Wind Energy: A Thorough Examination of Economic Viability

Energy and Energy Policy

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This paper will determine the economic viability of wind energy through examining recent developments in turbine technology, transmission technology, and the policy environment. Advances in turbine technology have the potential to increase the efficiency of wind-based electricity production. Similarly, the implementation of new transmission technologies, specifically those regarding High Voltage Direct Current, may have the power to bring wind-generated electricity to untapped markets. Finally, the policy environment is critical to shaping the terms upon which wind energy competes with traditional forms of electricity generation. A number of policy variables can have a strong effect on wind energy's bottom line, whether through affecting the price of wind energy or through the development of innovative technologies that reduce cost. Using this knowledge, we then draw up an analysis of the average cost of wind-generated electricity under two scenarios: servicing local markets and transmitting electricity to distant markets via HVDC. We then consider whether wind-generated electricity would be competitive in various markets. We find that wind energy generated in the interior U.S. is competitive in the distant California energy market under all conditions. Further, we find that under certain conditions, wind energy is economically viable to service the local markets near to where wind resources are found.

The Policy Environment for Wind Energy

Overview of the Problems and Challenges

Wind Power Energy has become increasingly popular to investors, government officials, and the general public since its commercial advent in the ١٩٧٠s. The awakening of significant investments in wind energy was caused by a growing realization of the need for energy security. However, there are numerous problems and challenges to developing wind energy, both in the short and the long term.

The U.S. Department of Energy identifies several key challenges in wind energy development: risk perception, the transmission and grid limits, the low competitiveness of wind energy, low-speed wind location usage, lack of infrastructure for transmission, regulatory policy, environmental policy, environmentalists, and general public opinion (DOE ٢٠٠٧, ٨, ١٨). We will address each of these challenges in turn, with a specific focus on the policy problems that these challenges embody.

Risk perception is a challenge for any developing technology; however, this is particularly the case with wind energy, since it depends on the presence of an uncontrollable input: wind. Many industries operate in the presence of natural constraints; for example, globally agriculture too depends on weather (rain and sunny days). But while agriculture has a thousand-year history and large data sample from which to estimate the risk, wind energy is a relatively young technology with little acquired knowledge. Even though the technology for installing wind energy at better locations is cost efficient compared to other technologies, the market considers new technologies as very risky (DOE ٢٠٠٧, ٨, ١٩).

From the investor point of view, wind energy itself is still perceived as too costly. The marginal cost of wind energy is competitive with the latest conventional[١] technologies; nonetheless, the fixed costs of wind energy's technical development is still too high (DOE ٢٠٠٧, ٨, ١٩). Reduction of these costs will enable the wind energy to be used at an even more competitive rate. Policies such as the Renewable Electricity Producer Tax Credit have the potential to cut the cost of turbines through promoting innovation and creasing stable market demand.

[١] Conventional refers to all non-renewable energy resources, primarily: Coal, Natural Gas, and Nuclear

As an additional setback, developments in wind energy must occur in tandem with investments in transmission technology: otherwise, there is no way to deliver wind-generated electricity to the market. Transmission channels operate under strict regulations and operational policies. These transmission restraints and the lack of knowledge of wind generated energy's impact on the grid suspend wind energy development (DOE ٢٠٠٧, ٨, ١٩). Therefore, developing wind energy without the development and research of transmission is inefficient.

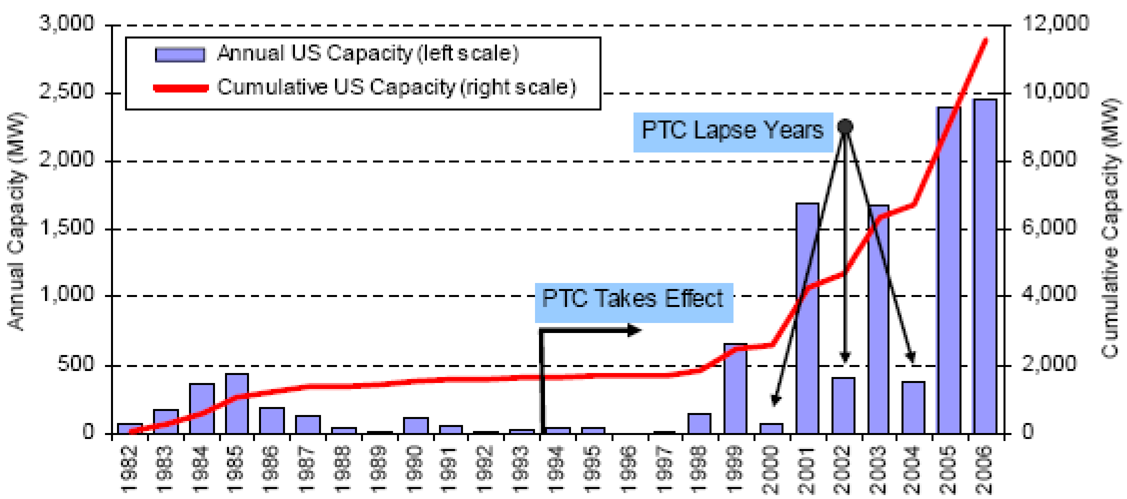
We therefore conclude that wind energy and transmission development are closely related. The fall in cost of wind energy yields only a limited result if such energy may not reach its consumers cost-efficiently (DOE ٢٠٠٧, ٤٤). Transmission development is encouraged by the growth in wind energy, which in turn cannot develop without cost-efficient transmission. Policy has the potential to influence these developments in two ways: ١) by fostering the development of new turbine technologies; and ٢) by increasing the attractiveness of an investment in wind energy. Ultimately, developing domestic Energy production will ultimately help "secure [the US] energy economy" (DOE ٢٠٠٧, ٢٢).

