Wind Power

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Introduction

This report is the result of a travel study in England in May & June 2003 by the class EMSC_470W at the Pennsylvania State University. This report will discuss technical, economic, social, and political aspects of wind energy, as well as three case studies of wind farms visited in England during the trip.

Technical

Figure (1) shows the first three bladed wind turbine, the Gedser, created in 1956 in Denmark by Johannes Juul [1]. This efficient design paved the way for the modern wind turbines of the 21st century that we see today shown in Figure (2) [2]. Since the 1950's the engineering of wind turbines has become

Figure 1: The Gedser Wind Turbine [1]

Figure 2: A Modern wind turbine at Lambrigg Wind farm, UK. Photo by Jonathan Mathews, May 2003.

A wind turbine converts kinetic energy in the wind into mechanical energy by turning central shaft. This mechanical energy is then converted into electrical energy by an electric generator in the hub of the turbine [2]. The maximum power obtained in a stream of wind is calculated from the derivative of the equation of kinetic energy:

$$P_{max} = \frac{1}{2}\dot{m}V_0^2 = \frac{1}{2}\rho A V_0^3,$$

Referenced from [2]

In the equation, $\mathbf{P}_{max}$ = maximum possible power, $\dot{m}$ = mass flow rate, $\mathbf{V_0}$ = velocity, ρ = air density, and A = cross sectional area of the 'circle' created by the rotation of the turbine blades. It should be noted that $\mathbf{P}_{max}$ is representative of the theoretical power yield if the velocity of the air surrounding the rotor dropped to zero. Because this theoretical value is never achieved, an efficiency factor needs to be added to the equation

to compensate for the energy losses in the wind and in the mechanical parts inside the hub. Today's wind turbines operate efficiencies of 40-50% [3]. Seeing that the output power is linearly related to the cube of the wind velocity, wind velocity is a very important factor in determining where wind turbines should be placed. A difference in wind speed by a factor of 2 results in a difference of output power by a factor of 8.

Disadvantages of Wind Power

One disadvantage of using wind turbines is that they create noise. The enormous blades cut through the wind and the sound created can be heard within close range. In addition, there mechanical noise created from the turning shaft and gears inside the hub. However, today's wind turbine engineers have eliminated almost all mechanical noise in the turbine and are currently working on eliminating the aerodynamic noise from the blades [2]. Wind turbines are also subject to the fate of weather. Nothing can be done when the wind stops blowing and electricity generation is stopped. Because of this, it is important to consider what additional options are available to pick up the lost electricity from wind in an electric grid when the wind stops blowing.

Advantages of Wind Power

In the past two decades, wind power has taken off as a producer of commercial electricity. Today it is the world's most promising renewable energy technology and currently the world's most rapidly growing energy source, whether conventional or renewable [3]. The wind industry is quite labor intensive and because of the rise of wind power, there has been a significant increase in jobs created. Generating power from the wind provides us with a clean form of electricity generation and creates zero CO_2 emissions.

A Case Study – Harlock Hill Wind Farm

Figure – Harlock Hill. Photo referenced from [4]

Harlock Hill Wind Farm is the UK's first cooperatively owned wind farm. Located in Ulverston, England, the farm is comprised of 5 – 500kW machines, which produce a

total output of 2.5MW of electric power. This is enough electricity to power approximately 1,300 homes [4].

Harlock Hill is unique in that it is owned by a cooperative. A cooperative functions very similarly to a small company in that all members of the company own shares in the company. Each member of the company is allowed equal voting rights in the company, and every member votes to elect a board of directors for the company. Each shareholder must own at least the minimum of one share (£300), and all profits to the company are distributed among the company shareholders [5]. The Harlock Hill cooperative currently includes 1,300 shareholders in and outside England [5].

A Case Study - Blyth Offshore Wind Farm

The Blyth Offshore Wind farm is located off the Coast of Blyth in England. The farm consists of two – 2MW wind turbines planted in the North Sea approximately 100 meters from shore. This wind farm is very popular as it is considered the first truly offshore wind farm in the world when it was built in 1992. The farm is owned by Blyth Offshore Wind Limited, a consortium comprised of Shell, AMEC Border Wind Ltd., Powergen Renewables, and Nuon UK [6]. See Figure (4) below for a picture of the two turbines at Blyth.

Figure (4) - Blyth Offshore Wind Farm. May 2003. Photo by Jonathan Mathews

Offshore wind is an attractive method of electricity generation compared with onshore wind for several reasons. Wind speeds at sea are greater and thus generate larger amounts of power for electricity generation [7]. Offshore wind also travels at a more constant speed, and thus decreases the failure of wind turbines due to fatigue [7]. Putting the turbines away from land and out to sea decreases the NIMBY (not in my backyard!) response by the public.

