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WIND ENERGY ASSESSMENT OF MAINE USING GIS

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Abstract

The project involved an assessment of wind energy potential in Maine for the Union of Concerned Scientists. The analysis was performed using Geographic Information Systems (GIS), as well as an economic analysis outlining the long term investments of setting up a 50 MW wind farm. The project resulted in the construction of several wind class maps assessing Maine's wind potential. It was also determined that class 5 or higher winds are needed to be competitive electricity generation prices.

Acknowledgments

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I. Introduction

I.1. Overview

Today, most of the world's energy demands are met by fossil fuels. Fossil fuels, which include coal, oil, and natural gas, are non-renewable energy sources. These fossil fuels are found in deposits below the earth, where they were formed from plants and animals that roamed the earth 300 million years ago. Currently, about 90% of our total energy consumption is supplied by the combustion of fossil fuels. The main reason for the using fossil fuels is that they are cheap and readily available.

However, consequences of using fossil fuels are very serious to the environment. Burning fossil fuels creates pollution such as smog and acid rain, which are responsible for causing health problems, as well as damage to ecosystems and property [1]. Fossil fuels are finite and will run out eventually; at current world consumption, coal is predicted to last around 1500 years while petroleum and natural gas, will run out in the next 50 years [2].

Energy is a very important aspect in the world and since we depend upon it for our very existence, we must face current problems and explore ways to resolve them. This is a must in order to reduce pollution and survive when fossil fuels eventually become nonexistent. One possible answer to these problems is renewable energies as an alternative means to meet our energy demands.

Possible renewable sources of energy such as wind, biomass, hydroelectric, solar, nuclear, and others were examined by the project group, and after considerable investigation and research it was determined that wind energy was the best choice. The process of choosing wind energy over other renewable energies and choosing New Hampshire over other New England states for our analysis is shown in section B of the Methodology part of this report.

I.2. Justification and Goals

This IQP will investigate the possibility of using wind energy as a renewable energy source for Maine. As the world's countries continue to develop, and the need for energy increases, we must consider the immediate and future effects of implementing new energy sources. This project group has evaluated many possibilities and feels that wind energy is one the most promising energy sources available that will have minimal negative effects in the long run. Wind class and wind velocity maps are useful for estimating the cost of electricity that would be produced by a wind farm placed at a certain geographic location. By implementing currently existing data, and maps, it is possible to create new maps that show possible wind farm locations within a region. Identifying these locations is an important aspect of energy production. When additional energy is required in a region, there is no question that wind turbines could provide the necessary energy. Knowing these locations will give developers immediate information to determine whether there is sufficient wind to meet their energy needs. The project will also provide some of the economics involved with wind farm sites, which will also help future energy selections. There have been other IQP's conducted on wind energy, and there will undoubtedly be many more to come. This information will assist future IQP's or MQP's who wish to examine a particular wind energy site.

This project is a good topic for fulfilling the objectives of the IQP because it incorporates the implementation of available technologies such as computers, software (Idrisi), maps, etc to help in the analysis for suitable wind farm sites in New Hampshire, which is a great benefit to society. This project satisfies the objective of the IQP in the WPI student's catalog, which states that IQPs must relate technologies to society.

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II. BACKGROUND

II.1 Introduction

Presently, the most common way for power plants to produce electricity is to burn fossil fuels. Fossil fuels, which include coal, oil, and natural gas, are non-renewable energy sources that are found in deposits below the earth's surface and are formed from plants and animals that roamed the earth up to 300 million years ago. Currently, around 90% of our total energy consumption is supplied by the combustion of fossil fuels. Table 2.1 shows the breakdown of various fossil fuels used to produce electricity compared to other types. This section will summarize the fossil fuels used in electrical power plants: coal, oil, and natural gas [1].

Fuel Type	Total Percentage of Usage
Steam Coal	52.3%
Natural Gas	10.7%
Nuclear Power	21.7%
Renewable energy	12.1%
Residual Fuel	1.8%
Import Electricity	1.2%
Distilled Fuel	0.3%

Table 2.1: Electricity generation energy consumption by fuel type in 1995.

II.1.1. Coal

Coal is not a simple or "pure" form of carbon like graphite or diamond. Rather, it consists of a very complex mixture of organic chemical substances containing carbon, hydrogen and oxygen, and along with smaller amounts of nitrogen and sulfur. Coal, created from decomposed plant matter in conditions of high temperature and pressure, takes shorter amounts of time to form than other fossil fuels and is also not uniform. Its makeup varies from deposit to deposit. The types of original plant matter and the extent to which the plant matter decomposed are factors that affect the variations. There are over 1200 distinguishable types of coal that are known today [2].

Coal is burned worldwide at a rate of 1.9 billion tons per year for generating electricity, making it the most popular of the fossil fuels. The reason why coal is so popular is because it is very economical compared to other fuels. Improved technology in equipment integrated with the help of computers has resulted in steady increase of coal production. Another reason why coal is popular is because it is the most abundant and widespread of all the fossil fuels. About 97% of the fossil fuel reserves are coal and 20% of that amount are located in the United States. At current world consumption, the supply is predicted to last around 1500 years. This is a very long time compared to other fossil fuels such as petroleum and natural gas, which will run out in the next 50 years [1].

II.1.2. Oil

Many of us hear the word “oil” and we think of fuels such as gas, oil that has been refined for automobiles and anything that has combustion engine. There are many other uses for oil in the world. However, this section will focus on the use of oil by power plants due to the fact that our goal is to examine alternative sources of energy to produce electricity instead of fossil fuels.

Oil, like coal, is also a fossil fuel and is made up of complex mixture of hydrocarbons. Hydrocarbons contain complex molecules made up of different combinations of hydrogen and carbon atoms that exist in huge amount on earth. The reason why oil is favorable is because it is not volatile like natural gas. However, the differences between gathering oil and coal is the fact that oil needs a very favorable geological setting to collect adequate quantities in tapped reservoirs [3].

There are certain ecological effects of mining coal or tapping oil. One of the more serious is that they can destroy natural habitants including plants and land and sea animals. Transporting oil from one place to another also involves a very high risk of spill. The oil spill, which is very toxic, causes death in large numbers of wild life and is difficult and time consuming to clean up. However, the burning of coal to produce electricity causes the most pollution to the planet due to the production of coal dust, which expands through the air in a local area, and causes many cases of cardiac and respiratory effects. Also, the sulfur and nitrous dioxides pumped into the atmosphere will descend upon the local area in the form of acid rain, causing health problems and damage to ecosystems and property. As of 1994, power plants were under-regulated and releasing 350 tons of sulfur compounds and 250 tons of nitrogen compounds into the air every day [5].

II.1.3. Natural Gas

Natural gas is mostly made up of methane (CH_4) gas. Typically methane is measured in Cubic Feet at standard pressure and temperature. Methane is formed by the "decay of organic matter when there is not sufficient oxygen available to oxidize the carbon"[6]. If oxygen is present, water and carbon dioxide will be formed. Natural gas comes from the ground, just as coal and oil do, so the transformation from organic substance to natural gas has been taking place for thousands of years. When natural gas is burned, it produces CO_2 and water, as it's major waste product.

As the name says, natural gas is present in gas form, and must be collected as such. To do this, pipelines are used to take the gas from under ground to the place where it is going to be used. Natural gas comes from different types of gas wells. One type of well is an associated well. An associated well is one that contains oil and natural gas. The other type of well, called a gas only well, contain only natural gas. "Roughly 40% of the natural gas produced in the United States comes from associated wells"[6]. Pipeline quality natural gas has an energy content ranging between 950 and 1150 BTU. When taken from the ground, the gas may contain several different contaminants, which along with it. These contaminants may change the energy content of the gas, so as a result, some contaminant may have to be removed. Some of the contaminants may be hydrogen sulfide or carbon dioxide. As a result, some gas may need to be pipelined to a processing or treatment facility where these contaminant are stripped out. If they are left in the gas, they may cause corrosion of the pipelines. It is imperative that the Hydrogen Sulfide be removed from the natural gas because it is extremely poisonous. Water must also be removed to prevent pipeline blockage from freezing. Many inert gases may also be present in the gas, which could be economical to strip out and use for other things. Natural gas may also contain many hydrocarbons such as propane, butane, pentane, and ethane. These could also cause blockages of the pipeline in the right conditions, and are also of individual economic value. Occasionally some contaminant are not economical to be removed and do not affect the gas significantly, are left in the natural gas [6].

In the U.S., 18 states contain significant levels of natural gas supply. These states are Texas, Louisiana, Oklahoma, New Mexico, California, Wyoming, Colorado, New York, Pennsylvania, Alabama, Mississippi, and Michigan. 70% of the gas is in the first four states mentioned. Canada also contributes much of their natural gas to the U.S. market.

The residential and commercial sectors used 37 percent of the U.S. gas supply in 1994. Natural gas is the number 2 fossil fuel used in the U.S. while coal being the first. 23% of the gas went to electricity generation in 1990, while the remainder was used in the industrial sector.

In 1994, the electric utilities paid an average price of $2.230 per million BTU of natural gas. While oil ranged in price from $2.409 to $3.60 depending on the quality. The $3.60 are for #2 Grade oils. Coals had an average price of 1.355 per million BTU. In 1994, the natural gas industry was valued at 80 billion dollars [6].

II.1.4. Why Fossil Fuels are Still Being Used

With all the pollution and ecological effects, fossil fuels are still being used for the production of electricity instead of renewable energies such as solar, wind, or biomass. One main reason is that the world has been structured to use fossil fuel ever since they were first used in the late 1800's. It is not very easy to convert to use other energy source since there are many uncertainties in the availability of alternative fuels. Other energy sources generally either produced a low-grade heat that is less efficient than fossil fuels.

Coal, oil, natural gas or fossil fuels in general, are non-renewable resources and they are limited. Even with the abundance of coal, at 5% growth rate coal is predicted to last 85 years because it will be used more and more as other fossil fuel runs out. Because of this situation and the mass pollution causes by burning these fossil fuels and its effects on the environment, renewable energies are being looked at more seriously than ever [4].

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II.2. Possible sources of renewable energy

Today more than ever, the use of renewable energy as an alternative or complementary source of energy to fossil fuels is possible with the advances in technology. in this section we will discuss some possible sources of renewable energy that are efficient, cleaner than fossil fuels, and are already implemented in many countries around he world.

II.2.1. Wind Energy

This section introduces wind energy, wind turbines followed by their economical and environmental benefits over current sources of energy such as coal. Winds are created from the heating of the earth's surface by the sun. Like most forms of natural energies, winds contain vast quantities of potentially useful energy. It is estimated that the earth generates enough wind to supply more than ten times the current demand of energy.

Before continuing, a wind energy system must be defined. A wind energy system is a system that transforms the kinetic energy in the wind to electrical energy. Mechanical windmills are powered by the wind, which slowly spins their high-density rotors with a high starting torque. Wind turbines are modern versions of windmills, they usually consist of 2 or 3 rotating blades sitting on top of a tower of height 30 meters or more [4]. Turbines however, have low-density rotors with low starting torque and high rotational speed. Today mostly wind turbines are used as means of producing electrical energy from the wind.

Wind turbines that produce electricity have been around since the 1920's but they were never considered as a reliable and efficient source of electricity due to their poor efficiency and reliability. Europeans have been designing windmills since the 1180s[4]. They used these turbines in their farms as wind or water mills to ground grains. Their experience proved to be a valuable tool, which was demonstrated in the 1940s when US, Germany and Denmark set out to make wind turbines that produced electricity. The U.S. venture, even though heavily funded by the government, was a total disaster. The first American turbines proved to be large, inefficient and unreliable. The Germans were unsuccessful in designing and constructing a useful and reliable wind turbine although they did not fail as bad as the Americans. However, Denmark was successful and they made several wind turbines. These turbines, although not as big as the ones Germans and American's made, where low tech but highly efficient [1].

Today Denmark is considered as the leader in wind turbine technology. Even today with all the advances in technology the American industry is still not as advanced as that of Denmark. Zond systems, a main US turbine manufacturer, hired Finn Hensen, former managing director of Vestas, one of Denmark's leading manufacturers, as their head of design program in order for them to take advantage of the Dane's experience [1]. Their current success was largely due to their vast experience and the fact that they increased the size of their turbines in small increments while the Americans took big unsuccessful leaps in making big turbines

Wind turbines can be grouped together to form a wind farm. The power from each wind turbine is collected and combined with those of other neighboring wind turbines through a wiring network. Next the collected power from all these wind turbines is passed through a substation and then to consumers via utility grids. Today there are approximately 25,000 wind turbines worldwide, generating 2,600 megawatts (MW) and five billion kilowatt-hours (kWh) of electricity annually [6].

Wind energy is considered to be one of the world's fastest growing energy sources. Currently there are some 40 manufacturers of wind turbines worldwide. Wind power capacity grew by 32% to 4,912MW in 1995 and grew by an additional 1,200 MW in 1996 worldwide[7]. The Top five manufacturers and their market performance during 1997 are listed in the following table:

Rank	Manufacturer	country	MW sold 1997	% market share 1997	MW Sold Total	% Total
1	NEG Micon A/S	DK	309	19.7	1294	16.4
2	Vestas wind systems A/S	DK	290	18.5	1483	18.9
3	Enercon	D	223	14.3	731	9.2
4	BONUS Energy A/S	DK	22	14.1	710	9
5	Gamesa	E	93	5.9	189	2.4
9	Zond	USA	38	2.4	56	0.7
	TOTAL		***1542***	***98.4***	***7896***	***100***

Table 2.2: Top five wind turbine manufacturers [8].

We can clearly see that the top players in wind turbine manufacturing are from Denmark, one English and one German. Zond systems the biggest American company was ranked 9th and was the only American company in the top 11.

The success of wind turbines depends on the public perception. In recent polls taken the U.S. and Europe the majority of the people were found to favor the use of renewable energy and wind energy as a whole. Those who understood the benefits of wind energy and renewables were willing to overlook their visual effects. Noise was never an issue to them [6].

San Gorgonio Pass was one of the only places where there were lots or protests, supported by high profile people, against wind turbines. The protesters were concerned about the destruction of natural habitats by these wind turbines, still when a poll was taken, it was shown that the majority of people still supported wind energy. The poll showed that 51% supported wind energy, 21% did not, and 23% were neutral. Also, 66% felt more development should be encouraged [6].

Wind turbines have few downfalls, one of them in the view the public is the “missing tooth effect”. A wind turbine is highly visible when it is not working due to lack of wind or maintenance. When people see a wind turbine not working they begin to think that they are not as efficient as they actually are and that sticks in their mind. Other downfalls include erosion, bird kills, noise, and visual effects. Over time erosion can be a problem where these wind turbines are planted in deserts where a hard packed surface must be disturbed to install these turbines. Birds will sometimes fly into the blades and get seriously injured if not killed.

Earlier wind turbines were quite noisy and that was one of their disadvantages, People would often complain about their excessive noise. Noise is no longer a major problem since the technology in turbine manufacturing has improved greatly. However one might still be disturbed by the noise if you live approximately, less than 650 ft. from the wind turbines [8].

Wind turbines have two sources of noise, mechanical noise from the generator or gearbox, and aerodynamic noise from the blades. With the new advancements in technology mechanical noise is virtually non existent in the modern turbines. The reduction in noise is largely due to the concerns that the designers had about vibrations that lead to unreliability.

When vibrations were reduced so were mechanical noises. Major components have been elastically dampened and some insulation has been used. Aerodynamic noises have also been reduced greatly in the past ten years. Aerodynamic noises, such as the "swish" which is also known as "white noise", is the sound of the blades when they break the wind.. White noise is created from the edge of the blades that have the highest rotational speed. The higher the rotational speed the greater the noise. Better designed rotor blades have reduced this noise dramatically. Another aerodynamic noise is "Pure tones" which are the most annoying. This kind of noise is made when the rotor blade does not have a smooth surface. Today manufacturer's take great care in designing and installing the blades so that they are as smooth as possible.

The Electric Power Research Institute (EPRI) provided a statement about wind technology's advances that said "Alone among the alternative energy technologies, wind power offers utilities pollution-free electricity that is nearly cost-competitive with today's conventional sources". The energy generated by a wind turbine pay for the materials used to make it within months. In general winds exceeding 6 m/s are needed in wind farms for them to be cost effective[6].

When considering a source of energy one should always consider how cost effective it is, and whether it is economically suitable to use such a source of energy. According to studies done in Denmark and Germany the length of time for which the wind turbine could pay for itself, also known as payback, depend on the windiness of their location, and the amount of power the turbine could make. The results of this study are shown in the Table 2.3.

Plant	Payback (month)
Nuclear	0.7
Coal	0.7
Wind @ 7m/s	2.5-7.5
Wind @ 5.5 m/s	3.8-11.4
Wind @ 4 m/s	6.3-22.7

Table 2.3: Payback of various sources of electricity (http://www.igc.org/awea).

However, on average it is believed that wind turbines can pay for themselves within 3.3 months. Selecting the site for these wind turbines is key too as the power produced by these wind turbines is a function of the *cube* of the wind speed. That means if the wind speed increases from 5 m/s to 6 m/s, the power generated will double. This is a substantial increase in power in an industry where it is so hard to create more efficient ways to produce electricity.

It can be seen from the Table 5. that wind turbines do not have paybacks as good as coal or nuclear plants. On the other hand wind turbines emit 360 times less SO_X, NO_X (where X can be 2 and/or 3) and CO_2 (from their generators) to generate an equivalent amount of electricity over the 25 year life span of a wind turbine. This is also demonstrated in following table:

Plant Type	SO_X (tons)	NO_X (tons)	CO_2 (tons)
Wind	[Kg 40]	0.3	87
Coal	14	108	31,326

Table 2.4: Emission comparison between a wind turbine and a coal plant [6].

Wind Energy also offers other benefits making it an even more desirable source of power in the long run. These benefits offer a better fuel diversity lessening the dependence on fossil fuels which are limited, cause pollution, and are subject to rapid price changes. Another benefit of wind energy is that it creates more jobs per unit of energy produced than all other forms of energy. The higher employment rate is due to fact that the turbines require maintenance on top of them having to be designed and manufactured, shipped and installed. Even with this higher employment rate the cost of producing electricity is very competitive to other forms that are dominating now. The lower cost of wind energy is due to its source of energy, wind, which is free, and the high efficiency of late model turbines. Another benefit of wind turbines is long-term income to farmers and ranchers who own the land where the turbines are located.

Wind turbine reliability and efficiency has increased slowly with technology. During the oil crisis that took place in 1973 through 1978, where the price of oil rose dramatically, markets started looking for different means of producing electricity and the interest in wind turbines expanded. Since then the technology in wind turbines has improved greatly and now there are wind turbines that can produce electricity at a cost as low as 4 cents/kWh in some locations, a great improvement to the 20 cents/kWh cost of electricity in 1980 [4]. Although efficiency is an important feature in any wind turbine it is not nearly as important as the turbines' durability and reliability. When designing a wind turbine great amounts of effort and ingenuity is put into making them as reliable as possible. For a wind turbine to be effective and cost efficient it must only require a few hours of maintenance for every thousand hours of operation. The value of a wind turbine is in the energy it produces and thus a wind turbine must be working as much as possible. A design that needs constant maintenance is considered useless.

Wind turbines have proved to be an excellent complementary source of energy to fossil fuels in Denmark and England. We feel that U.S. should also take advantage of its' vast natural resources, such as land and wind, and use them to be less dependant on the limited fossil fuels, and prevent further damage to its ecological system by reducing the amounts of toxic gasses released into the atmosphere each year from burning fossil fuels

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II.2.2. Biomass Energy

Biomass is another promising source of renewable energy for many areas of the Country including New England. Biomass power is produced from many energy conversion processes, and exists in many different forms including gas, solid fuel, and liquid fuel. In general, a gas or steam turbine is used to produce electricity. The term Biomass mostly refers to natural plant material such as wood or other plant life, but can also include much of the biological content that is contained within household trash, as well as animal waste [5]. For example, ethanol alcohol would be considered a biomass substance because it is produced primarily from corn [2] A typical elemental content of dry plant biomass fuel would be about 44% oxygen, 50% carbon, and 6% hydrogen. However, anywhere from .5 - 5% of the total biomass makeup can be ash [5].

Releasing the energy held within biomass is a relatively simple process. The energy that is contained within biomass material initially comes from the sun, and through the process of photosynthesis, it is converted into sugars, starches, and Lignocellulose. The energy can then be released by making the material react with oxygen [5].

There are several ways to use biomass to produce usable energy. The first is to co-fire it with coal. Coal is actually biomass, that has been buried underground for a long period of time. The similarities between biomass and coal make it conceivable to burn them in the same power plant. When coal is mixed with biomass, power plants give off less harmful emissions. A coal plant can also be completely converted to biomass power by simply using 100% biomass fuel, and discontinuing the use of coal completely [5].

Some of the other methods of biomass energy production are Pyrolysis, gasification, and direct firing to produce steam and drive a steam turbine. Pyrolysis is a method in which biomass is converted into a liquid fuel by heating it under the right conditions, with very little oxygen present. The method produces a fuel gas when, at room temperature, is in a liquid phase. Gasification involves heating the material to 500 or 600 degrees centigrade. This burns off 80% of the biomass leaving behind a mixture of carbon monoxide and hydrogen gas. This gas mixture is often called synthesis gas, syngas, or producer gas and can be used for fueling a gas turbine or other uses. Direct firing simply involves burning the biomass fuel directly to produce heat. The heat is used to produce steam, which in turn drives a steam turbine, which is used to develop electricity [5]

One possible source of biomass comes from live trees. Using a method called coppicing, biomass is collected from trees which grow back quickly after being cut. The method shortens the time between harvesting, by not having to replant new trees and wait for them to grow large enough to cut. These trees could have their growth cut from them every few years, for up to about thirty years. In one year, using this method, it is possible for ten tons of tree biomass to be harvested per hectare of land. This method helps keep the forests from depleting, because it reuses trees, rather than continual tree cutting without replenishment [3]

Currently, much of the biomass material that is used, comes from the wasted portion of plants, such as sawdust, chips of wood not used by a lumber company, or residue from paper mills.(?) Small boilers are often on the sites of companies that produce biomass waste. These boilers make use of what would normally be useless material, but may have a relatively low efficiency of about 25% [5]. The paper industry is currently a major consumer of their own biomass waste to produce electricity. The American Paper Institute has estimated that it generated the equivalent of approximately "1.6% of the U.S. energy supply" for their own energy purposes. This adds up to "about 1.4 quadrillion BTU" in the year 1991 [4].