Governmental incentives and programs

There are multiple incentives, monetary and logistical, that government provides to foster growth of Wind Power Energy development: research, development, and deployment co-operation (RD&D), production tax-credit (PTC), Wind Energy Program (WEP), Wind Powering America (WPA), Distributed Wind Technologies (DWT), Energy Policy Act ٢٠٠٥ (EPA), Energy and Policy Conservation Act (EPCA), Federal Energy Management Program (FEMP), Renewable Portfolio Standards (RPS), Advanced Energy Initiative (AEI), Advanced Wind Turbine Program (AWTP), and Clean Renewable Energy Bonds (CREB).

The RD&D programs are fostered to develop new technologies in a manner that would help investors manage Wind Power farms that are economically feasible. This is achieved by conducting research that reduces the technology cost (DOE ٢٠٠٧, ٢٢). In addition to funding private research, the Department of Energy also aims to conduct its own basic research in wind energy in order to make high-risk energy sources more attractive to investors in the long run (DOE ٢٠٠٧, ٢٣). Some research requires significant upfront expenditures. For example, there are turbine testing projects that require such facilities and infrastructure (DOE ٢٠٠٧, ٢٣). These programs help the government develop data to estimate national standard parameters while reducing the commercial risk for investors (DOE ٢٠٠٧, ٢٣). Such projects are usually run either by federal agencies or in public-private partnerships (DOE ٢٠٠٧, ٢٣). Since the projects have benefits for the government and significantly reduce risk for investors, the public-private testing projects are economically justified. These partnerships have the potential to unearth new innovations that may replace the prevailing turbine technology with something cheaper and more powerful.

The Renewable Electricity Production Tax Credit (PTC), meant to incentivize investments in wind energy, has often had just the opposite effect. Founded as a part of the Energy Policy Act of ١٩٩٢, the PTC supports energy generated through renewable energy sources by allocating a ٢ cents/kWh tax credit (٢٠٠٧) for the first ١٠ years of operation (٢٨). The program has been highly successful at stimulating investments in wind-generated electricity. The DOE estimates that PTC stimulated the production of nearly ١٢GW of wind power (٢٠). However, the PTC has received sporadic support since its inception, causing large demand shocks in the turbine market. The figure below illustrates the fluctuations in demand attributable to the PTC.



Source: Wiser et. al ٢٠٠٧

The swings in wind power growth have made the demand for turbines very volatile, driving some turbine firms into bankruptcy. Turbine production was largely outsourced to European firms (٢٠), an event which may have prompted a significant loss of human capital in the U.S. turbine industry. In addition, the variability in tax credit policy may have the effect of driving up the price of turbines once the credit is reinstated, as pent-up demand outstrips the small supply of turbine manufacturers able to weather the storm. The shortage of turbine production capacity leads firms to raise their prices for turbines, thus negatively impacting the overall competitiveness of wind-generated electricity. Finally, the uncertainty associated with the PTC may discourage potential investors, who must include the risk of policy change in their rate-of-return calculations. By decreasing the policy uncertainty surrounding the PTC, the market for turbines will become more stable, with the effect of lowering prices, increasing orders, and attracting technical talent to the turbine industry, thereby increasing the rate of technological innovation.

Transmission

Transmission policies will also have a large effect on the economic viability of wind-generated electricity. As we have seen, wind power markets are quite dependent on that availability of high voltage transmission lines, without which they will not be able to transport large amounts of electricity any sizeable distance. Due to this dependence on transmission lines, wind energy is particularly sensitive to the cost of transmission. Furthermore, once the transmission line is built there is the possibility of under-utilization due to low wind yield (٢٧). So for companies that have to develop their own transmission network, the wind energy itself might be extracted cost-efficiently yet the transportation may raise the costs to a prohibitively-high level. One way measure DOE suggests is to reduce current average distance between ٥٠ national load centers from ٥٠٠ miles to ١٠٠ miles, reducing the transmission cost upper bracket and lowering the risk of transmission blockage of next generation wind development (٥١). Another proposal involves the use of High Voltage Direct Current, rather than High Voltage Alternating Current, to span the vast distances between wind resources and the utilities that receive them. We will investigate this later proposal in the upcoming section.

