COMPARATIVE ANALYSIS OF WIND ENERGY PRODUCTION IN OKLAHOMA

By

EKATERINA ERMILOVA

Economist – mathematician
Novosibirsk State University
Novosibirsk, Russia
1997

Master of Science in Economics
Novosibirsk State University
Novosibirsk, Russia
1999

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 2003

COMPARATIVE ANALYSIS OF WIND ENERGY

PRODUCTION IN OKLAHOMA

Thesis approved:

Thesis Advisor

Dean of the Graduate College

ACNOWLEDGEMENTS

In the very beginning, I would like to thank the people and organizations that made this work possible and helped me a lot during my study.

First of all, I am very grateful to the Edmund Muskie/ Freedom Support Act Program and Open Society Institute for providing me with a scholarship to come to Oklahoma State University. For me this was more than a scholarship, it was an opportunity.

I would like to express deepest appreciation to my academic advisor Dr. Kent Olson. Without his help and support this work definitely could not be done. Also, I am very grateful to all the members of my graduate committee Dr. Arthur L. Stoecker, Dr. Keith D. Willett and Dr. Stephen J. Stadler for their advises. I would like especially thanks Dr. Stadler and his assistant Pete Earls for providing wind resource maps of Oklahoma and helping me to work with them.

Special words must be said about the OSU Environmental Science Graduate Program and Environmental Institute. They are doing a great job in developing an interesting and flexible Environmental Science program in the University. Especially I would like to thank the Director of the Environmental Institute Dr. Will Focht and graduate program coordinator Talya Henderson.

Last, but not least, I would like to thank my family and friends. I am very grateful to my family for their extraordinary support, especially my mother Tatiana and my sister Polina. I would like to express appreciation to all my friends in Novosibirsk, Moscow, Stillwater, OK and Durham, NC, who allowed me to develop into the person I am now.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Current Situation in the Energy Sector

Renewable energy sources discussions actively started after the energy crisis in the 1970s. That period shows the danger of relying primarily on one type of energy resource, especially when those resources are non-renewable. There were three main reasons that encouraged major government and private organizations to look more attentively at renewable resources:

1. Oil, natural gas, and coal reserves are limited, and prices have an increasing trend through time due to the non-renewable nature of the resources. Thus, there is a potential danger that lack of energy and high energy prices could become a constraint to national and world economic development.
2. World reserves of oil, natural gas, and coal are distributed unevenly through the different countries. Naturally, countries with large reserves have a competitive advantage; however, very often they could not really use it. In the 1970s, dependence on the less developed countries with large oil and natural gas reserves provoked an economic crisis in developed countries.
3. Constantly increasing use of fossil fuels during the twentieth century led to global environmental problems that touch all countries, such as global warming, and could not be ignored any more.

In this period, humanity realized the necessity of developing alternative energy sources for efficient economic development and simple survival in the future. However, alternative energy sources had one major disadvantage: with existing technologies, energy production from renewable sources was a lot more expensive than energy production from the traditional sources. Consequently, many studies were focused on developing new technologies that could produce energy from renewable sources at a competitive price. During the last 30 years major improvements have been made in renewable energy technology, but the problem has not been solved completely, and traditional sources are still the cheapest if we are not taking into consideration external costs.

1.2. Alternative Energy Sources

There are several alternative energy sources that could be considered as potential substitutes for traditional energy sources in the future:

- solar energy;
- biomass energy;
- windpower;
- hydroelectric power;
- geothermal energy;
- ocean energy;
- nuclear energy.

Each of those alternative energy sources has its own advantages and disadvantages compared to fossil fuel. During the last 30 years, there have been a great number of scientific publications devoted to alternative energy sources. Development of the renewables even became an important part of US official energy strategy. Nowadays in the US, special attention is paid to renewable energy sources and to the importance of so called sustainable energy – energy that plans for the future, but that meets the needs of today (National Energy Policy, 2001). Official energy policy defines the following three main challenges in the US energy sector:

1. using energy more wisely (increasing efficiency of energy use),
2. repairing and expanding the energy infrastructure, and
3. increasing energy supply while protecting the environment.

For the last challenge, the use of alternative energy sources is the most effective answer. Recent development of renewable energy sources came through major technological improvements, became significantly cheaper, and eventually was included as an important part of official national energy policy. However, the current situation with renewable energy production is not entirely satisfactory; for example, in year 2000 the following fuels were used to generate electricity (National Energy Policy, 2001):

- Coal, 52% of electricity;
- Nuclear fuel, 20%;
- Natural gas, 16%;
- Hydropower, 7%;
- Oil, 3%;
- Renewables, 2%.

The share of renewables in electricity production is still very small (excluding hydropower sources that have their own high ecological risks) and is in the last place among all the fuels. Thus, we can conclude that, in spite of the all efforts to develop renewables, the goal of sustainable energy has still not been obtained. The main problem still seems to be economic efficiency. Traditional energy sources are simply a lot cheaper than alternative energy and in spite of the fact that the public has become more conscious of the environmental problems associated with traditional energy, renewable energy production still has a very small fraction of total energy production.

Given the general cost disadvantages of renewables, we can say that among the renewables, we are especially interested in the energy sources that could decrease the environmental impact of energy production and produce energy at the least possible cost. This makes wind energy a promising research object. The facts are that wind energy currently is one of the most environmentally friendly sources of energy, and it shows good potential as a cost competitor with coal and natural gas. Wind energy is responsible for 6% of renewable electricity generation and 0.1 percent of total electricity supply in the US. The 2001 National Energy Policy report provides the following data concerning electricity generated from renewable sources (Table 1).

TABLE 1

ELECTRICITY GENERATION FROM RENEWABLE ENERGY SOURCES, 1999

	Solar	**Wind**	**Geothermal**	**Biomass**	**Hydropower**
Current net summer capacity (MW)	**350**	**2600**	**2870**	**6170**	**79130**
Annual generation (millions of kWh)	**940**	**4460**	**13070**	**36570**	**312000**
Expected growth in generation (%)	**PV: 19.3** **Thermal: 21**	**5.3**	**3.3**	**3.0**	**-0.1**
Cost (cents/kWh)	**20**	**4 - 6**	**5 - 8**	**6 - 20**	**2 - 6**

Source: National Energy Policy, National Energy Policy Development Group, 2001, p. 6-13.

As we can see from Table 1, wind energy is one of the cheapest and fastest growing sources of renewable electricity generation. Wind energy development is very promising and can not only protect the environment, but also be economically effective relative to other renewable sources.

1.3 Wind Energy Overview

From ancient times, people have used windmills to grind their corn and grain. Thus, we could say that wind energy is one of the oldest energy sources used by humans. At the end of the nineteenth century, experiments for electricity generation with the use of wind power began. Interest in wind power was at its peak during the 1970s energy crisis. During the 1980s, a rush for tax credits almost ruined the industry's reputation, because of the low reliability of wind converters. However, since that time technology has been significantly improved. The cost of wind energy decreased by 80% during the last two decades. In the US, this industry is very well developed in California, because of excellent climate conditions and tax credits available in the 1980s. Wind energy potential, the number of operating facilities, and installed capacity in the US are presented in Table 2.

TABLE 2

WIND ENERGY POTENTIAL, NUMBER OF OPERATIONAL FACILITIES, AND ANNUAL PRODUCTION (1998) OF WIND ENERGY IN EACH STATE

	Potential, mln.mWh per year	Facilities	Capacity, kW		Potential, mln.mWh per year	Facilities	Capacity, kW
North Dakota	1,180	22	849	Massachusetts	33	4	360
Texas	1,170	8	189,811	Virginia	17	0	0
Kansas	1,070	77	2,879	Arkansas	13	0	0
Montana	1,040	2	130	New Jersey	13	0	0
South Dakota	1,000	1	10	Arizona	9	3	28
Nebraska	869	2	1,260	North Carolina	8	0	0
Wyoming	774	5	69,810	Ohio	7	0	0
Oklahoma	733	4	200	Connecticut	6	4	55
Minnesota	669	142	274,931	Vermont	6	1	6,050
Iowa	551	42	257,992	West Virginia	6	0	0
Colorado	461	2	21,600	Maryland	5	1	4
New Mexico	436	1	660	New Hampshire	5	13	89
New York	73	2	20	Delaware	4	1	2
California	72	98	1,657,001	Rhode Island	2	1	10
Wisconsin	70	7	20,380	Tennessee	2	0	0
Idaho	68	0	0	Georgia	1	1	25
Michigan	67	6	657	Hawaii	1	6	11,200
Nevada	63	1	10	South Carolina	1	0	0
Illinois	61	4	26	Alabama	0	0	0
Maine	52	7	142	Alaska	0	2	650
Missouri	50	0	0	Florida	0	0	0
Oregon	50	12	24,943	Indiana	0	0	0
Washington	39	0	0	Kentucky	0	0	0
Pennsylvania	38	13	40	Louisiana	0	0	0
Utah	34	1	18	Mississippi	0	0	0

Source: Review of States' Policy Incentives for the Development of Wind Energy Facilities. Oklahoma Wind Power Initiative. Available at: http://www.seic.okstate.edu/owpi/Policymkr/Library/state%20summary2.pdf [2002, November, 25].

As we can see from the table, the states with the largest estimated potential for wind resources are not the same as the states with the highest wind energy production. For example, the state with the largest wind energy production is California (1657 mWh); however, it's only in 14th place according to wind potential. Earlier we mentioned that production tax credits for the wind energy industry were provided in California. This fact indicates that state government encouragement may influence wind energy development in a particular state.

Oklahoma is in 8th place according to wind resources potential, with possible production of 733 million mWh per year. However, there are currently only four operating facilities producing a total of 200 kWh. The largest, a 170 kW capacity unit, is owned by Drapery manufacturing. Practically, we can say that currently there is little commercial production of wind energy facilities. In fact, it consists of one on-going project (section 1.5).

Wind energy development could be very important for Oklahoma, because about 60% of the state's energy comes from coal – the most environmentally dangerous fuel. To improve its ecological situation, Oklahoma may move to more environmentally friendly fuels, such as natural gas (currently about 33% of state energy) or renewable energy.

Interest in wind energy in Oklahoma significantly increased during the last two years. Traditionally, the Oklahoma economy was based on energy production from fossil fuels (mainly oil and gas) and energy was exported to other states. That was a profitable business during the oil boom; however, it makes the state's economy very much dependent on the oil price situation and oil reserves. Oklahoma has almost run out of its oil reserves and has to look for new development opportunities. One of the opportunities may be development of renewable energy producing capacity that will not depend on reserves of limited resources. However, for successful development, a careful economic evaluation of Oklahoma's potential wind resources should be made.

1.4. Wind Energy: Literature Overview

Economic Evaluation of Wind Energy in the Literature

In several of the books devoted to wind energy, the authors do an economic evaluation of wind energy with the intent of determining the economic efficiency of wind energy development. Researchers use different evaluations and very often take different factors into consideration during these economic analyses.

The literature devoted to wind energy economic evaluation can be divided into two large groups:

- Evaluations of wind energy project feasibility from a private point of view;
- Evaluations of the environmental costs of wind energy projects.

Unfortunately, there are few studies that take into consideration both of these factors simultaneously. Researchers prefer to concentrate either on economic feasibility of wind energy projects exclusive of environmental costs, or on environmental costs alone. Be that as it is, economic evaluation of wind energy is not easy, due to rapidly changing technology. It requires a lot of data to make proper estimates. At the same time, the estimation of environmental costs is a challenging problem; both from methodological and informational points of view, and combining this two in one study is a difficult job.

Let's examine, first, books and articles describing the economic evaluation of wind energy from a private point of view. Among these sources there are books entirely devoted to wind energy and books devoted to alternative energy sources in general.

In Paula Berinstein (2001), there is a special section devoted to the economics of wind energy. There, she briefly reviews government incentives for wind energy, and then gives figures on the capital costs of wind energy and the cost of wind energy production. Thus book gives interesting current statistical information about wind energy; however, the author does not address any environmental impacts.

The book by Tony Burton, et alt (2001) has a chapter devoted to wind-turbine installation and wind farms. It consists of the following sections: project development, visual and landscape assessment, noise, electromagnetic interference, ecological assessment and finance. In each section, the authors describe methods that support the evaluation of different kinds of wind farm impacts. Economic evaluation is concentrated in the last section (finance). The authors suggest the use of discounted cash flow analysis to evaluate the economics of wind energy projects. They provide an example calculation of net present value (NPV) and internal rate of return (IRR) for hypothetical projects. An advantage of this book is that it has a lot of necessary methodological information about the basic characteristics and performance of wind turbines. A drawback is that the authors do not provide any actual statistics or data.

In another book also entirely devoted to wind energy, Paul Gipe (1995) describes economic evaluation and environmental costs of wind energy in two different sections. Economic evaluation is actually a part of the technology chapter. In this section he describes the cost of wind energy, with consideration of installation costs, operating and maintenance costs, and fuel costs. He even has a small paragraph devoted to social and environmental costs; however, without any numbers. He admits that "...monetary value ultimately [should] be placed on social costs to give the market accurate price signals."(P. Gipe, p. 243). Then he describes environmental costs more precisely in the next chapter.

Non-government organizations interested in alternative energy development usually conduct their own analyses of wind farm environmental and economic performance. This information is usually the most recent available and can be found on the organization's web sites. Two sources of this kind have been the most useful to me. First, is the article "The Economics of Wind Energy" on the American Wind Energy Association web-site (www.awea.org). Second, the web-site of the National Wind Coordinating Committee (www.nationalwind.org) contains an article "Wind Energy Costs". Both articles provide useful information about different kinds of costs of wind energy (capital, operating and maintenance).

Bent Sorensen's book (2000) has a chapter devoted to detailed technical analysis of wind energy. However, in the last chapter the author addresses a social-economic assessment of energy supply systems. He suggests using life-cycle analysis for energy systems economic assessment.

The application of life-cycle analysis (LCA) seems to be very reasonable, because it incorporates all direct and indirect impacts of technology, and one of the main goals of this analysis is to evaluate electricity production with consideration of all available impacts, including externalities. Sorensen describes five main type of impacts which should be taken into consideration during LCA (Sorensen, 2000):

1. Economic impact.
2. Environmental impact.
3. Social impact.
4. Security and resilience.
5. Development and political issues.

Using this methodology, he conducts a LCA for wind energy for current Danish wind energy systems (Sorensen, p. 821) where he describes all of preceding impacts except economic. Unfortunately, he does not do an NPV or IRR of the project; however, he does include an analysis of environmental and social impacts.

The best example of publications concentrated on environmental costs is the book, *Environmental Costs of Electricity* (1991) wherein the environmental costs of electricity production for different kinds of energy sources are evaluated. The big advantage of the book is that all the costs are monetized and the methodologies are precisely described. From the title you can see that incorporating environmental costs into the economic evaluation of projects is not the goal of the book. However, it could be considered as a very good first step for that kind of analysis.

In conclusion, wind energy is a rapidly developing field. Technology is changing quickly and economic evaluation has to keep up with it. However, this is not an easy task, because of the amount of required data. The main drawback of the existing economic evaluation of wind energy studies is that not all the costs are incorporated in the analysis; especially, environmental and social costs.

Wind Energy in Oklahoma

In Oklahoma, an organization devoted to wind energy development was founded in 2000 by the University of Oklahoma and Oklahoma State University. This joint project is called the Oklahoma Wind Power Initiative (OWPI). The main goal of the project is to initiate and strengthen opportunities for long-term economic development of wind energy production in Oklahoma. In the very beginning, the OWPI planned to conduct an evaluation of the main available resources for wind energy in the state, including:

- evaluating the wind resource of Oklahoma,
- evaluating the land use and economics of regional wind production,
- evaluating the necessary infrastructure,
- evaluating the possibilities of federal and state incentives for wind energy production, and
- establishing educational and training programs.