Municipal Solid Waste is a source of biomass that will continue to grow for many years as population increases, and even though municipal solid waste is not usually thought of when the topic of biomass is mentioned, it is a large and important part of biomass energy [4,8]. Although some of the waste will be reclaimed through recycling programs, it is estimated that approximately 150 tons of non-recoverable waste will be created each year, by the year 2000. There is nothing that can be done with this waste except dump it into a land fill or use it to produce energy by burning it in an incinerator, or other energy production processes [4].

Presently, there is a consistent amount of available municipal solid waste available for biomass energy. In 1994 there were more than 209 million tons of municipal solid waste generated. Of which, 81.3 million tons (38.9 percent of the total waste stream) is paper and paperboard. Yard wastes account for the other about 30.6 million tons, which is 14.6 percent. Plastic and metals account for 19.8 million tons (9.5 percent) and 15.8 million tons (7.6percent). Food and glass account for 14.1 million tons (6.7percent) and 13.3 million tons (6.3 percent). Finally, 34.2 million tons (16.4 percent) account for the rest of the municipal solid waste.

Today, there is more interest in the municipal solid waste as an alternative source for energy. However, in the early 1960's, 27 million tons of municipal solid waste was incinerated for the sake of getting rid of the waste itself, not for recovery of energy. Also, there were no policies for air pollution control. Many of these incinerators were shut down in the 80's because of the steady decline in the MSW from 1960 to 1980. In the 1990's, the combustion of MSW to produce energy increased steadily and is predicted to reach a high of 34 million tons in the year 2000.

There are two popular types of facilities that are responsible for converting MSW to energy. The first type, the Waste-to-Energy facility, is primarily located in the eastern part of the United States due to the limited amount of landfill space there. In the Waste-to-Energy facility, hazardous materials such as batteries and very large materials like stoves and refrigerators are removed before the combustion of these wastes. Noncombustible materials like metals are usually separated from the ash with magnetic separators, but they can also be removed before the combustion process. The waste is generally reduced by 90 percent in volume after the combustion process. These remaining ashes are then buried in the landfill.

The second type of municipal solid waste facilities is a Landfill Gas facility. Landfill Gas facilities are more environmentally friendly than Waste-to-Energy facilities, because the produced methane gas burns much cleaner than the contents burned in the Waste-to-Energy facilities. In Landfill Gas facilities, MSW contains a large amount of organic materials that makes a variety of gaseous materials when dumped, compacted, and covered in landfills. Anaerobic bacteria thrive on the non-oxygen environment, resulting in the degradation of the organic materials and the production of mostly carbon dioxide and methane. Carbon dioxide usually leaches out of the landfill because it is soluble in water and is lighter than air. Methane, like carbon dioxide, is less soluble in water, but is lighter than air, dissipates out of the landfill instead. Most of these facilities are distributed very evenly throughout the United States. However, California and New York have the most out of all the states.

Landfill gas is collected from wells that are drilled 30 to 100 feet into a landfill. What determines the amount available of gas includes the type and compactness of the refuse, the amount of rainfall the area receives, and the length of time it has been buried. The landfill gas can be upgraded and used in the natural gas pipelines that are used by power plants. This makes it highly economical since there is no need to build new plants to accommodate the output of Landfill Gas facilities [8]. As well as using landfill gas facilities, it is possible to use digesters to process municipal solid waste into methane. The process would occur more quickly than it would naturally in a land fill [3].

There are several environmental issues, which should be addressed before using biomass fuels. Biomass fuels are relatively clean fuels, but they still produce nitrogen oxide when burned. Nitrogen Oxide is a green house gas just as CO_2 is, except more severe. However, it is conceivable to cut the levels of nitrogen oxides down using catalytic converters on the power plants that are burning the fuel [3].

An advantage of biomass, is, when managed properly, it can prevent the levels of the green house gas CO_2 from increasing. The basis for this theory is plants consume CO_2, and when the plants are used to produce energy that CO_2 is released back into the air. Therefore there is no net CO_2 placed into the air, and the sulfur levels are far lower than fossil fuels. Sulfur can contribute to the formation of acid rain, so low sulfur emissions are desirable. The average sulfur content of biomass might be around .04%. However, biomass trees and crops must be replanted as they are taken, in order for the CO2 theory to work [5].

To continually grow plant biomass, the same conditions are needed as would be needed to successfully grow any crop: 1. Must have good supply of sunlight. 2. Need water supply. 3. Good soil for growing plants. 4. Need Nutrients 5. Control pests and disease [5].

Another environmental issue of biomass, is the effect of biomass on the fresh water supply. To grow some types of biomass may require irrigation. Approximately 60% of the fresh water is used for irrigation purposes already. This is necessary to grow food. However, only about one half of the water that is used for irrigation is able to be recycled. Much of the other half evaporates or is soaked up by the plants being grown, and eventually evaporates(transpiration). The water cycle requires that the water eventually comes back to the earth, but it may not end up on the same location on the earth [6].

There is also the issue of polluting the ground water. When crops are grown, many chemicals, including pesticides, are used to grow crops. These chemicals can get into the ground water and cause harm to water's quality [7].

In addition to the environmental issues regarding biomass, there are several economic issues that need to be addressed. These issues must be dealt with if biomass is to be a viable source of energy in our future. One of the major issues is the cost per energy content of biomass.

Plant biomass must be dried near the area where it was grown, because the cost of shipping undried biomass, with such a poor energy density would be too expensive. Dried biomass has an approximate energy density of 19 Giga-Joules (GJ) per ton, while it's coal equivalent is 26 GJ [5]. Compared to coal, plant biomass seems uncompetitive, although, if the biomass can be grown close to the power facility to minimize transportation costs, competitiveness may increase.

It is predicted that biomass crops will become economical by the year 2010 [1]. The predicted cost of a biomass plantation in the U.S. by the same year is 1.9 to 2.7 dollars per giga-joule (GJ) of biomass [3].

If excess residues from agricultural or logging operations could be collected the following costs can be expected. Dry wood chips have ranged in cost from $26 to $38 per ton. This adds up to about 1.50 to 2.20 for one million Btu's of energy. Coal prices in the past couple years have been ranging from about $1.06 per million Btu to $1.25 per million Btu. Sometimes in certain parts of the country such as California the cost for wood chips can get as high as $54 dollars per ton. So, it can be said that biomass is not currently competitive, when compared to coal. The Union of Concerned Scientists have shown that there is little potential for the cost of biomass, in the next ten years, to be economically competitive with the fossil fuel industries [4].

References:

1. Annual Energy Outlook 1997: With Projections to 2015. (Energy Information Administration, December 1996.) p. 54.

2. Annual Energy Review 1996 (Energy Information Administration, July 1997) p. 261

3. Boyle, Godfrey. Renewable Energy: Power for a sustainable future. (Oxford University Press, Oxford, 1996) p. 162, 163, 165,166, 169,170, 174
4. CRC Handbook of **Energy Efficiency** (CRC Press, Tokyo, 1997) p. 781-783, 784

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   http://www.ratical.org/renewables/biomass.html, 1/20/99
   http://asd-www.larc.nasa.gov/biomass_burn/biomass.html, 1/20/99
   http://www.ucsusa.org/energy/biomass.html, 1/20/99
   http://www.seda.nsw.gov.au/renewable/biomass.htm, 1/20/99
   http://www.physics.adelaide.edu.au/~mferrare/best/biomass.htm, 1/20/99

II.2.3. Other Sources of Renewable Energy

Although currently biomass and wind energy tend to be some of the more promising methods of renewable energy production, there is also solar and hydroelectric energy. Hydroelectric energy is currently employed in many areas, but environmental issues have complicated further growth. Solar energy is very promising, although low efficiency and high initial cost are barriers to growth. However, with continued research and development solar energy may develop into an extremely viable source of energy.

Solar energy is a renewable energy source that can be converted directly to electricity through the use of photovoltaic cells. The photovoltaic effect was first discovered in 1839 by French physicist Edward Becquerel when he exposed his silver plated wet cell battery to light and noticed a voltage change. In 1953 Bell labs increased the efficiency of the photovoltaic cell to 6% by using doped silicon, a significant increase over the 1839 cell [1].

There are many different types of solar cells, which mostly include variations of the silicon cell. Some of the common types of cells are the monocrystaline cell, silicon ribbon, polycrystalline silicon, polycrystalline thin film, and Gallium Arsenide cells. In the thin film category there are amorphous silicon, Copper Indium Diselenide, and Cadmium Telluride [1].

The different types of photovoltaic cells have different strengths and Weaknesses. For instance, the Gallium Arsenide cells are very efficient, but expensive to manufacture. Silicon cells have risen to a commercial efficiency of 16% and a laboratory efficiency of about 24% as of 1996. By the year 2006 it is predicted that 24% efficient cells will be available for commercial sale. The cost of solar cells has also dropped dramatically form 200,000 dollars per peak watt in 1959 to as low as 4 dollars per peak watt in 1992. To install photovoltaic cells into an interconnected grid system which supplies many people with electricity would cost about 11 dollars per peak watt. The cost would also include the necessary support structures and anything else necessary to get it started. A smaller system, which might be installed at a house or on a building, might cost about 12 dollars per peak watt. These are both based on 10% efficient cells [1].

The upside of photovoltaic cells is that they have limitless fuel, no moving parts, and are relatively low maintenance. The downside is that they have a high initial cost, can be damaged by high winds, water may be able to get into the panel, and the expansion and contraction of the panel due to heat could crack it. They also can be aesthetically displeasing, and they may need to be washed if rain is not available, as well as some cells containing toxic chemicals that could possibly leak out into the environment, although silicon cells are fairly safe to the environment [1].

Photovoltaic cells are not the only way to collect solar energy . Many different types of solar collectors could also be used. One type of collector is a parabolic trough concentrator. These concentrators are used to focus the energy of the sun to heat oil. They can then be used to produce steam, and develop electricity with an average efficiency of 14%, and a peak of 22%. To produce 80 megawatts using this method an average collector area would be about 464,000 square meters. There are also parabolic dish concentrators which concentrate their energy on a sterling engine and can possibly yield a 30% efficiency rating [1].

It can be seen that the potential for solar energy can not be overlooked, however it's relatively low efficiency, need for a large surface area, and relatively high initial cost may make it difficult to implement.

References:

1. Boyle, Godfrey. Renewable Energy: Power for a sustainable future. (Oxford University Press, Oxford, 1996) pages. 78,79,92-109, 105, 126, 127,129,130.

II.2.4. Hydroelectric energy

Every year 80 trillion kW of energy is deposited on the earth's oceans on earth from the sun, an amount that is roughly 8000 times the rate of consumption of energy on earth. Many people believe that this energy stored in the ocean can be harnessed for our use.

There have been several ideas on how to achieve this goal. Some of these ideas are old, such as tidal mills, and some are recent, such as ocean thermal energy conversion (OTEC). Schemes involving conspicuous ocean energy (waves, tides, currents) have been around since the 1940's. While schemes involving inconspicuous resources (salinity gradients, thermal gradients) are very recent. It is believed that the energy stored in inconspicuous resources are much greater than those in conspicuous forms, and recently more attention has been given to them.

One way to achieve OTEC is with a heat engine whose thermal cycle operates between warm water temperatures found on the surface of tropical oceans and near freezing temperatures found in the ocean's depths. One problem with OTEC is choosing a spot where one can send the electricity back to shore via power grids. Alternating current(AC) transmission is economical for distances within 30 km, while direct current(DC) is 400 km.(The Energy Sourcebook) Implementing OTEC is a challenging task since access to deep water is restricted to within 400 km of the shore. The places where this kind of system is effective are far from the shore and any human habitation.

Another option is by using tidal waves as a source of energy. The sun and the moon exert gravitational forces on the oceans creating two high tides followed by two low tides each day. The most widely integrated scheme to take advantage of these tidal waves involves a hydraulic head between the high tide and low tide. A dam at the mouth of the tidal bay is equipped with sluice gates, which allows the passage of free water through its turbines to generate electricity. The water would then be kept in a reservoir. This process is reversed 6 hours later with the low tides at which point the water is released from the reservoir back through the turbines and into the ocean. Using this method will allow the generation of electricity at different times of day each day and at 6-hour intervals each time. It is estimated that 3,000 GW of power, of which only 2% is usable, is continuously dissipated on the whole earth due to actions of tides.

There are some consequences involving the exploitation of tidal waves where the shorelines and wetlands would be affected due to the alteration of the tidal amplitudes. There are also environmental concerns about local marine life such as fish and shellfish due to the tidal power exploitation. (The Energy Sourcebook)

References:

1. David Ross, ENERGY FROM THE WAVES, Oxford, England. New York : Pergamon Press, 1981.

2. Ruth Howes & Anthony Fainberg, THE ENERGY SOURCE BOOK, New York, NY: American Institute of Physics, 1991.

II.2.5. GIS

For this project the GIS software, IDRISI 2.0, developed by the graduate school of geography at Clark University, is being learned. Idrisi contains all of the features discussed in the following sections.

GIS is the acronym for Geographic Information Systems, which "is a computer assisted system for the acquisition, storage, analysis and display of geographic data"[1]. There are several parts to a GIS, which consists of the Geographic Analysis System, Spatial and Attribute Database, Cartographic Display System, Map Digitizing System, Database Management System, Image Processing System, Statistical Analysis System, and Decision Support System.

The major feature, which defines a system as a GIS, is the ability to perform geographic analysis. The geographic analysis system is able to "analyze data based on their location". This means that you can find a certain attribute that is present in certain geographic locations, and then display the locations, that meet the criteria you are looking for. For example, consider a map containing information on the concentrations of moose in Litchfield New Hampshire, and a map which contains locations of different neighborhoods in Litchfield. If I wanted to find out if the concentration of moose in my neighborhood was high, I could produce a new map from the old maps, which would only show the locations of high moose concentration, and are present in my neighborhood. Another example would be if you wanted to determine if, and how much of, a certain kind of biomass is present at a certain location.

The information that is used to do geographic analysis is contained within the GIS database. The database contains maps and information about the maps. There are basically two types of databases used in a GIS. The first is the Spatial database. The spatial database contains information about the spatial aspects of a map, such as the location of a land area, and where it's boundaries are located. The second is the attribute database. The attribute database contains data "describing the characteristics or qualities" of the area in question.

Another major system of GIS is the database management system. The management system simply does what the title says. It manages the attribute and spatial databases, although typically it is designed to work mostly with attribute data. Using the database management system, data can be analyzed numerically using attribute data. The result of such an analysis might be some kind of statistical data. Also, the user can enter data into the database, so that the computer can use the data. The attribute data contained in the computer can also be converted into spatial graphical data, in the form of a map.

In order to see the information within the database, displayed in map form, it is necessary to have a display program. This is referred to as the Cartographic Display System. The display system takes data from the database and produces a graphical map.

If new map data is needed, it must be placed in digital form. This is done using the Map digitizing component of GIS. Digitizing takes actual paper maps and converts them into a digital form which can be used by the computer. It can be performed in a couple ways. The first is to use a digitizing tablet, which you trace out the features of map with a "mouse like" device. The other method is using a scanner to scan an entire image of the map into the computer.

The last three major components of GIS are the Decision Support System, Image Processing System, and the Statistical Analysis system. The Decision Support System is used to make decisions based on multiple criteria. An example of this might be the use of Boolean logic to decide whether certain criteria are true or false. The Image processing system is a system which allows remotely sensed images to be imported and analyzed. Remotely sensed images are produced from some remote location. This could be an aerial photograph or a satellite image. The Statistical analysis system does just what it says. It is a tool in performing statistical analysis on data. Most GIS systems use one of two ways to represent map data in digital form. This is Raster or Vector [1].

II.2.6 Raster and Vector Data

Raster and Vector are data structuring methods, which are used to represent maps in digital form. Although they can both portray similar data, their structure is quite different.

Raster oriented data representation uses a memory intensive grid of cells which is best used for the analysis of data which continually changes over space. "Each cell is given a numeric value which may then represent either a feature identifier, a qualitative attribute code or a quantitative attribute value"[1]. For example, a group of raster cells which border one another in the grid may have the value of 1. The number 1 could represent land area where moose are present. While the other cells in the grid may have the value of zero, which could simply indicate there are no moose present in those area. So, the numbers contained within the cell could represent use of land area. Another example of raster data representation could be using real data. In an elevation map each cell could contain the actual numeric value of elevation. So cells with the same value would indicate that those areas are at the same elevation. If our project were to focus on biomass, and we would like to know the concentrations of biomass suitable trees across the state of New Hampshire, a raster map would be the best choice.

Vector representations of data are less memory intensive and are more "database management oriented" than raster [1]. They also have the appearance of traditional maps in many cases. Vector representations use points connected by lines to represent map data. The lines that connect the points have both magnitude and direction, so they are actually vectors. Each point in a vector map has a location associated with it. A common way to represent the location of this point is with the use of a coordinate system. These points are often represented with Cartesian coordinate system. Using the points polygon's, and lines can be formed. A polygon could represent land use, a line could be a road, and a point could mark the location of something. Each of these would be associated with an id number, which is used to locate data within the database, describing the feature on the map. If a polygon was used to enclose an area, it might be represented by the number 2 as the ID number. This number would allow the computer to locate all of the information about that land area which is contained within the database. It might tell you the total area of the land, the type of soil on the land, or many other possibilities.

For geographic analysis, GIS software is an excellent tool for assisting in the analysis of many possible scenarios, and predicting immediate and long-term effects of those scenarios. The structure of the analysis may be in a raster or vector based map format, however Idrisi 2.0 is primarily a raster based system.[1]

References:

1. Eastman, Ronald J. Idrisi for Windows Manual Clark Labs for Cartographic and Geographic Analysis 1997. p. 2-1 – 2-7.

III. Methodology:

Producing wind energy potential maps requires many steps, from choosing a state to locating the maps to choosing the format and scale to performing the analysis. Here we will discuss each step explaining our decisions and methods while leaving the more technical details to appendices. The steps are listed in the proper order in which they were implemented. Most of the steps involve GIS using IDRISI since that was the most extensive part of the project.

III.1. Decision in choosing wind energy

There are three other sources of renewable energy worth considering besides wind energy, they are biomass, solar power, and hydroelectric power. These renewable sources of energy were reviewed in depth in the background section of this proposal. However, we shall briefly explain why wind energy was chosen as the most suitable renewable energies in New England.

Biomass, which involved burning of trees, municipal waste, and wood chips, was the next best option for renewable energy since it had no net increase in the production of carbon dioxide and was a source which could be reproduced over a long period of time. However, we found it to be more expensive than wind energy and that it was not a suitable means of renewable energy in New England due to the soil conditions of the area.

Solar power was also a good option for renewable energy, and can be converted directly to electricity through the use of photovoltaic cells. This is a very good source of renewable energy since they are limitless, no moving parts, and are relatively low maintenance. However, they produce small amounts of energy compared to wind and biomass, they have a high initial cost, can break down by high winds, and water can leak into their panels. These fuel cells contain highly toxic material that can be deadly if they ever leak out.

Hydroelectric power is already used extensively through out northern America in forms of dams, which produce a prominent portion of the electricity used today. These dams, although efficient, have negative side effects on the surrounding ecology since the dams effect the flow of rivers. Other forms of hydroelectric energy involve using the ocean, however they were not feasible for the oceans around America or they had negative impacts on the shore lines and marine life in that area.

When considering all these other alternative sources of renewable energy, we concluded that wind energy was the most efficient and environmental friendly of them all that could be implemented in the New England area.

III.2. Decision to Choose Maine

In deciding which state we would study for our project, we collected data regarding the population, energy generated and sold, toxins released, and wind speed in each of the states mentioned before. Maine had a population of 1,243,000 which was the second highest amongst New Hampshire (NH) (1,162,000), Vermont (VT) (589,000), and Rhode Island (RH) (990,000) [1]. Since ME had the highest population we could assume that the state would also be amongst the highest consumers of energy, which was evident when we looked at the electrical energy sales in the four New England states. Maine had sales of 11.6 million kilowatt-hours (Mkwh), which was the highest amongst NH which had sales of 9.0 Mkwh. Vermont and Rhode Island had sales of 5.5 and 6.6 Mkwh respectively, which shows that the three sates use less electricity than ME.

Choosing which state to study involves looking at the net generation capabilities for each of the four states. Maine was second to last in net generation capability at 2.7 billion kilowatt-hours (bill.kwh). The other three states, NH, VT, and RI had 13.9, 4.8, and 0.7 bill.kwh of net generation capability respectively [1]. This data makes ME the leading candidate since the state has the highest sales of electricity, yet it is one of the lowest in production. Maine also has the highest amount of toxic releases at 7,472 thousand pounds. NH, VT and RI had 2,362, 610, 2,879 thousands of pounds in toxic releases from chemical plants and cars respectively [1]. This finding also points out that ME needs cleaner alternative energy generation since it produces much more toxic waste when compared to NH which has nearly the same population.

We also looked at the average wind speed in each of the four states. Maine had an average wind speed of 8.8 mph which was second to last in the four states. NH, VT, and RI had wind speeds of 6.8, 9, and 11.1 mph respectively. Although ME has one of the lowest average wind speeds in the four states, it is still considered as the best candidate for wind energy site. This is because ME has the highest wind electric potential as a percent of contiguous U.S. in the New England region as shown in the figure below which was obtained from the National Wind Technology Center web page (http://www.nrel.gov/wind/potential.html).