Another policy proposal would force transmission lines to be able to direct energy from different energy producers to specific consumers. This is true in Sweden where consumers have the possibility of choosing their electricity provider based on whether or not the provider's electricity has some "green"[٢] or all "green" energy (Ek, ١٨١). In the case of electricity from "green" providers there was a premium consumers had to pay (١٨١). Such

[٢] "Green" refers to electricity generated from a renewable energy source.

measures may be effective in areas where the public has a strong positive attitude towards renewable energy, but previous research shows that one cannot expect the number of those willing to pay more for "green" to be high (١٨٣). Treating "green" energy as a different product with a different price would allow wind energy to compete with other forms of renewable energy in a luxury energy market. In such a market, wind would excel. Policies that served to separate renewable and traditional electricity transmissions therefore have the possible effect of making wind energy more economically viable. Austin Energy, a public-owned utility in Texas, has created such a market when it launched its GreenChoice program in ٢٠٠٠. The program has been very successful, and has the potential to take hold elsewhere, with significantly positive effects for wind energy.

Wind energy technology basics

The importance of wind speed

Kinetic energy in wind can be captured by wind turbines and converted to mechanical energy. Generators produce electricity from the mechanical energy. Simply, wind turbines work like a fan operating backwards. Instead of electricity making the blades turn to blow wind from a fan, wind turns the blades in a turbine to create electricity.

Wind turbines range in size from a few hundred watts to as large as several megawatts. The amount of power produced from a wind turbine depends on the length of the blades (or the term of swept area) and the speed of the wind. The power in the wind is proportional to the cube of the wind speed; the general formula for power in the wind is:

$$\mathbf{P = ١/٢ * \rho * A * V^{٣}}$$

where P is the power available in watts, ρ is the density of air (which is approximately $١.٢ kg/m^{٣}$ at sea level), A is the cross-section (or swept area of a windmill rotor) of air flow of interest and V is the instantaneous free-stream wind velocity.

Because of this cubic relationship, the power availability is extremely sensitive to wind speed. A doubling the wind speed increases the power availability by a factor of eight. Even a small variation in wind speed converts to a substantial difference in power output. The same turbine on a site with an average wind speed of ٨ m/s will produce twice as much as electricity as an on a site with ٦ m/s (ODPM, ٢٠٠٤.)

The usual cut in speed is ٥ m/s and full-load attained above ١٢ m/s, while the usual cut out speed is ٢٥ m/s[٣]. Thus developers expend considerable effort to identify and secure the sites which are most consistently in the optimum range. NREL divides wind speeds into wind power classes designated Class ١ (lowest) through Class ٧ (highest) (Table ١). Class ٢ and above wind speeds can provide sufficient energy to drive a small wind turbine. Utility sized turbines usually need at least Class ٣ wind conditions to operate.

Table ١ Wind power classes at ١٠ m and ٥٠ m elevation

Power class	١٠ m		٥٠ m	
	Wind speed (m/s)	Power Density (W/m٢)	Wind speed (m/s)	Power Density (W/m٢)
١	٠-٤٫٤	٠-١٠٠	١-٥٫٦	٠-٢٠٠
٢	٤٫٤-٥٫١	١٠٠-١٥٠	٥٫٦-٦٫٤	٢٠٠-٣٠٠
٣	٥٫١-٥٫٦	١٥٠-٢٠٠	٦٫٤-٧٫٠	٣٠٠-٤٠٠
٤	٥٫٦-٦٫٠	٢٠٠-٢٥٠	٧٫٠-٧٫٥	٤٠٠-٥٠٠
٥	٦٫٠-٦٫٤	٢٥٠-٣٠٠	٧٫٥-٨٫٠	٥٠٠-٦٠٠
٦	٦٫٤-٧٫٠	٣٠٠-٤٠٠	٨٫٠-٨٫٨	٦٠٠-٨٠٠
٧	٧٫٠-٩٫٤	٤٠٠-١٬٠٠٠	٨٫٨-١١٫٩	٨٠٠-٢٬٠٠٠

Wind speed is partly a function of height and generally weaker near the ground due to friction between earth's surface and air flow. So placing turbines on hills and on large towers gives access to higher wind speeds. A taller tower not only makes it possible to reach faster winds but also accommodate a bigger rotor for a larger swept area.

All these factors have driven manufacturers to make ever bigger turbines. The turbines of the mid-١٩٩٠s swept ten times the area of earlier machines (Gipe, ٢٠٠٤.) The size of wind turbines has doubled approximately every ٤~٥ years (Wizelius, ٢٠٠٧.) Turbines with an installed generator capacity of ٥ to ٦ MW and a diameter of ١١٠-١٢٠ m diameter are running as prototype, see figure ٣.