The web site of the OWPI provides information on a study devoted to the economic evaluation of wind energy in Oklahoma, *Oklahoma's Wind Resources: Economic Analysis* (OWPI, 2002). In this publication, the authors highlight six prime areas for potential wind energy development, with wind resources of class 4 and better. Then they assume that 15% of those areas will be developed with 9 MW of installed capacity per square mile (capital investments of $0.8 million per MW, $30/ Megawatt hour wholesale rate, 33% capacity factor). The results of this study are presented on Figure 1 and in Table 3.

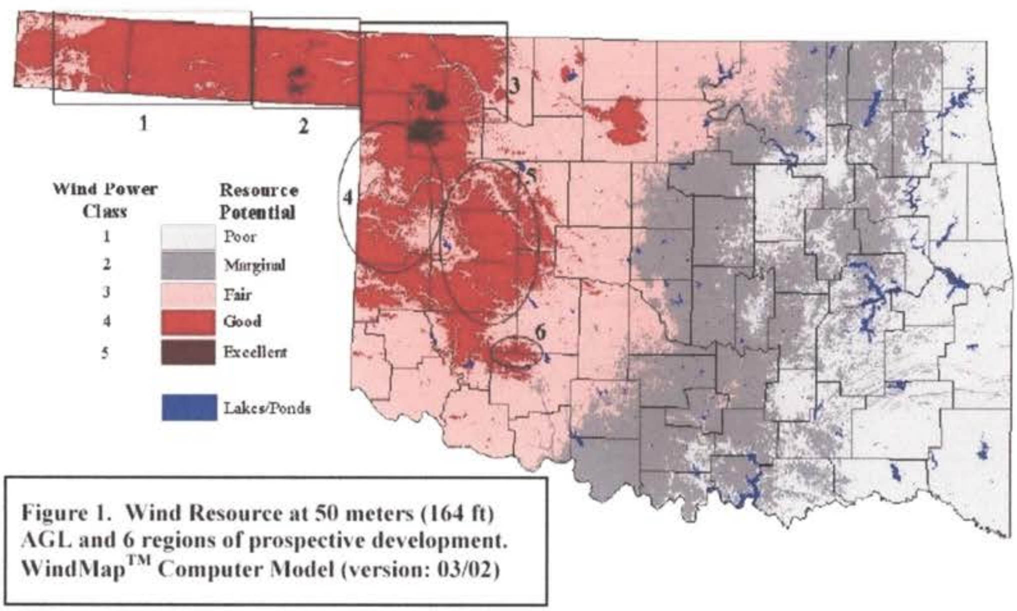

Figure 1. Wind Resources at 50 meters and 6 Regions of Prospective Development in Oklahoma. (Source: Oklahoma Wind Power Initiative, http://www.seic.okstate.edu/owpi/Policymkr/library/paper4.pdf).

TABLE 3

ECONOMIC EVALUATION OF 6 OKLAHOMA PROSPECTIVE REGIONS BY

OKLAHOMA WIND POWER INITIATIVE

Key	Region	MW capacity	Capital investment	Gross annual revenue	Estimated average lease payments
1	Texas/ Cimarron Cos.	3870	$ 3096 M	$ 319 M	$ 9.6 M
2	Beaver Co.	2460	$ 1968 M	$ 203 M	$ 6.1 M
3	Woodward-Buffalo-Alva	4350	$ 3480 M	$ 358 M	$ 10.8 M
4	Cheyenne-Arnett	2810	$ 2248 M	$ 232 M	$ 7.0 M
5	Weatherford-Hobart	3240	$ 2592 M	$ 267 M	$ 8.0 M
6	Slick Hills	520	$ 416 M	$ 43 M	$ 1.3 M
	Totals	**17250**	**$ 13800 M**	**$ 1422 M**	**$ 42.8 M**

Source: Oklahoma Wind Power Initiative, http://www.seic.okstate.edu/owpi/Policymkr/library/paper4.pdf

This is an economic evaluation, but not one that addresses all of the costs and benefits of wind power development. In its current form, it provides little guidance for either prospective investors or policy makers.

1.5. Current Wind Energy Development in Oklahoma

Bergey Wind Power Co., Norman, Oklahoma

Bergey Wind Power Company is one of the leading small scale wind turbine producers in the United States, located in Norman, Oklahoma. Karl Bergey was a designer of small aircraft who did his first feasibility studies of wind energy in 1970 and established the company in 1977. From the very beginning, the company has cooperated closely with the University of Oklahoma (OU). In fact, student wind power projects started in 1973. In 1974 Mike Bergey, the current company president and CEO, started his career in wind power with a project at OU.

Today, Bergey Wind Power Co. is a nationally recognized manufacturer of small wind turbines. It has about 2400 wind turbines installed all over the United States and in more than 90 foreign countries. The company works with 350 dealers inside the country and 250 international dealers. Bergey Wind Power also has a China Subsidiary, Beijing Bergey Windpower, where they, in fact, produce turbines.

According to Mike Bergey, they are working mainly for two markets:

- the domestic market (on-grid wind turbines, for people who want to reduce their electrical bills), and
- the international market.

Unfortunately, 99% of the domestic clients are outside the state of Oklahoma. This happens mostly because of two reasons:

(1) there are no government incentives for wind development in Oklahoma, and

(2) electricity generated from fossil fuels in the state is very cheap.

Cost is still a crucial factor in wind energy development. The range of production electricity costs according to Bergey Wind Power Co. is from 7 to 25 cents per kWh, depending on wind power density and land cost in the area. That's why in the states with government incentives and more expensive electricity, wind energy is developing more intensively. Many of the company's turbines are installed in California where electricity cost from fossil fuel is about 20 c/ kWh, and in Iowa, Maine, New York and Massachusetts.

The company is also actively working in the international market in Canada, Europe, South America and China. Canada and China deserve specific mention, because of their big interest in wind energy. In Canada, wind energy development is spurred more by the private sector, and in China by the intention of the government to supply electricity for rural areas with the use of affordable resources.

In both cases, however, the production cost of electricity is crucial. For the United States, without any government subsidies, the payback period for wind energy investment is about 10 years. Very few people will invest in a project with such a long payback period.

As to production, Bergey Wind Power produces two main kinds of wind turbines:

- BWC XL.1 (1 kW class wind turbine);
- BWC Excel (10 kW class wind turbine).

Bergey Wind Power Co. is also very conscious of the environmental impacts of their turbines. According to Mike Bergey, there are two main environmental impacts:

- noise pollution (the company is actually working to reduce noise pollution to make it below background noise);
- visual impact (this is very hard to evaluate; however, you have some flexibility to reduce this with small wind turbines).

After installation, the company gives a 5-year warranty on its turbines. They estimate the life cycle of the wind turbine at up to 30 years. In 30 days, they inspect the installed turbine, than again in 180 days and after that every 2 years.

Now they also can provide their customers with a hybrid system, for example, one that combines wind turbine and solar batteries to make system work more effectively by providing electricity generation when winds are calm (Figure 2).

Figure 2. Bergey hybrid system: wind turbine with solar battery (Photo was taken by E. Ermilova on January, 31 in Bergey Wind Industry, Norman, OK).

<u>Blue Canyon Windpower LLC</u>

A wind energy project is now being developed in Oklahoma by Blue Canyon Windpower LLC. Its' parent companies are Zilkha Renewable Energy of Houston, Texas and Kirmart Corporation of Wichita Falls, Texas. Currently there is a 20-year agreement between Blue Canyon and Western Farmers Electric Cooperative (WFEC) to purchase electricity from a 64

MW wind energy facility. Blue Canyon is supposed to construct and operate 39 wind turbines (NEG Micon NM72 C 1,65 MW capacity), the electricity from which will be purchased by WFEC.

Commercial operation of the facility will start in the end of 2003. During construction, the project will employ about 100 people; after that, about 6 – 8 employees will be required for operation and maintenance of the facility. According to project plans, turbines will be installed in Comanche and Caddo counties.

On the figure below you can see a simulation of Oklahoma's first wind farm (intersection of Highways 58 and 19) created by Zilkha Renewable Energy.

Figure 3. A simulation of first Oklahoma's wind farm; look from intersection of Highways 58 and 19. Source: Oklahoma Wind Energy Initiative web-site, http://www.seic.okstate.edu/owpi/Stakehld/landownr/Mar2003Issue_Full.pdf

CHAPTER II

PROBLEM STATEMENT

2.1. General Objective of the Study

A review of the literature indicates that wind-generated electricity technology has improved in quality in the last 2 decades, that the cost of generating electricity from this source has fallen considerably, and that Oklahoma has some promising sites for wind power development.

Currently, however, wind-generated electricity has rarely been subjected to a complete economic analysis and there is no economic evaluation of wind-generated electricity in Oklahoma that provides adequate information to investors and policy makers. The research for this study is designed to close this gap in our knowledge.

More specifically the objective is:

To estimate the economic feasibility of wind power capacity installation for electricity production in Oklahoma and to compare it with natural gas power plants in current conditions.

The primary tasks are:

1. **Investment Analysis from a Private Perspective:** This part of the study will determine if wind energy has a positive present value of net private benefits (PVNPB) in Oklahoma and compare the present value of net private benefits for wind turbines and natural gas power plants.
2. **Investment Analysis from a Social Perspective:** This part of the study compares a natural gas power plant and a windmill farm in terms of the present value of net social benefits (PVNSB).
3. **Investment Analysis from a Geographic Perspective:** This part of the study determines the economic feasibility of wind power generation by county, for all 77 Oklahoma counties.
4. **Government Subsidy Analysis:** This part of the study examines whether the state should subsidize wind energy, especially considering the externalities associated with energy production from gas-fired generating plants.

Investment analysis from a private perspective differs from investment analysis from a social perspective in terms of the treatment of taxes, discount rates and external costs analyzed from private and social points of view. Differences in the economic payoff from these two perspectives are the basis for government subsidies, if any.

2.2. Investment Analysis

The discounted net benefits from hypothetical wind and natural gas projects will be evaluated and compared. The present value of net benefits will be calculated for each type of project in current Oklahoma conditions according to the following formula:

$$PVNB = \sum_{t=1}^{T} Bt / (1+i)^t - \sum_{t=1}^{T} Ct / (1+i)^t \quad (1)$$

where

PVNB – present value of net benefits;

Bt – annual benefit from the project;

Ct – annual cost of the project;

i – discount rate;

T – last year of project realization.

To make a proper comparison it is important to analyze both types of hypothetical projects in the same conditions. This will require:

1. making and following the same assumptions for the benefits and costs for both types of projects.
2. collecting adequate technical, economic and ecological information about both types of projects.

2.2.1. Benefits Assumptions

Benefits from the projects will be equal to:

$$TB = \sum_{t=1}^{T} Pt * Vt / (1+i)^t \quad (2)$$

where

TB – total benefits for T years;

Pt – price per kWh for year t;

Vt – electricity produced in kWh in year t.

There are two primary tasks involved in estimating benefits:

(1) making an accurate forecast of electricity prices, and

(2) making an accurate forecast for electricity production.

1. ***Price forecasting problem***. The timeframe for our calculations will be equal to the life cycle of a project (assumed to be 25 years). Thus, we have to forecast electricity prices for that time period. To do this, there are two main theoretical approaches:

   • make a price forecast or use someone else's price forecast. Making one's own proper price forecast is difficult and time consuming, requiring a lot of statistical information and special statistical models. Since this is not a purpose of this dissertation, reliance on forecasts of others would be the preferred approach;

   • use current prices. The drawback of this approach is obvious – electricity prices may not be stable over time in the face of economic growth and resource depletion. However, the use of current prices provides an opportunity to estimate the feasibility of the project in current conditions and then sensitivity analysis can be done to determine how much price changes could influence the final results.

One more important problem connected with prices is what kind of price should we take into consideration: the market price or the social price? The market price can be calculated using existing data. The social price requires that external costs be added to the market price. Both of those prices could be used in the research for different purposes.

2. ***Evaluating the amount of electricity production*** – in this case the problem will be slightly easier for a natural gas power plant, because with a given capacity we can calculate the potential amount of electricity production. For a windmill farm, the problem

will be a bit more difficult. Windmill productivity will depend on wind speed and frequency; thus we have to evaluate wind speed in the particular region of Oklahoma where we want to put the windmill. Luckily, we have estimates of Oklahoma wind resources made by the Oklahoma Wind Power Initiative, based on Oklahoma Mesonet stations data.

The second problem in this case is to estimate sales of the produced electricity. As we know, electricity demand has a very large seasonal component; for example, in Oklahoma demand significantly increases in summer when people start to use their air-conditioners, but demand decreases in other times of the year. This means that sometimes producers are not able to sell all the electricity that they could produce. Furthermore, the average wind speed in summer in Oklahoma is lower than in winter. Thus, electricity production from windmills decreases when demand for electricity is increasing.

The other problem in this regard is the location of production facilities relative to the transmission system. Many parts of Oklahoma are not well served by transmission lines. We will make the optimistic assumption that all electricity generated will be sold and transmitted without additional investment required from electricity producers. Electricity retailers are required by law to buy electricity generated by renewable sources, but they are not required to build transmission systems for this purposes.

2.2.2. Costs Assumptions

Costs for energy production for each project will be calculated according to the following formula:

$$TC = \sum_{t=1}^{T} CIt / (1+i)^t + \sum_{t=1}^{T} Ot/ (1+i)^t + \sum_{t=1}^{T} Tt/ (1+i)^t + \sum_{t=1}^{T} Dt/ (1+i)^t + \sum_{t=1}^{T} EVt/ (1+i)^t \quad (3)$$

where,

TC – total cost of the project;

CIt – capital investment in the project;

Ot – operating and maintenance costs;

Tt – transmission costs;

Dt – distribution costs;

EVt – environmental costs (externalities).

To estimate ***capital investment costs*** we need to know the technical characteristics of the implemented project and the cost of the required equipment. However, this is not enough; to make our projects comparable, we have to evaluate similar projects. For example, a natural gas power station will produce probably 3 times more electricity than a windmill with the same capacity. This happens because windmill farms are totally dependent on the wind, and the capacity factor (a ratio equal to annual electricity production divided by full capacity of the facility) usually is not more than 30 – 40%; most of the time windmills do not produce at full capacity.

Estimates of ***operating and maintenance costs*** can be found in the literature. The most important parameter for our comparison will be the costs of raw materials. For natural gas power plants, this cost will be high due to the cost of natural gas; however, for windmills the fuel (wind) is free of charge. Consequently, operating costs will be higher for natural gas power plants.

Transmission costs could play an important role in the analysis. According to wind resource estimates, regions with plentiful wind resources and regions with the need for electricity are different, and the average transmission distance for wind electricity could be greater than for electricity from natural gas power plants. Furthermore, windmill location absolutely depends on wind resources while natural gas power plants can be put anywhere it seems more effective for minimizing transportation and transmission costs and costs of acquiring natural gas.

It is very likely that ***distribution costs*** will not play a significant role in the study because there will be no difference in the cost of distribution of electricity produced from wind energy and from traditional sources. However, it could become important in the case where windmill energy is used only for self-consumption without transporting energy to other regions. In this case there will be no transmission or distribution costs for wind energy.

Last, but not least, are ***environmental costs***. In the first stage of the analysis we will identify what kinds of environmental impacts each of the projects produce. Then we will evaluate the economic cost of those environmental impacts. This could be crucially important for a comparison of alternative energy sources, because traditional electricity production has major environmental impacts (such as CO_2 emissions). However, those costs usually are not taken into consideration. On the other hand, wind energy has fewer environmental impacts, so if environmental costs are taken into consideration it could make wind energy more competitive with the natural gas power plants.

In first stage we analyze both technologies as they are without taking into consideration external, ecological or social conditions. In the next stage we include taxes and external costs in the analysis.

2.3. Investment Analysis from Private and Social Perspectives

To analyze projects from private and social points of view, two different indexes will be used in the study: ***present value of net private benefits (PVNPB)*** and ***present value of net social benefits (PVNSB)***. Net private benefits will represent the net gains received by private investors from energy projects. Net social benefits will represent the net gains received by the whole society.

$$\mathbf{PVNPB = PVNB - \sum_{t=1}^{T} TXt/ (1+i)^t + \sum_{t=1}^{T} EVt/ (1+i)^t} \qquad \textbf{(4)}$$

where,

PVNPB – present value net private benefits;

PVNB – present value net benefits (equation 1);

TXt – taxes in year t;

EVt – environmental costs (externalities).

$$\mathbf{PVNSB = PVNB + \sum_{t=1}^{T} TXt/ (1+i)^t} \qquad \textbf{(5)}$$

where,

PVNSB – present value net social benefits.