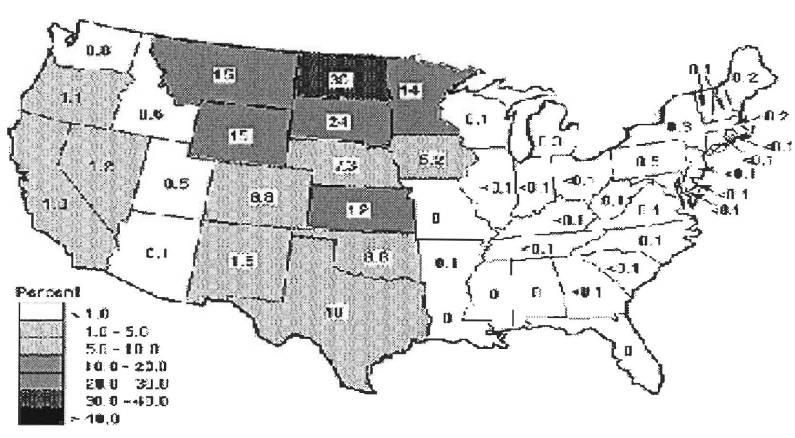


Figure 3.1 Wind Electric Potential as a Percent of Contiguous U.S.

According to the figure above ME has a wind electric potential as a percent of contiguous U.S of 0.2%, while the other New England states have only 0.1%.

Maine therefore is a leading candidate for wind energy since it had the highest population and electrical energy sales, yet it was amongst the lowest in electricity generation. ME also produces the most toxins and has the highest wind electric potential as a percent of contiguous U.S at 0.2%. Finally the most important factor for choosing ME was because Steve Clemmer at UCS recommended that we do the project on Maine since there was some interest on setting up a wind farm in that state.

At the beginning of the project we considered New Hampshire as the candidate for a wind farm site because it is a growing state and its population is increasing every year which makes it a large consumer of electricity. Another reason for considering NH was that another IQP group (iqp #:95C002I) had already done a study for wind energy potential (but not GIS) in parts of Maine, therefore, to avoid duplication of certain results we avoided ME initially.

III.3. Data and Information

After performing the necessary background research, and making the decision to study Maine, the next step was to find possible sources of GIS information. GIS Information includes digital elevation models (DEM), Land use and Land Cover Maps (LULC), Wind Resource Maps, State and County boundaries, Wind Resource Maps, paper maps, and any other useful resources. However, paper maps were only considered for visual analysis in this project, because of the time constraints, as well as the need for a digitizer.

One of the first sources was the "Index to topographic and Other Map Coverage" map of Maine, obtained from USGS (by calling 1-800-USA-MAPS). This map was very helpful for selecting a map scale and finding out which maps represent a particular area of the state. It also portrays the latitude and longitude coordinates of the USGS maps. The USGS GeoData Web Site contains numerous types of digital data, data formats, and software. The data coverage includes Digital Elevation Models (DEM), Digital Line Graphs (DLG), and Land Use and Land Cover (LULC) for the state of Maine. (See Appendix F.) Also, LULC data which had been taken from the USGS by the Environmental Protection Agency (EPA) and processed into Arc/Info export format, was located using the previous project group's report. (See Appendix F.) The URL for the previous data is also given in the LULC users guide at the GeoData Web site.

The next very useful source of information was Clark University's Map Library, which was utilized to assist in finding digital maps. (See Appendix F) While the library did not have any of the required digital maps of Maine, it referred us to the map library home web page. Using links from the map library home page, the Wind Energy Resource Atlas was found at http://www.nrel.gov/wind/database.html. Various maps relating to the wind potential in New England as well as the average velocities, and percentage of land area were found. These maps were updated from maps created in 1979 and 1980, and strengthened our decision to study wind energy in Maine as mentioned in the section "Decision to do Maine."

The Idrisi project's URL, http://www.clarklabs.org/14links/14links.htm, was also utilized. A list of state level GIS sites were found and much of the data contained on these web sites originally came from USGS. Most of this data comes in an Arc/Info export format (.e00), and therefore must be converted as explained in Appendix E.

The last important resource utilized was the last previous project group, (SWP 9805) who provided us with the spreadsheet data for the Wind Resource Database map originally produced by the Pacific Northwest Laboratories (PNL). The data can not be used in its present format, but will be converted into a useable format as explained in Appendix B.

III.4. Deciding on a Map Scale and Format

The map scale is an important decision for a GIS project because each scale has a certain resolution, accuracy, and coverage. In digital form, map scale is irrelevant but still it serves as a way of identifying the attributes of a map. We decided on the 1:250,000 scale maps for the following reasons.

The United States Geological Survey at http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html contains digital elevation models in the 1:250,000 scale and 1:24,000 scale that can be downloaded free of charge. The 1:24,000 scale covers an area of 7.5 minutes by 7.5 minutes, and the 1:250,000 scale represents an area of three arc seconds by three arc seconds. The 1:250,000 maps can be downloaded in an older format that is readable by Idrisi (See Appendix G.). The LULC maps are also available in 1:250,000 scale. The site also contains digital line maps in 1:100,000-scale and 1:200,000 scale. The digital line maps are in a scale that Idrisi does not inherently recognize according to the software user's manual. Other formats and scales are available to download in SDTS format which format requires conversion software to convert it into a form readable by most GIS software (See Appendix D.). Several of the 1:250,000 scale maps were in compressed form and in a non-STDS format which includes all digital elevation models that represent pieces of Maine. Also, in order to incorporate surface roughness, the digital LULC maps in 1:250,000 scale, were also downloaded in the CTG format (See Appendix H.). On first attempt the decompression of the maps failed, the problem has been solved to date, but the files can be downloaded in an uncompressed format as well. These files were never made into a completely useable form despite several attempts.

Using the state of Maine's GIS web site, it was determined that Maine would require 709 1:24000 scale maps in order to obtain coverage of the whole state. At this point The United States Geological Survey (USGS) was contacted and it was determined that two weeks would be required to receive the data. Based on a talk with Kevin St. Martin, a Geography professor at Clark University, it was determined that 709 maps at this scale would be very tedious to use, as well as too data intensive for a desktop computer to handle. This led to the decision to use the 1:250,000 scale Digital Elevation Maps. Only 24 of these maps would be required for the entire state coverage, although they are 1/3 the resolution of the larger scale (1:24,000) maps (See Appendix G.). This was an acceptable loss, since in Powering the Mid-West (PMW) flower resolution maps were used (1:2,000,000 scale with a resolution of 1km).

III.5. Downloading and formatting the Data:

At this point the location of all the necessary data was known, and we could proceed to download all 24 of the 1:250,000 scale DEMS from the GeoData web site. This was simply done by downloading the 1:250,000 DEMs for coverage by state, and then selecting ME, under this category there are several regions of ME to be downloaded. The state is separated in 1 x 2-degree coverage on the map Index from USGS. Each downloadable map comes in a zipped file and represents the east and west half of a 1 x 2 or 1 x 1 degree coverage. Once all of the maps were downloaded and unzipped, it is easiest to place all of the unzipped files in one directory, because Idrisi will only recognize data within its working directory, which is specified in the ENVIRON menu. These files must be imported into Idrisi using the DEMIDRIS module as outlined in Appendix H.

Once all of the DEM files are imported into Idrisi the CONCAT module was used to concatenate all of the maps together, resulting in one large map of Maine and its surroundings, as shown below in Figure 3.2. The map represents the area between 42 degrees and 48 degrees latitude and -66 to -72 degrees longitude. This is the reference for all of the maps used in the entire Maine wind energy assessment.

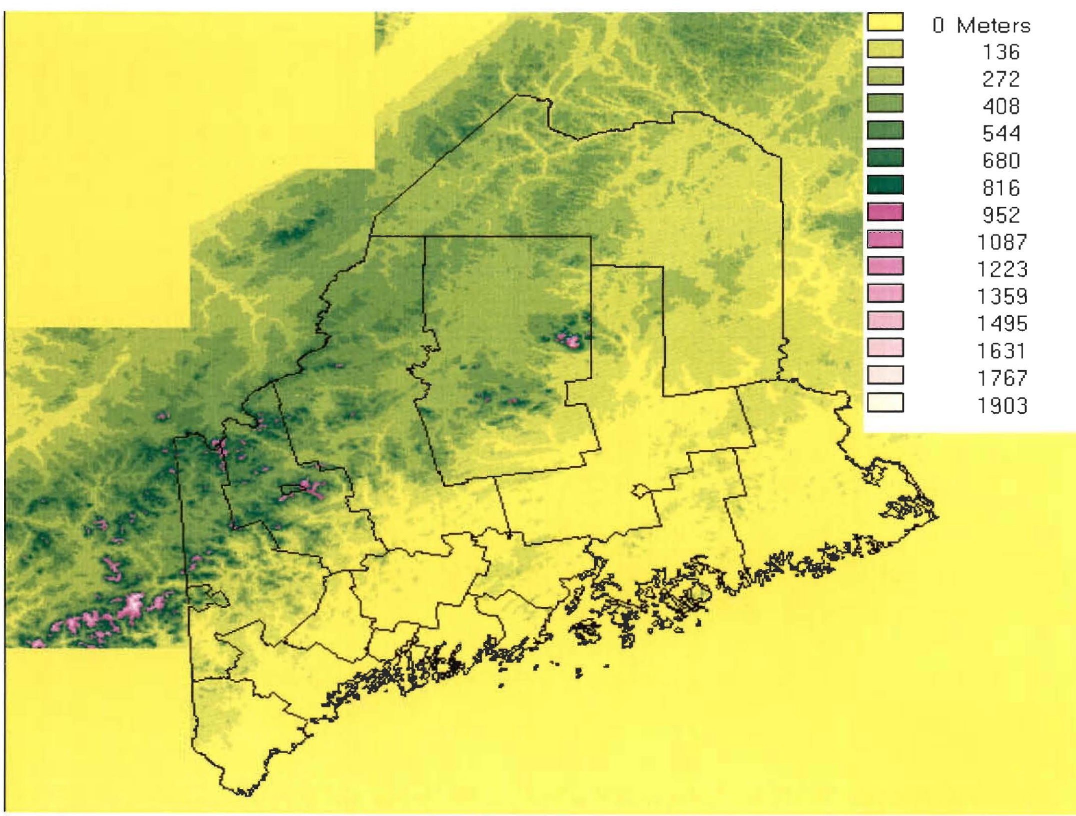


Figure 3.2: Elevation Above Sea Level in Meters.

At this point it was necessary to go back to the Wind Resource Database and format it appropriately. (See Appendix H.6.) After unsuccessful formatting attempts with UltraEdit, the "find and replace white space" option was used in Microsoft Word, as suggested by the previous IQP group. The file was then formatted properly, and only required documentation, which can be done using the DOCUMENT module in Idrisi. (See Appendix H.) The final result can be seen in Figure 3.3.

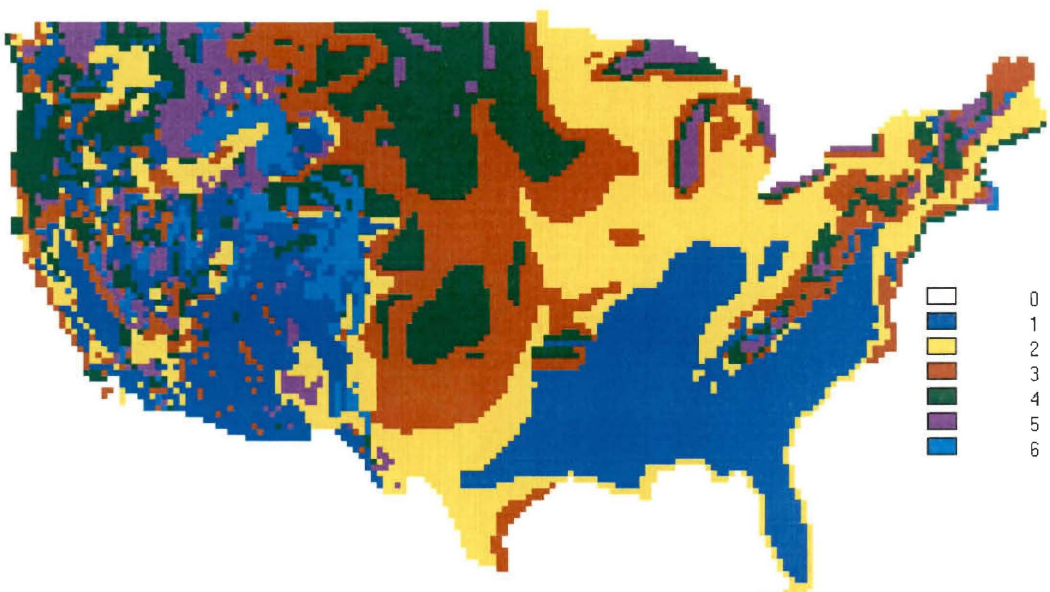


Figure 3.3: Wind Class Map Created by the Pacific Northwest Laboratories.

The next step was to crop the wind resource database map so that it represents the same area as the DEM. We accomplished this by using the WINDOW module in Idrisi, which created a new map of that area. The PROJECT module was then applied to expand the number of columns and rows from up to 7201 by 7201, the same as the DEM, and change the minimum latitude and longitude so that it matches the DEM of Maine. The result of this operation can be seen in Figure 3.4

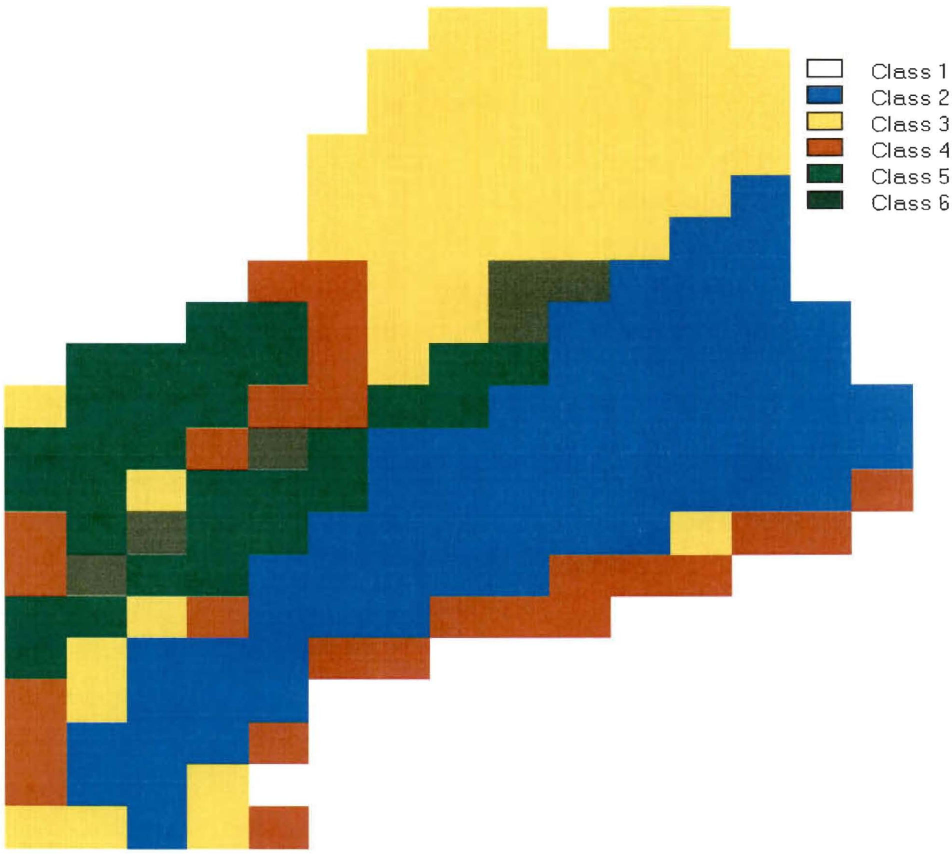


Figure 3.4: Wind Class Map of Maine from PNL.

III.6 Analysis of the Maps

With all of the maps in the appropriate format, the analysis could begin. The first and most important step within this project is to find the average elevation of a 12-kilometer radius area for every cell in the DEM of Maine. 12 kilometers was chosen because it was used in “Powering the Mid-West.” In flat areas a larger radius could be used, but because Maine is relatively hilly twelve kilometers is a good choice.

There are two methods that can be used to find the average elevation of a map within a circular area. The first is using the FILTER module in Idrisi 2.010. However, this module is very limited with the size of the filter, and does not automatically generate a circular filter, but in an attempt to accomplish the task a circular filter image was created using several Idrisi modules. (See Appendix C.)

After the filter image file was created with Idrisi, it was put into the appropriate form for filtering by using Emacs, because the FILTER module that came with Idrisi 2.010 can not handle such a large filter. (See Appendix C.) The project team sent the circular filter kernel to Clark Labs so that it could be processed using an in-house beta version of Idrisi32, the newest version of the Idrisi GIS software. However, Clark Labs never completed the circular average because the filter was not being processed quickly enough by their computer systems.

Shortly after the averaging filter was sent to Clark labs, an independent filtering software, Hovey’s Idrisi Map Walker which was found at the Idrisi Resource Center at Saltzburg University in Austria, and was used to create the circular averaged map. A square filter which had the equivalent area to that of the circular filter was also processed on a test map to get a comparison of the difference between the average of a circular and a square filter. By running both filters on a test map and recording the coordinates of a point on the map a percent difference of the averages was found to be 2.07%.

Following the creation of the average elevation map, the exposure map was created. This map was created by simply subtracting all of the data in the average elevation map from the DEM map. The results of the operation can be seen in Figure 3.5.

Figure 3.5: Exposure Map (actual elevation – average elevation).

There are basically two formulas that describe the change in wind velocity with height that can be used to produce experimental wind velocity maps. The first involves a logarithmic relationship and the second a simple power-law relationship. To make new maps based on these formulas requires the application of map algebra using the Image Calculator, SCALAR, and OVERLAY modules within Idrisi. (See Appendix H)

The first relationship applied to the maps is the logarithmic power law:

$$\frac{V}{V_{ave}} = \frac{Ln(\frac{50+E}{Z_O})}{Ln(\frac{50}{Z_O})}.$$

The "V" is the corrected wind velocity for a 50m hub height, V_{ave} is the median velocities for each wind class given on the PNL map, Z_O is the surface roughness length, and 50 is the assumed hub height of fifty meters. The surface roughness length of 0.03, 0.10, and 0.8 represent cropland, mixed woodland/cropland, and forestry respectively. For this project a Z_O of 0.8 was assumed because Maine is mostly covered by forest. Using this formula and its reciprocal, velocity maps for the negative and positive exposure areas were produced separately. The maps are representative of the corrected wind velocity at a hub height of fifty meters.

Once the average corrected wind velocities at fifty meters were calculated using the formula above, the two maps for positive and negative exposure were combined to form one average wind velocity map using the OVERLAY module in Idrisi. (See Appendix H) The same procedure was then repeated with the wind classes downgraded by 1 class in the wind resource map. (See Map)

The second relationship is a power-law Formula:

$$\frac{V}{V_{ave}} = \left(\frac{50+E}{50}\right)^{1/n},$$

which is applied in a similar way to that of the logarithmic relationship, although the precise method of processing in Idrisi was slightly different. This formula was used in order to produce maps that have no dependence on surface roughness and to use another model for how wind speed varies with height.

As with the logarithmic relationship, the power law formula must be inverted for negative exposure, and then the absolute value of the negative exposure must be substituted for the positive exposure to produce the negative exposure portion of the velocity map. Once both maps were calculated the OVERLAY module was then applied to form a velocity map. (See Appendix H) With all of this complete the resulting map could be multiplied by the map of median average velocities for the wind classes from the Pacific Northwest Laboratory wind potential map. This particular step was combined into the positive and negative exposure maps separately for the logarithmic wind velocity relationship. The OVERLAY option is used to complete this step. The result is a complete wind velocity map using a 1/5 exponent in the power law. (See Map. 3.) The same procedure was used using a 1/7 (See Map 4) and 1/9 exponent in the power law.(See Map. 5.)

Reference:

1. U.S. Beureau of the Census, STATISTICAL ABSTRACT OF THE UNITES STATES: 1997. Washington , DC, 1997

III.7. Budget

<u>Maps:</u>
7.5 minute X 7.5 minute digital elevation maps (DEM) will require 218 of then to cover the state
$45 for the 1st map + $1 for each extra map   Total = $ 262

Line distribution map approximately , $100

Land use and land cover maps (LULC), $218

Total Map Cost = $ 580

<u>Travel to UCS:</u>
$37 each trip × 4 trips = $148

<u>Software</u>
Idrisi 3.0 Update = $100

<u>Student contribution:</u>
$45 each student × 3 students = -$135

TOTAL COST OF PROJECT: $580 + $148 + $100 = $828

TOTAL BUDGET REQUEST: $580 + $148 + $100 – $135 = <u>$693</u>

IV. GIS Results:

Two basic formulas were applied to calculate the wind potential based on exposure, E. The first was using a logarithmic relationship and the second was using a ratio of heights raised to a variable exponent. The logarithmic formula is

$$\frac{V}{V_{ave}} = \frac{Ln(\frac{50+E}{Z_O})}{Ln(\frac{50}{Z_O})} \,,$$

while the exponential power-law formula is

$$\frac{V}{V_{ave}} = (\frac{50+E}{50})^{1/n} \,,$$

where n typically varies from 3 to 7.

In Powering The Midwest, the PNL map was assumed to be based upon mostly flat, open areas and therefore hilly terrain and forested terrain was reduced by one or two wind classes. The previous IQP group in their assessment of Massachusetts applied the same approach, but this approach is probably not correct, since the PNL map may already account for the hilly and forested terrain in most of New England.

IV.1. MAPS: Results of Formula Application

The First map shows the application of the logarithmic relationship with a downgrade of one wind class in the PNL map, while the second map applies the same relationship without a wind class downgrade. The last three maps are a result of the application of the exponential formula with an exponent of 1/5, 1/7, and 1/9 respectively, but without class downgrades due to hillyness or forestry. The brief discussion of each map following incorporates the comments of Harley Lee at Endless Energy Corp. The maps shown are classified in the form of wind classes.