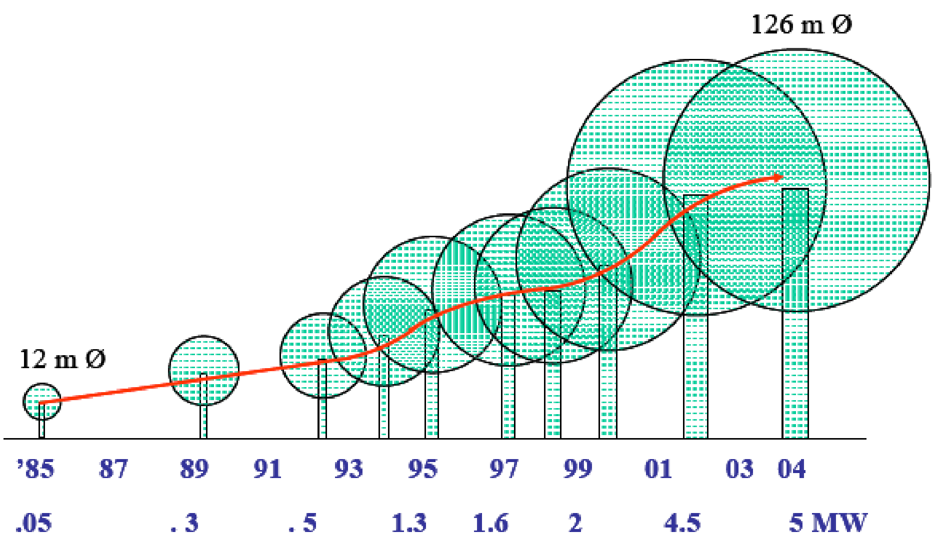


Figure ٣ the development of wind turbine size.
Source: Gijs van Kuik et al., ٢٠٠٦.

Intermittence

Wind speed variation has system-wide effects for the electricity generation sector. Wind speed can decrease or increase by a factor of two very rapidly. Each time this

[٣] Cut-in Speed is the minimum wind speed needed to turn a wind turbine and produce electricity. Cut-out Speed is the maximum wind speed that a turbine can handle. Turbines automatically stop spinning at winds speeds greater than the cut-out speed to prevent damage to the turbine.

happens, generation from a 'wind carpet' – namely, the total number of turbines in a relevant geographical area – decreases or increases by a factor of eight. Fluctuation in wind availability leads to sudden drop-outs and surges in electricity supply, requiring 'up regulation' and 'down regulation' by conventional generating plants (Szarka, ٢٠٠٧.) The bigger the 'wind carpet', the more pronounced these effects are. This creates the problem of 'intermittence', which has two different components. The first is the total absence of wind energy – and therefore of generation – during high pressure events. The second is rapid up or down variation in wind speeds and power output. The first can be predicted by weather forecasts with increasing accuracy. Predictions of the second are improving – due to better methodologies and tools (epically under short time-frames) – but will always remain a problem because wind speed variation is inherently a stochastic phenomenon (Szarka, ٢٠٠٧.)

Operation

Turbines produce direct current (DC) or alternating (AC) power, depending on the generator. (In our case the prime mover is the rotor.) However, neither way is ١٠٠ percent efficient at transferring wind power. The rotor will deliver more power to the generator than the generator produces as electricity. This leads to another fundamental consideration on the size of wind turbines. The size of a generator indicates only how much power the generator is capable of producing if the wind turbine's rotor is big enough, and if there's enough wind to drive the generator at the right speed. Thus further confront the fact that a wind turbine's size is primarily governed by the size of its rotor (Gipe, ٢٠٠٤.)

Wind speeds are crucial for generating utility-compatible electricity. To adapt wind speed variation, electrical generators can be operated either at variable speed or at constant speed. In the first case, the speed of the wind turbine rotor varies with the wind; in the second, the speed of the wind turbine rotor remains relatively constant as wind speed fluctuates.

In nearly all small wind turbines, the speed of the rotor varies with wind speeds. This simplifies the turbines' control while improving aerodynamic performance. When such wind machines drive an alternator, both the voltage and frequency vary with wind speed. The electricity they produced isn't compatible with the constant-voltage, constant-frequency AC produced by the utility. Electricity from these wind turbines cannot be used in most our daily equipments. The output from these machines must be treated or conditioned first, usually equipped with features to produce correct voltage and constant frequency compatible with the loads.

Although nearly all medium-size wind turbines, such as the thousands of machines installed in California during the early ١٩٨٠s, operated at constant speed by driving standard, off-the-shelf induction generators, a number of manufacturers of megawatt-size turbines today have switched to variable-speed operation[٤]. Many of these use a form of induction generators, which may improve aerodynamic performance.

[٤] NREL, see http://www.nrel.gov/ for further information.

Estimating output

Annual energy production (AEP[٥]) is calculated by applying the predicted wind distributions for a given site to the power performance curve of a particular wind turbine. The site wind distributions are normally based on a Rayleigh distribution[٦] that describes how many hours (or probability) each year the wind at a given site blows at a particular wind velocity (Figure ٤(a)).