As we can see from the formulas, PVNPB does not include environmental costs (PVNB initially included them, but we add environmental costs with the opposite sign). On the contrary PVNSB includes environmental costs.

We are planning to calculate ***taxes*** according to current Oklahoma tax law. Considering the fact that there is no special tax regulation encouraging renewable energy (for example, production tax credits and renewable standard portfolios) in Oklahoma, taxes will be calculated identically for wind energy and traditional energy. However, in the government subsidy analysis we could estimate the effect of tax encouragement and do an analysis with consideration of production tax credits.

We have already mentioned ***environmental costs*** and their importance in the analysis. Environmental costs will be a significant parameter in differentiating between private and social costs, because the private sector does not consider costs of environmental pollution.

The main differences between private and social net benefits are presented in table 4.

TABLE 4

MAIN DIFFERENCES BETWEEN PRIVATE AND SOCIAL NET BENEFITS

	Generation		**Transmission**		**Distributions**	
	Private	***Social***	***Private***	***Social***	***Private***	***Social***
Capital Investment		Differ from private, if state has unused resources		Differ from private, if state has unused resources		Differ from private, if state has unused resources
Operating and Maintenance Costs		Differ from private, if state has unused resources		Differ from private, if state has unused resources		Differ from private, if state has unused resources
Taxes	Private cost	Social benefit	Private cost	Social benefit	Private cost	Social benefit
Discount Rate	Equal to opportunity cost of funds	Equal to social discount rate	Equal to opportunit y cost of funds	Equal to social discount rate	Equal to opportunit y cost of funds	Equal to social discount rate
Environmental costs	Not considered by private investors	Considered by social decision makers	Not considered by private investors	Considere d by social decision makers	Not considered by private investors	Considere d by social decision makers

After getting results from the investment analysis and identifying who gets benefits and how much both from the private and social points of view, we can move on to the next stage – government subsidy analysis. In other words, we can analyze how we can increase the efficiency of electricity production in Oklahoma by subsidizing private producers/ investors.

2.4. Government Subsidy Analysis

For the government to consider subsidizing wind energy, the PVNSB should be more than zero, and the present value of net social benefits must exceed the present value of net private benefits.

$$\mathbf{PVNPB_w < PVNSB_w > 0}$$

Where w – wind.

Alternatively, the social rate of return must be greater than the rate of return on the next best social alternative, and the social rate of return must exceed the private rate of return. Government should subsidize until:

$$\mathbf{ROR_p = ROR_s}$$

where,

ROR_p – private rate of return;

ROR_s - social rate of return.

Those indices hold the key to whether the government should subsidize wind energy development or not, and what should be the amount of any subsidies.

CHAPTER III

TOOL FOR PROBLEM SOLVING

To solve the problem formulated in chapter II a model of the hypothetical alternatives was created in Microsoft Excel spreadsheets. This model consists of 3 main sections:

1. **Production Section** – this part of the model is used to estimate the annual capacity of wind generators to produce electricity.
2. **Costs and Benefits Evaluation Section** – in this section of the model, the principal costs and benefits from wind energy production like sales revenue, capital investment, operating and maintenance costs, and external costs will be estimated.
3. **Financial Results Section** – finally, based on the estimates from the previous two sections, the financial results for all alternative projects will be calculated (cumulative cash flows, income statement and internal rate of return, present value of costs and benefits).

Now let's examine each section more precisely, including all the assumptions and limitations of the model.

3.1. Production Section.

As already mentioned, the main goal of this section is to determine how much electricity wind generators will produce annually. There are two ways to configure the model for this purpose:

a. *Simple way:* with given capacity and capacity factor, calculate electricity production.

$$EP = Cap * CapFactor * Hours$$

EP- electricity production (kWh);

Cap – capacity (kW);

CapFactor – capacity factor (percentage of time equipment operates at it's full capacity);

Hours – working hours in the year (hours).

b. *Difficult way:* with given air density, rotor diameter, and wind speed, calculate power (Pwr) produced according to this formula

$$\mathbf{Pwr = 0.5 * \rho * \pi * (D/2)^2 * V^3}$$

ρ - air density(kg/m^2);

π - constant;

D - rotor diameter, so [π* $(D/2)^2$] will be equal to rotor area (m^2);

V - wind speed (m/s).

The first way will be used to estimate general models for Oklahoma. The second way will be used later to calculate potential wind energy production for different Oklahoma counties with different wind speeds.

3.2. Costs and Benefits Evaluation Section

The cost-benefit evaluation section consists of four subsections:

a. Sales Forecast.

b. Capital Investment Evaluation.

c. Operating and Maintenance Costs Evaluation.

d. Taxes.

In each section, the different types of costs will be evaluated according to the available data. A series of assumptions will be made for each section; however, the model is flexible enough to embrace any future changes, if necessary.

a. Sales Forecasts.

There will be two main assumptions for this part of the problem:

- No electricity will be used for own consumption (we assume that all produced electricity will be sold).
- Prices per kWh of electricity produced in this model are base period prices. Different types of electricity prices (residential, commercial or industrial) can be used for calculations.

b. Capital investment evaluation.

According to the available information, 1 WM of installed capacity costs about $1 million for wind turbines and $420,000 for natural gas turbines. The whole sum of investments will be made in the first year.

c. Operating and maintenance costs evaluation.

We are going to include in the analysis the following operating costs (Table 5).

TABLE 5

OPERATING AND MAINTENANCE COSTS FOR WIND ENERGY PRODUCTION

Operating Costs Element	Value (cents/ kWh)
Maintenance and repair	0.9
Land use	0.1
Insurance	0.003
Transmission	0.02
Management fees	0.15
Environmental costs	0.1*
Total O & M	**1.273**

Source: Wind Energy Costs. (1997, January). In National Wind Coordinating Committee [On-line]. Available: **http://www.nationalwind.org/pubs/wes/wes11.htm** [2002, December, 5]. * - Environmental Costs of electricity, 1991.

As noted, environmental costs are included in operating and maintenance costs, because these costs will appear during the whole life cycle of a wind farm. All these figures are average parameters taken from the literature. In later analysis of wind energy economic evaluations in different Oklahoma counties, these figures can be changed to consider different counties characteristics.

Special attention should be given to the environmental costs of wind energy. Two major environmental impacts of this renewable energy source are visual and noise impacts. Both of them mainly affect the cost of land in the wind farm areas (people just don't want to live close to wind farms). Thus, we can say that environmental costs are correlated with the cost of land in the area of construction. This assumption will be included in the calculation of the electricity production for wind farms in different Oklahoma counties.

d. Taxes.

The following taxes will be taken into consideration in the model:

Total income tax [45%]: federal income tax [39%] + state income tax [6%];

Local property tax [11 – 13.5%];

In the subsidy analysis, federal tax credits will be taken into consideration if the model shows the necessity of government support for wind farms.

3.3. Financial results

There will be three main spreadsheets developed in the financial results portion of the model (appendixes 1.1-1.3, 2.1-2.3):

a. Cash flow table – this spreadsheet determines the main cash flows before and after taxes, including cumulative cash flows.
b. Income statement – this spreadsheet determines annual and cumulative net income
c. Internal rate of return- this spreadsheet determines project internal rates of return before and after taxes.

To develop the proposed model we have to accumulate a large amount of different types of information. The kinds of information required will be discussed in the next chapter.

CHAPTER IV

REQUIRED INFORMATION

Table 6 indicates the principal types of information needed for the economic evaluation of wind energy performed in this study.

TABLE 6

PRINCIPAL COMPONENTS OF COST-BENEFIT ANALYSIS AND DATA REQUIRED FOR ANALYSIS

Components	Required Data
1. Benefits analysis	
1.1. Price forecast	Statistics of current and projected electricity prices in Oklahoma
1.2. Amount of electricity produced	Wind resources, technical characteristics of wind converters, technical characteristics of natural gas power plants
2. Costs analysis	
2.1. Capital investment	Technical characteristics of equipment and equipment prices
2.2. Operating and maintenance costs	Technical characteristics, cost of maintenance, labor input, raw material consumption and prices
2.3. Transmission costs	Distance to the existing electric grid
2.4. Environmental costs	Major environmental impacts, economic evaluation of adverse environmental impacts from projects.

All this information will be used for mathematical simulations of hypothetical projects at different stages. A "cradle to grave" approach, or life cycle analysis (LCA) will be used. LCA incorporates all direct and indirect impacts of the technology.

4.1 Electricity production and prices in Oklahoma

Table 7 presents summary statistics for Oklahoma electricity production in 1999 from the Energy Information Administration. The capacity for electricity production is equal to 13.7 MW. More than 55 million mWh was produced and purchased at an average price of 5.37 cents/ kWh.

TABLE 7

SUMMARY STATISTICS FOR ELECTRICITY PRODUCTION IN OLAHOMA IN 1999

Item		**Value**	**U.S. Rank**
Primary Energy Source	Coal		
Net Summer Capability (megawatts)		13,690	23
	Utility	12,861	22
	Nonutility	830	29
Net Generation (megawatthours)		55,015,641	25
	Utility	50,278,792	24
	Nonutility	4,736,849	23
Electricity Consumption (MWh) (excludes line losses)		47,859,333	27

Utility Retail Electricity Sales (megawatthours)	46,736,630	27
Nonutility Retail Sales and Direct Use (megawatthours)	1,122,703	28
Utility Average Retail Price (cents/kWh)	5.37	41

Source: State Electricity Profiles. Energy Information Administration [On-line]. http://www.eia.doe.gov/cneaf/electricity/st_profiles/oklahoma/ok.html

As shown in Figure 4, Oklahoma's electricity was mainly generated from coal (more than 60%) and natural gas (about 33%). Wind energy did not play any significant role in electricity production in Oklahoma.

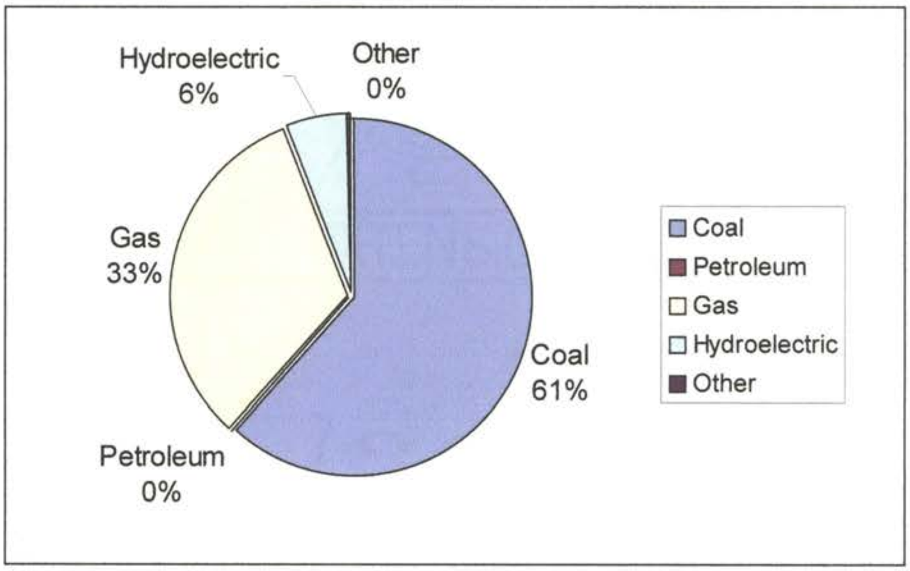

Figure 4. Electricity Generated by Energy Source in Oklahoma, 1999. (Source: State Electricity Profiles. Energy Information Administration [On-line]. http://www.eia.doe.gov/cneaf/electricity/st_profiles/oklahoma/ok.html)

4.2. Oklahoma wind resources

One of the initial research projects of the Oklahoma Wind Power Initiative (see section 1.4) was to evaluate available wind resources and create wind maps for Oklahoma. The Geography Department of Oklahoma State University, under the supervision of Dr. Stephen J. Stadler, conducted this study. The following data were used in the analysis:

1. Elevation data – a DEM (digital elevation model) was used to construct an appropriate elevation grid. In general, wind is stronger at higher elevations.
2. Vegetation data – LULC (land use/ land cover) data were used to estimate vegetative "roughness" for the wind power model. The main idea is that if there are a lot of trees the wind speed will slow down.
3. Oklahoma Mesonet data – Oklahoma Mesonet is a unique surface weather network, with 114 stations, that covers all the state of Oklahoma. Every hour, Mesonet stations measure weather conditions for Oklahoma, including wind speed and direction.

Based on these data, a model for calculating Oklahoma wind resources was created. As a final result, two maps of Oklahoma wind resources were created of wind resources at heights of 50 and 10 meters (Fig.5 and Fig.6). This research work is very important, because it can be used to help identify optimal locations for small and big windmills and more precisely evaluate their economic efficiency. The availability of Mesonet data creates a unique opportunity for Oklahoma to make better wind resource evaluations and thus the opportunity to use them more efficiently.

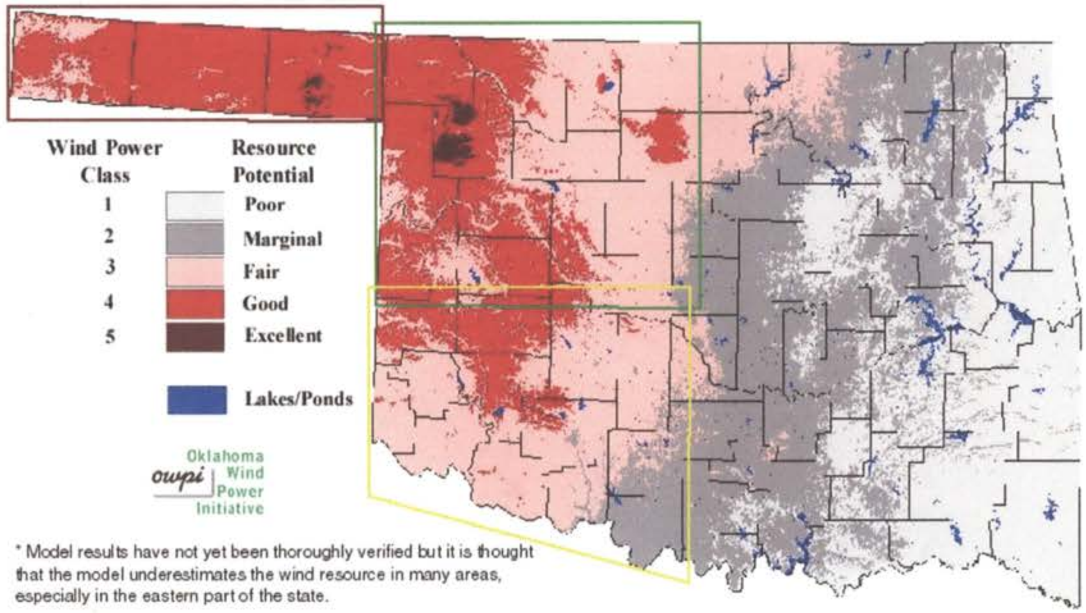

Figure 5. Oklahoma wind power resources at 50 meters height (source: Oklahoma Wind Power Initiative, http://www.seic.okstate.edu/owpi/WindRes/windmap.htm).