The first map (Figure 4.1) seems to give a reasonable portrayal of the northern part of Maine, but shows only class 1 in the eastern part. Based on Harley Lee's comments it is unlikely that the eastern part of Maine would be class 1, but should be more towards class 2.

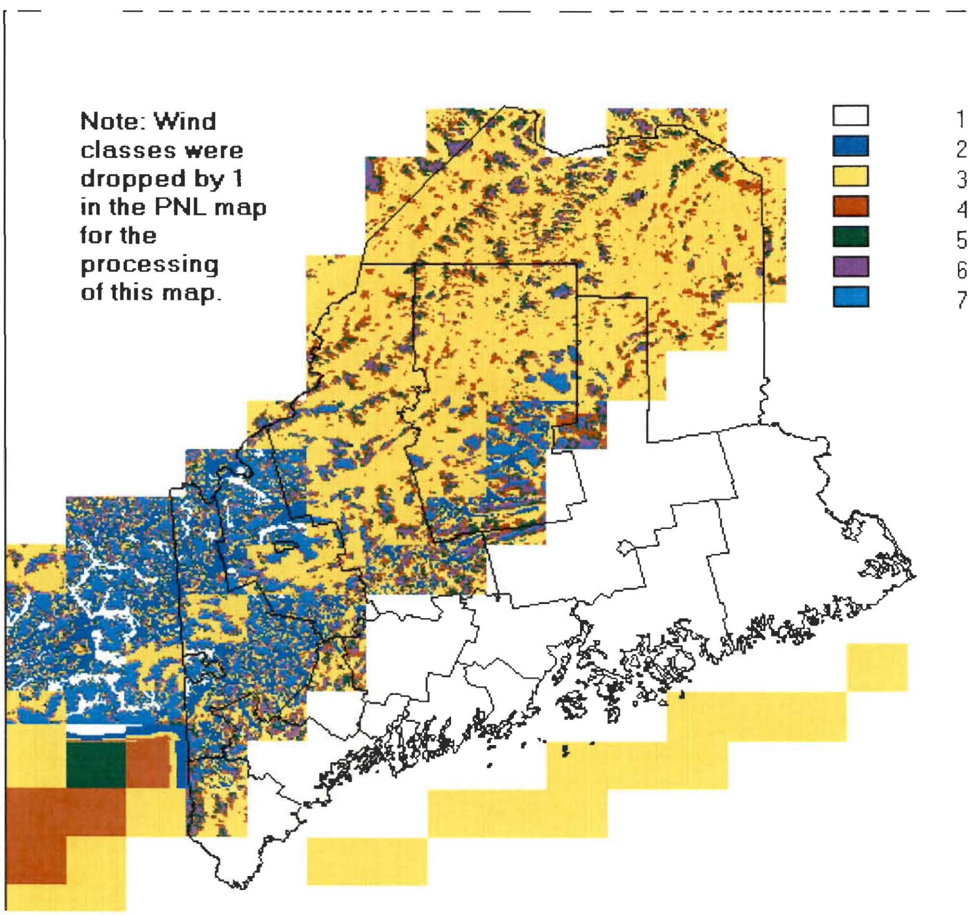


Figure 4.1: Wind Class using the Ln power relationship.

The next map (Figure 4.2) shows substantial amounts of class 3 wind throughout Maine. This could be a possibility, but much of the class 3 is probably class 2, because the PNL map clearly shows eastern Maine as class 2. The map also contains considerable class 7 winds, which is highly unlikely, except on top of mountains, because Maine's second highest peak barely reaches class 7 according to Harley Lee.

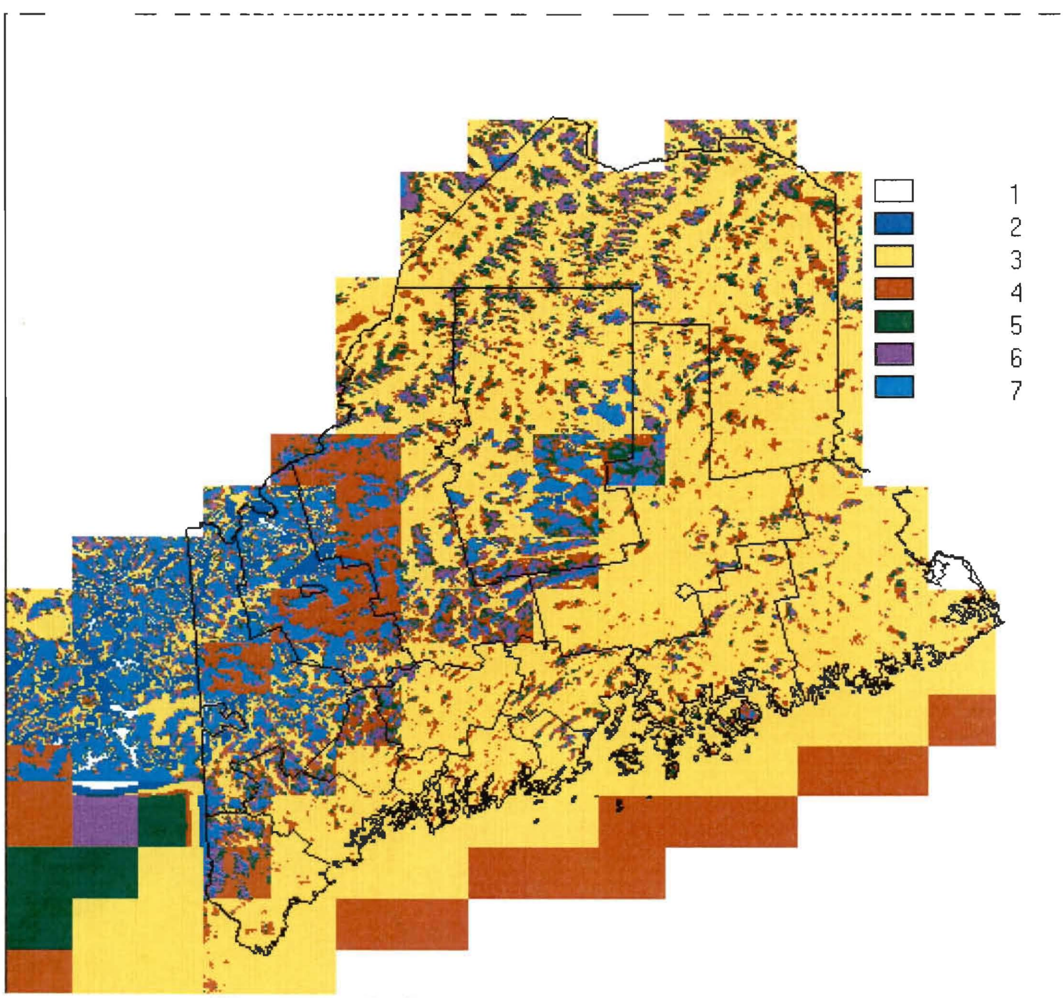
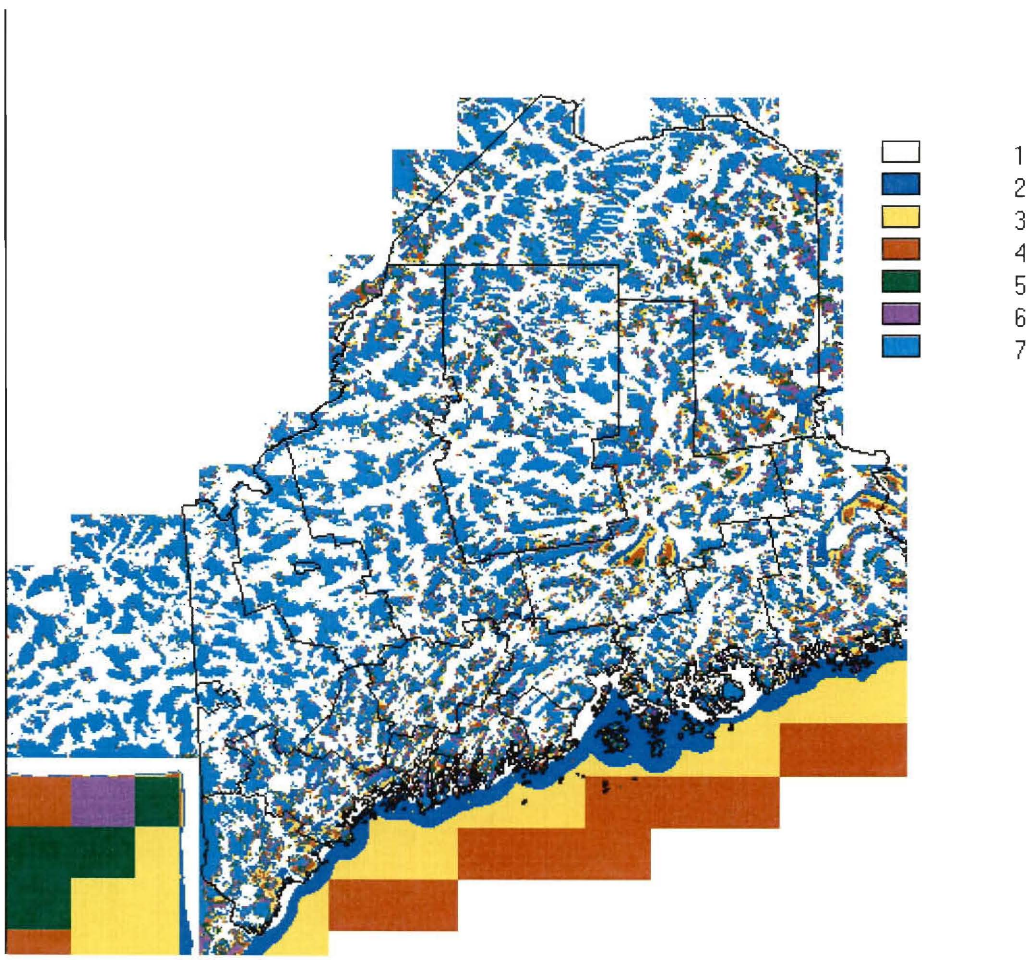


Figure 4.2: Wind Class using the Ln velocity relationship with height.

The next map (Figure 4.3) shows the results of applying an exponent of 1/5 to the exponential power law formula. It can be seen that class 7 winds or class 1 winds consume most of the state, but obviously this is not the case in reality. The map is an extreme case, which may, in some places be accurate, but is highly unlikely in most places.



Figue 4.3: Wind Classes using the Power Law with an exponent of 1/5.

Applying the power- law with a 1/7 exponent helps reduce some of the class 7 winds shown in the 1/5 map (Figure 4.3), resulting in a far more accurate wind classes. There is still a large amount of class 7 winds, but this could be reasonable in highly mountainous regions. Most of the class 7 areas were originally shown as class 5 or 6 in the PNL map, and are in mountainous regions of Maine, according to the exposure map. The resulting map is shown in Figure 4.4.

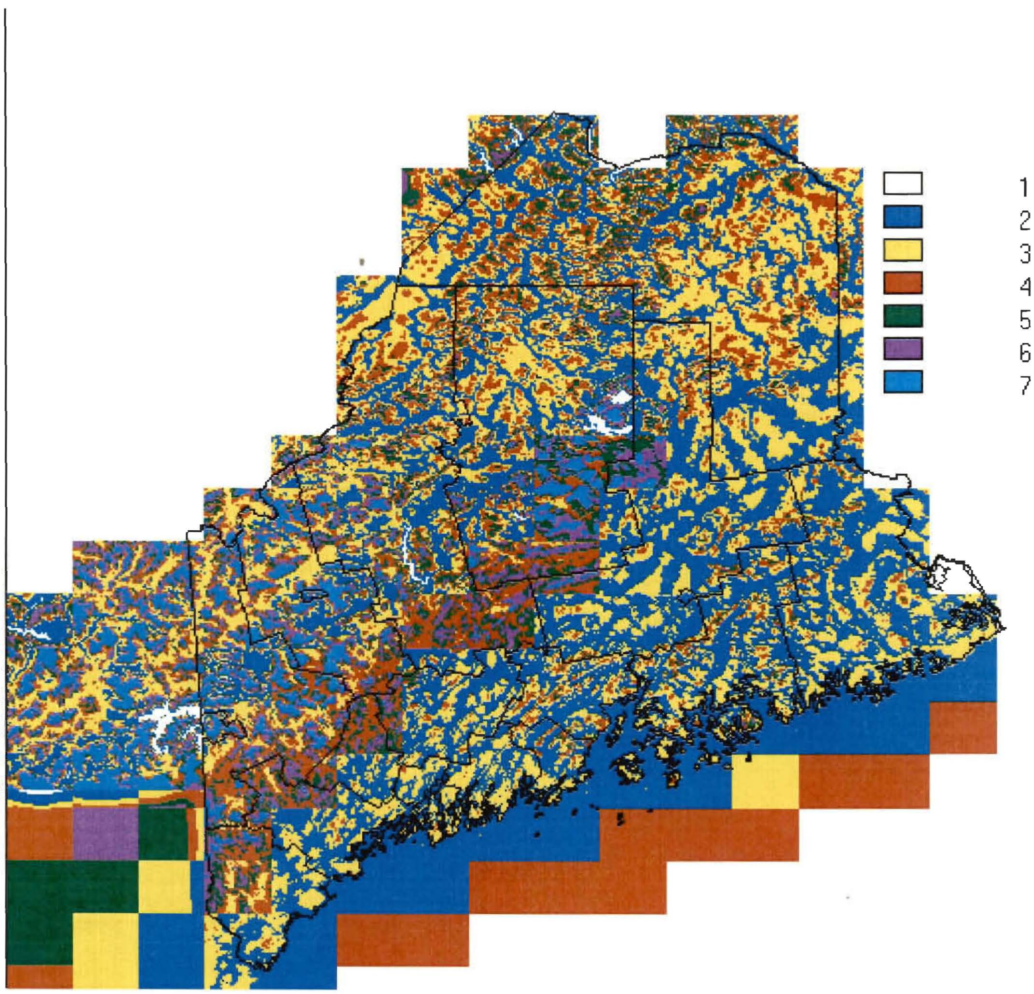


Figure 4.4: Wind Classes using the Power Law with an exponent of 1/7.

The final map, shown in figure 4.5, applies the exponent of 1/9, and the class 7 winds are now downgraded significantly compared to the previous two maps. In the PNL map the northern part of Maine was shown as class 3, while the eastern part of the state was mostly class 2. Looking at the map, it is clear that there is a significant amount of class 3 wind in the northern part of the state, and class 2 in the southeasterly part of the state. If the wind classes in these areas were averaged they could very well end up in a class 2 and 3 category as described by the Battle Pacific Northwest Laboratories. All of the other regions appear to average in a similar manner.

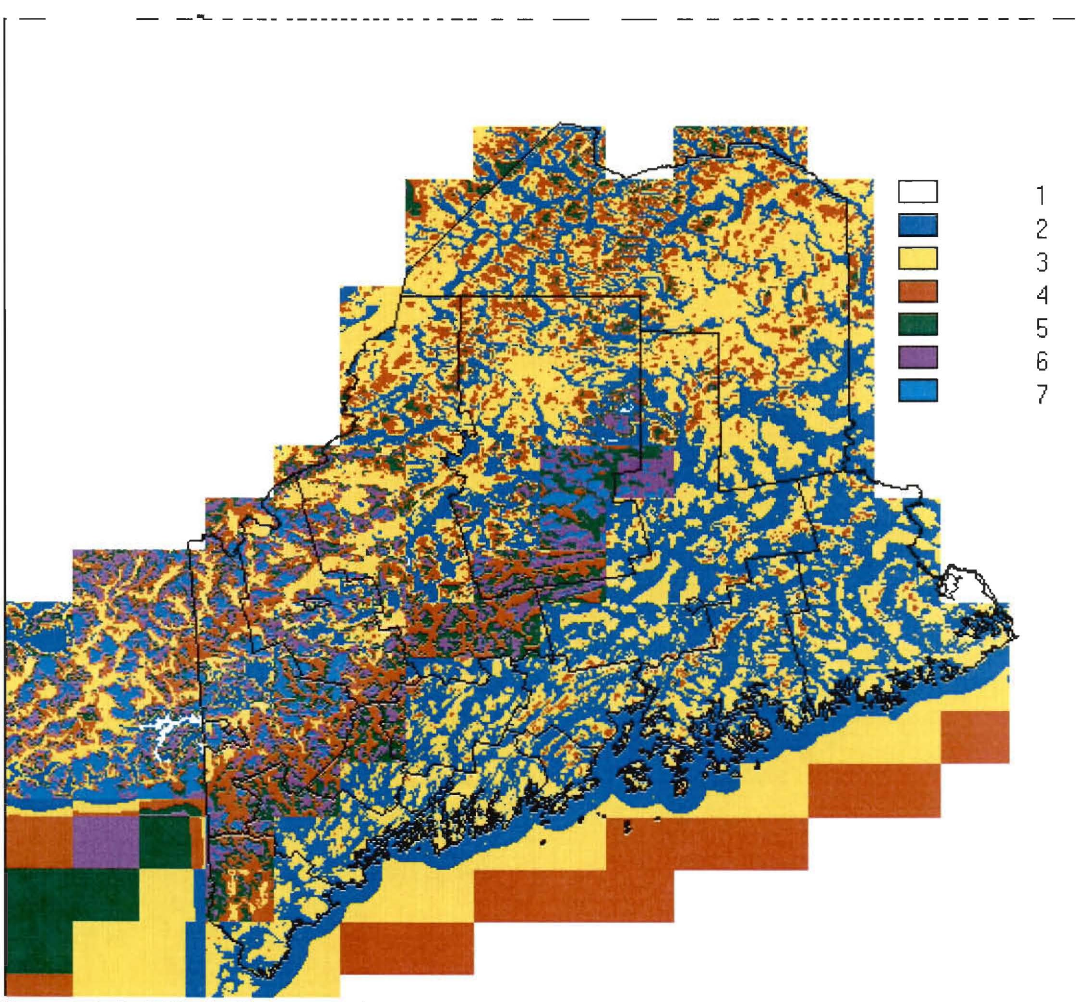


Figure 4.5: Wind Classes using the Power Law with an exponent of 1/9 at 50m.

IV.2. Discussion of Results:

In the negative exposure areas there is a decrease in wind velocity and in many cases a decrease in wind class as well. In the positive exposure areas there is a general increase in velocity and therefore an increase in wind class in some areas. This is expected, because positive exposure will yield a greater wind class because surrounding terrain does not cover it. In the negative exposure areas the surrounding terrain shelters the wind site from the open wind, and typically yields a decrease in wind class from the average. The 1/9 power law map appears to be the most reasonable map, because except for a few regions there is not more than an increase or decrease of one class when compared to the PNL map.

To further assess the validity of the Wind Class maps, they can be compared to actual data measured by the National Renewable Energy Laboratory (NREL). Unfortunately, velocities for only two sites could be obtained from NREL. Out attempts to find other data points were unsuccessful. Endless Energy Corporation does have data for 12 Maine sites, but it is a proprietary and beyond the budget of this IQP.

At 10 meters the average wind velocities measured by the NREL are 4.593 m/s at Caribou, and 3.904 m/s at Portland. Using the exponential Power law with a one seventh exponent these data points were interpolated to a 50m-hub height to make comparisons of our results possible, yielding a velocity of 5.780 m/s for Caribou and 4.913 m/s at Portland. It should be noted that using a 1/7-power law relationship to interpolate the wind velocity from 10m to 50m might not be correct, but given no other data, this is generally used (Michael Brower.).

The experimental wind velocities for each of the wind maps above are given in the following table and figures:

	Caribou (m/s)	Portland (m/s)
Map 1:	6.464	2.856
Map 2:	6.767	6.4
Map 3:	6.968	6.784
Map 4:	6.738	6.178
Map 5:	6.729	6.227

Table 4.1: Predicted wind speeds for Caribou and Portland.

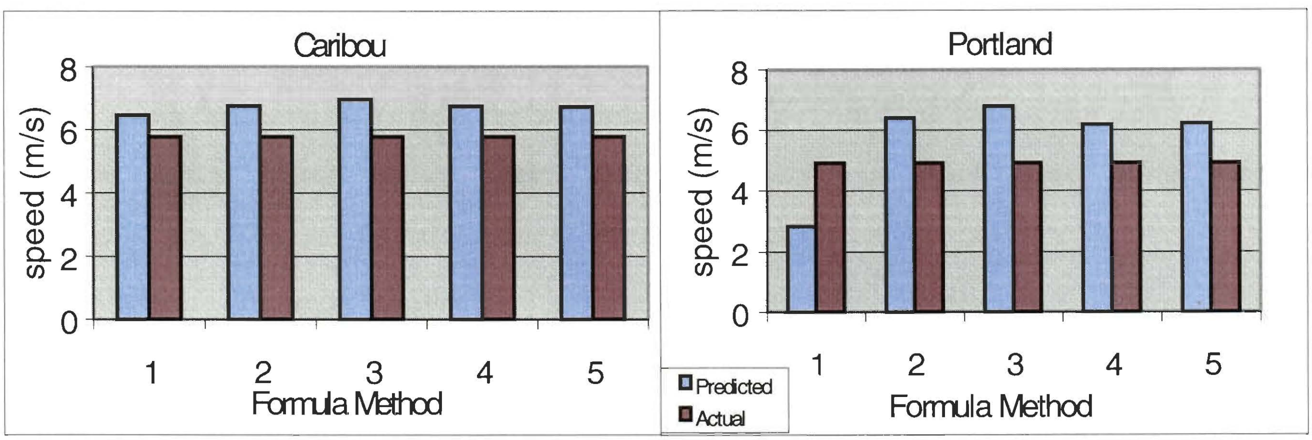


Figure 4.6: Predicted Vs. Actual Wind Speeds for Caribou and Portland.