The second step in this process requires the power curve for the chosen turbine. Figure ٤ (b) is an example of a power curve for a ١.٥-MW turbine that is characteristic of current technology.

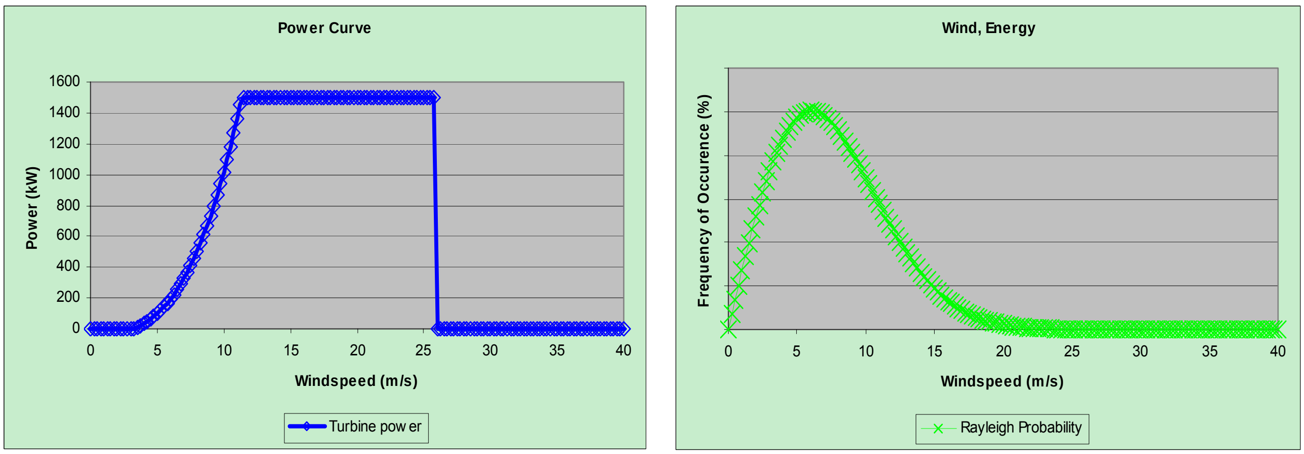
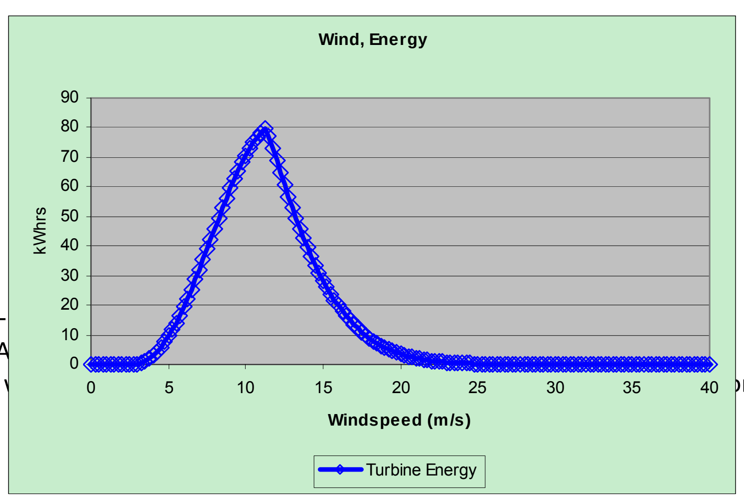


Figure ٤ (a) (b) Power curve method of calculating annual energy output

What may not be stated upfront is that wind speeds of ١٠-٢٥ m/s are necessary to reach a ١,٥٠٠ kW output. The power output of a turbine for wind speeds must be determined specific to a specific site. Wind turbine developers can properly install a turbine that is well-suited for each site.

The product of first two curves will be a curve such as that shown in Figure ٤ (c). By integrating the area under this curve, it is possible to determine the annual energy production. For a more accurate calculation it is necessary to account for both the mechanical and electrical power conversion efficiency, which varies at different turbine power level losses as described in the operating characteristics above, and the projected machine availability.



[٥] Many companies use the jargon 'A

[٦] A subset of a Weibull distribution ... r methodology information.

Figure ٤ (c) Power curve method of calculating annual energy output

Conclusion

Wind turbine technology is in good health: the availability of turbines is ~٩٨%, which means that during ٢% of the time they cannot produce due to maintenance or failures. In general, elementary design rules dictate that the bigger the turbines are to deploy as much as possible.

In United States, the overall potential is vast. Wind power energy has been estimated as one of the country's most abundant energy resources. About one-fourth of the total land area of United States has winds powerful enough to generate electricity as cheaply as natural gas or coal at today's prices. The wind energy potential in all of the top states – North Dakota, Kansas, South Dakota, Montana, and Nebraska – is principle sufficient to provide all the electricity the country's current uses (Table ٢.) In fact, ٢٠% of the land areas in these Midwest and the Rocky Mountain states belong to NREL Class ٤, which are sufficient to make your wind energy business profitable.