There are currently a total of 10 operating offshore wind farms in the world located in the countries of Denmark, Holland, Sweden, and the UK. Ireland, Belgium, Italy, and Germany all have currently proposed offshore projects [7]. The United States also has proposed its first offshore project to be built off the coast of Cape Cod [7].

Although almost 100% of existing wind farms in the world are on-shore, the construction of this farm 11 years ago set an example that will pave the way for the construction of many more offshore wind farms in the future [3]. The United Kingdom is currently proposing to construct 6GW worth of offshore wind power by 2010. Currently a highly anticipated topic within the field of renewable electricity generation, offshore wind power will only be seen gaining publicity in the years to come.

A Case Study – Lambrigg Wind Farm

Completed in September 2000, this Cumbria wind farm consists of five – 1.3MW turbines, which produce a total output of 6.5 MW [8]. This project cost £4.2million and these turbines were the largest of any on-shore farm in England when they were completed [8]. This farm generates enough electricity to power approximately 4,000 homes and will displace approximately 14,000 of CO_2 emissions per year [8]. See Figure (5) for a picture of Lambrigg Wind Farm.

Figure (5) – Jonathan Mathews & Joshua Taron at Lambrigg Windfarm.
Photo by Jonathan Mathews. May 2003.

Since construction, National Wind Power Limited (owner of the farm), commissioned RBA research to survey 234 residents living close to farm face-to-face on their opinion of the farm. The study showed that 74% favored it and 8% opposed [9].

One significant advantage of on-shore wind farms is that they currently cost 30-70% less than offshore farms. This alone has been much of the reason for few offshore projects.

Economic Trends

Since the boom of wind energy in the 1980's, competition in the wind industry has increased significantly [3]. Figure 6 below shows the constant decrease in cost per unit of electricity produced as the size of wind turbines increases.

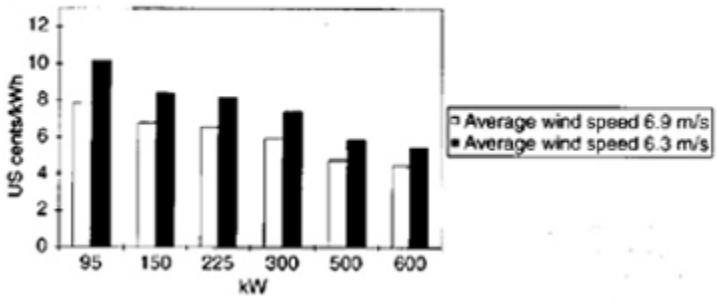

Figure 6
Cost per unit of electricity produced as size of wind turbines increases.

Referenced from [10]

Figure 7 below shows both the increase in average turbine size and efficiency of turbines from 1980-1997. This upward trend is still increasing in 2003. General Electric has just put on the market their 3.6 MW single turbine! [11].

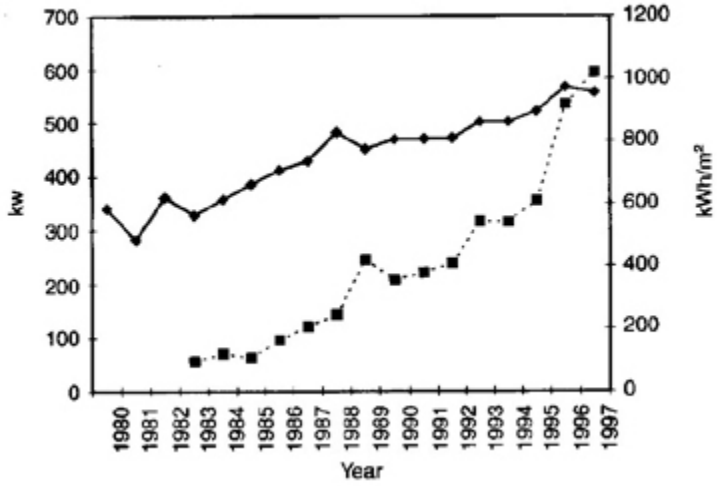

Figure 7
Development of average wind turbine size sold in market (left axis), and efficiency (kWh/m^2) of swept rotor area (right axis)

Referenced from: [3]

Incentives/Policy – United States

The 1992 National Energy Policy included enactment of a production tax credit for corporate entities building renewable energy production facilities (currently at $0.019 per kWh). The credit is available to new renewable energy facilities placed into commercial service after enactment of the law, and prior to the latest deadline, December 31, 2003. The nature of this tax credit is that it inflates each year, bringing more money to producers. At the current rate, project revenue's are approximately $0.05 per kWh. Previously scarce financing for wind projects has now become widely available in our

country. In order to qualify for the tax credit, each individual wind turbine must create commercial power and transmit it to the grid by December 31, 2003. Every wind turbine in a project that failed to accomplish this would result in a loss between $350,000 and $1,000,000 worth of this production tax credit. Because of the deadline and the chance of mechanical failure of turbines, insurance has been created for the production tax credit. A bill to extend the federal production tax credit is currently pending [12].