The predicted wind speeds are all higher than the interpolated actual wind speeds, except in map 1 (Figure 4.1) at Portland. The lower value at Portland can be attributed to the wind classes being reduced by one in that map and it should be noted that with a movement of only 90m along the ground, the predicted wind velocity could change substantially. In other words, a more accurate result may only be the difference of finding the velocity directly next to the points shown in Table 4.1 which is only a one-pixel difference on the wind maps shown. The variation in predicted wind speeds may also be a result of not querying the exact same point as the other maps, although the location query was made within a 1/100th of a degree of the coordinates specified by NREL. Also, the Portland site has a significant change from negative to positive exposure within a very short distance, this creates a large variation in wind speed within a small area when using formulas based on exposure. In general, the wind class maps are expected to be more accurate than the comparison between predicted and actual measurements.

V. Economic Analysis

The economic aspects of setting up a wind farm at locations for various wind classes were necessary for this project. To achieve this goal, economic calculations for each wind class, from 2-6, was done and the results were tabulated. Some of the economic methods used for the analysis include initial cost, annual revenue, maintenance cost, cost of capital, net present value (NPV), internal rate of return (IRR), modified internal rate of return (MIRR), and annual worth and cost. These different economic topics and their formulas will be described in more details in later sections. The economic aspects for different wind classes was analyzed in detail by a previous IQP group analyzing wind potential for Massachusetts (SWP9805). Therefore, one of our objectives was to improve, update, and better explain their results and data. These improvements and updates included modifying the values for the capacity factor, wind power density, wind turbine (NEG MICON 750/44), and cost of generation.

V.1. General Theory

The basis behind any economic analysis depends upon two key determinants, revenues and expenses generated by the project. For the case of a wind farm revenues include selling the electricity generated by the turbine at a cost of 3.663 cents/kWh to various power distribution companies. Expenses include the initial cost of the turbine, installation, transmission lines, land, and maintenance.

For this project we assumed all the values are current to the year 2000 because we felt that would be the earliest that the wind farm would actually be installed. All the revenues and expenses are calculated over a twenty-year period, thus such variables as inflation must be taken into account, which means that the value of money decreases every year at rate of 3%. When dealing with long-term investments economic functions such as NPV, IRR, and MIRR must be considered, since the money spent on the project could have been otherwise invested in stocks and bonds. Once all the calculations are done for each wind class, a price of generating electricity per kilowatt hour is derived.

V.2. Annual Average Output

The annual average output is the average electricity produced in one year for a given wind turbine with units in kWh. This is an important element for the economic analysis since it is used to derive a value a value for the annual revenue. The formula is for the annual average output is:

$$O = P \times CF \times A \times 8760 \ \frac{1kW}{1000W} \times \frac{hours}{year} \ [kWh]$$

where O is the annual average output, P is the maximum wind power density, CF is the capacity factor, and A is the swept area by the blades of the turbine.

The power density and capacity factors were obtained from Powering the Midwest (PTM) on page 27. All the Data used was updated from the last IQP group. The table below (Table 5.1) shows both the old and the update values for the power densities and the capacity factors.

Wind Class	Old Wind Power density at 50 M (W/m^2)	Updated Wind Power Density (W/m^2)	Old Capacity Factor (percent)	Updated Capacity Factor (percent)
2	250	225	22.3	18.3
3	350	320	30.0	25.1
4	450	410	36.7	30.7
5	550	500	42.3	35.5
6	700	640	48.6	41.1

Table 5.1: Wind Power Densities and Capacity Factors.

The updated values were taken from the later version of PTM owned by the UCS. The value for the swept area by the blades of the turbine was obtained from the technical specifications for the turbine shown in Appendix I.

Calculating the capacity factor was found to be extremely difficult so the values had to be taken from the article "POEJECT FINANCIAL EVALUATION" given to us by Steve Clemmer of UCS. However, the article mentioned above had only capacity factors for wind classes 4 and 6. Therefore, updated data from PTM shown in the table 6 were used. For further information regarding the capacity factor see Appendix J which contains explanations by Dr. Micheal Brower and a URL to Danish Wind Turbine Manufacturers Association, where a JAVA Graphical User Interface (GUI) is used to calculate the Capacity Factor for various wind turbines given the user has the required parameters.

The results for the annual average output is shown in Appendix K.

V.3. Initial Cost

The initial cost for a wind turbine depends on many factors, these include the price of the wind turbine, substation, transmission lines, service center, land, and indirect/permitting as mentioned in PTM page 25. These factors together make up the unit cost, assuming a 50 MW wind farm the unit cost was given as \$1032/kW in PMW (updated version). The previous IQP group used a substantially lesser value of \$942/kW which was in the original version of PTM.

The formula is for the Initial Cost is:

$$IC = PR \times UC \ [\$]$$

where IC is the initial cost, PR is the power rating of the wind turbine (750kW), and UC is the unit cost (\$1032/kW). The calculation and the result is shown in Appendix K.

V.4. Annual Revenue

The annual revenue is the amount of money a project makes in a year. The revenue for a wind farm consists only of the amount of money it gets from selling the electricity it produces at a given price. The price to generate electricity in the year 2000 was predicted from Table A1 of the article "*Competitive Electricity Prices: An Update*" to be 3.663 cents/kWh for the industrial section of the northeastern region of US. The method and calculation for getting this value is shown in Appendix M. For long term projection of annual revenue the effects of inflation must be considered. It is generally believed that the inflation rate is 3% for and the electricity deflation rate is 1%. To get the net inflation rate for electricity, the 1% deflation rate of electricity must be subtracted from the 3% general inflation rate; the result is 2% inflation of electricity every year as represented on page 52 in the book "Annual Energy Outlook". The formula for the projection of annual revenue is shown below:

$$AR = O \times (P \times (1 + EI)^n)\ [\ \$\ ]$$

Where *AR* is the annual revenue, *O* is the annual average output, *P* is the price charged in year 2000 (3.663 cents/kWh), *EI* is the electricity inflation rate (2%), and *n* is the number of years from year 2000. For examples and calculation see Appendix M.

V.5. Maintenance Cost

The maintenance cost is the cost of keeping the wind turbine in optimal working condition which includes parts and labor. This maintenance cost is defined by multiplying the average annual output by a operational and maintenance constant found to be $0.008/kWh for year 2000, found in table1 on page 6-13 of the article "*Renewable Technology Characterization*" by the Department of Energy. Since the data assumes a twenty-year life span, inflation must once again be taken into account. The formula used to calculate the maintenance cost is shown below:

$$MC = O \times 0.008 \times (1 + IR)^n\ \ [\ \$\ ]$$

where *MC* is the maintenance cost, *O* is the annual average output, *IR* is the inflation rate of 3%, and *n* is the number of years from year 2000

The calculation for individual wind classes is shown in Appendix M.

V.6. Cost of Capital

The cost of capital for the twenty-year life span of the turbine is defined on chapter 12, page 145 in "*Handbook For Interactive Qualifying Project Advisors and Students*", by Douglas W. Woods as "both the interest rate that must be paid to acquire funds (including equity) and the rate that could have been earned if the funds were invested externally, i.e., in stocks or bonds. Which of these measured is most appropriate to use depends on the circumstances". The formula for cost of capital is shown below:

$$k = k_D(1-T)(\frac{D}{D+S}) + K_{sp}(\frac{S}{D+S})$$

where, k is the cost of capital, k_D is the interest rate paid on the firm's debt (8%), T *is* the firm's marginal tax rate-federal and state combined (0.4), D is the market value of the firm's debt, S is the market value of the firm's stock ($\frac{D}{S}$=0.6), k_{SP} is the return required on the stockholder's equity invested in the project, and can be calculated using the formula shown below:

$$k_{SP} = R_F + \beta_P(1+\frac{D}{S}(1-t))(k_M - R_F)$$

where, R_F is the risk free rate which is the same as the T Bond rate (5), k_M-R_F is the expected risk premium on the market (8), β_p is the project's beta coefficient if it were financed entirely with equity (1). When calculated using all the values above, which were obtained from the previous IQP group who had obtained the data from Professor Douglas

W. Woods and were confirmed by and Professor Dieter Klein before used again in this project, the value of k was found to be equal to 11.3.

V.7. Net Present Value

The net present value (NPV) is the summation of the net annual profit of a investment over the life of the investment expressed in term of the present value of money. NPV also take into account inflation, as all other economic calculations for long term investments. NPV is defined as:

$$NPV = PV - I$$

where PV is the total present value of the future cash flow, and I is the investment. For a project to be deemed profitable over its life span the value of NPV must be greater than zero. In order to find NPV, the net present value of the future cash flow of each year must be calculated and then added. The present value for the cash flow of each year can be calculated by multiplying the net cash flow for each year by the present value interest factor (PVIF). PVIF is a variable that changes with each additional year and acts as a function to represent the net future cash flow in term of money in hand today. PVIF is represented by the following formula:

$$PVIF_{k,n} = \frac{1}{(1+k)^n}$$

where k is the annual compound rate of interest or cost of capital to the investor calculated to be equal to 11.3 (see previous section), and n is the number of years for year 2000. The NPV calculations for each individual wind class is shown in Table N.1 in Appendix N.

V.8. Internal Rate of Return

The internal rate of return (IRR) is defined as the interest rate that yields a zero net present value. The IRR is the rate of interest earned on the funds invested on the project. An investment is deemed acceptable if the value of IRR is greater and equal to the value of cost of capital. . IRR is the value of *r,* which satisfies the equation below:

$$I = \frac{F_1}{(1+r)^1} + \frac{F_2}{(1+r)^2} + \frac{F_3}{(1+r)^3} + \ldots.. + \frac{F_n}{(1+r)^n}$$

where I is the initial investment ($774,000), F_n is the future net cash flow for a given year, and n is the number of years from year 2000.

IRR is generally preferred over the NPV as a means of estimating the profitability of an investment since IRR is only a function of profitability, while NPV is a function of profitability and scale or money invested. For the calculations and results see Table N.2 in Appendix N.

V.9. Modified Internal Rate of Return

The modified internal rate of return (MIRR) is a premium measure of an investment's rate of return. MIRR considers both the cost of the investment and the interest received on reinvestment of cash. To find the value of MIRR the formula for IRR is used except that the reinvestment rate for the future net cash flows, r is replaced by k

the cost of capital. The formula for MIRR is shown below:

$$r^* = (\frac{[F_1(1+k)^{n-1} + F_2(1-k)^{n-2} + F_3(1+k)^{n-3} + ... + F_n]}{I})^{\frac{1}{n}} - 1$$

where, r^* is the MIRR, F_n is the future net cash flow at n years from year 2000, k is the cost of capital (11.3), and I is the initial investment ($774,000). MIRR can be thought as the rate on a loan of equivalent sum to generate as much future net cash flow F_n in year n, as this project (wind farm). The calculations and results of MIRR are shown in Table N.3 in Appendix N.

V.10. Annual Worth

Annual worth (AW) is defined as "*uniform annual cash flow whose total present value over the life of the investment is equal to the net present value*" (IQP handbook, page133). AW can also be thought as excess return over cost of an investment taking into account inflation. The formula for AW for each individual wind class is shown below:

$$AW = \frac{NPV}{PVIFA_{kn}} \qquad \text{where,} \qquad PVIFA_{kn} = (\frac{1-(1+k)^{-n}}{k})$$

NPV is the net present value for each individual wind class, k is the cost of capital (11.3), n is the number of years from year 2000. The calculations for AW is shown in Appendix M.

V.11. Annual Cost

Annual cost (AC) is defined as "*the uniform annual cash flow whose present value is the same as the present value of the project's total life cycle costs*" (IQP handbook, page134). In order to get a final figure for the cost of electricity for each wind class that average annual revenue must be subtracted from the annual worth of the wind turbine to get a value for the total annual cost. The total annual cost must then be divided by the total annual output of the wind turbine to get a value in terms of cost per kWh. This can be represented in the formula below:

$$\text{cost per kWh} = \frac{AR - AW}{O}$$

where AR is the annual revenue for each wind class, AW is the annual worth for each wind class, and O is the annual average output for each wind class. In order to get the final cost per kWh we must subtract the cost per kWh calculated above from the generation cost. The final cost per kWh can then be calculated for each wind class and is shown in Appendix M.

V.12. Payback Period.

The payback period is the number of years that it takes for a project to generate enough net cash flows to pay back it's initial cost. The formula for the payback period is shown below:

$$F_t = S_t - O_t$$

where, F_t is the Net cash flow for year t, S_t is the revenue generated in year t, and O_t is the expenses in year t. In the economic analysis shown in Appendix K, the payback period was calculated by adding the net savings for each year until a value that matched the initial cost ($774,000) was reached. The results are shown in Table N.4 in Appendix N. The payback for wind class 2, was determined since our analysis was over a 20 year period and the total net cash flows summed over 20 years for that wind class did not reach the initial cost of the project.

VI. Conclusion and Recommendations

VI.1. Conclusion

The objective of the GIS analysis was to create wind class maps, which could be used to accurately portray the wind potential in the state of Maine. Producing accurate wind class maps can be extremely difficult due to the complicated topology and wind velocity profiles of the earth. Our wind class maps were produced to get a comparison of many different possible wind relationships, and try to get as close as possible to the actual wind classes. Realistically, as one moves from point to point throughout the state of Maine, there are many different relationships of velocity with height, but there are no formulas that will accurately predict the wind velocity at every point, although a combination of our maps may predict the velocity accurately. Based on our data, and comments from Harley Lee, our 1/9 power-law map appears to be the most accurate map.

Wind energy is not only a function of height, but also a function of slope of a hill or mountain, as well as numerous other factors, and if these factors could also be taken into account, a more accurate map could be made. Another approach and the most accurate, would be to collect hundreds or thousands of wind measurements and use GIS software to interpolate the data into a continuous surface. In any case, to obtain a realistic prediction it is necessary to obtain more wind velocity measurements since two points are not really good indicators of overall wind potential.

The main goal of the economic analysis was to produce the Final cost per kWh for generating electricity at each wind class over a 20-year period. The results for the final cost of generation are shown in Table 6.1.

Wind Class	Cost of Generation (cents/kWh)
2	18.45
3	9.68
4	6.33
5	4.61
6	3.25

Table 6.1: Final Cost of Generation.

It can be seen from the table above that the cost of generation for wind class 6 (3.25 cents/kWh) is less than the cost of generation for a typical power plant (3.663 cents/kWh). Thus, it can be concluded that a wind farm in areas with wind class 6 or higher would generate electricity at a very competitive rate. Wind class 5 is also a good candidate for a wind farm site since it can generate electricity at a reasonable price (4.61 cents/kWh). Although the price is higher than the typical cost of generation, it can still be competitive if tax breaks are given or perhaps the consumer would be willing to buy wind power generated electricity.

Areas with wind class 4 or less were determined to generate electricity at a much higher cost and therefore were noncompetitive with the typical power plant. Therefore it can be concluded that for the state of Maine only areas yielding wind class 5 or above would be a feasible means of generating electricity.

VI.2. Recommendations

During the course of the Wind Energy Assessment of Maine we attempted to solve many issues relating to GIS. It should be taken into consideration that when performing a GIS project a considerable amount of time is spent on gathering data and making it useable, and when gathering data it is best to consider the larger picture. Raster analysis is extremely data intensive, and maps can require large amounts of RAM. For this project the maps of Maine, in uncompressed form, ranged between 97 to 200 MB each.

It should be noted that the higher the map resolution and size, the more memory the computer would require. These issues are imperative when considering a map scale and resolution. For small areas, such as a town, using 7.5-minute maps might be a good choice. However, these maps are more difficult to work with because of their UTM (Universal Transverse Mercator) Projection, and if more than one is needed, additional processing is required. Also, as mentioned in the methodology, to cover a whole state with 7.5 minute maps would require several hundred maps in many cases.

The 3 arc second (90m resolution) maps are also referred to as 1:250,000 scale maps, and are recommended for a statewide GIS analysis. Although they are 1/3 the resolution of the 7.5 minute maps, the resolution is high enough for a wind energy analysis of an entire state. Another reason to use 1:250,000 scale maps is that a PC may not be able to handle the necessary calculations in a reasonable amount of time, depending upon the operation being performed, map size, and resolution. An Idrisi 2.010 calculation can take anywhere from 2 seconds to several days to complete, while most calculations for this project took between 5 minutes and 30 minutes on the AMD K6-2 266 outlined in Appendix A. The recommended computer setup for a raster GIS project of this size is a Pentium II 450MHz, with 128 MB of RAM, and a 10 GB hard drive. Hovey's MapWalker software is more processor dependent while Idrisi is more hard drive dependent.

It is also recommended that USGS be contacted at 1-800-USA-MAPS as soon as possible in order to get a map pricing list, as well as State map Indexes of topographic and other Map Coverage. The pricing list can be helpful if you are going to be purchasing maps from USGS, and the Map Coverage maps are extremely helpful for determining which maps cover which areas of a state, as well as determining the spatial coordinates of the maps in latitude and longitude. Also, the difference between a circular and square average was determined during the course of this project. If time constraints do not allow processing a circular average, then the square is the probably a good estimate.

It is also recommended that an averaging filter be applied to the PNL map before using the map to produce new maps. By applying the filter, a smoother version of the map will result and will more accurately portray the transition between different wind classes. Also, it is recommended that at least half of the group members work on the GIS analysis. For our project there was insufficient time to complete a power line analysis, even though several emails were sent, and web sites were searched to locate power line maps. A second GIS person would allow simultaneous completion of both the power line, and wind class portions of the project. Lastly, due the massive amounts of Arc/Info files available over the Internet, it might be useful to assess using Arc/Info rather than Idrisi for a wind energy or Biomass project. Information on Arc/Info can be obtained from the ESRI (Earth Sciences Research Institute.)

For the economic part of this project several important recommendations have to be suggested if another group wishes to continue with, or implement such a project. One of the main recommendations is to obtain the actual capacity factors, cost of wind turbine

per kWh ($1032 kWh), and maintenance cost per kWh (0.8 cents/kWh) for the wind turbine model used instead of using the data obtained from PTM. Another recommendation is to obtain an actual cost of generation for a typical plant for a certain year, rather than using the linear interpolation method used in this project
(See Appendix L).

Several other helpful recommendations include obtaining a current version of PTM, more accurate wind power density values, and an available economic advisor. Finally, we recommend that the IQP group use UCS as a resource as much as possible.

Appendix A

Materials and Data

1. Computers used:
   AMD K6-2 266 MHz with 64 MB SDRAM, Hard drive 5.7 GB UDMA. Running under WIN 95 OS.

   Intel PII 300 MHz with 32 MB RAM, Hard drive 3.2 GB EDO. Running under WIN 95 OS.

2. Software:
   IDRISI 2.010, a Raster based GIS software developed by Clark Labs at the graduate school of geography at Clark University.

   Hovey's IDRISI MapWalker, obtained from the IDRSI Resource Center at Saltzburg University, Austria.

   Microsoft Office 97

   Mathcad

3. Data:
   Wind Resource Database, a digital Raster image with a resolution of 1/3 deg. Longitude by 1/4 deg. Latitude originally made by Battelle Pacific Northwest Labs and Obtained by a previous IQP group (SWP 9805)

   NREL wind speed data at 10 meters for Portland and Caribou.

   USGS elevation maps with a resolution of 3 arc seconds.

Appendix B.

Idrisi 2.010 Image files.

Idrisi image files are simply ASCII text files that consist of a single column of numbers. Each number represents a cell within the map, and therefore represents the value contained within that cell. In order for Idrisi to use this file you must also have a documentation file that has the same name as the image file and a .doc extension. The documentation file contains attribute information regarding the number of rows and columns a map contains, in addition to other attributes. Using this file Idrisi can properly format image files for display, but the image file must be in the format described above. To create documentation files see Appendix H.

Appendix C

Creating Circular and Square Filter Kernels

1. Square Filters in Idrisi

Square filters kernels are relatively simple to create using the Edit option in Idrisi or any text editor. They are simply an ASCII text file with a .fil extension and contain numbers in the following format.

```
7
7
1 1 1 1 1 1 1
1 1 1 1 1 1 1
1 1 1 1 1 1 1
1 1 1 0 1 1 1
1 1 1 1 1 1 1
1 1 1 1 1 1 1
1 1 1 1 1 1 1
```

The first two numbers represent the number of columns and rows contained within the filter kernel, while the rest of the file represents the filter kernel itself. There must be an odd number of rows and columns for the filter to be applied properly. This is because when the kernel is applied to a map image, the center value is placed over each cell in the map, and all of the values in the kernel will then correspond to a value in the raster image. In the filter kernel above, the 0 would be centered over each image and the ones would be placed over the corresponding cells nearby. When the FILTER module is executed all of the values within the kernel will be multiplied by the values in the corresponding raster cells. Then all of the new values will be added together and the cell with the zero centered over it will take on the new value. An average could be taken by simply dividing the entire raster map by the number of ones using SCALAR. The kernel can contain any whole numbers that you want, but for the purpose of averaging, they should all be ones. (Including the center value.) The center value does not have to be zero. Also, by checking the "normalize" option in the FILTER module an average will be taken if all of the kernel values are one. The normalize option divides the entire kernel by the total number of cells within the kernel.

It is not possible for the FILTER module in Idrisi 2.010 to process larger filters because of a bug within the software. The maximum allowable filter size is not known by the project group, but is somewhere less than 199 columns by 199 rows. The new Idrisi32 will handle larger filters, but how large is unknown. However, Clark Labs has informed me that the in -house beta version of Idrisi32 exhibits some difficulty when calculating large circular filters.

2. Circular Filters with Idrisi 2.010.

There is no easy way to produce a circular filter kernel using Idrisi 2.010. In fact, Idrisi 2.010 does not support circular filters at all, but they can be approximated using a square filter kernel. As mentioned in the procedure, the purpose of creating a circular filter for this project is to find the average land elevation within a circle of 12-kilometer radius. To do this, several Idrisi image analysis modules can be used.