However, few of those potential good sites with a high wind speed have been fully developed yet. In what follows, we will point to how wind energy development is likely to be cost-effective. Albeit the one-time investment on turbines is high, the margin cost per output will be relative small. In a certain future, with growing large turbine machine, supporting technologies (HVDC system in next section) and governmental incentive instruments (subsidies and/or tax credits), electricity produced by giant wind turbines in Midwest will be market competitive and become candidate solution to the country's energy independence.

Table ٢ Comparison of wind energy potential vs. installed capacity in selected contiguous states (GWh/year)

Source: *Makhijani, ٢٠٠٧. http://www.ieer.org/carbonfree/ and EPA.*

State	**Wind potential**	**Installed capacity**
North Dakota	١,٢١٠	١٤٦
Kansas	١,٠٧٠	٢٢٧
South Dakota	١,٠٣٠	٩٧
Montana	١,٠٢٠	١
Nebraska	٨٦٨	٣١
Wyoming	٧٤٧	٦٤٣
Oklahoma	٧٢٥	٣٥٣

Transmission Technologies: HVDC

High-voltage direct current (HVDC) systems offer an alternative solution to the problem of electrical transmission, one with strengths not offered by the traditional AC grid system. While DC-based systems are not a new technology—at the advent of the electrical era, Thomas Edison envisioned that they would become the predominant choice—the ability to incorporate them with the existing AC grid is a relatively new development.

In general, transmitting electricity from the generator to the consumer at a higher voltage reduces the amount of power lost in the process. However, there are functional limitations that make transmitting across high-voltage AC lines an ineffective option. HVAC lines lose large amounts of power due to induction, capacitance, the “skin effect” (wherein the current moves to the outside of the cable, forming a “skin” and thus failing to utilize the cable in its entirety), and the ionization of the air around the cable, which draws electrons away from the path of transmission. HVDC, by eliminating the alternating current, eliminates these problems, but introduces a new challenge: switching to an HVDC grid necessitates either the construction of DC generators to replace the AC generators currently in use, or the systematic conversion of AC to DC at the point of transmission. As AC generators are generally understood to be less expensive and easier to maintain than DC generators, the second option is more desirable.

While crude technologies for this sort of conversion existed as early as the ١٩٣٠s, it was not until the ١٩٧٠s that conversion between the AC power emitted from generators and the DC power suitable for high-voltage (and thus low-loss) transmission could be achieved with a great degree of efficacy. The converter station—the keystone of HVDC technology— is generally designed with dual-conversion capability; each can convert AC power to DC (a process called rectification) and DC power to AC (inversion). The device operating at the core of the conversion process is the thyristor, a semiconductor which can only carry current in one direction. The thyristor acts as a sort of “gateway” in the converter, allowing the voltage and the direction of power flow to be controlled remotely.
Most often, thyristors are arranged in a series to form thyristor valves, in a type of system known as natural commutated conversion. This basic system can be improved with the addition of commutation capacitors, which, inserted between the converter transformers and the thyristor valves, increase the accuracy with which the valves “fire” in synchronicity to control the direction and magnitude of power. This kind of system is known as a capacitor commutated converter. A third kind of converter station, the voltage source converter, is built with semiconductors which can turn off or on via remote control almost instantaneously, allowing for an even greater degree of load control, as well as the ability to control active and reactive power independently of one another. This allows the converter station to act as a mechanism to control reactive power, further regulating the voltage of the system.

Thyristor valves are arrayed in groups of six, performing six commutations per period. The number of thyristors that comprises each valve can be varied to produce the desired voltage output. As they are the most fundamental element of the converter station and therefore of HVDC technology, development of new models of thyristor have driven improvements in HVDC technology overall. For instance, photons can be used to trigger their valve action, allowing the development of light-operated thyristors with an ٨٠% reduction in necessary components.

HVDC systems are not flawless; they have important drawbacks to consider. The synchronous pulses that allow the converter station to operate create harmonics which can cause interference with neighboring telecommunications systems, as well as mechanical damage over the long term. Usually, harmonic filtering systems must be installed to counteract the potential for damage. The station itself is susceptible to a high level of load stress, requiring observation and maintenance as it is subjected to wear. However, the most significant disadvantage of an HVDC system is the cost of the converter station, which must be designed and constructed to work in conjunction with the existing generator at a site.

Even with this cost in mind, HVDC can still be a more economical option overall in situations where AC systems are inappropriate or fall short of meeting a demonstrated need. In areas where adjacent regions wishing to share power have networks with different nominal frequencies, HVDC cables are sometimes used to allow power exchange. They can also be used to transmit power underwater, or overhead in cases where AC lines would be too expensive or unsightly—DC lines require only two main conductors, whereas AC lines require three and thus consume more space and materials.