The Tribal Energy program Grant is sponsored by the US Department of Energy and provides financial and technical assistance to tribes for feasibility studies and shares the cost of implementing wind energy installations on tribal lands. The size of the grant varies and in the past has ranged from $2-3 million [12].

Another important part of the United States Wind Energy policy are Renewables Portfolio Standards (RPSs). These standards specify that a minimum percentage of electric supply portfolios must be obtained from renewable energy sources. While this is not a federal legislation, several states have enacted these standards into their state energy policies [13].

The department of energy hopes to make the US wind technology industry a world leader by capturing 25% of the market by 2005 [14].

Incentives/Policy-United Kingdom

In 1989, the UK government enacted the Non-Fossil Fuels Obligation under the Electricity Act to ensure that renewable energy technology could compete in the open market [15]. The legislation enabled privatization of power supply and meant that regional utilities would have to contract specific quantities of non-fossil power from nuclear and renewable energy power plants [16]. The Fossil Fuel Levy (FFL), a tax on all electricity, works with the NFFO

A second important policy the United Kingdom has enacted is the Renewables Obligation. The Renewables obligation requires power suppliers to derive from renewables a specified proportion of the electricity they supply to their customers. This starts at 3% in 2003, rising gradually to 10% by 2010. A price cap will limit the cost to consumers and the obligation is guaranteed in law until 2027. The Renewables Obligation came into force in April 2002 as part of the Utilities Act of 2000. [17]

Public Perceptions/Acceptance

In general people are favorable to wind energy. Recent polls in the UK show that 80-90% of public favors wind energy [18].

On May 17, 2003, Joshua Taron and I conducted a face-to-face interview with Ms. Nuala Henderson, a resident in Cornwall, England and worker at the hostel in Penzance where we stayed for two nights. As she is the only person we interviewed, her responses provide us with no significant findings, other than a data to compare with previous studies. Also, some of her responses were inconsistent with the questions we asked. The following is result of our interview:

Brad & Josh: Do you think there is a problem with the way energy is currently being produced: 1.) In the UK? and 2.) In the world?

Ms. Henderson: Yes, not enough research, funding, or interest. Also, not enough interest by important people; the general public want renewables, but they don't want a farm near home. The general public foresees wind power as a feasible option.

Brad & Josh: 1.) How many wind farms are there in Cornwall? 2) How many are proposed to be built? What are some factors in these decisions?
Ms. Henderson: There are 4 farms in Cornwall, 5 being proposed (single farms)--Not enough research into wind, too much into wave--not enough into personal wind for residences--hard to get granted permission for personal farm (noise, heath, view, influence on livestock)
--lots of complaints about ruining the landscape and also birds getting caught in the blades.

Brad & Josh: Is wind a viable option to produce a large percentage of the energy load in the UK? Have you always felt this way? When did you begin to feel this way?
Ms. Henderson: In the Mid 80's, becoming popular in theory--1974, environmental--1990's, boom of production

Brad & Josh: Would you support a wind farm project within sight distance of your house?
Ms. Henderson: Not a large-scale farm because of space and beauty of landscape.

Brad & Josh: What have been the impacts on society of the farms (economy?)?
Ms. Henderson: Pre 1979, Thatcher cut funding for renewables. As a result of this people more aware of the need for renewables.

Figure (6) below shows the results of a study done by the Dutch wind developer Energy Connection. These results show the trend in percent of acceptance during the course of a wind project and that "acceptance grows as people learn that many of their misgivings were ill-founded" [19].

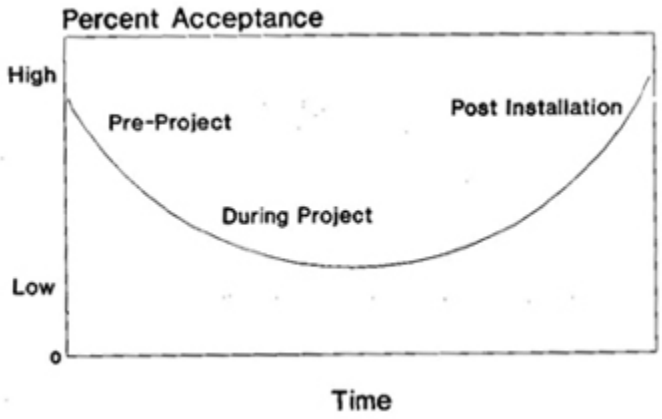

Figure 6
Referenced
from [21]

There are several ways to increase public acceptance of wind turbines. One way is to educate the public about the environmental benefits [4]. If people do not realize and understand that producing electricity via wind turbines is a clean and non-polluting form of electricity generation, they are going to be less likely to advocate it. Another way to increase public acceptance is to design wind turbines that are more pleasing to the eye [4]. As sad as it is, some people would rather not have an environmentally friendly wind turbine that could generate their electrical needs if it is going to be considered as ugly and unnatural. Regardless of eye-pleasability, many people just do not want wind turbines

near their homes. This is referred to as the "not in my backyard" response otherwise referred to as NIMBY [4]. It has also been shown that interest and favorability have increased when people living close to turbines were allowed to own parts of the project [2].