First an image with the exact same spatial characteristics must be displayed using the Display Launcher. Then the "digitize" option must be selected from the tool bar. This looks like a red cross hair. The option to "digitize" a point should be selected, and the cursor should be moved to any point on the map where the 12 kilometer circle will be contained entirely on the map, and then click the left mouse button. This places a point on the map, and represents the center of the circular filter. Now close the map and select "yes" when prompted to save the vector file. The vector file is the point you just created, and is placed on a map containing the exact same spatial parameters as the original map.

Next, under reformat, vector/raster conversion, select POINTRAS. This module changes a vector point file into a raster image. Enter the vector point file name, and then enter a name for the new image file under image file to be updated, and leave all other options in there default position, and select OK. The INITIAL module will then appear asking you to create a blank image file. Enter the name of the map you used to digitize the point in the box titled "image to copy parameters from." Leave all other options in their default form.

Next, under analysis, database query, distance operators, select the module DISTANCE. Enter the new raster file created using POINTRAS in the "Feature image" box, and enter an output file name. The Distance module will then calculate the distance from the point in all directions using the cell resolution. A new image will be displayed representing this. Now, by knowing the cell resolution, which is approximately 90 meters for this project, the area only within 12 kilometers can be found (or any distance.). To do this the RECLASS module can be used. This is under analysis, database query, in the menus. The following information was entered.

Assign a new value of: 1
To all values from: 0
To just less than: 399

and then,

Assign a new value of: 0
To all values from: 399
To just less than: 999999

This creates a Boolean image where 1 represents all of the area within the 12-kilometer radius. The reason for using 399 in the assignments is because our map resolution was specified in arc seconds. If each cell has a resolution of about 90 meters, then it would require about 133 cells to make up 12 kilometers, but each cell represents 3 arc seconds, so 3 times 133 cells equals 399 arc seconds.

Using the WINDOW module from the tool bar the circular area should be windowed in on as closely as possible, but making sure the window contains the whole circle. Now the windowed region can be saved as a new image, which represents the circular filter. The circular part of the filter is made up of ones while the remainder of the square filter is made up of zeros. Next, by using the CONVERT module under the reformat menu, the binary image file can be converted to an ASCII format. The ASCII output file type is selected with an integer data type. Once the file has been converted the file can be opened in a text editor. The file is in a one-column form on the left side of the page. Before this can be used as a filter kernel it must be reformatted into rows and columns which match that of the windowed image file documentation. Any text editor could be used to do this if the method is known. However, the project group used Emacs to reformat the text. First open Emacs then in order to get the filter in the right format a script had to be written in EMACS. We had some outside help for this part of the project but the sequence and the steps to creating the script for EMACS is shown below:

```
(fset 'FILTER
  "\C-e\C-d\C-e ")
(setq last-kbd-macro
  [escape ?2 ?7 ?1 escape ?x ?a ?m ?a ?n backspace backspace backspace
backspace ?s ?a ?a backspace ?m ?a ?n return return])
```

The first line of the file which we would convert needs to be blank.
so your file should starts as follows:

```
----------------------------------------- top.

1
0
0
1
.
.
1
----------------------------------------- bottom.
```

Now that the file has been reformatted, it should appear in the form of a circle of ones with zeros filling the remainder of the space outside the circle. Certain rows or columns of zeros may have to be removed to make sure there is an equal number of rows or columns of zero's beyond the circle of ones on each of the four sides of the square filter. This is to facilitate the filter being centered properly. In the end the filter should contain an odd number of rows and an odd number of columns. In the case of this project the filter kernel contained 265 rows by 265 columns. The filter kernel is now ready to be processed with the DEM map of Maine or any other map with the same spatial characteristics. However, Idrisi 2.010 will not run this filter. Idrisi32 may process it, but there is no guarantee since it had not been released at the date of this report.

3. Circular and Square Filtering with Hovey's MapWalker software.

The project group discovered this software at http://dwst02.edvz.sbg.ac.at/geo/idrisi/irchome.htm (under FAQ) after defining the procedure for filtering above. This software is much easier to use than Idrisi for filtering, and has more useful options than Idrisi 2.010. The software has been written to the CD included with the report.

For square filtering simply subtract "1" from the desired filter row length, and then enter half of this number into the software, and select the desired option. The project selected "mean" to find an average and the "adjust for resolution" option is was checked. This option will multiply the map by the cell resolution. The map that is to be processed can then be specified and the output file as well. The map can then be processed, and the output will be the average of the desired filter area.

For Circular filters the software will prompt you for the number of pixels that correspond to the number of cells in the radius of your circular area. For this project 133 was entered to correspond to the 12-kilometer radius in our 1:250,000 scale DEM of Maine. Also, it should be noted that the circular average took 90 to 92 hours of processing time for our image of Maine, with a data output type of real. The MapWalker software also allows the user to ignore a certain value in the image to be processed. This is helpful when performing a smoothing operation, because the background value can be ignored.

Appendix D

1. SDTS files in General

SDTS is the acronym for Spatial Data Transfer Standard. These files are available for free from the USGS over the internet. They contain many different types of Vector and Raster data in a single format, and typically come as a zipped and tarred file. Winzip and Pkunzip can be used to decompress them and de-tar them, however make sure the CR/LF option is turned off in Winzip or the files will not work. When they are de-tarred and unzipped a large number of files will be created. Each of these files contains some sort of information relating to the data layers contained within the files. However, the file that is of the most interest has "catd" in last four letters of its file name. There are graphical viewers for the SDTS format available from USGS, which will display DEM SDTS files and DLG SDTS files. By selecting to view the file with the "catd", you will gain access to all data contained within the SDTS files.

In the DLG SDTS files there will be at least one file, or possibly many files where the last two digits in the file name will be 01, 02, 03, etc. These numbers correspond to different data layers, such as hydrography, transmission lines, or boundaries. For the DLG SDTS files to work properly a special file called the "master data dictionary"??? must be downloaded with them, and placed in the same directory. The dictionary file to use is different depending upon the scale of the map being used, and contains information that is common to all SDTS DLG files of the selected scale.

2. The boundaries of Maine.

The Maine boundaries were retrieved from a 1:2,000,000-scale SDTS map file from the USGS at ftp://edcftp.cr.usgs.gov/pub/data. The name of the file was ME.bound.sdts.tar.gz . An SDTS file is not importable into Idrisi 2.010, but there is conversion software available at ftp://ftp.blm.gov/pub/gis/sdts/dlg/. These are dos based programs, which will allow several different conversion options. The one that was of interest to the project team is the SDTS to Idrisi Vector file converter.

To use the SDTS to Idrisi converter it is required to enter the base file name, which is the first four letters of most of the SDTS files, and the two digit code for the layer you want to convert, which are the 01, 02, etc. mentioned in Appendix D.1. Ounce entered the program will then perform the conversion by creating three new files which Idrisi uses to properly display vector files. Once the conversion is performed an error message is typically displayed. This does not affect the conversion process generally. After the file is converted it must be documented properly using the DOCUMENT module in Idrisi. (See Appendix H.) The maximum and minimum latitude and longitude coordinates were obtained by using the DLG Viewer obtained from USGS, and after the file was documented, it was easily layered on top of the Maine raster images for display.

3. Digital Elevation Model(DEM) in SDTS format

Digital Elevation Model files can also be obtained from USGS in STDS format. Currently the files which are available over the Internet are the 7.5 minute DEMs.(See Appendix D) These files are not directly importable into Idrisi, but there is a MS-Windows based conversion software which allows for relatively easy conversion to standard DEM format. The software was available at ftp://ftp.blm.gov/pub/gis/sdts/dem/win95/. After performing the conversion, the standard DEM format can be easily imported into Idrisi using DEMIDRIS. The conversion software was tested by the project team, and appeared to perform its job adequately. It requires only that the STDS file to be converted is entered into the software. There will be twenty files that make up an STDS DEM map. The file, which should be entered into the conversion software, should be the one with the "catd" as the last four letters of its file name. However, other files in the directory may work as well.

Appendix E

Converting Arc/Info(.e00) export format files to Idrisi.

1. Obtain free software

The Idrisi Resource Center's Web Site at Saltzburg University in Austria has a link to download an Arc/Info to Idrisi conversion software. This software is supposed to convert the files given certain information. However, the project team made no successful conversions, although several were attempted. There has been no Indication by any of the group's sources that the software does not work, and with some experimentation a successful conversion may still be possible. The proper way to use the software is not obvious, and may require some additional knowledge of Arc/Info files or computer science.

2. Worcester Based Software Company

Based on sources from Idrisi-L, Idrisi's News group, it was discovered that there is a Worcester Massachusetts based company, which writes an Arc/Info to Idrisi conversion software. The approximate cost of the software is $90.00.

3. Using ArcView

ArcView is a software package written by ESRI (Earth Sciences Research Institute) who also writes Arc/Info. All files which are used by ArcView are in a "shape" file format (.shp). By importing an Arc/Info file(.e00) file into ArcView it can be converted to a shape file and then the SHAPEIDR module can be used in Idrisi 2.010 to convert the file to an Idrisi format. The project team has not successfully performed this, although attempts were made. The copy of ArcView that was utilized was on a computer system at Clark University, which did not allow certain file access, and this is attributed to the difficulty. The group was unable to attempt the conversion on a less restrictive system.

4. Using Arc/Info

If a copy of Arc/Info is available the file can be converted into a general ASCII form using the UNGEN command. The .e00 file is then importable into Idrisi.

Appendix F

Useful GIS and Geography related Data Sources.

1. The United States Geological Survey (USGS)

USGS Home: http://www.usgs.gov
GeoData:http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html
FTP Site1: edcftp.cr.usgs.gov/pub/data
FTP Site2: ftp.blm.gov/
USGS Phone #: 1-800-USA-MAPS

The USGS is the most valuable source of data available, but be aware that not all map data is correct. The project team can only verify that the 1:250,000 scale DEMs were correct.

2. Eros Data Center.

Phone #: 1-800-252-4547
Eros Data Center: http://edcwww.cr.usgs.gov/

The Eros Data Center is part of the USGS and is responsible for much of their digital map data.

3. Environmental Protection Agency

ftp://ftp.epa.gov:/
ftp://ftp.epa.gov:/pub/EPAGIRAS/

The project team obtained several Arc/Info export format Land use / Land Cover (LULC) maps from this site. Other GIS digital map data is also available from this site.

4. State GIS Resources.

Many states maintain their own GIS databases, where much of the data is free or available to order on CD-ROM at a cost. Some useful web sites for New England are:

New Hampshire, Granit.net: http://nhresnet.sr.unh.edu/granit/overview.html
Maine GIS: http://apollo.ogis.state.me.us/
Vermont GIS: http://geo-vt.uvm.edu/

The following website contains links to many state GIS resources throughout the country.

http://tulip.itc.nrcs.usda.gov/gis/State_GIS_WEB_Sites.html

5. The GIS Data Depot

http://www.gisdatadepot.com/

This is a privately owned website which contains GIS data which has been donated by people or found on the Internet. It will also help you track down certain data if the data is available somewhere.

6. Other useful sources and links to data for a GIS project

A. Clark University map Library Home Page.

http://maplib.clarku.edu/

The site contains links to many sources of data, and other useful geography related web sites.

B. The Wind Resource Database

http://www.nrel.gov/wind/usmaps.html
- A necessary starting point for a wind energy project.

C. GIS Linx

http://www.gislinx.com
-Contains links to GIS data and information.

Appendix G

1. Obtaining DEM files in their native format from USGS.

The Digital Elevation Model files (DEM) in their native format are available from USGS in the 1:250,000 scale. (See Appendix E) At this time the native 7.5 minute DEM maps must be ordered from the Eros Data Center, but obtaining the 1:250,000 scale DEMS from the Internet is a fairly simple task. First go to the GeoData website listed in Appendix E, and select the 1:250,000 scale DEMS option. It should ask you whether you want to select them by state or select them visually on a map. The project team selected by state, which is to make sure all of the maps for the state of Maine, were obtained. If the "by state" option is selected, all of the states to choose from will be listed. The project group chose Maine and then a link to the ftp site was displayed. There are two maps for every 1 by 2-degree quadra angle, which is usually indicated by a "W" or "E", depending on whether it is the western or eastern portion of the Quadra Angle. The by state option displays all of the maps which contain any piece of the state, no matter how small. If there is only a western or eastern half of the map, then it means that the other part of the 1 by 2-degree quadra angle does not contain data for that state. If you choose to select data visually on a map then it will display a map of the U.S. and you must click on the state you want to download. You must then download each map for that state individually by clicking on it. This option tends to make it difficult to tell which map you actually want to download.

Appendix H

Idrisi modules for this project.

1. RECLASS

The RECLASS module is used to change a range of values in a raster image into a specified single integer value. The RECLASS module is located in the Analysis, database query, menu within Idrisi 2.010. To use the module is simple. First select the image or values file option, then select the classification type, and enter the input and output files. The input and output files correspond to the input map and the output filename. For the purpose of this project, the only classification type used was the User-defined reclass, using map image files. When this is selected the following appears on the right.

Assign a new value of: ?
To all values from: ?
To just less than: ?

Assign a new value of 0 to all values from 3.9 to just less than 5 would take all values from 3.9 to all numbers infinitely close to, but not exactly 5, in the map and assign them the new value of 0. All other values in the map will be rounded or truncated into integer form, but will not be reclassified in any other way. Additional reclasses can be performed at the same time, so that all data within a map can be reclassified to different integer values at the same time. The reclassification file can be saved if the "save as a reclass file" option is checked. Using this option will allow the file to be recalled later and the same reclassification can be performed again without having to retype the reclassification values. The same general procedure outlined above was used to reclassify the wind velocity maps into wind class maps.

2. OVERLAY

Overlay is a Map Algebra Function. It allows you to do several mathematical operations on two maps. One such operation would be to add the two maps together. The overlay function also allows one map to cover over another map except when the first map has areas of 0 value. The only things that are required by the overlay module are the two map filenames and an output filename. Then a mathematical operation can be selected. In the case of the first covers second option. Each cell in the first map will cancel out the value in the second map (cover it). Except when the first map has a value of zero the value of the second map will be taken and assigned to that cell in the new map.

The project group used the first covers second except when 0 option to overlay the positive and negative velocity exposure maps. The option can be used because of the background value of 0 in each of the maps. Where the background is 0 in the positive exposure map, the negative exposure map will show through. In the case of the logarithmic velocity relationship, the background values were already 0, and could be easily overlaid. However, for the exponential power law it was necessary to subtract the background value of the positive map from each of the maps using SCALAR (See

Appendix H.4) By performing this operation the background was made zero, and the positive and negative velocity exposures could be overlaid. After the overlay was complete the original background value was then added back in to the resultant map.

3. Image Calculator

Image Calculator is simply a module, which performs all of the same calculations as can be performed by the OVERLAY, TRANSFOR, and SCALAR modules under the analysis, mathematical operator's menu. The only difference is that it is structured in the form of a calculator, and can perform large operations using either logical or mathematical expressions in the form of one formula. The calculator is only combining the modules used in the mathematical operator's menu into one module. When the module is run it still creates temporary maps as it goes through each operation, and can use up to one or more gigabytes of space on a computer's hard disk drive temporarily. The project needed about one gigabyte of free space before the wind energy power formulas could be processed using image calculator.

The project group entered the following formula into image calculator for the positive exposure of the logarithmic wind relationship:

WINDV = [NORMAL] *(LN((50 + [EXPOSP] / (.8))) / (LN(50/.8))

NORMAL represents the Pacific Northwest labs wind resource map, which had been reclassified using EDIT/ASSIGN to be representative of the median velocities for each wind class. (See Appendix H.7) EXPOSP is the positive exposure map created from the DEM map of Maine along with the average elevation map. The WINDV represents the corrected average velocity for all of the positive exposure areas of Maine. For the negative exposure, the absolute value of the negative exposure map was taken and entered into the formula. Then the formula was inverted in order to force a drop in wind velocity. It was entered into image calculator as follows, where ABNEG is the absolute value of the negative exposure map. ABNEG was processed using the TRANSFOR module in Idrisi 2.010.(See Appendix H.5)

WINDVN=[NORMAL] * ((LN(50/.8))/ LN((50+[ABNEG])/(.8)))

The Power Law was entered into image calculator in the following manners:

NEWMAP = ((50+[EXPOSP])/(50))^(1/5)

The formula represents the exponential power law relationship for the positive exposure areas only. NEWMAP is the corrected wind velocities, EXPOSP is the positive land exposure, and 1/5 is an exponent where the denominator can be variable. 1/7 and 1/9 were used as well as 1/5 for an exponent for comparative purposes. For the negative exposure areas the same procedure was applied as outlined for the logarithmic velocity relationship.

4. Scalar

Scalar is map algebra module within the analysis, mathematical operators menu. It allows a scalar value to be applied to one map mathematically. This includes adding, subtracting, multiplying, dividing, etc. by a scalar value. The name of the input map, the output files name, and the scalar value need to specified within the module.

5. Transfor

Transfor is a map algebra module within the analysis, mathematical operators menu that is capable of performing complex mathematical functions on a single image. The functions are such things as the natural log, square root, etc.

6. Project

The Project module is within the reformat menu. The purpose of the project module is to change the reference system and datum of a map. To do this it requires that you specify the input map, as well as the reference system parameter file for that map. The reference system parameter file is a file, which contains information regarding the projection of a map including its reference system and datum. The input reference file will automatically appear in the box in most cases, but the output file and the new reference parameter file must be entered. The new system you wish to project the map into can change the datum alone or the projection, or both. It will also ask you for a background value, raster or vector image, and re-sampling type. The default of zero is usually fine for the background value. The re-sampling type is generally based upon whether your data is qualitative or quantitative. For qualitative data a good choice would be nearest neighbor. See the Idrisi help module for more info regarding that choice. When continue is pressed a new window will appear displaying your maps current minimum and maximum latitude and longitude values as well as the number of rows and columns. If desired, these values can be changed at this point in order to make your map have the same attributes as another map.

Specifically, for this project the project module was employed to change the maximum and minimum latitude and longitude of the Maine region of the Pacific Northwest labs (PNL) map. The map initially was in a Latlong reference system with 17 columns and 19 rows. However for the map to be useable it must contain the same number of rows and columns as the DEM used as well as representative of the same area. Since the DEM maps have 7201 rows by 7201 columns, as well as having different latitude and longitude coordinates project was used to change the values of the Maine region of the PNL map.

The reference system of Latlong was automatically displayed. Next the reference system of Latlong was specified for the output map, and the output file name was entered. When the option to change the latitude and longitude coordintes were displayed, they were changed to match the DEM of Maine. This only required that the maps background area be enlarged and does not affect the geographical referencing of the map. The rows and columns were specified to be 7201 by 7201 as stated above. This will boost the resolution of the map artificially and allow overlaying with the DEM of Maine, even though in reality it is still a very low-resolution map. This operation took approximately three hours for the computer to complete. It is the second longest calculation performed. The first was the circular averaging.

7. Edit/Assign

Edit and Assign are two separate modules within Idrisi, but they are typically used in conjunction with each other. The edit and assign modules are similar to the reclass module. However, reclass is typically used with quantitative data while edit/assign is typically used with qualitative data. Using the edit function a values file can be created. To create a new values file simply check that you wish to create a values file and then type in a name for the file and press OK. A values file is just a text file, which is used to contain certain data for reclassification (in this case.) A typical values file may look like this.

1 3
2 4

The first column represents the current value of a cell within a map. The second column represents the new value you wish to assign to that cell. The values file, which has the extension .val must be saved after it is created by pressing save. Once the file is created it is used in conjunction with the Assign module under the Data Entry menu. Assign only requires that you enter the map you wish to reclassify and the values file which you created. It will then take the data in the first column and force it to be the data in the second column. This is the procedure that was performed on the PNL wind class map of Maine. All of the wind classes were reclassified into velocities using the following values file.

1 2.8
2 6.4
3 6.7
4 7.25
5 7.75
6 8.4

8. Digitize

The digitize module allows users to perform on screen digitizing of either vector or raster maps. To activate the digitize module in Idrisi 2.010 you must select the red cross hairs from the tool bar at the top of the screen. The module will give the option of digitizing a point, line, or polygon. If you wish to create a map with only points present, select the point option. The only differences between the line and polygon option are that you must end the digitizing at the same point you started from. When digitizing you must generalize the lines by clicking at many points along the line in the map you are trying to digitize. By doing this you are creating a new vector file with only the features you digitize. Idrisi will ask you if you want to save the vector file when you close the map you are digitizing. The digitized map will have the same spatial attributes as the original map you are digitizing. Digitizing was performed for the creating of the circular filter with Idrisi.(See Appendix H.8)

9. Document

The document module is located under the file menu in Idrisi 2.010. It allows the user to specify the spatial attributes of a digital map by manually entering them.
For this project the reference system of Latlong was entered as well as the maximum and minimum x and y coordinates for the DEM image of Maine. The coordinates are -72 to –66 degrees on the x-axis, and 42 to 48 degrees on the y-axis. A unit distance of 1 was also specified and the reference units were specified to be degrees. It was not necessary to change the remaining attributes.

Next, document was used to specify the spatial attributes in the Pacific Northwest Laboratories Map. The map contained 174 columns and 100 rows, as given by the previous IQP group, and the maximum x and y coordinates were specified to be 24.5 and 49.5 longitude, and 67 and 125 degrees latitude.
The WINDOW module was then applied to produce the map of Maine, and document was used to specify the attribute as specified in the dem, except the project module must first be used to expand the rows and columns from 17 by 19 to 7201 by 7201.

Document was also used on the SDTS file of the boundaries for Maine. When the file was converted to Idrisi vector form, it was necessary to specify the maximum and minimum x and y coordinates as well as the reference system and reference units. All of this information is the same as the DEM of Maine.