Whether the benefits and drawbacks of an HVDC system make it an efficient option or a wasteful is widely variable based on individual situations; the site of generation and consumption, the path of transmission, the type of power, and the nature of the existing grid can all be factors. However, over long distances, HVDC has proven to be an excellent choice. In addition to stability it adds to the grid, an HVDC system succeeds where as an AC cable would fail, because the latter suffers from greater line losses and the need for intermittent substations to regulate current. Therefore, AC systems can only effectively transmit power a certain distance before becoming ineffective. (See Figure ٧٤.)

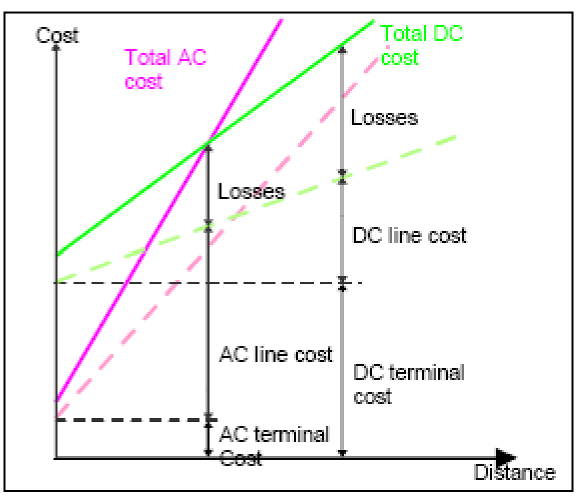


Figure ٧٤

Even after accounting for the costs associated with converter stations, HVDC becomes a more efficient option than AC systems over long distances. The break-even point is generally assumed to be between ٤٠٠ and ٥٠٠ miles *(*Rudervall*)*

Is it Competitive? A Cost Analysis of Wind Energy

Overview of the section:

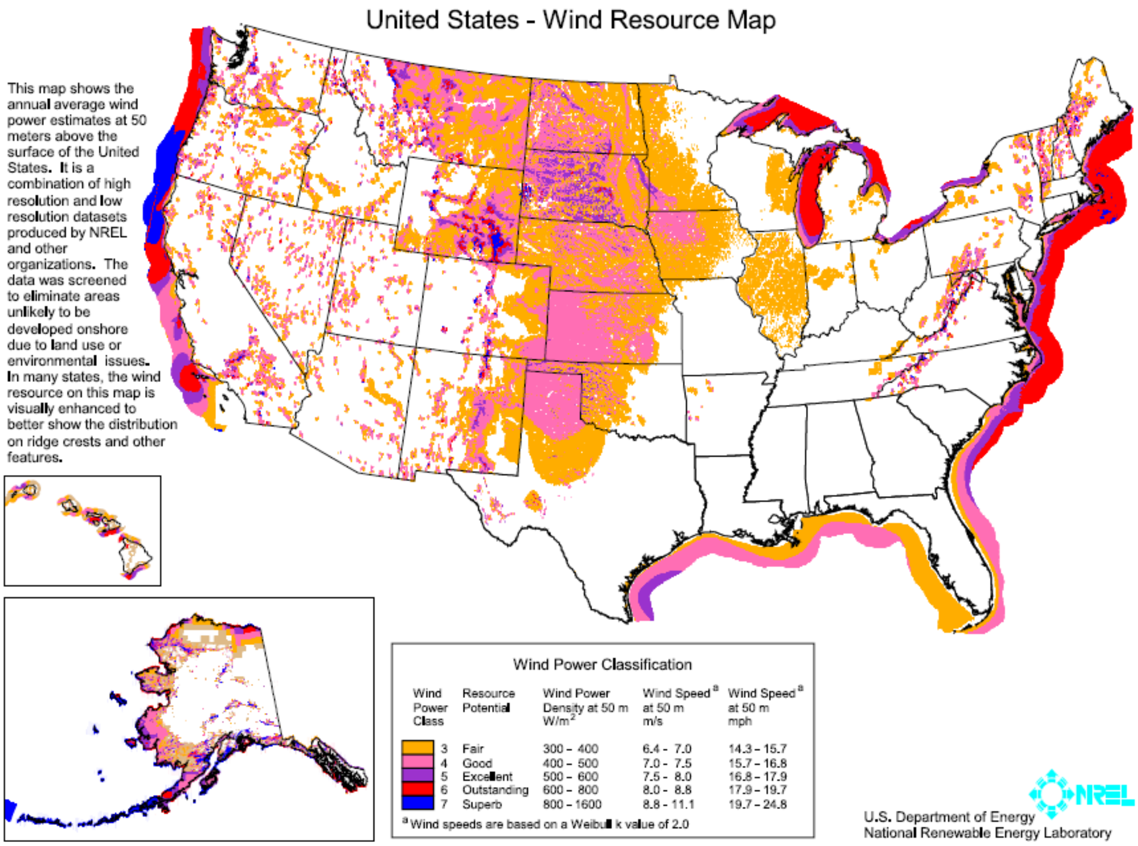
In this section we will discuss the feasibility of wind-based electricity generation in America. We will first address the two primary disadvantages of wind-based electricity generation: availability and variability of resources. We then present two scenarios of the potential market for wind-generated resources in America. The first assumes that wind-generated electricity will compete in the market of the nearest major metropolitan area. The second assumes that wind-generated electricity will take advantage of variation in the price of electricity across states. Specifically, we consider the proposed Frontier Line, an HVDC line that would transmit large amounts of electricity to Western cities from remote generation sites. We then analyze the cost of wind-generated electricity under both scenarios. We find that wind-generated electricity is not competitive in nearby energy markets, but is competitive to service Californian demand. Finally, we consider the impact of two polices would have on the economic viability of wind energy: the Renewable Electricity Producer Tax Credit and a cap-and-trade.

