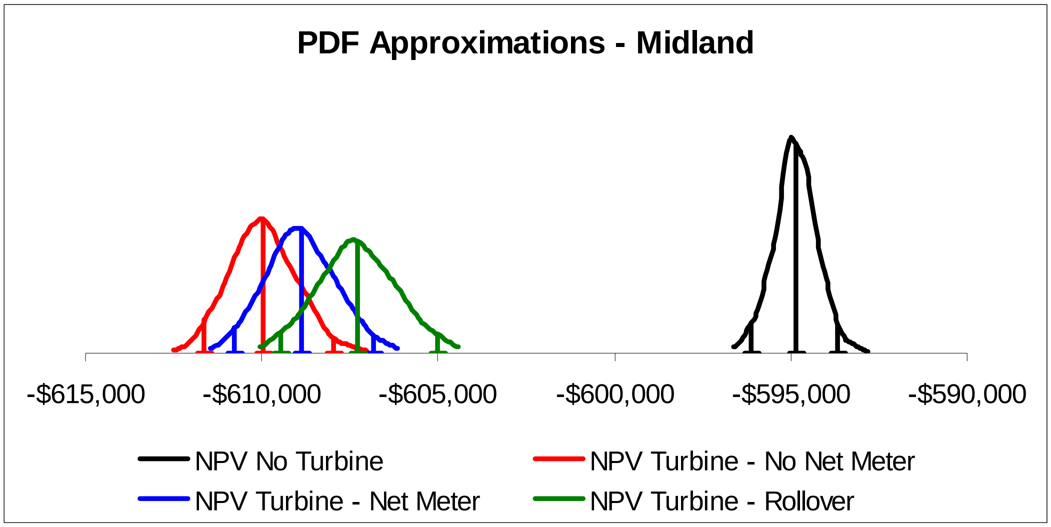

Figure 3. NPV Probability Distributions for Midland

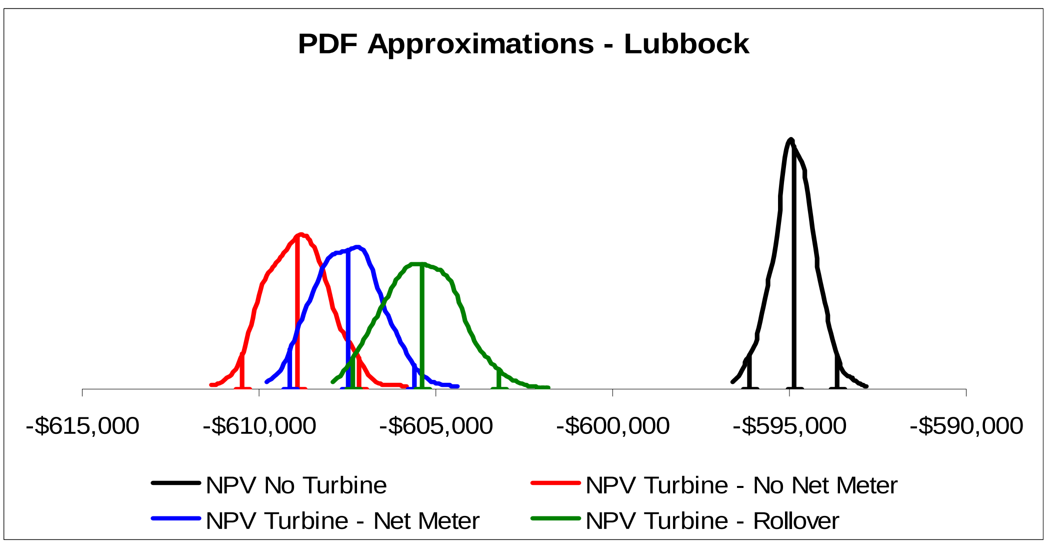

Figure 4. NPV Probability Distributions for Lubbock

In both Midland and Lubbock the best scenario was not to install a turbine. This scenario had both a much higher mean NPV as well as a much lower variability than the other scenarios. The mean and variability is the same in both Midland and Lubbock for not installing a turbine because all variables included are the same from site to site. In the other three scenarios Lubbock has a slightly higher mean NPV than Midland due to the higher average wind speeds. The next best option would be to install a turbine with one-meter net metering so that the excess electricity produced in each month could "rollover" and be credited toward the electricity consumed the following month. In this case, the electric company is essentially paying the retail price of electricity to the farm for all electricity produced. As seen in figures 3 and 4, this option had a slightly higher mean NPV than the other scenarios with the turbine. The worst turbine situation in both Lubbock and Midland is where the turbine owner is not paid for the excess electricity produced. This scenario had the lowest mean NPV. All three scenarios with the turbine installed have similar variability, but they are considerably larger than the scenario without the turbine. This is because when considering the turbine we incorporate more risk into the model due to variations in wind speeds. The variance in the scenario without a turbine is due solely to the stochastic prices. The more risk included in a model, the larger the variance.

Wind energy, is a cleaner, renewable alternative to other sources of energy, but this number is not quantifiable in this case study analysis. Since there is a push to increase clean, renewable fuels in the United States, the government could provide assistance to turbine owners. As seen in table 2, this case study found that small-scale wind turbines in Lubbock and Midland can not compete with traditional sources of electricity; therefore to be considered as a viable investment would require some sort of incentive. The government subsidizes many different projects; one possible way to promote small-scale wind energy would be to subsidize the projects. The government could give farmers interested in installing small-scale wind energy a lump sum to assist in the turbine costs.

Table 2. Expected NPV for Model Farm

Scenario	Lubbock	Midland
No Turbine	-$595,219	-$595,219
Turbine without Net-Metering	-$608,481	-$609,483
Turbine with Net-Metering	-$607,747	-$609,101
Turbine with “Rollover” Net-Metering	-$606,677	-$608,510