Generation Potential: United States vs. United Kingdom

Today there is roughly 4,000 MW of installed wind generating capacity. The DOE hopes to achieve 10,000 MW of installed wind generating capacity by 2010.

In a study executed by the US Energy Information Administration, a potential of close to 1 million MW within 20 miles of existing transmission lines in the USA was identified, far greater than the country's total existing generation capacity. Figure 8 below shows the annual United States wind power resources.

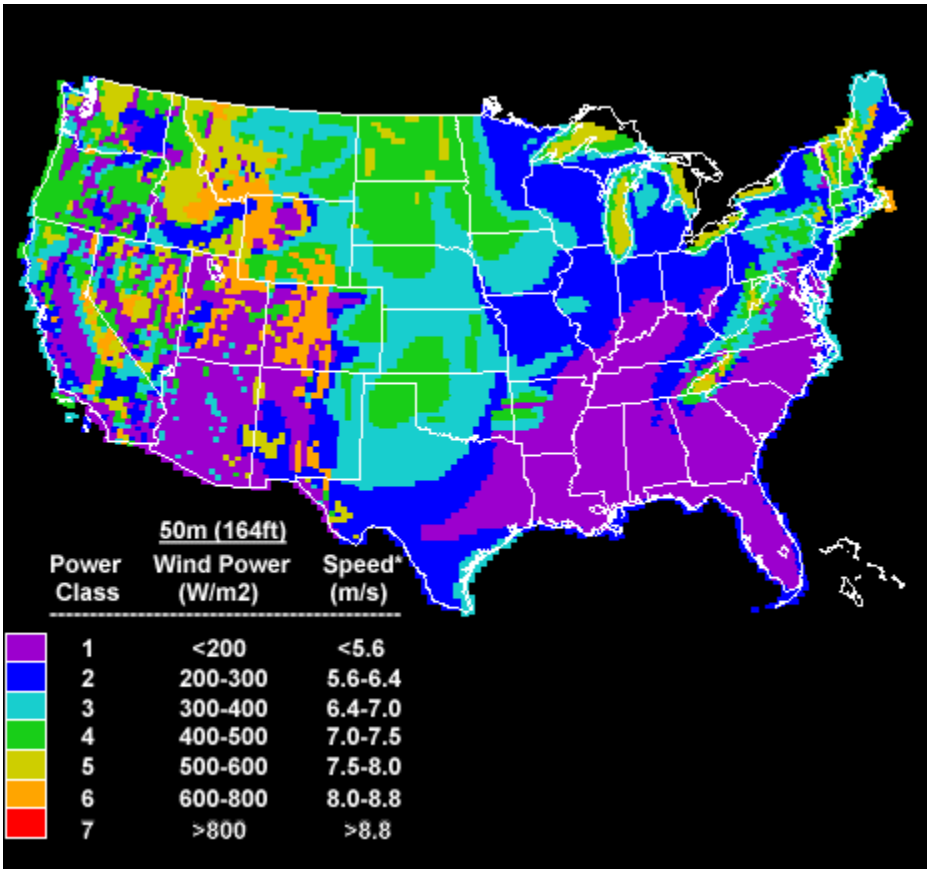

Figure 8

United States Annual Wind Power Resources.

Referenced from: [21]

The United Kingdom currently has approximately 580 MW of installed wind generating capacity [22]. The UK is expecting 6,000 MW of offshore wind turbines by 2010 in addition to the 1,500 MW of offshore wind farms already given consent in 2003 [23].

Permitting – United States

One key aspect of building a wind farm is obtaining the permission to do so. Virtually all wind projects are required to obtain a permit from one or more agencies [24]. Typically engineers in the United States must obtain local, state, and federal permits in order to construct a wind farm. Primary permitting jurisdiction at the local levels includes local planning commissions, zoning boards, city councils, or county board of supervisors [24]. State permitting authorities might include state historic preservation offices, industrial development and regulation agencies, public utility commissions, natural resource and environmental protection agencies, or siting boards [24]. Depending on the state where the wind project proposed, state and local permitting may be necessary, or the state level may be all that is necessary [24]. Federal permitting may involve federal land management agencies, power administration agencies, and/or the United States Fish and Wildlife Service [24]. When federal agencies or federally managed lands and resources are involved, the requirements of the National Environmental Policy Act may apply [24].

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