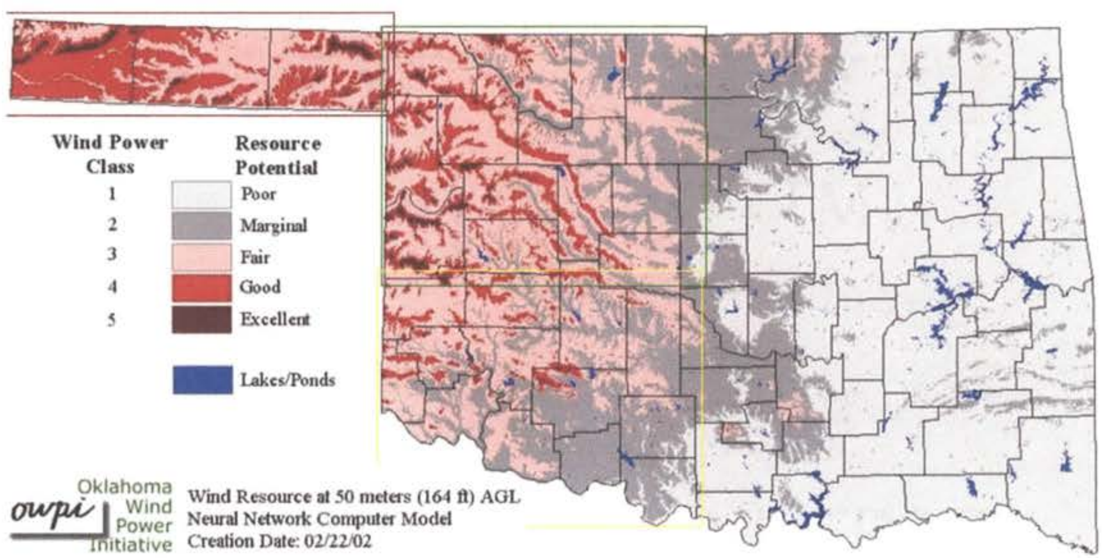

Figure 6. Oklahoma wind power resources at 10 meter height (source: Oklahoma Wind Power Initiative, http://www.seic.okstate.edu/owpi/WindRes/neuralnetwork.htm).

The OWPI also made a general economic analysis of wind energy in Oklahoma based on these maps, as mentioned in chapter I of this study.

4.3. Calculation of Wind Energy and Power

To estimate how much energy could be produced from an area with a particular wind class it is necessary to use the basic physical principles of kinetic energy. The following formula determines the kinetic energy of an object with given mass and velocity:

$$KE = ½ * M * V^2$$

Where

KE – kinetic energy;

M – mass of the object;

V – velocity of the object.

To realize the kinetic energy of air molecules moving through the rotor let's imagine a huge hockey puck with a section area of A and thickness of D passing through the blades over a given time. The volume of this parcel could be calculated according to the simple geometry formula:

$$Vol = A * D$$

Where,

Vol – volume of the parcel of air;

A – section of the cross-sectional area;

D – thickness of the parcel of the air passing over a given time.

Density of the air is mass divided by volume or:

$$\rho = M / Vol$$

where,

ρ – density of the air.

If we suppose that a parcel of air with thickness D moves through the blades over time T, then velocity is:

$$\mathbf{V = D / T}$$

Now we can make some substitutions in the kinetic energy equation, considering that $\mathbf{M = \rho * Vol}$, $\mathbf{Vol = A * D}$ and $\mathbf{D = V * T}$:

$$\mathbf{KE = \frac{1}{2} * M * V^2}$$

$$\downarrow$$

$$\mathbf{KE = \frac{1}{2} * \rho * A * V * T * V^2}$$

$$\downarrow$$

$$\mathbf{KE = 1/2 * \rho * A * T * V^3}$$

To evaluate power (Pwr) we just have to divide kinetic energy by time:

$$\mathbf{Pwr = KE / T = 1/2 * \rho * A * V^3}$$

Now we can estimate the basic parameter known as **"Wind Power Density" (WPD),** which is power divided by the cross-sectional area, or:

$$\boxed{\mathbf{Pwr / A = 1/2 * \rho * V^3}}$$

Two major conclusions can be made form this expression:

1. Power is proportional to the cube of the wind speed. This means that, with increasing wind speed electricity production will increase exponentially.
2. Wind power density does not depend on the size of a rotor (A); it only depends on the density of the air and the wind speed.

This information is important, because "wind classes" are based on Wind Power Density or mean wind speeds. Consequently, to understand how much electricity could be produced in a particular area with an estimated wind class (marked from 1 to 7) we have to understand the above indexes. Wind power density and wind speed at different heights are presented in the table 8.

TABLE 8

CLASSES OF WIND POWER DENSITY

Wind Power Class	Height 10 meter		Height 50 meter	
	Wind Power Density, W/m2	**Speed, m/s (mph)**	**Wind Power Density, W/m2**	**Speed, m/s (mph)**
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)

Source: Elliott, Schwartz. Wind Energy Potential in the United States.
http://www.nrel.gov/wind/wind_potential.html

Finally, Oklahoma wind power maps and basic knowledge about wind power density can be combined to determine the amount of wind energy produced in a given area.

4.4. Wind power turbines technical characteristics

In this section we describe the main types of wind turbines and briefly discuss current problems and trends in wind turbine design. There are two main types of turbines in the world today:

- Horizontal Axis Turbines (HAWT);
- Vertical Axis Turbines (VAWT).

The main difference is the orientation of the rotor axis. In the case of HAWT, the rotor axis is parallel to the ground; for the VAWT the rotor axis is roughly perpendicular to the ground. HAWT work as propellers and they must be kept perpendicular to the wind to operate as efficiently as possible. VAWT can operate with wind from any direction. However, we should notice that horizontal axis turbines are more widely used; for example, about 93 percent of California wind generating capacity is HAWT.

Turbines can be classified also by size of the turbine. According to size they may be classified as:

- small (up to 100 kW);
- intermediate (between 100 kW and 1 MW);
- large (more than 1 MW).

Small and intermediate size turbines are currently considered to be most technically efficient and are widely used in US and Europe. However, some researchers believe that in the future large turbines will be used, because they provides economies of scale.

Development of the perfect wind turbine generator is still a very challenging problem. During the last 30 years, the creation of more efficient wind generators was the major factor responsible for decreasing wind energy costs. Today, the main research efforts are concentrated on perfecting two- and three-bladed horizontal axis machines.

Historically, wind turbine designs were driven by three major philosophies for dealing with wind loads (Thresher, Dodge, 1998):

2) withstanding the loads;

3) shedding or avoiding the loads;

4) managing loads mechanically and/ or electrically.

The first turbines were originally developed by Paul la Cour in the 1890s. This type is considered to be the typical "Danish" configuration. In the beginning it was a "traditional" four-blade rotor. During World War II, the elimination of one blade was a major innovation and three-blades rotors appeared. Second and third approaches were developed later and now each of them took a very important place in wind turbines design.

Today, the main turbine design considerations include the following parameters:

- wind regime;
- cost;
- rotor type;
- generator type;
- load and noise minimization;
- control approach.

In spite of some, differences all major turbine designs currently share a trend for increasing lightness and flexibility, the probable keys to improving technological effectiveness and achieving lower costs.

4.5 Wind and Natural Gas Energy Environmental Impacts

An extremely important consideration, besides the technical characteristics of different energy sources, is the environmental impact of the technology. Environmental externalities will play a significant role in our analysis. The principal types of pollution from electricity production are (*Environmental Costs of Electricity*, 1991):

1. Air pollution.
   - Carbon dioxide (CO_2);
   - Sulphur dioxide (SO_2);
   - NOx and ozone;
   - Acid deposition;
   - Particulates.
2. Water pollution.
3. Land pollution.

Although wind generated electricity is believed to be one of the most environmentally friendly sources of electricity, it would be wrong to say that wind energy does not have any environmental impacts. In the literature, several environmental problems are identified for the wind energy (Cassedy, 2000, Berinstein, 2001, Sorensen, 2000):

1. Noise (could be reduced with improved technology).
2. Danger to animals, especially birds.
3. Electromagnetic interference (could be eliminated with modern technology).
4. Excessive land use (although combinations of land use might be possible).

All those environmental impacts should be taken into consideration in an analysis of the technology. Thus, the calculation of electricity costs should include the costs of these externalities and energy sources should be compared, based, in part, on the external costs of energy production. The social cost of energy is usually underestimated because of externalities. This is a well-known problem for energy generated from fossil fuels, but it is a potential problem for wind-generated electricity as well.

Table 9 summarizes the external costs of renewable electricity generation technologies.

TABLE 9

ENVIRONMENTAL COSTS Of VARIOUS RENEWABLE ENERGY TECHNOLOGIES

Technology type	**Cents/kWh**
Solar	0 – 0.4
Wind	0 – 0.1
Biomass	0 – 0.7

Source: Environmental costs of electricity, 1991, p. 36.

For the natural gas power plants, the main externalities will come from air emissions, in particular NO_x and CO_2 emissions. External costs from natural gas power plants have been estimated at 0.8 – 1.2 cents/ kWh of delivered electricity, for the different types of power plants (Table 10).

TABLE 10

EXTERNAL COSTS FOR NATURAL GAS-FIRED UNITS

Externality	**Existing Steam Plant**	**Combined Cycle**	**Combined Cycle with add-on control for emission**
NO_x, lbs/ MMBTU fuel input	**0.248**	**0.42**	**0.42**
Particulates, lbs/ MMBTU fuel input	**0.003**	**0.003**	**0.0002**
CO_2, lbs/ MMBTU fuel input	**110**	**110**	**110**
Total			
$/ kWh Generated	**0.010**	**0.010**	**0.007**
$/ kWh Delivered	**0.012**	**0.011**	**0.008**

Source: Environmental costs of electricity, 1991, p. 33.

Although we can see that natural gas power plant environmental costs are significantly higher than windmill farm environmental costs according to the above estimates (about 10 times), we can not make any conclusions yet about one source of energy or the other, because we have to take into consideration all costs and benefits from both technologies.

CHAPTER V

RESULTS

5. 1. Analysis of Wind Energy Development in Oklahoma

The main goal of our investment analysis will be to answer the question: Is wind energy development reasonable for Oklahoma? This depends not only on the costs and benefits of wind energy development, but also on the costs and benefits of electricity that could be produced from other sources. For Oklahoma, the other source is clearly natural gas. As many as 25 new plants with gas turbines could be build, according to permits on file with the Oklahoma Department of Environmental Quality. The costs and benefits of wind energy development also depend on the location of wind turbines. Thus, the analysis will be divided into three primary sections:

1. Investment Analysis from a Private Perspective.
2. Investment Analysis from a Social Perspective.
3. Wind Farm Development on a County Basis.

In the first two sections, the analysis assumes the best locations for the wind turbines. The third section explains how the best locations are determined.

5.1.1. Investment Analysis from a Private Perspective Without and With Environmental Costs

First, we describe the assumptions used in evaluating the costs and benefits of natural gas turbines and wind turbines. Then we use the Excel model described earlier to estimate the PVNPB for both types of hypothetical projects. This is followed by a comparison and analysis of the results.

We compare two energy projects with the same capacity (our hypothetical capacity is 1MW). It's very important that we compare projects operating in the same environment with respect to taxes, land cost, and regulations. Thus, we assume identical taxes and land costs for both types of investments. To calculate operating costs for both types of turbines, we begin with the average Oklahoma land cost and property tax. Table 11 shows the general assumptions for both (wind and natural gas turbine) projects.

TABLE 11

VALUES FOR PARAMETERS ASSUMED TO BE IDENTICAL FOR NATURAL GAS AND WIND TURBINES

Parameter	Value
Capacity, kW	**1000**
Life time of the project, years	**25**
Land cost, $/ acre	**678**[a]
Property tax, mills per $	**80.17**[b]
Assessment rate for property tax, %	**11**[c]
Income tax, % of net income	**45**[d]
Electricity price, c/ kWh	**7**[e]

a. Source: National Agricultural Statistics Service. 1997 Census of Agriculture – County Data. http://www.nass.usda.gov/census/census97/volume1/ok-36/ok2_06.pdf b, c. Agricultural Economics Publications. Oklahoma Cooperative Extension Service (OSU). http://agweb.okstate.edu/pearl/agecon/resource/index.html d. Oklahoma Tax Commission. http://www.oktax.state.ok.us/ e. Energy Information Administration. http://www.eia.doe.gov/cneaf/electricity/st_profiles/oklahoma/ok.html

Natural gas turbine project

Although natural gas and wind projects have several identical assumed parameters, other key parameters differ. There are different capacity factors, discount rates, capital, and operating costs. The main assumptions for the natural gas project are presented in table 12.

TABLE 12

MAIN ASSUMPTIONS FOR NATURAL GAS TURBINES

Parameter	Value
Capacity factor	0.8
Investment costs, $/kW	420[a]
Operating costs	
Operating and maintenance, c/kWh	1[b]
Land use, c/ kWh	0.01[c]
Fuel cost, $/ Mcf	5[d]
Transmission costs, c/ kWh	0.01[e]
Discount rate, %	5[f]

a. Permit Files of Oklahoma Department of Environmental Quality. b. Chambers, Ann. Distributed Generation: A Nontechnical Guide. Table 1-1, p.5. c. Author expert evaluation with consideration of average Oklahoma land cots. d. Energy Information Administration. http://www.eia.doe.gov/cneaf/electricity/st_profiles/oklahoma/ok.html e. Identical for wind energy transmission cost without transmission coefficients. f. Bloomberg Information System.

As we can see from Table 12, natural gas turbines have a high capacity factor, 0.8. The capacity factor is equal to the annual energy production divided by the full-capacity production of the turbine.

A natural gas price of $5 /Mcf is used in the analysis. According to the Energy Information Administration the average price of natural gas delivered to electric utilities in Oklahoma in 2001 was $4.62 / Mcf (Natural Gas Annually 2001, Table 23). Unfortunately for wind energy, according to the same source, natural gas forecast prices will not significantly change. They will vary from $3.13 / Mcf to $4.69 /Mcf during the 2003 – 2025 period. Of course, we can't expect that prices will follow the forecast exactly, but the overall expectation of natural gas prices to go down is very important for us. It means that our evaluation of natural gas prices is pessimistic and in reality with lower natural gas prices our project will be even more profitable.

The 5 % discount rate is based on information taken from the Bloomberg Information System. Two large Oklahoma electricity producers, OGE Energy Corporation and American Electric Power Co. Inc., had a weighted average cost of capital equal to 4.81% and 5.06%, respectively, in year 2002. The 5% discount rate approximates the average cost of capital for these two producers.

Wind turbine project

The assumptions for the key wind turbine parameters are presented in Table 13.

TABLE 13

MAIN ASSUMPTIONS FOR WIND TURBINES PROJECT

Parameter	
Capacity factor	0.27[a]
Wind power density, W/m^2	396[b]
Investment costs, \$/kW	1000[c]
Operating costs	
Operating and maintenance, c/kWh	0.9[d]
Land use, c/ kWh	0.028[e]
Fuel cost, \$/ Mcf	0
Transmission costs, c/ kWh	0.1[f]
Management fees, c/kWh	0.15[g]
Insurance, c/kWh	0.003[h]
Discount rate, %	7[i]

a. Average based on excel model described above. b. Average for 26 Oklahoma counties with the best wind resources. c, d, e, f, g, h. National Wind Coordinating Committee, Wind Energy Costs, http://www.nationalwind.org/pubs/wes/wes11.htm . i. Expert evaluation based on the Bloomberg Information System.

The typical 1 MW wind turbine is actually a very large structure; the 1 MW turbine is mounted on a tubular steel tower. The rotor diameter is about 54 meters; the tower height could vary from 40 to 82 meter depending on the wind conditions.

Wind energy has a lower capacity factor than natural gas power plant, because wind turbine electricity production totally depends on the speed of the wind, and, as we know, this is not a constant parameter. The average wind power density for the 26 Oklahoma counties with the highest wind speed (most promising areas) was taken as an average wind estimate.

Investments costs per kW are higher for wind turbines than for natural gas turbines; however, operating costs for wind turbines are significantly lower due to the fact that they do not need fuel. We assume that transmission costs would be much higher for wind generated electricity. The problem is that windmill location depends on the wind speed in an area, and there is no guarantee that the best wind conditions will be those with existing transmission facilities. Natural gas turbines can be installed closer to transmission lines.

