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Is it Feasible for the US to Convert All Electricity Production to Wind Power?

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Introduction

In recent years, global climate change has become a significant issue as people became concerned about the influx of greenhouse gases into the atmosphere which potentially cause damaging effects to the planet. However, conservation efforts, which may curtail the effects of global climate change, may have great economic consequences and would cost more than geoengineering efforts to prevent climate change. Conservation efforts to reduce carbon emissions, such as reduction of electricity usage, could cost economies greater than $100 billion dollars per year worldwide (Teller et al., 1997), while geoengineering projects would cost on the order of a few billion dollars a year (Teller et al., 1997). Therefore, if humankind is able to maintain its standard of living and continues to demand vast amounts of electricity, then electricity conservation would not be the answer. Either, geoengineering projects would need to be made to curtail the effects of greenhouse gases or conservation would have to come in the form of changing the method of electricity generation.

One answer to reduce emissions from electricity generation is to change from predominately fossil fuel burning power plants to wind turbines. Wind turbines are clean and produce no carbon emissions. By replacing coal fired power plants with 2 million 1-MW capacity wind turbines, about 1 GtC per year would be saved from being emitted into the atmosphere (Pacala and Socolow, 2004). In the US, carbon emissions from electricity production amount to 2.3 GtC per year as of 2006 or about 32% of all US carbon emission (Department of Energy – Energy Information Administration 2007). By changing all fossil fuel burning plants with turbines, which include coal, natural gas, and petroleum, theoretically, 2.3 GtC could be saved each year from entering the atmosphere. Figure 1 gives a breakdown of carbon emissions by power plant type. Coal power plants by far give off the most carbon emissions. To replace all coal plants with wind turbines in the US would save about 1.9 GtC per year.

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Figure 1. Carbon dioxide emissions from the electric power sector. From Department of Energy – Energy Information Administration.

Currently, most of our electricity production comes from the burning of fossil fuels while renewable sources of energy, such as wind, makes up a small fraction of total electricity supply. As of the end of 2005, the US had an electricity supply capacity of around 1,000,000 MW which provided 4,000,000 GWh of electricity (Edison Electric Institute, 2008). Wind power only had a capacity of16,800 MW, which is estimated to provide 48,000 GWh of electricity or approximately 1% of US production for 2008 (American Wind Energy Association, 2008). Throughout the US, over 5200 MW of capacity has been installed in 2007 alone, a 45% increase in capacity from the year before, showing that the wind power industry is strong and growing (AWEA, 2008). Demand for turbines has grown so much that manufacturing capacity has been saturated and orders at many of the largest manufacturers have been backlogged until 2009 (Hill, 2007).

Currently, the future may look encouraging for the wind power industry, but can wind power replace most, if not all, electricity generation in the US? This paper try to answer this question by examining the conditions needed for large scale wind power generation and make rough estimates of inputs needed for 100% wind turbine electricity generation.

US Wind Resource

Wind resource in the US is that wind turbines cannot be placed anywhere. Wind resource varies greatly upon topography and general wind circulation around the Earth. Prime areas for ample wind resource generally occur on coastlines, large flat plains, mountain ridges and summits, and funneling valleys (Elliot, 1986). Figure 2 shows US wind power density.

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Figure 2. Annual Average Wind Power Resource. Darker Regions indicate areas of greater resource. Most of the Great plains are covered with acceptable wind resource, greater than 7 m/s (Class 3). From Elliot (1986).

Besides topography and wind circulation, it is additionally important that turbines are in accessible areas. These accessible areas typically include the plains and coastlines. In the US, there is significant wind resource on the Atlantic and Pacific coastlines, the Texas Gulf Coast, and the shorelines of the Great lakes. In addition, most of the Great Plains provides excellent wind resource. . There may be many great locations to place turbines within the mountains since high level winds tend to blow harder all year round than those at lower altitudes. However, accessibility becomes an issue since these areas are accessed by few roads and turbines can be surrounded by deep snow and there is the risk of turbine blades icing. In addition, given the topography of a mountainous region, several turbines in the same region receive uneven wind exposure because of interaction of air along the boundary layer (Elliot, 1986).

There can also be high wind resource in lower altitude valleys if wind can be funneled through a narrow constriction to enhance wind speeds. Many of these valleys are already main transportation paths through mountains and already have great accessibility. Given their lower altitude, weather tends to be less extreme than at mountain ridges. However, small scale topographic features combined with large scale funneling effects lead to local wind variability and thus cause difficulty in the turbine placement process. (Elliot, 1986). Figure 3 shows percentage of land with suitable wind resource, which is related to surface topography.

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Figure 3. Percent of the land area estimated to have Class 3 or higher wind power in the contiguous United States. From Elliot (1986).

There is also some seasonal variability in wind resource. The winter months generate the greatest wind resource when upper wind speeds are at their greatest. The summer experiences the minimum available wind resource. This is a result of the polar front, which is associated with the Jet Stream, changing position from winter to summer. The Jet Stream moves to the middle latitude of the US during the winter while it moves to the north of the US during the summer. The strong prevailing winds of the Jet Stream provide more wind resource (Elliot, 1986).