10. Palette Workshop

The Palette Workshop allows you to create custom color palettes for use when displaying Idrisi image files. The palette workshop is located in the analysis menu. For this project two custom palettes were created. The first was a quantitative palette, which was used for the display of the DEM of Maine. The creation of the Palette was necessary for the lower elevations to be visible when displaying the map. The second palette created was a qualitative palette for displaying the wind class maps. The qualitative palette contained 7 colors to represent 7 wind classes. This palette was also created for visual effects.

11. Extract

Extract is a module that allows you to extract statistical data from an image based upon a "feature definition image". The module takes one image and extracts the data from that image based upon a second map with the same spatial attributes. The feature definition image will contain regions of the map, such as counties. Each county would represent a certain category, such as category 1. In that case the county would all have the value of 1 in the raster image. For example, if we take a digital elevation map and a map of counties which matches the elevation map, we can extract the average elevation from the DEM in the areas that represent each of the counties. EXTRACT would display the data for all counties based upon which category they fall within.

Specifically for this project the module was used for extracting the average elevation within the circular region of a 12 kilometer radius. (See Appendix C.2 on filtering.) The tabular output option was checked so the results would immediately be displayed

12. Distance

Distance allows the calculation of a simple liner distance from a feature. The module only requires a feature definition image only. It can then find the distance from the feature within the image base upon the images resolution. For this project the module was used to find the distance from a point in order to create a circular filter.(See Appendix C.2) It should be noted that distance will find the distance from lines and polygons as well. The result of applying the distance module is a map where each cell contains the data representing the distance from the closest point of your feature.

13. Convert

Convert changes the data type and file type of an image to a data type and file type that is specified. The file types are ASCII, binary, or packed binary, while the data types are real, integer, and byte.
For the project convert was used to convert the file type from binary to ASCII (a simple text file) in order to create a circular filter (See Appendix C.2). Converting between byte, integer, and real data is usually done to conserve memory on a computer. Real is floating point data and takes up the most memory, while byte data uses the least memory (8 bits.) Integer data uses 16 bits of memory and real data uses 32 bits.

14. Import/Export

The Import/Export module is located within the file menu in Idrisi 2.010. The module has many functions which all pertain to the importing of digital data into Idrisi and exporting data from Idrisi. The import function is needed because much of the data available will not work as is, in Idrisi. Idrisi requires the proper documentation in order to display images properly. Import contains the modules to properly import data and document it, so it may be displayed. The Export functions simply allow you to choose from a number of file formats that can be used in other software outside of Idrisi. An example would to convert an Idrisi image file into a bitmap file using an export module.

Some examples of the import modules are DEMIDRIS, CTG, and DLG.

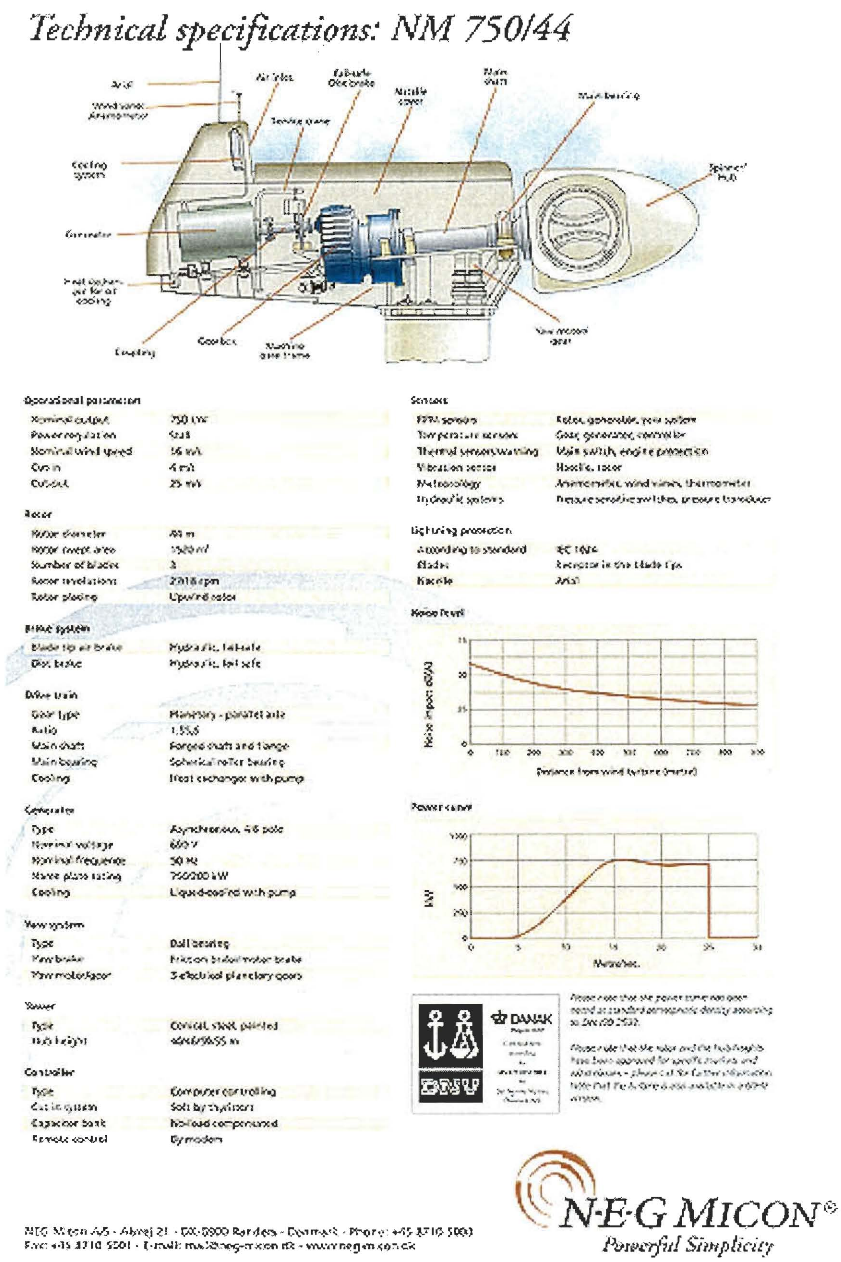
a. DEMIDRIS

The DEMIDRIS module is used to import Standard government format digital elevation models(DEM) into Idrisi.

b. CTG and DLG

The CTG and DLG modules are both designed to import the CTG and DLG government file formats into Idrisi. Both of these formats contain many layers of data, and each layer contains a different geography. The CTG modules and DLG modules allow you to extract each layer individually. A layer is usually represented by a number. For example 9 may represent hydrography while roads and trails may be represented by a 1. To find the actual codes for CTG and DLG layres consult the Idrisi users manual or call the USGS.

<u>**Appendix I**</u>



Technical specifications: NM 750/44

Operational parameters	
Nominal output	750 kW
Power regulation	Stall
Nominal wind speed	16 m/s
Cut in	4 m/s
Cut out	25 m/s

Rotor	
Rotor diameter	44 m
Rotor swept area	1520 m²
Number of blades	3
Rotor revolutions	27/18 rpm
Rotor placing	Upwind rotor

Brake system	
Blade tip air brake	Hydraulic, fail-safe
Disc brake	Hydraulic, fail safe

Drive train	
Gear type	Planetary - parallel axle
Ratio	1:55.6
Main shaft	Forged shaft and flange
Main bearing	Spherical roller bearing
Cooling	Heat exchanger with pump

Generator	
Type	Asynchronous, 4/6 pole
Nominal voltage	690 V
Nominal frequency	50 Hz
Name plate rating	750/200 kW
Cooling	Liquid-cooled with pump

Yaw system	
Type	Ball bearing
Yaw brake	Friction brake/motor brake
Yaw motor/gear	3 electrical planetary gears

Tower	
Type	Conical, steel, painted
Hub height	40/46/50/55 m

Controller	
Type	Computer controlling
Cut in system	Soft by thyristors
Capacitor bank	No-load compensated
Remote control	By modem

Sensors	
RPM sensors	Rotor, generator, yaw system
Temperature sensors	Gear, generator, controller
Thermal sensors/warning	Main switch, engine protection
Vibration sensor	Nacelle, rotor
Meteorology	Anemometer, wind vanes, thermometer
Hydraulic systems	Pressure sensitive switches, pressure transducer

Lightning protection	
According to standard	IEC 1024
Blades	Receptor in the blade tips
Nacelle	Arial

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Figure I.1: Technical Specifications of the Turbine Used.

Appendix J

Insight on Capacity Factor

The capacity factor is a form of describing the efficiency of any system. For a wind turbine the capacity factor has many variables including wind speed, location, height, turbine, surface roughness, swept area, temperature, humidity, and more…To find the capacity factor for a wind turbine we contacted several people including turbine manufacturers and several government sources. The most useful information we obtained was provided by Dr. Micheal Brower who sent us the following email explaining one method of finding the capacity factor

" I would ask a couple of wind turbine manufacturers for their latest power curves. Then run a simulation in a spreadsheet using a range of mean wind speeds and a standard frequency distribution (people often use a Rayleigh distribution, which is a Weibull distribution with the shape factor k = 2.0). Plot the power output as a function of mean speed, then apply that plot to your wind speed map.

A complicating factor is the air density. Wind turbine power curves usually assume standard sea-level air density (1.225 kg/m^3). Look up a standard atmosphere table and plot the standard density as a function of elevation. Then apply that function to the elevation map to come up with a map of (approximate) mean air density. Divide it by 1.225, then multiply that map of air density ratios by the expected power output from the previous exercise, and you'll get a rough idea of the turbine output in both high and low elevations. "

From our research we understand that the capacity factor in its simplest terms is as follows:

$$Capacity\ Factor = \frac{Average\_annual\_output}{Maximum\_annual\_output}$$

it is generally believed that the maximum value for the capacity factor is 59%.
For this project we used the capacity factors from PM, knowing full well that they are inaccurate, however, we thought that was the best estimate for them.

The Danish Wind Turbine Manufacturers Association's web page at http://www.windpower.dk/tour/wres/pow/index.htm was found to contain a java calculator that calculates the capacity factor along other useful information. Some of the examples of the calculations are shown in the following page.

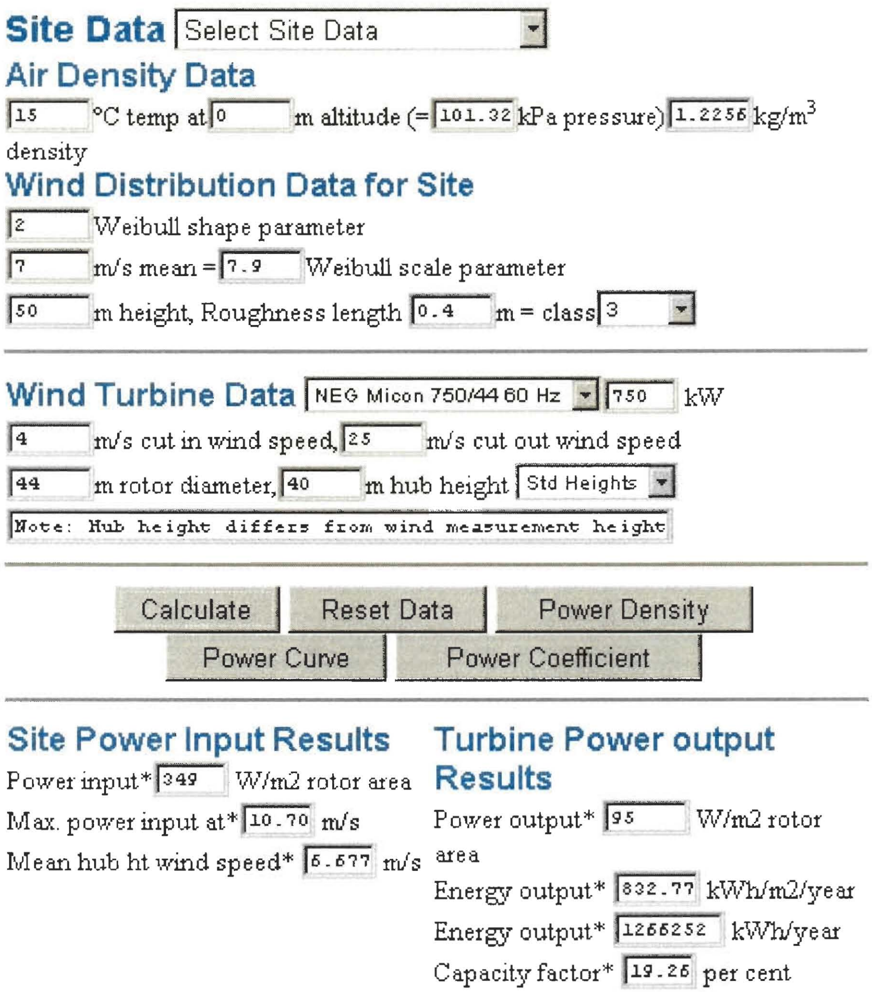

Figure J.2: Screen Shot of the Java calculator.

We used the java calculator shown above to to a sample calculation for a wind class 3 using the same turbine specified in Appendix I.

Note that we discarded any data from the java calculator above since we were uncertain about some of the values used in the calculation (Weibull shape parameter, Weibull scale parameter, roughness length and etc..)

Appendix K

Annual Average output Calculations

$$O = P \times CF \times A \times 8760 \ \frac{1kW}{1000W} \times \frac{hours}{year} \ [kWh]$$

Wind Class	Annual Average Output	Calculations
		P*CF*A*(hours in year)/(watts in kilowatts)
2	548444.8158	225*0.183*1520.5308*8760/1000
3	1069850.337	320*0.251*1520.5308*8760/1000
4	1676569.495	410*0.307*1520.5308*8760/1000
5	2364273.341	500*0.355*1520.5308*8760/1000
6	3503653.293	640*0.411*1520.5308*8760/1000

Table K.1: Annual Average output for Various Wind Classes.

Initial Cost Calculation

$$IC = PR \times UC \ [\ \$\ ]$$

IC= 750 kW * $1032/kW = $774,000

Appendix L

Finding the cost of generation

To find the cost of generating electricity in cents per kwH, the method of linear interpolation was used.

The basic equation of a line is (y2-y1) = m(x2-x1)

Modification of the equation is done to find the slope (m)

The data used to find the generation price was taken from Appendix A, region 7, on page 9 of Competitive Electricity Prices: An Update

where x1 = 2005, x2 = 2020, y2 = 3.63 and y1 = 3.53

$$m := \frac{(3.63 - 3.53)}{(2005 - 2020)}$$

After calculation the slope(m) is found and can be use to calculate cost of generation for any year by plugging in the year for x2 in the formula and keep x1 the same (2005) and y1 the same (3.63).

cost of generation in year1996

$m = -6.667 \cdot 10^{-3}$

$y96 := m \cdot (1996 - 2005) + 3.63$

$y96 = 3.69$

cost of generation in year 2000

$y00 := m \cdot (2000 - 2005) + 3.63$

$y00 = 3.663$

cost of generation in year 1999

$y99 := m \cdot (1999 - 2005) + 3.63$

$y99 = 3.67$

cost of generation in year 1998

$y98 := m\cdot(1998 - 2005) + 3.63$

$y98 = 3.677$

cost of generation in year 1997

$y97 := m\cdot(1997 - 2005) + 3.63$

$y97 = 3.683$

Below is a graph of the estimated cost of generation versus years

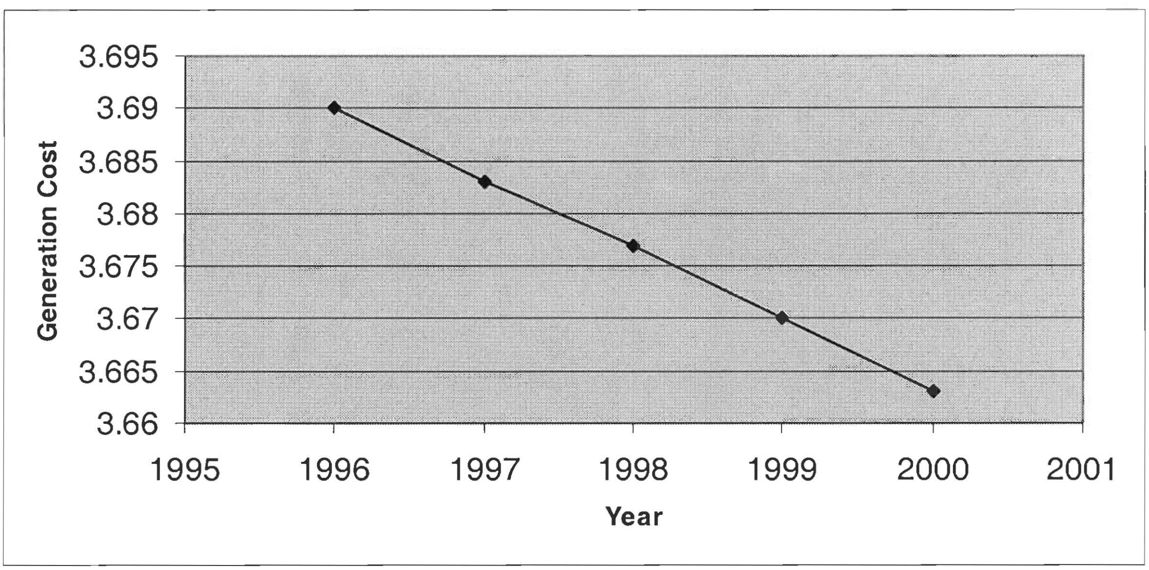

Figure L.1: Estimated Cost of Generation from year 1995 to 2000

Appendix M

Economic Analysis for Wind Class 6

InitialCost = $1032/kW * 750 kW = 774000 'PTM pg.25'						
POWER DENSITY	AREA SWE	ANNUAL OUTPU	ANNUAL MAINTENANCE			
	(r^2)*Pi		Corrected Annual Output * $0.008/kW h 'PTM pg.26'			
	Corr.P*Area*8760 [hr/year]*1/1000 [W/kW]					
640	1520.531	8524704.126	28029.22717			
CORRECTED CAPACITY FACTOR P VALUE			CAPACITY FACTOR			
Annual Output*Capacity Factor			Annual Output/Maximum Output			
3503653.396			0.411			
COST PER kW h (+ is profit, - is loss)						
((Annual Revenue-Annual Cost 0f Wind System)/(Corrected Annual Output))						
0.004158471						
FINAL COST PER kW H						
Cost per kW h + Original Generation Cost						
0.032471529						
	Class 6 Wind					
		INVESTMENT CASH FLOW PATTERN				
YEAR	INITIAL	ANNUAL	FUEL	MAINT.	NET	**TOTAL NET**
	COST	REVENUE	COST	COST	SAVINGS	**SAVINGS**
		kW h(rate*(1.02)^t)		maint.*(1.03)^t	C-D-E	
			0*(1.045)^t			
0	$774,000				($774,000.00)	
1		$130,905.60	$0.00	$28,870.10	$102,035.50	$102,035.50
2		$133,523.71	$0.00	$29,736.21	$103,787.51	$205,823.00
3		$136,194.19	$0.00	$30,628.29	$105,565.89	$311,388.89
4		$138,918.07	$0.00	$31,547.14	$107,370.93	$418,759.82
5		$141,696.43	$0.00	$32,493.56	$109,202.88	$527,962.70
6		$144,530.36	$0.00	$33,468.36	$111,062.00	$639,024.70
7		$147,420.97	$0.00	$34,472.41	$112,948.55	$751,973.25
8		$150,369.39	$0.00	$35,506.59	$114,862.80	$866,836.05
9		$153,376.77	$0.00	$36,571.78	$116,804.99	$983,641.04
10		$156,444.31	$0.00	$37,668.94	$118,775.37	$1,102,416.41
11		$159,573.20	$0.00	$38,799.01	$120,774.19	$1,223,190.60
12		$162,764.66	$0.00	$39,962.98	$122,801.68	$1,345,992.29
13		$166,019.95	$0.00	$41,161.87	$124,858.09	$1,470,850.38
14		$169,340.35	$0.00	$42,396.72	$126,943.63	$1,597,794.01
15		$172,727.16	$0.00	$43,668.62	$129,058.54	$1,726,852.55
16		$176,181.70	$0.00	$44,978.68	$131,203.02	$1,858,055.57
17		$179,705.34	$0.00	$46,328.04	$133,377.30	$1,991,432.86
18		$183,299.44	$0.00	$47,717.88	$135,581.56	$2,127,014.42
19		$186,965.43	$0.00	$49,149.42	$137,816.01	$2,264,830.44
20		$190,704.74	$0.00	$50,623.90	$140,080.84	$2,404,911.28

COST OF CAPITAL(K) =(COST OF DEBT AT)*.5 + (REQ'D RTN ON STOCK)*.5						
REQ'D RTN ON STOCK =T-BOND RTE+BETA*(1+DEBT/STK AT)*MKT RISK PREM .						
T-BOND RTE =5.0		BETA = 1.0	D/S AT =1*.6	MKT RISK PREM = 8.0		
DEBT CST	=8.0 K=(8.0	0*0.6)*.5+(5.0+1.0*(1+0.6)*8.0)*.5 =			11.3	
PRESENT VALUE OF NET SAVINGS:PV			=@NPV(F80/100,F56..F75)=		$887,784.54	
NET PRESENT VALUE OF PROJECT:NP			V=PV-INIT COST(F82-B55)=		$113,784.54	
INTERNAL RATE OF RETURN		TURN:IRR[@IRR(0.3,F55..F75)*100] =			13.38	
MODIFIED IR	R:MIRR = [(PV*(1.113)^20/INIT COST)^(1/20)-1]*100					
	= [(F82*(1.113)^20/B55)^(1/20)-1]*100					
	=	12.06590304				
LIFE CYCLE COST OF WIND SYSTEM =			PV OF FUEL& MAINT.COST+INIT COST			
		=@NPV(F80/100,D56..D75)+@NPV(F80/100,E56..E75)+B55				
	=	$1,048,006.22				
LIFE CYCLE COST-CURRENT ELECTRIC =			PV OF ELECTRICITY COST			
		=	@NPV(F80/100,C56..C75)			
		=	$1,161,790.75			
NPV WIND = LCC ELECTRICITY - LCC WIND						
	=	D98-C94				
	=	$113,784.54				
	ANNUAL C	=	LIFE CYCLE COST/PVIFA(k,n)			
		=	C94/(@PV(1,F80/100,20))			
		=	134194.7186			
	ANNUAL R	=	LIFE CYCLE COST/PVIFA(k,n)			
		=	D98/(@PV(1,F80/100,20))			
		=	148764.5594			