An important point for the analysis is that discount rate is higher for wind turbines. Wind energy investments are more risky than investments in traditional energy and this is assumed to be reflected in a higher discount rate (7%).

Comparison of natural gas and wind projects without environmental costs

Given these assumptions we calculated cash flows for both hypothetical projects. The results of those calculations are shown in the Table 14.

TABLE 14

RESULTS FOR NATURAL GAS AND WIND PROJECTS

	Natural gas	Wind
Capacity, kW	1000	1000
Capacity factor	0.8	0.27
Annual electricity production, kWh	7,008,000	2,399,876
Capital Investment, $	$420,000	$1,000,000
Operating costs, $	$4,586,358	$680,366
Discount factor	1.05	1.07
PVNPB, $	$1,991,549	$127,633
IRR, %	45.14%	8.67%
Payback period, years	2.19	8.39
Profitability ratio	5.75	1.14
Cost without environmental costs, c/ kwh	3.25	4.85

As we can see in the table above, natural gas turbines have much better financial indices than wind turbines. This is due to several factors:

1. Their higher capacity factor allows natural gas turbines to produce more electricity per year, leading to much higher sales and economies of scale.
2. Natural gas turbines have a lower discount rate and investment cost. Wind turbines have higher discount rate and investment cost, and even their low operating costs are not enough to offset the cost advantage of natural gas turbines.

Finally, the total cost of production for wind-generated electricity is 1.5 times higher than for natural gas (3.25 $/kWh to 4.85 $/kWh). One very important point must be made here: although wind turbines have higher costs, the PVNPB is positive. This does not mean, however, that the project is reasonable for development, especially since there is a better alternative. However, considering the fact that we take average estimates for wind projects, in areas where wind power density is higher than average, costs could be lower and financial indices could increase for wind power projects other than the "standard" case.

Comparison of natural gas and wind projects with environmental costs

The situation could change if companies were required (for example, by law) to take environmental costs into consideration. Assuming that companies now have to pay for the environmental damage they cause; wind energy has low environmental cost (0.1 c/kWh); and natural gas has high environmental costs (1.2 c/kWh) (Environmental Costs of Electricity, 1991). Companies do not actually consider those costs, but we can incorporate them in our analysis as part of the social cost of production for both energy sources.

TABLE 15

RESULTS FOR NATURAL GAS AND WIND PROJECTS WITH ENVIRONMENTAL COSTS

	Natural gas	Wind
Capacity, kW	1000	1000
Capacity factor	0.8	0.27
Annual electricity production, kWh	7,008,000	2,399,876
Capital Investment, $	$420,000	$1,000,000
Operating costs, $	$4,586,358	$680,366
Environmental costs, $	$2,018,304	$57,597
Discount factor	$(1.05)^t$	$(1.07)^t$
PVNPB, $	$1,353,323	$109,660
IRR, %	33.67%	8.44%
Payback period, years	2.91	8.50
Profitability ratio	4.23	1.12
Cost of production with environmental costs, c/kwh	4.45	4.95

Environmental costs for natural gas turbines are more than 35 times higher than for wind turbines due to incomplete gas combustion and discharges of CO_2 and NOx into the atmosphere. Looking at the results for natural gas we can see that environmental costs significantly decrease PVNPB (about 50%). The IRR falls from 45.14 % to 33.67%; however, it is still incredibly high. The payback period is prolonged to almost 3 years instead of 2.19.

Environmental costs do not influence the wind turbine financial indices so crucially. PVNPB is reduced only 16% and the difference in the IRR is only 0.23 %.

The most interesting thing now is the cost of energy production. With consideration of the environmental costs, the social cost of electricity production from wind turbines cost per kWh is only 10% higher than natural gas turbines.

With consideration of environmental costs, natural gas turbine production is still very attractive according to the financial indices; however, the social costs of production become very close to that of wind turbines. Wind turbines do not have good financial indices due to the fact that they require large investment in the first year.

Based on the conducted analysis and obtained numbers we can make the following conclusions:

1. It is economically feasible to develop wind energy in Oklahoma, because the typical 1 MW turbine has a positive PVNPB.
2. Consideration of environmental costs increases the efficiency of the wind energy project compared with the natural gas project, but not by enough to offset the economic advantage of natural gas turbines.

5.1.2. Investment Analysis from Social perspective

After calculating the efficiency of the two projects under the condition that a company has to pay all the costs including environmental, we can make the next step and calculate the present value of net social benefits (PVNSB) from the development of a particular project. Social benefits exceed private benefits by the amount of collected taxes, value produced that is captured by the government. Social costs exceed private costs by the value of environmental costs. Social benefits and costs must also be discounted at a lower rate than private benefits and costs. Most economists recommended a rate between 2 and 3 percent.

To calculate the Present Value of Net Social Benefits (PVNSB) we took company income after taxes without consideration of environmental costs, added taxes (property tax and income tax) and subtracted environmental costs. The results of those calculations are presented in Table 16.

TABLE 16

PRESENT VALUE NET SOCIAL BENEFITS FOR NATURAL GAS AND WIND TURBINE

	Natural gas	**Wind**
Project income after taxes, $	3,693,746	1,150,612
Taxes		
Property tax, $	48,150	114,643
Income tax, $	3,025,186	1,086,171
Environmental costs, $	2,018,304	57,579
Present Value Net Social Benefits, $	**2,551,754**	**574,084**
Present Value Net Private Benefits, $ (discount factor 5% for natural gas and 7 % for wind energy)	1,991,549	127,663
Present Value Net Social Benefits, $ (social discount rate of 3%)	3,227,336	1,324,282
Internal Private Rate of Return, %	45	8.7
Internal Social Rate of Return, %	51	13.0

As we can see, the PVNSB for both wind and natural gas projects are higher than the Present Value Net Private Benefits (PVNPB). This means that the net gains to society from both projects exceeds the net gains to private companies. This is an unexpected result, because we suspected that high environmental costs of the natural gas project would make PVNSB < PVNPB for natural gas fired power plants. However, PVNSB from the natural gas project is about 30% (in case of 5% discount rate) higher than the PVNPB. This occurs because taxes are social (not private) benefits, and also because the discount rate is lower from a social perspective.

According to the proposed logic, natural gas projects could be considered for a government subsidy, in spite of the fact that they are quite profitable and also in spite of their adverse environmental impact. However, the fact that natural gas projects have very good profitability indices could probably make them less likely candidates for government support. What government can do and in fact is doing now is making tougher environmental regulation for coal power plants, thus, encouraging investors to put their money in more preferable (for the whole society) natural gas power production.

Concerning the PVNSB from the wind energy project, we can say that it is significantly larger than the Present Value of Net Private Benefits for wind energy (about 4.5 times). Consequently, this shows that in reality wind energy development gives society a lot more than the private calculus indicates. It, too, is a viable candidate for a government subsidy.

Social and private internal rates of return are also very interesting. As we can see for both projects, social internal rates of returns are higher than private. It clearly shows that even with government subsidies, the return from the wind energy project would not exceed 13%, because this is the internal rate of return society gets from this project with consideration of all externalities.

5.1.3.Government Subsidy Analysis

As we have already shown, it is reasonable to analyze the possibility of government subsidies for both wind and natural gas energy. States do not generally subsidize natural gas development, but some states and the federal government have done so for wind energy development. In this section, we look at two of them already in use:

1. Production Tax Credits (1.8 c/kWh according to the federal regulation).
2. Renewable Portfolio Standard (retailer must purchase a fixed amount of electricity from renewable sources).

Production tax credit

Let's assume that our typical Oklahoma windmill with 1 MW capacity receives federal production tax credits. This means that the government will pay 1.8 c/kWh produced. How will it affect the financial indices for the wind project? The results are presented in Table 17.

TABLE 17

FINANCIAL INDICES FOR WIND PROJECT WITH INCLUSION OF PRODUCTION TAX CREDIT

Wind Power density, W/m^2	396
Land use, c/kWh	0.028
Property Tax, mills	80.17
PVNPB, $	437,842
IRR, %	12.49%
Payback period, years	6.41
Profitability Ratio	1.45
Cost of production without EC, c/kwh	4.85

As we can see, the financial indices are significantly improved. The PVNPB is raised more than 3 times, and the IRR increases by 4.1%. Production tax credits could significantly decrease the payback period and make the project more attractive to the investors. Also, notice that the IRR for this project is close to the optimal social IRR for wind projects (13%). This means that production tax credits not only improve the economics of the project, but also do it in an amount connected with an efficient allocation of resources.

Renewable Portfolio Standards

Renewable Portfolio Standards require retailers to purchase a fixed percentage of their energy from renewable sources. Texas has passed such a regulation and is headed to a 9% renewable portfolio by the 2008. Let's make an assumption that Oklahoma passes the same kind of regulation. In 1999 Oklahoma consumed 55,015,641 megawatt hours of electricity. If 9% is supposed to be produced from renewable sources (we suggest wind), then it means that annually about 4,951,408 megawatt hours should be produced in Oklahoma by renewable sources. This requires even higher installed capacity, because wind energy has a low capacity factor of 0.3. Thus, about 1,884 MW of wind energy capacity should be installed in Oklahoma to satisfy this requirement.

To realize this project, Oklahoma companies will have to invest nearly 2 billion dollars in wind turbine installation (a capital investment of $1000/kW). Due to economies of scale our results will be higher (Table 17), IRR will increase compared with the initial results without government support (9.92%). However, the IRR for the production tax credit is higher and it does not require such a large investment. Although the financial results do not look bad, it's up to the state to decid whether it is reasonable to encourage large investments in wind industry development. However, as we can see, for this project, the private IRR is still very far from the optimal social rate (13%).

TABLE 18

FINANCIAL RESULTS FOR THE RENEWABLE PORTFOLIO STANDARDS

PVNPB, $	426,520,370
IRR, %	9.92%
Payback period, years	7.52
Profitability Ratio	1.24
Cost of production without EC, c/kwh	4.53

The preceding analysis compares natural gas-generated electricity with wind-generated electricity under "average" wind conditions for the state of Oklahoma (average for the 26 best counties for wind development). According to this comparison, the economic advantage goes to natural gas. Some parts of the state have better than average wind conditions, however, and wind energy projects may look better in those regions. The next section analyzes this possibility.

5.2. Wind Farm Development on a County Basis for Oklahoma

Oklahoma is a large state with an unequal distribution of wind resources and the efficiency of wind farm installation will be different for different regions. Looking at wind energy development on a county basis we take into consideration four important parameters:

1. **Wind Power Density (W/ m^2)-**
   - there is a positive correlation of wind power density and wind energy efficiency; the higher the wind speed, the higher the capacity factor and electricity production.
2. **Cost of Land ($/ acre)** –
   - land is the main resource used for wind production (except wind itself). The cost of land is important not only because it must be rented (or purchased) for wind turbine installation, but because installed wind turbines will affect the nearest land. The main environmental effects from wind energy are noise pollution and visual disamenities, both of which impact the cost of the land near the wind generators.
3. **Property Tax (mills)** –
   - counties have different property tax rates. Given the high cost of plant and equipment equipment this could be an important source of differences in profitability.
4. **Transmission costs ($/ kWh)** –
   - the location of wind turbines is totally dependent on the quality of wind resources in an area; that's why transmission costs could be significant. Finding exact information about the existing or planned electricity grid is very difficult, so we decided to use average estimates. More transmissions grids are likely to be in the counties with the higher electricity consumption.

For our analysis we are going to use basic Geographical Information System (GIS) methods. The software package used for the calculations is ESRI ArcView GIS 3.3.

5.2.1. Assumptions for County Basis Calculations

Wind Power Density

To calculate the average wind power density for each Oklahoma county we used the initial grid for Oklahoma provided by the Geography Department of Oklahoma State University (Fig. 7). This grid, with a resolution of 375 meters, shows wind power density based on the Mesonet stations data at 50 meter height.

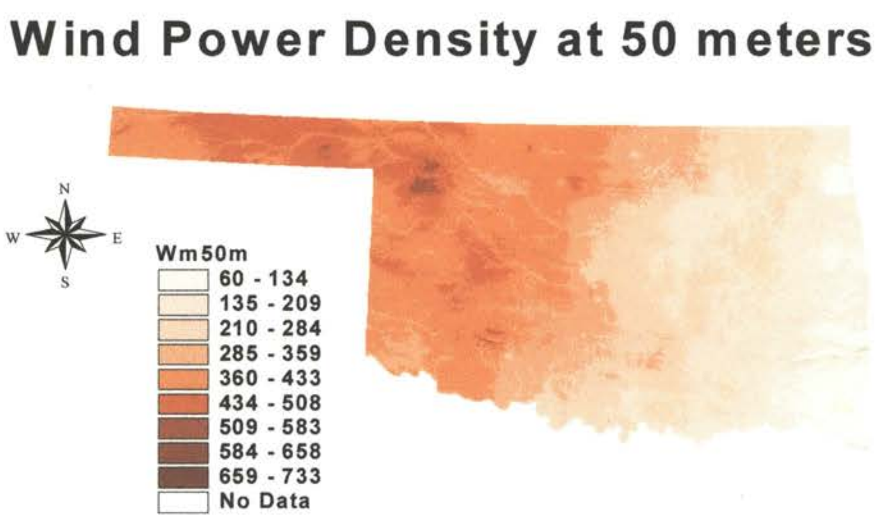

Figure 7. Wind Power Density (W/m^2) for Oklahoma at 50 m height. Source: Geography Department of Oklahoma State University (Dr. Steve Stadler).

Our first goal was to calculate the average wind power density for each Oklahoma county. Two main steps were taken to obtain this goal:

1. The wind power density grid was overlaid with the county polygon for Oklahoma.
2. Zonal statistics were determined for each county.

As already mentioned, we are using an ArcView GIS 3.3 software package to conduct the analysis and present results. The average wind power density for each county is presented in figure 8.

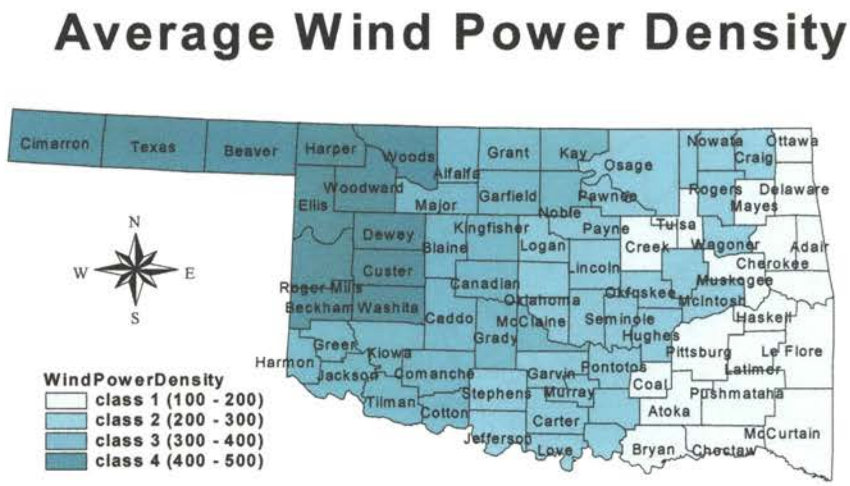

Figure 8. Average Wind Power Density (W/ m^2) for Oklahoma counties.

As can be seen from the map, wind class number 4 is the highest wind class for Oklahoma. The best wind conditions are located in the Northwestern part of the state. Wind power density declines while moving East, and the worst wind resources are in the Northeastern part of Oklahoma. I would like to underline that we are talking about commercial production with intermediate size turbines (100 kW – 1 MW), not about the small turbines (less than 100 kW) for personal consumption. For small turbines, additional economical analysis should be made.

Cost of the Land

As noted, different counties have different land cost. This will influence wind turbine development due to two main factors:

a. Land is used for turbine installation (rented or purchased).

b. Some environmental impacts from wind production will influence near by land.