Lastly, one has to consider all nearby obstacles when placing a turbine. Thus, plains tend to be the most reliable and efficient to place turbines since there are few obstacles to change wind flow. Although mountains provide areas of high wind speeds, only a small percentage of the land will be well exposed. Urban areas also provide poor resource because of the buildings becoming obstacles for wind flow (Elliot, 1986). .

Specifically, it is not economically viable for turbines to be placed unless wind speeds at the height of the rotor are at least 7 m/s (Archer and Jacobson, 2005). A table of wind speeds and their power densities generated can be seen in figure 4.

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Figure 4. Relationship of wind speed and wind power density. Wind power class 3 and above are considered economically viable. Wind speeds at altitude (50m) estimated using 1/7 power rule. From Elliot (1986).

Wind Turbine Material and Installation Costs

Important to calculating the cost of powering the US on only wind power is to understand the materials needed to build turbines. For larger, utility-scale turbines, the majority of materials needed to produce turbines are steel and fiberglass. Steel composes 95% of the tower, hub, and nacelle, and 80% of the turbine machinery. Fiberglass composes of more than 95% of most turbine blades though newer turbines may use carbon fiber or other lightweight materials. However, turbine blades make up 10% of the weight and thus, the material cost of towers is closely related to steel prices (AWEA, 2007).

Other variables that affect cost are based on manufacturing capacity. Turbine costs have surged 17% in 2006 and are projected to jump an additional 14% as a result of backlogged projects and lack of manufacturing capacity (Hill, 2007).

As of August 2007, the cost of a wind turbine for a typical 1.5 MW turbine, similar to a GE or Vestas model, is $2.5 Million including installation (Hill, 2007). Installation costs range from $0.5 million land installation to $1 million or more for offshore installation (National Renewable Energy Laboratory, 2006).

Wind Power Dollar and Land Cost Calculation

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To create a proper wind turbine field, turbines cannot be stacked upon each other. An ideal spacing to reduce turbulent flow is to place turbines 5 rotor diameters in rows while downwind spacing should be about 12 rotor diameters (Johnson, 2001). This means that for a 1.5 MW tower (80m rotor blades), each tower would need 38.4 ha of land while a 3 MW tower (100m rotor blades) would require 60 ha of land each. However, the base of the tower would only take up about 1.5 ha of land (Johnson, 2001). In order to supply the US with enough electricity with the same nameplate capacity of 1,067,019 MW, using 1.5 MW turbines, 711,346 turbines would need to be erected over 27,315,686 ha of land (2.8% of the land area of the continental US). If 3 MW towers are used, 355,673 turbines would be erected over 21,340,380 ha of land (2.2% of the land area of the continental US). However, the total land taken up by the foundations of 1.5 MW and 3 MW towers is about 1 million ha (0.1% of US land) and 500,000 ha (0.05% of US land), respectively.

The approximate cost of placing 1.5 MW towers at $2.5 million a turbine would cost $1.78 trillion. For 3 MW turbines, each turbine costs approximately $3.5 million (Fingersh, 2008), thus installation of all 3 MW towers would cost $1.24 billion. Therefore, there is a reduction in cost in dollars and land by using larger towers.

Other Costs of Wind Power

Although wind power would be carbon emissions free, there are still several problems that restrict wind power from being a dominant power source. One large problem, although wind power publicly is seen as a good solution to reduce carbon emissions, there is still perception of NIMBY (Not-in-my-backyard) issues (Wolsink 1999). Only few may want to live near a turbine because based on concerns of noise and aesthetics (Wolsink 1999).

Noise is of particular concern. A large wind turbine can be as loud as 108 dB at 20 rpm and will decrease in volume, in a worst case scenario, 3 dB for each doubling of distance away from the turbine. Thus, at 1 km away from the source, noise level may be as loud at 78 dB, the equivalent of loud conversation or traffic noise (Barhill Windfarms, 2005). This noise is especially annoying because of its pulsating nature with a frequency of approximately 1 Hz whereby each passing of a turbine blade is the equivalent of one pulse (Pedersen, 2004). In an area within 800 m of 550 kW turbine in Sweeden, there were 12 complaints within 800 m of the turbine (Pedersen, 2004). However, according to the AWEA, the noise generated from newer turbines at distances 750-1000 ft away only are as loud as 45 dB or the equivalent of noise generated from a regular kitchen refrigerator (AWEA, 2004). The sound generated is not only annoying for humans, but for animals as well. A study of marine life near offshore windmills showed to alter behavior because of emitted sound (Koschinski, 2003). Thus, when placing turbines, one must consider the noise emissions from turbine. Because of noise, turbines should be placed in sparsely populated areas with cropland instead of grazing land because of the possibility of annoying cattle.