According to Richardson (2006) using Stochastic Efficiency with Respect to a Function (SERF) in Simetar can rank risky scenarios as well as calculate the confidence premium (how much in monetary terms the decision-maker prefers one alternative to the other). In this case study the least risky alternative in both Midland and Lubbock for people with various risk aversions is not installing a turbine. The next best alternative for both locations would be to install a turbine with “rollover” net metering. In Midland, the smallest amount of money the model farm would accept to be indifferent between the two scenarios, or confidence premium would be $12,434; this figure is calculated assuming one-meter net metering is present. In Lubbock, the confidence premium is $10,531 to make small-scale wind energy feasible with one-meter net metering under the assumptions of this case study. The different confidence premiums in Midland and Lubbock are due to differences in wind speeds at each location. The government could provide subsidies to the model farms in the respective amounts to make one-meter net metering a viable alternative in each location.

Increase Electricity Price Scenario

Another option to make wind energy more feasible would be to increase the price electric companies are paying for electricity produced by wind turbines. This could be done by subsidies, voluntary increases in price, or changing government regulations to favor green energy produced by wind turbines. To find the price of electricity that would make a turbine economically feasible the case study will look at a scenario where the turbine owner would install the turbine solely for selling the electricity generated. This ignores all electricity consumed by the model farm to simplify calculations. The variables included in this NPV model are electricity generated; price paid to the turbine owner per kWh produced; price of the turbine; operation and maintenance costs; and tax savings from depreciation. In this case the price the electric companies will pay for wind energy is the variable that is changed to make NPV greater than zero.

Using this method, the results indicate that there is an 84.96% probability that a 10 kW Bergey turbine installed in Lubbock that sells all of the electricity it produced would break-even when the price of electricity sold is 1.88 times the current retail price of electricity. If the same turbine were installed in Midland, it would need a price 2.12 times the price of the stochastic retail electricity price to break-even in twenty years with an 83.26% probability. Lubbock requires a lower price of the electricity because they have higher average wind speeds that produce more electricity. At these prices, it does not make economic sense to use any of the electricity produced by the turbine on the farm since the turbine would be making more money for each kWh sold than what the farmer is paying for each kWh consumed. If the price needed for the turbine to break-even was less than the retail price of electricity the turbine owner would use electricity generated by the turbine on the model farm since they would be saving more money than they would be making by selling electricity.

Options to Increase Feasibility

Multiple turbines could be installed for this size of model farm to decrease the amount of electricity bought from the electric company. This would only be feasible if the turbines were subsidized in some way for farmers in both Midland in Lubbock. One 10 kW Bergey could be installed on a farm with lower electric consumption than the model farm in this study if the turbine was made more economically feasible.