The first factor is pretty straightforward: the higher the cost of land the more that wind-generated electricity will cost. The influence of the second factor is based on the fact that some environmental impacts of wind energy (noise and visual impact) most likely will lead to a decline in land value in near by areas. Nobody really wants to live in a noisy environment; some people just don't like to view windmills. Although this reduction in value is a real cost, we know of no reason why it would vary by county. So it is not included in the calculations.

Distribution of the land cost per acre is presented on Figure9.

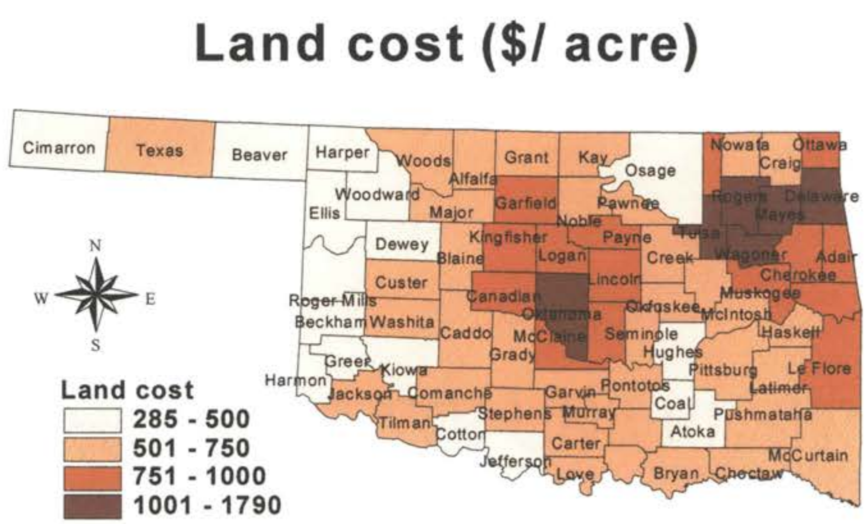

Figure 9. Average land cost per acre ($/acre) for Oklahoma counties.

On the map we can see that the highest land cost is in the two most populated urban areas (Oklahoma City and Tulsa). Generally, the further from the populated centers the lower is the land cost. The lowest cost land is primarily in the western part of the state and the panhandle.

Property tax

The data for Oklahoma property taxes by county was taken from the Agricultural Economics Publications website of Oklahoma State University (http://agweb.okstate.edu/pearl/agecon/resource/index.html). Based on this information, a map of property tax distribution was created in ArcView (Fig. 10).

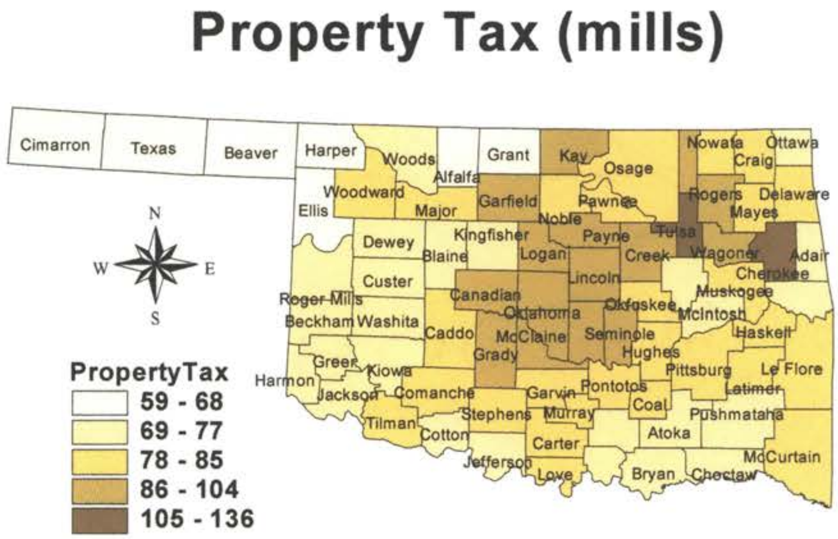

Figure 10. Property Tax Rate (mills) for Oklahoma counties.

The highest property tax rates are in counties around the most populated areas (Oklahoma City and Tulsa). Western Oklahoma and the panhandle have relatively low property tax rates.

Transmission costs

Accounting for differences in transmissions costs was probably the most difficult challenge. The problem is that existing data about the electric grid are very fragmentary, or not available in the appropriate format. Thus, it was necessary to make some assumptions. We expect that the higher the population density in the county, the more electric grids it has, and the lower the probability that new transmission lines would have to be built. Electricity consumption would be an even better proxy for the electric grid, but data for electricity consumption by county were not available. Instead we took per capita electricity consumption for Oklahoma and multiplied it by the county population. The map resulting from those calculations is presented as figure 11.

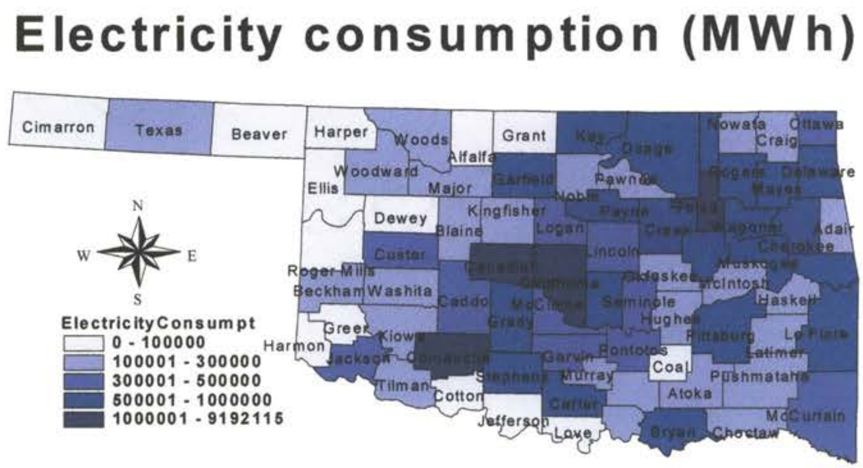

Figure 11. Electricity consumption (MWh) for Oklahoma counties.

It is not surprising that we have higher electricity consumption in the most populated areas (Oklahoma City, Tulsa), but on the map it can be clearly seen that electricity consumption is higher in the eastern part of Oklahoma and relatively lower in the western part, where there are better wind resources.

To calculate transmission costs for each county we consider that counties with the higher electricity consumption have a more developed transmission infrastructure and, thus, lower transmission costs for new sources of supply. We assign a transmission coefficient to each county depending on its electricity consumption (Table 19).

TABLE 19

TRANSMISSION COEFFICIENT FOR OKLAHOMA COUNTIES

Electricity consumption, MWh	Transmission coefficient
Less than 100,000	**5**
100,000 – 300,000	**4**
300,000 – 500,000	**3**
500,000 – 1,000,000	**2**
1,000,000 and more	**1**

In our calculations we multiply the average statewide transmission cost (0.02 c/kWh) by the transmission coefficient. Thus, transmission costs in the counties with low electricity consumption could be 5 times lower than in the counties with high electricity consumption.

5.2.2. Results for Oklahoma Counties Wind Energy Development

After obtaining all the data mentioned above and making all the necessary assumptions we calculated the main financial indices (PVNPB, IRR, profitability ratio, cost of production) for each Oklahoma county, using the Excel model described in chapter III, and then created maps of the results.

Figure 12 shows the distribution of PVNPB for Oklahoma counties.

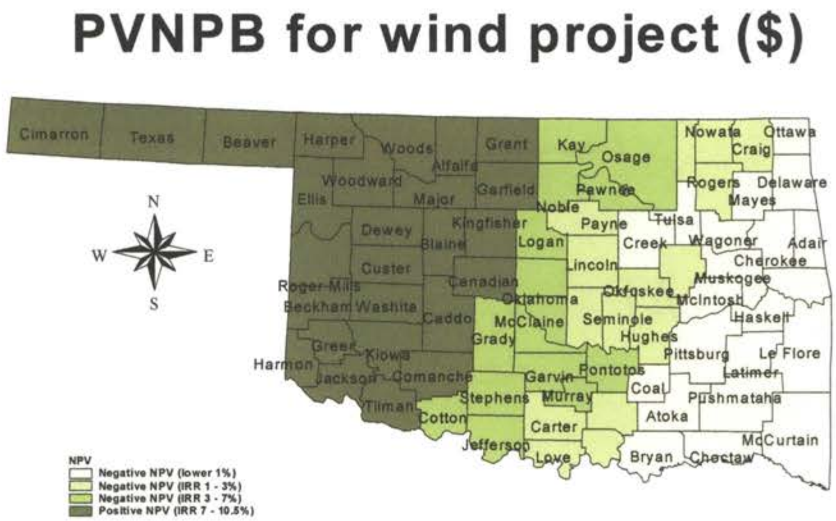

Figure 12. Present Value of Net Private Benefits ($) of wind energy development for Oklahoma counties.

As can be seen, the PVNPB distribution resembles the wind power density distribution. This means that wind speed is the main factor that influences the economic efficiency of wind energy projects. Dark green marks the counties with the positive PVNPB. Those counties are the best prospects for wind energy development. There are 26 of them, located in the western part of the state.

All other counties have a negative PVNPB. Wind energy development is unlikely in these counties in the absence of government incentives such as production tax credits and renewable standard portfolio regulations.

Counties marked with a light green have the lowest PVNPB in Oklahoma. Here, even large government incentives might not be enough to stimulate the development of wind energy.

In Figure 13 we can see the cost of wind energy production in the different counties. As noted, PVNPB remains positive as long as production costs vary from 4.32 to 5.21 c/ kWh.

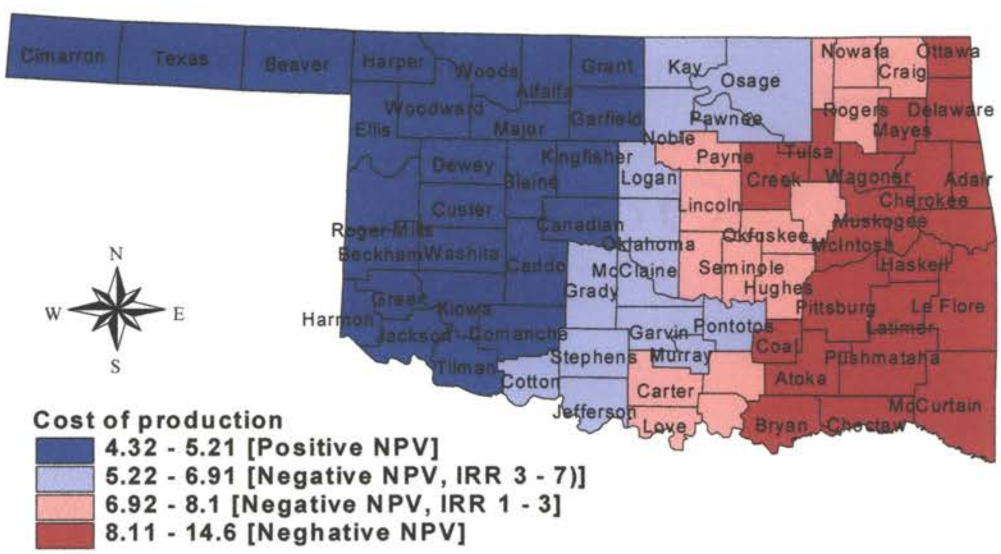

Figure 13. Cost of electricity production from wind energy for Oklahoma counties, c/ kWh.

Speaking about the prospective Oklahoma wind project in Caddo and Comanche counties mentioned in Chapter 1, we can say that it seems to be very logical to start development in those counties, because they present a good combination of high wind speed and closeness to electricity consumers. Their wind power density is class 3 and is a little bit lower than the one taken for average Oklahoma calculations (average, 396, Caddo, 378, Comanche, 367). The other parameters are also very close to our average scenario, like land cost (average 678 $/ acre, Caddo – 670 $/acre, Comanche – 720 $/acre), property tax (average 80.17 mills, Caddo – 83.63 mills, Comanche – 80.92). However, these counties have high electricity consumptions (Caddo 419,628 MWh, Comanche 1,600,514 MWh). According to our calculations (Appendix 3), IRR for Caddo and Comanche counties will be 7.88% and 7.6 % accordingly. The cost of production will vary from 5 c/kWh in Caddo to 5.07 c/kWh in Comanche without consideration of environmental costs.

These two are counties with very good locations for wind farm installation. On the one hand, they have a pretty high electricity consumption themselves (especially, Comanche). On the other hand, closeness to Texas makes possible future electricity exports to Texas for the renewable energy portfolio regulation, which Texas producers have to meet by 2008.

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Several important results were obtained from our analysis:

1. Wind energy development is efficient and practicable in Oklahoma. However, it is generally not as economically attractive as natural gas.
2. In 26 counties (in the Western part of the state) the PVNPB from wind energy development is positive. Thus, wind energy development in this region is profitable. However, it is not as profitable as natural gas energy development.
3. A wind project with average wind power density for each county is taken into consideration, but still there are particular sites with better than average conditions and efficiency there could be a lot higher.
4. Due to the fact that the Present Value of Net Social Benefits is larger than the Present Value of Net Private Benefits for wind energy development, some government support for wind energy development appears to be justified. Here again, however, the size of the subsidy that is justified is not large enough to make wind energy development competitive with natural gas energy development. Moreover, the PVNSB > PVNPB for natural gas projects, so a subsidy for them can be justified also.

5. For 36 counties (in the eastern part of the state) PVNPB will be negative due to low wind speed, and it is unreasonable to make an effort to develop wind energy there, and it certainly makes no sense to subsidize it.

References

1. Afgan, N.H. and M.G. Carvalho. Sustainable assessment methods for energy systems. Boston-Dordrecht-London: Kluwer Academic Publishers, 2000.
2. Annual Energy Outlook 2003 with Projections to 2025. On the web-site of Energy Information Administration. Available on-line: http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html#ng April 23, 2003.
3. Asmus, Peter. Reaping the Wind. Washington, DC, Covelo, CA: Island Press, 2001.
4. Berinstein, P. Alternative Energy: Facts, Statistics, and Issues. Westport, CT: Oryx Press, 2001.
5. Burton, T., Sharpe, D., Jenkins, N, and Bossanyi, E. Wind Energy Handbook. Chichester; New York: J. Wiley, 2001.
6. Carless, J. Renewable energy. A Concise Guide to Green Alternatives. New York: Walker and Company, 1993.
7. Cassedy, E.S. Prospects for Sustainable Energy. A Critical Assessment. Cambrige, United Kingdom: Cambrige University Press, 2000.
8. Chambers, Ann, Hamilton, Stephanie and Schnoor, Barry. Distributed Generation: A Nontechnical Guide. Tulsa, OK: PennWell Corp., 2001.
9. Edinger R. and S. Kaul. Renewable Resources for Electric Power. Westport, Connecticut and London: Quorum Books, 2000.
10. Elliott, D.L. and M.N. Schwartz. Wind Energy Potential in the United States. On the web-site of National Wind Technology Center. Available on-line: http://www.nrel.gov/wind/wind_potential.html November 6, 2002.
11. Energy Efficiency. Issues and Trends. (Moeller, ed.). New York, NY: Nova Science Publishers, Inc., 2002.

12. Environmental costs of Electricity. New York-London-Rome: Oceana Publications, Inc., 1991.

13. Gipe, Paul. Wind Energy Basics. A Guide to Small and Micro Wind Systems. Wight River Junction, VR, Totnes, England: Chelsea Green Publishing Company, 1999.

14. Gipe, Paul. Wind Energy Comes of Age. New York, Chechister, Toronto, Brisbane, Singapore: John Willey and Sons, Inc., 1995.

15. Hayward, David L. and Schmidt, Michael R. Valuing an Electric Utility: Theory and Application. Vienna, Virginia: Public Utilities Reports, Inc., 1999.

16. Hyman, Leonard S., Hyman Andrew S. and Hyman, Robert C. America's Electric Utilities: past, Present and Future. Vienna, Virginia: Public Utilities Reports, Inc., 2000.