Economic Analysis for Wind Class 5

Initial Cost = $1032/kW * 750 kW = 774000 'PTM pg 25'						
POWER DENSITY	AREA SWEPT	ANNUAL OUTPU	ANNUAL MAINTENANCE			
	(r^2)*Pi		Corrected Annual Output * $0.008/kW h 'PTM pg 26'			
	Corr.P*Area*8760 [hr/year]*1/1000 [W/kW]					
500	1520.5308	6659925.098	18914.18728			
CORRECTED CAPACITY FACTOR P VALUE			CAPACITY FACTOR			
Annual Output*Capacity Factor			Annual Output/Maximum Output			
2364273.41			0.355			
COST PER kW h (+ is profit, - is loss)						
((Annual Revenue-Annual Cost Of Wind System)/(Corrected Annual Output))						
-0.009473614						
FINAL COST PER kW H						
Cost per kW h + Original Generation Cost						
0.046103614						
	Class 5 Wind					
		INVESTMENT CASH FLOW PATTERN				
YEAR	INITIAL	ANNUAL	FUEL	MAINT.	NET	**TOTAL NET**
	COST	REVENUE	COST	COST	SAVINGS	**SAVINGS**
	kW h(rate*(1.02)^t)			maint.*(1.03)	C-D-E	
			0*(1.045)^t			
0	$774,000				($774,000.00)	
1		$88,335.40	$0.00	$19,481.61	$68,853.79	$68,853.79
2		$90,102.11	$0.00	$20,066.06	$70,036.05	$138,889.84
3		$91,904.15	$0.00	$20,668.04	$71,236.11	$210,125.95
4		$93,742.23	$0.00	$21,288.08	$72,454.15	$282,580.10
5		$95,617.08	$0.00	$21,926.73	$73,690.35	$356,270.45
6		$97,529.42	$0.00	$22,584.53	$74,944.89	$431,215.34
7		$99,480.01	$0.00	$23,262.06	$76,217.95	$507,433.29
8		$101,469.61	$0.00	$23,959.93	$77,509.68	$584,942.97
9		$103,499.00	$0.00	$24,678.72	$78,820.28	$663,763.25
10		$105,568.98	$0.00	$25,419.09	$80,149.90	$743,913.14
11		$107,680.36	$0.00	$26,181.66	$81,498.70	$825,411.85
12		$109,833.97	$0.00	$26,967.11	$82,866.86	$908,278.71
13		$112,030.65	$0.00	$27,776.12	$84,254.53	$992,533.23
14		$114,271.26	$0.00	$28,609.41	$85,661.86	$1,078,195.09
15		$116,556.69	$0.00	$29,467.69	$87,089.00	$1,165,284.09
16		$118,887.82	$0.00	$30,351.72	$88,536.10	$1,253,820.19
17		$121,265.58	$0.00	$31,262.27	$90,003.31	$1,343,823.50
18		$123,690.89	$0.00	$32,200.14	$91,490.75	$1,435,314.25
19		$126,164.71	$0.00	$33,166.14	$92,998.56	$1,528,312.81
20		$128,688.00	$0.00	$34,161.13	$94,526.87	$1,622,839.69

COST OF CAPITAL(K)=(COST OF DEBT AT)*.5 + (REQ'D RTN ON STOCK)*.5						
REQ'D RTN ON STOCK=T-BOND RTE+BETA*(1+DEBT/STK AT)*MKT RISK PREM .						
T-BOND RTE=5.0		BETA = 1.0	D/S AT=1*.6	MKT RISK PREM = 8.0		
DEBT CST	=8.0 K=(8.0	0*0.6)*.5+(5.0+1.0*(1+0.6)*8.0)*.5=			11.3	
PRESENT VALUE OF NET SAVINGS:PV			=@NPV(F80/100,F56..F75)=		$599,079.06	
NET PRESENT VALUE OF PROJECT:NP			V=PV-INIT COST(F82-B55)=		($174,920.94)	
INTERNAL RATE OF RETURN		TURN:IRR[@IRR(0.3,F55..F75)*100]=			7.84	
MODIFIED IR	R:MIRR = [(PV*(1.113)^20/INIT COST)^(1/20)-1]*100					
	= [(F82*(1.113)^20/B55)^(1/20)-1]*100					
	=	9.883459284				
LIFE CYCLE COST OF WIND SYSTEM =			PV OF FUEL & MAINT.COST+INIT COST			
		=@NPV(F80/100,D56..D75)+@NPV(F80/100,E56..E75)+B55				
	=	$958,900.03				
LIFE CYCLE COST-CURRENT ELECTRIC=			PV OF ELECTRICITY COST			
		=	@NPV(F80/100,C56..C75)			
		=	$783,979.08			
NPV WIND = LCC ELECTRICITY -LCC WIND						
	=	D98-C94				
	=	($174,920.94)				
	ANNUAL COST		LIFE CYCLE COST/PVIFA(k,n)			
		=	C94/(@PV(1,F80/100,20))			
		=	122784.8819			
	ANNUAL REV	=	LIFE CYCLE COST/PVIFA(k,n)			
		=	D98/(@PV(1,F80/100,20))			
		=	100386.6685			

Economic Analysis for Wind Class 4

InitialCost = $1032/kW *750 kW = 774000 'PTM pg 25'						
POWER DENSITY	AREA SWEPT	ANNUAL OUTP	ANNUAL MAINTENANCE			
	(r^2)*Pi		Corrected Annual Output * $0.008/kW h 'PTM pg 26'			
	Corr.P*Area*8760 [hr/year]*1/1000 [W/kW]					
410	1520.530844	5461138.581	13412.55635			
CORRECTED CAPACITY FACTOR PVALUE			CAPACITY FACTOR			
Annual Output*Capacity Factor			Annual Output/Maximum Output			
1676569.544			0.307			
COST PER kW h (+ is profit, - is loss)						
((Annual Revenue-Annual Cost Of Wind System)/(Corrected Annual Output))						
-0.026668319						
FINAL COST PER kW H						
Cost per kW h + Original Generation Cost						
0.063298319						
	Class 4 Wind					
		INVESTMENT CASH FLOW PATTERN				

YEAR	INITIAL COST	ANNUAL REVENUE	FUEL COST	MAINT. COST	NET SAVINGS	**TOTAL NET SAVINGS**
		kW h(rate*(1.02)^t)		maint.*(1.03)^t	C-D-E	
			0*(1.045)^t			
0	$774,000				($774,000.00)	
1		$62,641.00	$0.00	$13,814.93	$48,826.06	$48,826.06
2		$63,893.82	$0.00	$14,229.38	$49,664.44	$98,490.50
3		$65,171.69	$0.00	$14,656.26	$50,515.43	$149,005.93
4		$66,475.13	$0.00	$15,095.95	$51,379.18	$200,385.11
5		$67,804.63	$0.00	$15,548.83	$52,255.80	$252,640.91
6		$69,160.72	$0.00	$16,015.29	$53,145.43	$305,786.34
7		$70,543.94	$0.00	$16,495.75	$54,048.18	$359,834.52
8		$71,954.82	$0.00	$16,990.63	$54,964.19	$414,798.71
9		$73,393.91	$0.00	$17,500.34	$55,893.57	$470,692.28
10		$74,861.79	$0.00	$18,025.35	$56,836.44	$527,528.72
11		$76,359.03	$0.00	$18,566.11	$57,792.91	$585,321.63
12		$77,886.21	$0.00	$19,123.10	$58,763.11	$644,084.74
13		$79,443.93	$0.00	$19,696.79	$59,747.14	$703,831.88
14		$81,032.81	$0.00	$20,287.69	$60,745.11	$764,576.99
15		$82,653.47	$0.00	$20,896.33	$61,757.14	$826,334.13
16		$84,306.53	$0.00	$21,523.22	$62,783.32	$889,117.45
17		$85,992.67	$0.00	$22,168.91	$63,823.75	$952,941.20
18		$87,712.52	$0.00	$22,833.98	$64,878.54	$1,017,819.74
19		$89,466.77	$0.00	$23,519.00	$65,947.77	$1,083,767.51
20		$91,256.10	$0.00	$24,224.57	$67,031.54	$1,150,799.05

COST OF CAPITAL(K) = (COST OF DEBT AT)*.5 + (REQ'D RTN ON STOCK)*.5						
REQ'D RTN ON STOCK = T-BOND RTE+BETA*(1+DEBT/STK AT)*MKT RISK PREM.						
T-BOND RTE =5.0		BETA = 1.0	D/S AT =1*.6	MKT RISK PREM = 8.0		
DEBT CST	=8.0 K=(8.0	0*0.6)*.5+(5.0+1.0*(1+0.6)*8.0)*.5=			11.3	
PRESENT VALUE OF NET SAVINGS:PV			=@NPV(F80/100,F56..F75)=		$424,822.99	
NET PRESENT VALUE OF PROJECT:NP			V=PV-INIT COST(F82-B55)=		($349,177.01)	
INTERNAL RATE OF RETURN		TURN:IRR[@IRR(0.3,F55..F75)*100]=			3.88	
MODIFIED IR	R:MIRR = [(PV*(1.113)^20/INIT COST)^(1/20)-1]*100					
	= [(F82*(1.113)^20/B55)^(1/20)-1]*100					
	=	8.011131805				
LIFE CYCLE COST OF WIND SYSTEM =			PV OF FUEL& MAINT.COST+INIT COST			
		=@NPV(F80/100,D56..D75)+@NPV(F80/100,E56..E75)+B55				
	=	$905,117.56				
LIFE CYCLE COST-CURRENT ELECTRIC=			PV OF ELECTRICITY COST			
		=	@NPV(F80/100,C56..C75)			
		=	$555,940.55			
NPV WIND = LCC ELECTRICITY -LCC WIND						
	=	D98-C94				
	=	($349,177.01)				
	ANNUAL COST		LIFE CYCLE COST/PVIFA(k,n)			
		=	C94/(@PV(1,F80/100,20))			
		=	115898.1637			
	ANNUAL REVE	=	LIFE CYCLE COST/PVIFA(k,n)			
		=	D98/(@PV(1,F80/100,20))			
		=	71186.87306			

Economic Analysis for Wind Class 3

InitialCost = $1032/kW * 750 kW = 774000 'PTM pg 25'						
POWER DENSITY	AREA SWEPT	ANNUAL OUTPUT	ANNUAL MAINTENANCE			
	(r^2)*Pi		Corrected Annual Output * $0.008/kWh 'PTM pg 26'			
	Corr.P*Area*8760 [hr/year]*1/1000 [W/kW]					
320	1520.530844	4262352.063	8558.802942			
CORRECTED CAPACITY FACTOR P VALUE			CAPACITY FACTOR			
Annual Output*Capacity Factor			Annual Output/Maximum Output			
1069850.368			0.251			
COST PER kWh (+ is profit, - is loss)						
((Annual Revenue-Annual Cost 0f Wind System)/(Corrected Annual Output))						
-0.060192303						
FINAL COST PER kWH						
Cost per kWh + Original Generation Cost						
0.096822303						
	Class 3 Wind					
		INVESTMENT CASH FLOW PATTERN				
YEAR	INITIAL	ANNUAL	FUEL	MAINT.	NET	**TOTAL NET**
	COST	REVENUE	COST	COST	SAVINGS	**SAVINGS**
		kWh(rate*(1.02)^t)		maint.*(1.03)^t	C-D-E	
			0*(1.045)^t			
0	$774,000				($774,000.00)	
1		$39,972.39	$0.00	$8,815.57	$31,156.82	$31,156.82
2		$40,771.84	$0.00	$9,080.03	$31,691.81	$62,848.63
3		$41,587.28	$0.00	$9,352.44	$32,234.84	$95,083.47
4		$42,419.02	$0.00	$9,633.01	$32,786.01	$127,869.48
5		$43,267.40	$0.00	$9,922.00	$33,345.40	$161,214.89
6		$44,132.75	$0.00	$10,219.66	$33,913.09	$195,127.98
7		$45,015.40	$0.00	$10,526.25	$34,489.16	$229,617.14
8		$45,915.71	$0.00	$10,842.04	$35,073.68	$264,690.81
9		$46,834.03	$0.00	$11,167.30	$35,666.73	$300,357.54
10		$47,770.71	$0.00	$11,502.32	$36,268.39	$336,625.94
11		$48,726.12	$0.00	$11,847.38	$36,878.74	$373,504.67
12		$49,700.64	$0.00	$12,202.81	$37,497.84	$411,002.51
13		$50,694.66	$0.00	$12,568.89	$38,125.77	$449,128.28
14		$51,708.55	$0.00	$12,945.96	$38,762.59	$487,890.87
15		$52,742.72	$0.00	$13,334.34	$39,408.39	$527,299.26
16		$53,797.58	$0.00	$13,734.37	$40,063.21	$567,362.47
17		$54,873.53	$0.00	$14,146.40	$40,727.13	$608,089.60
18		$55,971.00	$0.00	$14,570.79	$41,400.21	$649,489.81
19		$57,090.42	$0.00	$15,007.91	$42,082.51	$691,572.31
20		$58,232.23	$0.00	$15,458.15	$42,774.08	$734,346.39

COST OF CAPITAL(K)=(COST OF DEBT AT)*.5 + (REQ'D RTN ON STOCK)*.5					
REQ'D RTN ON STOCK =T-BOND RTE+BETA*(1+DEBT/STK AT)*MKT RISK PREM.					
T-BOND RTE=5.0		BETA = 1.0	D/S AT =1*.6	MKT RISK PREM = 8.0	
DEBT CST	=8.0 K=(8.0	0*0.6)*.5+(5.0+1.0*(1+0.6)*8.0)*.5=			11.3
PRESENT VALUE OF NET SAVINGS:PV			=@NPV(F80/100,F56..F75)=		$271,087.49
NET PRESENT VALUE OF PROJECT:NP			V=PV-INIT COST(F82-B55)=		($502,912.51)
INTERNAL RATE OF RETURN		TURN:IRR[@IRR(0.3,F55..F75)*100]=			-0.47
MODIFIED IRR	R:MIRR=[(PV*(1.113)^20/INIT COST)^(1/20)-1]*100				
	=[(F82*(1.113)^20/B55)^(1/20)-1]*100				
	=	5.612078605			
LIFE CYCLE COST OF WIND SYSTEM =			PV OF FUEL & MAINT.COST+INIT COST		
		=@NPV(F80/100,D56..D75)+@NPV(F80/100,E56..E75)+B55			
	=	$857,668.57			
LIFE CYCLE COST-CURRENT ELECTRIC =			PV OF ELECTRICITY COST		
		=	@NPV(F80/100,C56..C75)		
		=	$354,756.06		
NPV WIND = LCC ELECTRICITY - LCC WIND					
	=	D98-C94			
	=	($502,912.51)			
	ANNUAL COST		LIFE CYCLE COST/PVIFA(k,n)		
		=	C94/(@PV(1,F80/100,20))		
		=	109822.4323		
	ANNUAL REVE	=	LIFE CYCLE COST/PVIFA(k,n)		
		=	D98/(@PV(1,F80/100,20))		
		=	45425.67446		

Economic Analysis for Wind Class 2

InitialCost = $1032/kW *750 kW = 774000 'PTM pg 25'						
POWER DENSITY	AREA SWEPT	ANNUAL OUTPUT	ANNUAL MAINTENANCE			
	(r^2)*Pi		Corrected Annual Output * $0.008/kW h 'PTM pg 26'			
	Corr.P*Area*8760 [hr/year]*1/1000 [W/kW]					
225	1520.530844	2996966.294	4387.558655			
CORRECTED CAPACITY FACTOR P VALUE			CAPACITY FACTOR			
Annual Output*Capacity Factor			Annual Output/Maximum Output			
548444.8318			0.183			
COST PER kW h (+ is profit, - is loss)						
((Annual Revenue-Annual Cost Of Wind System)/(Corrected Annual Output))						
-0.148263151						
FINAL COST PER kW H						
Cost per kW h + Original Generation Cost						
0.184893151						
	Class 2 Wind					
		INVESTMENT CASH FLOW PATTERN				
YEAR	INITIAL	ANNUAL	FUEL	MAINT.	NET	**TOTAL NET**
	COST	REVENUE	COST	COST	SAVINGS	**SAVINGS**
		kW h(rate*(1.02)^t)		maint.*(1.03)^t	C-D-E	
			0*(1.045)^t			
0	$774,000				($774,000.00)	
1		$20,491.32	$0.00	$4,519.19	$15,972.14	($758,027.86)
2		$20,901.15	$0.00	$4,654.76	$16,246.39	$32,218.53
3		$21,319.17	$0.00	$4,794.40	$16,524.77	$48,743.30
4		$21,745.56	$0.00	$4,938.24	$16,807.32	$65,550.62
5		$22,180.47	$0.00	$5,086.38	$17,094.09	$82,644.71
6		$22,624.08	$0.00	$5,238.97	$17,385.10	$100,029.81
7		$23,076.56	$0.00	$5,396.14	$17,680.42	$117,710.23
8		$23,538.09	$0.00	$5,558.03	$17,980.06	$135,690.29
9		$24,008.85	$0.00	$5,724.77	$18,284.08	$153,974.38
10		$24,489.03	$0.00	$5,896.51	$18,592.52	$172,566.89
11		$24,978.81	$0.00	$6,073.41	$18,905.40	$191,472.30
12		$25,478.39	$0.00	$6,255.61	$19,222.78	$210,695.07
13		$25,987.95	$0.00	$6,443.28	$19,544.68	$230,239.75
14		$26,507.71	$0.00	$6,636.58	$19,871.14	$250,110.89
15		$27,037.87	$0.00	$6,835.67	$20,202.19	$270,313.08
16		$27,578.63	$0.00	$7,040.74	$20,537.88	$290,850.97
17		$28,130.20	$0.00	$7,251.97	$20,878.23	$311,729.20
18		$28,692.80	$0.00	$7,469.52	$21,223.28	$332,952.47
19		$29,266.66	$0.00	$7,693.61	$21,573.05	$354,525.52
20		$29,851.99	$0.00	$7,924.42	$21,927.57	$376,453.09

COST OF CAPITAL(K) =(COST OF DEBT AT)*.5 + (REQ'D RTN ON STOCK)*.5					
REQ'D RTN ON STOCK =T-BOND RTE+BETA*(1+DEBT/STK AT)*MKT RISK PREM.					
T-BOND RTE =5.0		BETA = 1.0	D/S AT =1*.6	MKT RISK PREM = 8.0	
DEBT CST	=8.0 K=(8.0	0*0.6)*.5+(5.0+1.0*(1+0.6)*8.0)*.5=			11.3
PRESENT VALUE OF NET SAVINGS:PV			=@NPV(F80/100,F56..F75)=		$138,969.47
NET PRESENT VALUE OF PROJECT:NP			V=PV-INIT COST(F82-B55)=		($635,030.53)
INTERNAL RATE OF RETURN		TURN:IRR[@IRR(0.3,F55..F75)*100] =			#DIV/0!
MODIFIED IR	R:MIRR = [(PV*(1.113)^20/INIT COST)^(1/20)-1]*100				
	= [(F82*(1.113)^20/B55)^(1/20)-1]*100				
	=	2.141936107			
LIFE CYCLE COST OF WIND SYSTEM =			PV OF FUEL & MAINT.COST+INIT COST		
		=@NPV(F80/100,D56..D75)+@NPV(F80/100,E56..E75)+B55			
	=	$816,891.60			
LIFE CYCLE COST CURRENT ELECTRIC =			PV OF ELECTRICITY COST		
		=	@NPV(F80/100,C56..C75)		
		=	$181,861.06		
NPV WIND = LCC ELECTRICITY - LCC WIND					
	=	D98-C94			
	=	($635,030.53)			
	ANNUAL COST		LIFE CYCLE COST/PVIFA(k,n)		
		=	C94/(@PV(1,F80/100,20))		
		=	104601.038		
	ANNUAL REVE	=	LIFE CYCLE COST/PVIFA(k,n)		
		=	D98/(@PV(1,F80/100,20))		
		=	23286.87931		

Appendix N

Net Present Value Calculations

$$PVIF_{k,n} = \frac{1}{(1+k)^n}$$

Wind Class	Net Present Value
2	-$635030.53
3	-$502,912.51
4	-$349,177.01
5	-$174,920.94
6	$113,784.54

Table N.1: Net Present Value

Internal Rate of Return

$$I = \frac{F_1}{(1+r)^1} + \frac{F_2}{(1+r)^2} + \frac{F_3}{(1+r)^3} + \ldots\ldots + \frac{F_n}{(1+r)^n}$$

Wind Class	Internal Rate of Return
2	#DIV/0!
3	-0.47
4	3.88
5	7.84
6	13.38

Table N.2: Internal Rate of Return

Modified Internal Rate of Return

$$r^* = \left(\frac{[F_1(1+k)^{n-1} + F_2(1-k)^{n-2} + F_3(1+k)^{n-3} + \ldots.. + F_n]}{I}\right)^{\frac{1}{n}} - 1$$

Wind Class	Modified Internal Rate of Return
2	2.14
3	5.61
4	8.01
5	9.89
6	12.07

Table N.3: Modified Internal Rate of Return

Payback Period

$$F_t = S_t - O_t$$

Wind Class	Payback Period (years)
2	Unknown
3	21
4	15
5	11
6	8

Table N.4: Payback Period

Final Cost of Generation

Wind Class	Cost of Generation (cents/kWh)
2	18.45
3	9.68
4	6.33
5	4.61
6	3.25

Table N.5: Final Cost of Generation