Wind speeds in other locations can be collected to analyze economic feasibility of a turbine on a model farm. Higher wind speeds, class four or higher, would increase the NPV of a small-scale wind energy project. Finding an area where the crop's irrigation schedule more closely matches the wind speed pattern would also increase the profitability. AWEA's proposed 30% investment tax credit would be a step in the right direction to help make small-scale wind systems an ideal investment. Wind turbine technology improvements without much of a price increase would also increase profitability. A decrease in turbine prices will also increase the feasibility of the project. Both turbine price decreases and technology improvements could be a possibility if small-scale wind energy were to become more popular. Green, renewable energy is becoming more popular and with this popularity there could be a push for increased government support as well as consumer willingness to pay for small-scale wind energy.

Summary

Midland and Lubbock, areas with class three wind speeds were analyzed to see if small-scale wind energy would be an economically feasible option for cotton farmers. It was found that in these areas small-scale wind energy is a less profitable and a more risky alternative when compared to purchasing electricity from the electric company.

The study found Lubbock to have higher average wind speeds than Midland, thus making small-scale wind energy slightly more feasible. The best situation for small-scale wind energy was found to be “rollover” net metering in both locations; though not installing wind energy proved to be the best scenario in both Midland and Lubbock.

CHAPTER V

SUMMARY AND CONCLUSIONS

Wind power, though generating less than one percent of electricity in the United States, is the world's fastest growing source of energy (Mazza and Heitz 2005). The United States is third in global wind production behind Germany and Spain. In 2005, the United States led the way in new installed capacity with a 37% increase from 6,718 MW to 9,149 MW (Global Wind Energy 2006). In addition, incentives included in the Energy Policy Act of 2005 (EPACT) are expected to further stimulate the production of renewable energy.

In 2006 Texas became the leading wind producing state in the United States. Currently, Texas has enough installed wind energy capacity to power over 600,000 average American households (American 2006). There is enough Class 4 wind power in Texas to produce all of the electricity consumed in the state today (SECO 2006a). Along with many other states, Texas has gone even further to support renewable energy by adopting its own renewable energy portfolio standards. Texas is ahead of schedule to meet these goals in part from the strong support of rural communities (SECO 2006b). Though Texas has been proactive in installing wind generation statewide, there are still a few factors that are impeding the further development of wind energy in the State. First, utility rates in Texas are relatively low which makes it difficult for wind energy, often a more expensive alternative, to compete and become successful. Second, the rules and regulations concerning agreements between electric companies and producers with small scale wind energy are different throughout the state, therefore making it difficult for the producer to know what their options are. And lastly, large-scale wind energy has not spread to its potential in Texas in part due to high transmission costs as well as some electric company's policies.

Small-scale wind energy (less than 100kW) production could potentially bypass some of the problems associated with large-scale wind projects, thereby increasing the production of renewable energy from wind in Texas.

Objectives

The primary objective of this study is to analyze the profitability of the use of small-scale wind production for electricity production in Texas. A secondary objective is to incorporate the risk of varying wind speeds to better predict the profitability.

Results

The case study found small-scale wind energy to be a more expensive alternative to purchasing retail electricity on the model farms in Lubbock and Midland. Both locations have class three wind speeds as seen in figure 1. Though in the same wind speed class Lubbock had higher average wind speeds than Midland, thus making wind energy slightly more feasible. The study found both Lubbock and Midland do not have enough wind to make small-scale wind energy a viable option on the model cotton farm.

The most feasible of the scenarios with a turbine installed was "rollover" net metering where the excess electricity produced one month was rolled over to the next month and credited to electricity consumption. The least feasible of the turbine scenarios was a turbine without net metering of any sort. The model farm in both

Midland and Lubbock would be more profitable by purchasing electricity from their existing retail electric provider.

Recommendations for Future Analysis

There are several limitations to this study. First, this study focused on only two locations in Texas, one in Midland and one in Lubbock. Wind speeds can vary from site to site within a small area, therefore when choosing a location to install a turbine wind speeds for that exact location should be collected. The study looked at an irrigating cotton farmer; irrigation patterns vary from crop to crop. Planting a different crop would result in different irrigation patterns, making wind energy either more or less beneficial for the irrigating farmer. The effect of different government regulations or subsidies could also be analyzed to find the most effective form of assistance to make small-scale wind energy more profitable.

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