17. Milligan, M.R. "Modeling Utility-scale Wind Power Plants. Part 1: Economics". *Wind energy*, 2: 167-193, 1999.

18. Milligan, M.R. "Modeling Utility-scale Wind Power Plants. Part 2: Capacity Credits". *Wind energy*, 3: 167-206, 2000.

19. National Energy Policy (2001). On the web-site of The White House. Available on-line: http://www.whitehouse.gov/energy/National-Energy-Policy.pdf [2002, November, 25].

20. Natural Gas Annually 2001. On the web-site of Energy Information Administration. Available on-line: http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/natural_gas_annual/current/pdf/table_023.pdf [2003, April, 23].

21. Oklahoma's Wind Resource: Economic Analysis. (2002). On web-site of Oklahoma Wind Power Initiative. Available on-line: http://www.seic.okstate.edu/owpi. Accessed September 20, 2002.

22. Review of States' Policy Incentives for the Development of Wind Energy Facilities. (2000). On Oklahoma Wind Power Initiative. Available on-line:

http://www.seic.okstate.edu/owpi/Policymkr/Library/state%20summary2.pdf Accessed November 25, 2002.

23. Righter, Robert W. Wind Energy in America. A History. Norman, OK: University of Oklahoma Press, 1996.

24. Pasqualetti, Martin J., Gipe, Paul and Righter, Robert W. Wind Power in View. Energy Landscape in a Crowded World. San Francisco, CA: Academic Press, 2002.

25. Skantze, Petter L. and Ilic, Marija D. Valuation, Hedging and Speculation in Competitive Electricity Markets. A Fundamental Approach. Boston, MA: Kluwer Academic Pubishers., 2001.

26. Soares, Claire M. Environmental technology and Economics. Boston, MA: Butterworth-Heinemann, 1999.

27. Sorensen, B. Renewable Energy. San Diego, San Francisco, New York, Boston, London, Sydney, Tokyo: Academic Press, 2000.

28. State electricity profiles. Oklahoma. (2002). On web-site of Energy Information Agency. Available on-line: http://www.eia.doe.gov/cneaf/electricity/st_profiles/oklahoma/ok.html Accessed on November 6, 2002.

29. The Economics of Wind Energy. (2002). On the web-site of American Wind Energy Association. Available on-line: http://www.awea.org Accessed September 20, 2002.

30. The Future for Renewable Energy. Prospects and Directions. London, UK: EUREC Agency, 1996.

31. The Oklahoma WinCharger. (2003). Vol.3, #2. On the web-site of the Oklahoma Wind Power Initiative. Available on-line: http://www.seic.okstate.edu/owpi/Stakehld/landownr/Mar2003Issue_Full.pdf Accessed April, 8, 2003.

32. Thresher, R.W. and D.M. Dodge. "Trends in the Evolution of Wind Turbine Generator Configurations and Systems". *Wind Energy*, 1 : 70-85, 1998.

33. Tutorial. Oklahoma Wind Power Initiative. (2002). On the web site of Oklahoma Wind Power Initiative. Available on-line: http://www.seic.okstate.edu/owpi/EducOut/default.htm Accessed on October 16, 2002.

34. Walker, John F. and Jenkins, Nicholas. Wind Energy Technology. Chichester, England: John Wiley and Sons, 1997.

35. Warkentin, Denise. Electric Power Industry in Nontechnical Language. Tulsa, OK: PennWell, 1998.

36. What are the factors in the cost of electricity from wind turbines? Available on-line: http://dexter.okstate.edu/servlet/com.sun.webaccess.mail.Mail/1/cost.html Accessed October 16, 2002.

37. Wind Assessment for Oklahoma. (2002). On web-site of Oklahoma Wind Power Initiative. Available on-line: http://www.seic.okstate.edu/owpi. Accessed September 20, 2002.

38. Wind Energy Costs. (1997). On the web site of National Wind Coordinating Committee. Available on-line: http://www.nationalwind.org/pubs/wes/wes11.htm Accessed September 25, 2002.

39. Wind Energy Environmental Issues. (1997). On the web site of National Wind Coordinating Committee. Available on-line: http://www.nationalwind.org/pubs/wes/wes02.htm Accessed September 25, 2002.

40. Woelfle, Gretchen. The Wind at Work. An Activity Guide to Windmills. Chicago, IL: Chicago Review Press, Inc., 1997.

Appendices 1 – 3

Appendix 1-1. Operating and maintenance costs of a natural gas power plant

Years	O & M, $	Land use, $	Fuel, $	Insurance, $	Transmission, $	Management Fees, $	Total O & M, $
cents/kWh	**1**	**0.010**	**500**	**0**	**0.01**	**0**	
1	$0	$0	$0	$0	$0	$0	$0
2	$70,080	$678	$119,639	$0	$701	$0	$191,098
3	$70,080	$678	$119,639	$0	$701	$0	$191,098
4	$70,080	$678	$119,639	$0	$701	$0	$191,098
5	$70,080	$678	$119,639	$0	$701	$0	$191,098
6	$70,080	$678	$119,639	$0	$701	$0	$191,098
7	$70,080	$678	$119,639	$0	$701	$0	$191,098
8	$70,080	$678	$119,639	$0	$701	$0	$191,098
9	$70,080	$678	$119,639	$0	$701	$0	$191,098
10	$70,080	$678	$119,639	$0	$701	$0	$191,098
11	$70,080	$678	$119,639	$0	$701	$0	$191,098
12	$70,080	$678	$119,639	$0	$701	$0	$191,098
13	$70,080	$678	$119,639	$0	$701	$0	$191,098
14	$70,080	$678	$119,639	$0	$701	$0	$191,098
15	$70,080	$678	$119,639	$0	$701	$0	$191,098
16	$70,080	$678	$119,639	$0	$701	$0	$191,098
17	$70,080	$678	$119,639	$0	$701	$0	$191,098
18	$70,080	$678	$119,639	$0	$701	$0	$191,098
19	$70,080	$678	$119,639	$0	$701	$0	$191,098
20	$70,080	$678	$119,639	$0	$701	$0	$191,098
21	$70,080	$678	$119,639	$0	$701	$0	$191,098
22	$70,080	$678	$119,639	$0	$701	$0	$191,098
23	$70,080	$678	$119,639	$0	$701	$0	$191,098
24	$70,080	$678	$119,639	$0	$701	$0	$191,098
25	$70,080	$678	$119,639	$0	$701	$0	$191,098
Total	$1,681,920	$16,272	$2,871,347	$0	$16,819	$0	**$4,586,358**

Appendix 1-2. Discounted Cash Flow of a Natural Gas Power Plant

Discount coefficient **1.05**

Years	Sales, $	Investments, $	O&M, $	Propoerty tax, $	Environmental costs,$	Annual Income, $	Discounted cash flow before tax, $	Cash flow after taxes, $	Discounted cash flow after taxes, $	Cummulative Profit after Taxes, $
1	$0	$420,000	$0	$3,704	$0	-$423,704	-$423,704	-$423,704	-$423,704	-$423,704
2	$490,560	$0	$191,098	$3,556	$0	$295,906	$281,815	$189,756	$180,720	-$233,947
3	$490,560	$0	$191,098	$3,408	$0	$296,054	$268,530	$209,116	$189,674	-$24,832
4	$490,560	$0	$191,098	$3,259	$0	$296,202	$255,871	$195,967	$169,284	$171,136
5	$490,560	$0	$191,098	$3,111	$0	$296,351	$243,808	$186,599	$153,515	$357,735
6	$490,560	$0	$191,098	$2,963	$0	$296,499	$232,314	$179,952	$140,997	$537,687
7	$490,560	$0	$191,098	$2,815	$0	$296,647	$221,362	$180,033	$134,344	$717,720
8	$490,560	$0	$191,098	$2,667	$0	$296,795	$210,927	$180,115	$128,004	$897,835
9	$490,560	$0	$191,098	$2,519	$0	$296,943	$200,983	$171,729	$116,233	$1,069,564
10	$490,560	$0	$191,098	$2,370	$0	$297,091	$191,508	$163,400	$105,329	$1,232,965
11	$490,560	$0	$191,098	$2,222	$0	$297,239	$182,479	$163,482	$100,364	$1,396,446
12	$490,560	$0	$191,098	$2,074	$0	$297,388	$173,876	$163,563	$95,632	$1,560,009
13	$490,560	$0	$191,098	$1,926	$0	$297,536	$165,679	$163,645	$91,123	$1,723,654
14	$490,560	$0	$191,098	$1,778	$0	$297,684	$157,868	$163,726	$86,827	$1,887,380
15	$490,560	$0	$191,098	$1,630	$0	$297,832	$150,425	$163,808	$82,734	$2,051,188
16	$490,560	$0	$191,098	$1,482	$0	$297,980	$143,334	$163,889	$78,833	$2,215,077
17	$490,560	$0	$191,098	$1,333	$0	$298,128	$136,576	$163,971	$75,117	$2,379,048
18	$490,560	$0	$191,098	$1,185	$0	$298,277	$130,137	$164,052	$71,575	$2,543,100
19	$490,560	$0	$191,098	$1,037	$0	$298,425	$124,002	$164,134	$68,201	$2,707,233
20	$490,560	$0	$191,098	$889	$0	$298,573	$118,155	$164,215	$64,985	$2,871,448
21	$490,560	$0	$191,098	$741	$0	$298,721	$112,585	$164,297	$61,922	$3,035,745
22	$490,560	$0	$191,098	$593	$0	$298,869	$107,277	$164,378	$59,002	$3,200,123
23	$490,560	$0	$191,098	$444	$0	$299,017	$102,219	$164,460	$56,220	$3,364,582
24	$490,560	$0	$191,098	$296	$0	$299,165	$97,400	$164,541	$53,570	$3,529,123
25	$490,560	$0	$191,098	$148	$0	$299,314	$92,808	$164,622	$51,044	$3,693,746
Total	$11,773,440	$420,000	$4,586,358	$48,150	$0	$6,718,932	$3,678,234	$3,693,746	**$1,991,549**	

Appendix 1-3. Income Statement of a Natural Gas Power Plant

0.45

Years	Sales, $	Investments, $	O&M, $	Depreciation, $	Propoerty tax, $	Environmental costs,$	Income before tax, $	Cummulative income before tax, $	Income tax, $	Net income, $
1	$0	$420,000	$0	$0	$3,704	$0	-$423,704	-$423,704	$0	-$423,704
2	$490,560	$0	$191,098	$60,018	$3,556	$0	$235,888	-$187,816	$106,150	$129,738
3	$490,560	$0	$191,098	$102,858	$3,408	$0	$193,196	$5,380	$86,938	$106,258
4	$490,560	$0	$191,098	$73,458	$3,259	$0	$222,744	$228,125	$100,235	$122,509
5	$490,560	$0	$191,098	$52,458	$3,111	$0	$243,893	$472,017	$109,752	$134,141
6	$490,560	$0	$191,098	$37,506	$2,963	$0	$258,993	$731,010	$116,547	$142,446
7	$490,560	$0	$191,098	$37,506	$2,815	$0	$259,141	$990,151	$116,613	$142,527
8	$490,560	$0	$191,098	$37,506	$2,667	$0	$259,289	$1,249,440	$116,680	$142,609
9	$490,560	$0	$191,098	$18,690	$2,519	$0	$278,253	$1,527,693	$125,214	$153,039
10	$490,560	$0	$191,098	$0	$2,370	$0	$297,091	$1,824,784	$133,691	$163,400
11	$490,560	$0	$191,098	$0	$2,222	$0	$297,239	$2,122,024	$133,758	$163,482
12	$490,560	$0	$191,098	$0	$2,074	$0	$297,388	$2,419,411	$133,824	$163,563
13	$490,560	$0	$191,098	$0	$1,926	$0	$297,536	$2,716,947	$133,891	$163,645
14	$490,560	$0	$191,098	$0	$1,778	$0	$297,684	$3,014,631	$133,958	$163,726
15	$490,560	$0	$191,098	$0	$1,630	$0	$297,832	$3,312,463	$134,024	$163,808
16	$490,560	$0	$191,098	$0	$1,482	$0	$297,980	$3,610,443	$134,091	$163,889
17	$490,560	$0	$191,098	$0	$1,333	$0	$298,128	$3,908,572	$134,158	$163,971
18	$490,560	$0	$191,098	$0	$1,185	$0	$298,277	$4,206,848	$134,224	$164,052
19	$490,560	$0	$191,098	$0	$1,037	$0	$298,425	$4,505,273	$134,291	$164,134
20	$490,560	$0	$191,098	$0	$889	$0	$298,573	$4,803,846	$134,358	$164,215
21	$490,560	$0	$191,098	$0	$741	$0	$298,721	$5,102,567	$134,424	$164,297
22	$490,560	$0	$191,098	$0	$593	$0	$298,869	$5,401,436	$134,491	$164,378
23	$490,560	$0	$191,098	$0	$444	$0	$299,017	$5,700,453	$134,558	$164,460
24	$490,560	$0	$191,098	$0	$296	$0	$299,165	$5,999,618	$134,624	$164,541
25	$490,560	$0	$191,098	$0	$148	$0	$299,314	$6,298,932	$134,691	$164,622
Total	**$11,773,440**	**$420,000**	**$4,586,358**	**$420,000**	**$48,150**	**$0**	**$6,298,932**		**$3,025,186**	**$3,273,746**

Cost of production without envr costs, c/kWp **3.25**

Appendix 2-1. Operating and maintenance costs of a wind turbine

Transmission costs	0.02
Transmission coefficient	5

Years	O & M, $	Land use, $	Insurance, $	Transmission, $	Management Fees, $	Total O & M, $
cents/kWh	**0.9**	**0.028**	**0.003**	**0.1**	**0.15**	
1	$0	$0	$0	$0	$0	$0
2	$21,599	$678	$72	$2,400	$3,600	$28,349
3	$21,599	$678	$72	$2,400	$3,600	$28,349
4	$21,599	$678	$72	$2,400	$3,600	$28,349
5	$21,599	$678	$72	$2,400	$3,600	$28,349
6	$21,599	$678	$72	$2,400	$3,600	$28,349
7	$21,599	$678	$72	$2,400	$3,600	$28,349
8	$21,599	$678	$72	$2,400	$3,600	$28,349
9	$21,599	$678	$72	$2,400	$3,600	$28,349
10	$21,599	$678	$72	$2,400	$3,600	$28,349
11	$21,599	$678	$72	$2,400	$3,600	$28,349
12	$21,599	$678	$72	$2,400	$3,600	$28,349
13	$21,599	$678	$72	$2,400	$3,600	$28,349
14	$21,599	$678	$72	$2,400	$3,600	$28,349
15	$21,599	$678	$72	$2,400	$3,600	$28,349
16	$21,599	$678	$72	$2,400	$3,600	$28,349
17	$21,599	$678	$72	$2,400	$3,600	$28,349
18	$21,599	$678	$72	$2,400	$3,600	$28,349
19	$21,599	$678	$72	$2,400	$3,600	$28,349
20	$21,599	$678	$72	$2,400	$3,600	$28,349
21	$21,599	$678	$72	$2,400	$3,600	$28,349
22	$21,599	$678	$72	$2,400	$3,600	$28,349
23	$21,599	$678	$72	$2,400	$3,600	$28,349
24	$21,599	$678	$72	$2,400	$3,600	$28,349
25	$21,599	$678	$72	$2,400	$3,600	$28,349
Total	$518,373	$16,272	$1,728	$57,597	$86,396	**$680,366**