Aesthetics are also an issue since turbines can be quite prominent on the landscape. Large turbines can be 80-100m tall based on nameplate capacity. Beside in cities, wind turbine towers will be the tallest objects in most settings. Because of their size, they are seen as eyesores and were an obstacle to the Cape Wind Project (Kennedy, 2005). Also, they can be visually annoying because of the reflection of sunlight off of the rotor blades. Lastly, constantly rotating nature of the blades also prove to be annoying to some turbine neighbors (Wolsink, 1999).

Besides not being pleasant to the senses, there are some environmental issues with turbine placement. Turbines can cause local changes in weather patterns given that they create more drag and cause turbulent flow in the boundary layer (Keith, 2004). This turbulent flow encourages convection in the boundary layer which causes seasonal regional differences in temperature up to

+/- 2 degrees Celsius; however change in global average temperature would be negligible (Keith, 2004).

Physical Problems for Implementation

Besides the sheer cost of installing turbines, the current electricity infrastructure is simply not set up for large scale wind turbine usage. Although the US could be carbon emission free in electricity production by using wind power, it is very difficult for wind to become the primary resource for electricity because of wind variability. Such variability in wind speed makes predicting supply to the grid a problem. Because of wind variability, in order to have a dependable energy source, wind power would need to work in conjunction with a controllable electricity source in which supply can be controlled to fit the demand of the grid.

Currently transmission rules reflect the current setup of electric utilities where plants can control and plan their supply while wind power does not have that luxury. In fact, current rules penalize producers for changes in their supply different from their scheduled supply determined the day before. However, new federal laws in 2007 have changed rules to effectively remove these penalties for wind power (Texas State Conservation Office, 2007).

Transmission of wind power is difficult simply because the grid was created for more centralized power plants of higher capacity. Instead, in the case of wind power, production is spread over a much larger area with each facility only producing a small amount of power.

In addition to limitations in grid capacities, for wind power to be transported over long distances, there is the problem of "rate pancaking." As power is transported over long distances, producers will need to pay multiple transmission line owners to have access to their transmission lines. To avoid such a problem, the transmission grid would need to be owned by a single entity over a very large geographical area (AWEA, 2003). Also a problem with long distance transmission is the power lost from transportation of electricity over hundreds or even thousands of miles.

Lastly, there is simply just a lack of transmission capacity in rural areas in the Great Plains where wind power generation would occur. Current transmission lines are built to deliver electricity from large power plants to large load centers, thus the absence of transmission capacity in less populated areas. However, new laws for eliminating schedule imbalance penalties effectively increase transmission capacity by introducing extra efficiency in power transmission (AWEA, 2003).

Conclusion

Converting all electricity to wind power is a very expensive endeavor and may not be economically viable for the time being. Teller (1997) estimated that global carbon emissions conservation would cost $100 billion a year. To place 3 MW towers would cost $1.24 trillion. However, the expected lifespan of a turbine tower is only 30 years. Therefore, averaged over the lifespan of a turbine, the project costs $41 billion. On top of this figure, the maintenance of a single turbine costs, besides turbine replacement, is $50,000/year excluding maintenance, making the operating cost an additional $17.8 billion, making for an extra maintenance cost of $58.8 billion. Although this remove approximately 1/3 of US carbon emissions, this only cuts out a fraction of worldwide emissions and economically may not be the best decision. However, wind energy has a great advantage in that turbines would require no fuel and therefore $38 billion in fuel costs would be saved annually. When maintenance costs decrease, more electric utilities will build large scale wind turbine farms even when tax subsidies are removed.

Figure 5. Revenue and expense data for Electric Utility Companies from 1995-2006.

In addition, manufacturing capacity has not caught up with demand (Hill, 2007). If we consider last year's manufacturing of turbines in the US was 5200 MW of production. At this rate, it would take around 70 years to produce enough turbines to replace old turbines. Manufacturing supply would have to expand to keep up pace with turbine replacement after their useful lifetime.

Lastly, large scale wind power implementation cannot occur until the grid is updated to handle decentralized power generation. Otherwise, power distribution will be incredibly inefficient because of lost power over long pathways of transmission lines. More towers would need to be erected to meet the demand and power will continue to be expense. Lastly, wind variability will be such that electricity can not be controlled and scheduled for different demand throughout the day. The grid would have to be updated to handle wind variability or possible wind power could only make up a majority of power production while coal or gas power could handle the base load.

If costs do fall and the grid can be updated, wind power could become a viable option. With the expansion of capacity and economies of scale from building large wind fields, and increasing turbine lifespan, costs may be able to drop significantly to make wind power a majority of our electricity producing needs. However, until then, wind power will not be the dominant electricity generator, but it is still cheap to build on the small scale. However, Denmark has already shown that wind power can make up a significant fraction of total power production where their 20% of their power needs is produced by wind turbines (Danish Energy Association, 2008). There may be still hope that wind power can be a solution to significantly reduce carbon emissions.

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