Appendix 2-2. Discounted Cash Flow of a Wind Turbine

Discount factor **1.07**

Years	Sales, $	Investments, $	O&M, $	Propoerty tax, $	Environmental costs,$	Annual Income, $	Discounted cash flow before tax, $	Cash flow after taxes, $	Discounted cash flow after taxes, $	Cummulative Profit after Taxes, $	Discounted cummulative cash flow after taxes, $
1	$0	$1,000,000	$0	$8,819	$0	-$1,008,819	-$1,008,819	-$1,008,819	-$1,008,819	-$1,008,819	-$1,008,819
2	$167,991	$0	$28,349	$8,466	$0	$131,177	$122,595	$131,177	$122,595	-$877,642	-$820,226
3	$167,991	$0	$28,349	$8,113	$0	$131,530	$114,883	$131,530	$114,883	-$746,112	-$651,683
4	$167,991	$0	$28,349	$7,760	$0	$131,882	$107,655	$131,882	$107,655	-$614,230	-$501,395
5	$167,991	$0	$28,349	$7,408	$0	$132,235	$100,881	$128,934	$98,363	-$485,296	-$370,230
6	$167,991	$0	$28,349	$7,055	$0	$132,588	$94,533	$113,108	$80,645	-$372,188	-$265,365
7	$167,991	$0	$28,349	$6,702	$0	$132,941	$88,584	$113,302	$75,498	-$258,885	-$172,506
8	$167,991	$0	$28,349	$6,349	$0	$133,293	$83,008	$113,496	$70,680	-$145,389	-$90,541
9	$167,991	$0	$28,349	$5,997	$0	$133,646	$77,783	$93,530	$54,435	-$51,859	-$30,182
10	$167,991	$0	$28,349	$5,644	$0	$133,999	$72,886	$73,699	$40,088	$21,841	$11,880
11	$167,991	$0	$28,349	$5,291	$0	$134,352	$68,298	$73,893	$37,564	$95,734	$48,666
12	$167,991	$0	$28,349	$4,938	$0	$134,704	$63,997	$74,087	$35,198	$169,821	$80,681
13	$167,991	$0	$28,349	$4,586	$0	$135,057	$59,967	$74,281	$32,982	$244,103	$108,385
14	$167,991	$0	$28,349	$4,233	$0	$135,410	$56,190	$74,475	$30,905	$318,578	$132,199
15	$167,991	$0	$28,349	$3,880	$0	$135,763	$52,651	$74,669	$28,958	$393,247	$152,508
16	$167,991	$0	$28,349	$3,527	$0	$136,115	$49,334	$74,863	$27,134	$468,111	$169,665
17	$167,991	$0	$28,349	$3,175	$0	$136,468	$46,226	$75,057	$25,425	$543,168	$183,990
18	$167,991	$0	$28,349	$2,822	$0	$136,821	$43,314	$75,251	$23,823	$618,420	$195,776
19	$167,991	$0	$28,349	$2,469	$0	$137,174	$40,585	$75,445	$22,322	$693,865	$205,290
20	$167,991	$0	$28,349	$2,116	$0	$137,526	$38,027	$75,639	$20,915	$769,505	$212,774
21	$167,991	$0	$28,349	$1,764	$0	$137,879	$35,631	$75,833	$19,597	$845,338	$218,451
22	$167,991	$0	$28,349	$1,411	$0	$138,232	$33,385	$76,027	$18,362	$921,365	$222,522
23	$167,991	$0	$28,349	$1,058	$0	$138,584	$31,280	$76,221	$17,204	$997,587	$225,169
24	$167,991	$0	$28,349	$705	$0	$138,937	$29,308	$76,415	$16,120	$1,074,002	$226,557
25	$167,991	$0	$28,349	$353	$0	$139,290	$27,461	$76,609	$15,103	$1,150,612	$226,839
Total	$4,031,791	$1,000,000	$680,366	$114,643	$0	$2,236,783	$529,645	$1,150,612	**$127,633**		

Appendix 2-3. Income Statement of a Wind Turbine

0.45

Years	Sales, $	Investments, $	O&M, $	Depriciation, $	Propoerty tax, $	Environmental costs,$	Before Tax Income, $	Cummulative before tax income, $	Income tax, $	Net Income, $
1	$0	$1,000,000	$0	$0	$8,819	$0	-$1,008,819	-$1,008,819	$0	-$1,008,819
2	$167,991	$0	$28,349	$142,900	$8,466	$0	-$11,723	-$1,020,542	$0	-$11,723
3	$167,991	$0	$28,349	$244,900	$8,113	$0	-$113,370	-$1,133,912	$0	-$113,370
4	$167,991	$0	$28,349	$174,900	$7,760	$0	-$43,018	-$1,176,930	$0	-$43,018
5	$167,991	$0	$28,349	$124,900	$7,408	$0	$7,335	-$1,169,595	$3,301	$4,034
6	$167,991	$0	$28,349	$89,300	$7,055	$0	$43,288	-$1,126,307	$19,480	$23,808
7	$167,991	$0	$28,349	$89,300	$6,702	$0	$43,641	-$1,082,667	$19,638	$24,002
8	$167,991	$0	$28,349	$89,300	$6,349	$0	$43,993	-$1,038,673	$19,797	$24,196
9	$167,991	$0	$28,349	$44,500	$5,997	$0	$89,146	-$949,527	$40,116	$49,030
10	$167,991	$0	$28,349	$0	$5,644	$0	$133,999	-$815,529	$60,299	$73,699
11	$167,991	$0	$28,349	$0	$5,291	$0	$134,352	-$681,177	$60,458	$73,893
12	$167,991	$0	$28,349	$0	$4,938	$0	$134,704	-$546,473	$60,617	$74,087
13	$167,991	$0	$28,349	$0	$4,586	$0	$135,057	-$411,416	$60,776	$74,281
14	$167,991	$0	$28,349	$0	$4,233	$0	$135,410	-$276,006	$60,934	$74,475
15	$167,991	$0	$28,349	$0	$3,880	$0	$135,763	-$140,244	$61,093	$74,669
16	$167,991	$0	$28,349	$0	$3,527	$0	$136,115	-$4,128	$61,252	$74,863
17	$167,991	$0	$28,349	$0	$3,175	$0	$136,468	$132,340	$61,411	$75,057
18	$167,991	$0	$28,349	$0	$2,822	$0	$136,821	$269,160	$61,569	$75,251
19	$167,991	$0	$28,349	$0	$2,469	$0	$137,174	$406,334	$61,728	$75,445
20	$167,991	$0	$28,349	$0	$2,116	$0	$137,526	$543,860	$61,887	$75,639
21	$167,991	$0	$28,349	$0	$1,764	$0	$137,879	$681,739	$62,046	$75,833
22	$167,991	$0	$28,349	$0	$1,411	$0	$138,232	$819,971	$62,204	$76,027
23	$167,991	$0	$28,349	$0	$1,058	$0	$138,584	$958,555	$62,363	$76,221
24	$167,991	$0	$28,349	$0	$705	$0	$138,937	$1,097,493	$62,522	$76,415
25	$167,991	$0	$28,349	$0	$353	$0	$139,290	$1,236,783	$62,680	$76,609
Total	**$4,031,791**	**$1,000,000**	**$680,366**	**$1,000,000**	**$114,643**	**$0**	**$1,236,783**		**$1,086,171**	**$150,612**

Cost of production without envr costs, c/kWp **4.85**

Appendix 3.Paramenters and results of wind mill development for Oklahoma counties

	Wind Power density, W/m2	Land cost, $/ acre	Cost of land use, c/kWh	Property Tax	Electricity consumption, MWh	Transmission coefficient	NPV, $	IRR, %	Payback period	Profitability Ratio	Cost of production with EC, c/kwh	Cost of production without EC, c/kwh
Beaver	454	325	0.005	59.33	81518	5	$273,773	10.53		1.28	4.42	4.32
Woodward	452	358	0.015	79.73	257288	4	$259,871	10.34		1.27	4.46	4.36
Texas	446	511	0.008	65.53	279849	4	$252,750	10.26		1.26	4.48	4.38
Harper	435	291	0.005	68.02	49576	5	$221,863	9.88		1.23	4.58	4.48
Ellis	423	285	0.005	67.71	56716	5	$191,289	9.49		1.20	4.67	4.57
Washita	419	558	0.009	74.56	160168	4	$178,073	9.32		1.19	4.71	4.61
Custer	415	602	0.010	77.21	363844	3	$169,284	9.20		1.18	4.73	4.63
Roger Mills	411	381	0.006	74.79	47822	5	$154,576	9.02		1.16	4.79	4.69
Cimarron	407	320	0.005	60.07	43814	5	$154,358	9.02		1.16	4.79	4.69
Dewey	406	385	0.007	69.42	66013	5	$145,586	8.90		1.15	4.82	4.72
Beckham	403	475	0.008	74.03	275562	4	$137,168	8.79		1.15	4.85	4.75
Woods	401	587	0.010	73.3	126501	4	$131,578	8.72		1.14	4.87	4.77
Kiowa	399	448	0.008	71.07	142339	4	$128,863	8.69		1.14	4.87	4.77
Blaine	393	549	0.010	74.76	166682	4	$109,955	8.44		1.12	4.94	4.84
Garfield	390	693	0.012	87.81	804641	2	$99,453	8.30		1.11	4.97	4.87
Alfalfa	385	713	0.013	67.45	84969	5	$89,139	8.17		1.10	5.03	4.93
Grant	379	664	0.012	62.03	71594	5	$77,449	8.02		1.08	5.07	4.97
Caddo	378	670	0.012	83.63	419628	3	$67,089	7.88		1.08	5.10	5.00
Tillman	377	551	0.010	82.27	129256	4	$62,639	7.83		1.07	5.12	5.02
Comanche	367	720	0.013	80.92	1600514	1	$45,332	7.60		1.05	5.17	5.07
Greer	368	395	0.007	70.83	84357	5	$43,678	7.58		1.05	5.20	5.10

Major	367	583	0.011	79.52	105011	4	$36,925	7.49		1.05	5.22	5.12
Canadian	365	978	0.018	86.77	1220567	1	$33,715	7.45		1.04	5.22	5.12
Harmon	364	402	0.008	70.28	45693	5	$33,094	7.44		1.04	5.24	5.14
Kingfisher	362	768	0.015	74.12	193822	4	$25,540	7.34		1.03	5.27	5.17
Jackson	356	609	0.012	74.14	395814	3	$13,727	7.18		1.02	5.31	5.21
Grady	346	656	0.013	87.63	633492	2	-$20,196	6.73		0.99	5.45	5.35
Kay	342	695	0.014	86.96	669177	2	-$31,062	6.59		0.98	5.50	5.40
Noble	333	573	0.012	77.52	158818	4	-$53,857	6.28		0.95	5.62	5.52
Cotton	322	485	0.010	72.29	92054	5	-$83,524	5.87		0.92	5.77	5.67
McClain	305	947	0.021	87.75	386085	3	-$138,466	5.12		0.87	6.06	5.96
Stephens	297	542	0.013	79.12	601007	2	-$148,454	4.98		0.86	6.11	6.01
Logan	283	837	0.020	87.63	472154	3	-$197,952	4.29		0.81	6.43	6.33
Cleveland	284	1577	0.038	97.79	2895167	1	-$202,667	4.23		0.81	6.44	6.34
Garvin	275	672	0.017	80.38	378709	3	-$213,865	4.05		0.79	6.54	6.44
Osage	272	436	0.019	80.53	618474	2	-$218,199	3.99		0.79	6.57	6.47
Jefferson	267	421	0.011	77.09	94893	5	-$239,265	3.69		0.77	6.71	6.61
Murray	258	615	0.016	85.22	175687	4	-$271,865	3.22		0.74	6.93	6.83
Pawnee	256	521	0.014	80.9	231206	4	-$273,821	3.19		0.74	6.95	6.85
Pontotos	253	593	0.016	82.69	489120	3	-$282,307	3.06		0.73	7.01	6.91
Oklahoma	258	1688	0.045	103.6	9192115	1	-$287,198	3.02		0.72	7.01	6.91
Payne	251	777	0.021	87.21	949068	2	-$290,864	2.94		0.72	7.06	6.96
Pottawatomie	237	809	0.023	89.1	911921	2	-$335,628	2.28		0.67	7.42	7.32
Carter	229	709	0.021	82.31	634953	2	-$353,974	1.99		0.66	7.60	7.50
Nowata	229	596	0.025	80.28	147099	4	-$356,410	1.95		0.65	7.63	7.53
Johnston	226	557	0.017	72.3	146320	4	-$359,080	1.89		0.65	7.67	7.57
Washington	225	752	0.032	87.55	681926	2	-$370,817	1.74		0.64	7.74	7.64
Marshall	220	558	0.017	69.99	183495	4	-$375,624	1.63		0.63	7.84	7.74
Lincoln	223	838	0.026	90.23	446489	3	-$382,140	1.57		0.63	7.84	7.74
Seminole	217	557	0.018	86.42	346475	3	-$395,435	1.36		0.61	7.99	7.89

Love	216	533	0.017	81.93	122910	4	-$397,421	1.32		0.61	8.02	7.92
Hughes	214	473	0.015	80.83	196995	4	-$401,543	1.25		0.61	8.07	7.97
Okmulgee	212	732	0.024	76.55	552336	2	-$402,125	1.23		0.61	8.09	7.99
Rogers	214	1004	0.032	89.85	983181	2	-$408,597	1.16		0.60	8.11	8.01
Okfuskee	211	587	0.019	79.64	164427	4	-$410,779	1.10		0.60	8.17	8.07
Craig	210	659	0.022	79.19	208074	4	-$414,114	1.05		0.59	8.20	8.10
McIntosh	203	644	0.022	73.37	270789	4	-$430,866	0.76		0.58	8.41	8.31
Wagoner	205	1100	0.037	92.58	800160	2	-$439,199	0.68		0.57	8.43	8.33
Bryan	197	684	0.024	75.83	508480	2	-$447,253	0.50		0.56	8.61	8.51
Mayes	196	1080	0.038	78.51	534020	2	-$455,849	0.37		0.55	8.69	8.59
Atoka	194	430	0.015	76.45	193168	4	-$458,840	0.31		0.55	8.75	8.65
Muskogee	194	768	0.027	84.25	966619	2	-$463,692	0.25		0.55	8.77	8.67
Pittsburg	190	631	0.023	78.61	611738	2	-$470,446	0.13		0.54	8.89	8.79
Tulsa	198	1790	0.062	114.66	7839995	1	-$481,649	0.04		0.53	8.84	8.74
Coal	186	457	0.017	83.73	83939	5	-$491,070	-0.20		0.52	9.13	9.03
Creek	186	724	0.027	92.07	937614	2	-$493,918	-0.23		0.52	9.14	9.04
Ottawa	173	977	0.039	73.79	461994	3	-$523,835	-0.80		0.48	9.67	9.57
Latimer	167	579	0.024	83.95	148811	4	-$549,329	-1.19		0.46	10.02	9.92
Haskell	162	670	0.028	78.51	164121	4	-$560,195	-1.43		0.45	10.27	10.17
Choctaw	155	507	0.023	76.23	213530	4	-$578,381	-1.77		0.43	10.64	10.54
Adair	148	913	0.042	71.6	292807	4	-$599,727	-2.19		0.41	11.10	11.00
Cherokee	163	951	0.040	135.81	591807	2	-$600,277	-1.94		0.41	10.54	10.44
Pushmataha	147	570	0.027	72.41	162381	4	-$600,408	-2.20		0.41	11.14	11.04
Sequoyah	144	762	0.037	76.13	542412	2	-$611,131	-2.39		0.40	11.35	11.25
Delaware	139	1114	0.055	79.14	516038	2	-$632,503	-2.79		0.38	11.78	11.68
Le Flore	135	902	0.046	81.33	669581	2	-$644,988	-3.03		0.36	12.08	11.98
McCurtain	109	745	0.047	84.01	478807	3	-$729,186	-4.81		0.28	14.70	14.60

VITA 2

Ekaterina Ermilova

Candidate for the Degree of

Doctor of Philosophy

Title of Study: COMPARATIVE ANALYSIS OF WIND ENERGY PRODUCTION IN OKLAHOMA

Major Field: Environmental Science

Biographical:

Education: BS, Mathematical Economics, 1997, Novosibirsk State University (Russia); MS, Economics, 1999, Novosibirsk State University (Russia); Completed the Requirements for the Doctor of Philosophy in Environmental Science degree at Oklahoma State University in May 2003.

Experience: work as a researcher for Institute of Petroleum Geology of the Siberian Branch of the Russian Academy of Science, city Novosibirsk, from June, 1998 to June, 2001, have 6 scientific publications.