The Availability of Wind Resources

One legitimate drawback to wind-based electricity generation is that the inputs to production are geographically fixed. Unlike fossil fuels or uranium, wind resources cannot be extracted from the earth and transported to demand sites. Instead, they must be converted to electricity at the site where they are found, and the electricity must be transmitted to demand sites.

This limitation is not inherently problematic, because in many scenarios wind resources are very close to demand sites. Denmark, for example, receives a large proportion of their energy from offshore winds that are quite close to demand sites. The U.S. also has abundant offshore wind resources, and with ٥٣% of the US Population living in a coastal county (Crosset ٢٠٠٤), many electricity demand sites have a large potential supply of wind-generated electricity nearby.

The map below is published by the National Renewable Energy Laboratory (NREL), a facility operated by the U.S. Department of Energy. It illustrates the availability of wind resources at different wind power classes (WPCs). Current technology limits wind-based electricity generation to WPCs of ٤ and above, which roughly corresponds to winds average speeds greater than ١٢.٥ mph. These correspond to the pink, purple, red, and blue areas on the map below.



Source: NREL

In the above map, offshore wind resources stand out as exemplary. However, our analysis will focus exclusively on terrestrial wind resources. Unfortunately, terrestrial wind resources are concentrated in the Great Plains, far from electricity demand sites. To access such markets, electricity must be transmitted substantial distances.

The remoteness of wind resources adds to the cost of wind-generated electricity in two ways: ١) it necessitates large capital investments in transmission lines; and ٢) it increases the size of transmission losses. However, the extent of these costs are poorly understood. Our cost analyses will consider these costs, and their effect on the commercial viability of wind energy.

Scenario A: Transmission to Local Electricity Markets

Our first scenario estimates the cost of wind-generated electricity delivered to the nearest electricity demand site. Due to the particularly remote location of terrestrial wind resources, we hypothesized that transmission costs would form a significant portion of overall electricity costs, and thus attempted to minimize transmission costs by calculating the shortest distance from each wind resource site to the nearest electricity demand site.

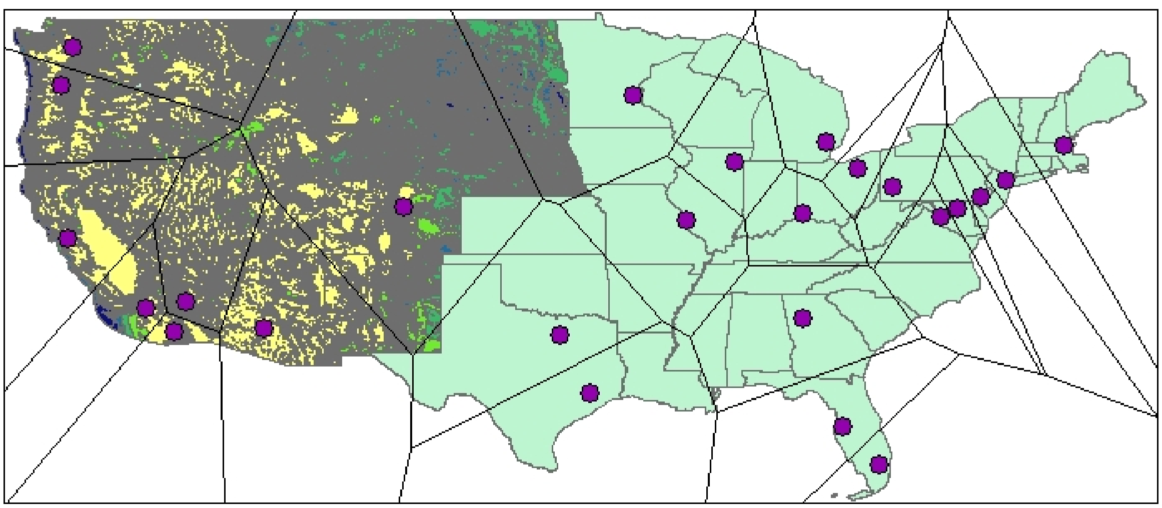
Wind resource site data was made available by NREL in the form of GIS (Geographic Information System) files. These files contain the Wind Power Class data for each square kilometer of land in the Western states. Because NREL's wind resource database is still being built, data files were unavailable for many states of interest, including

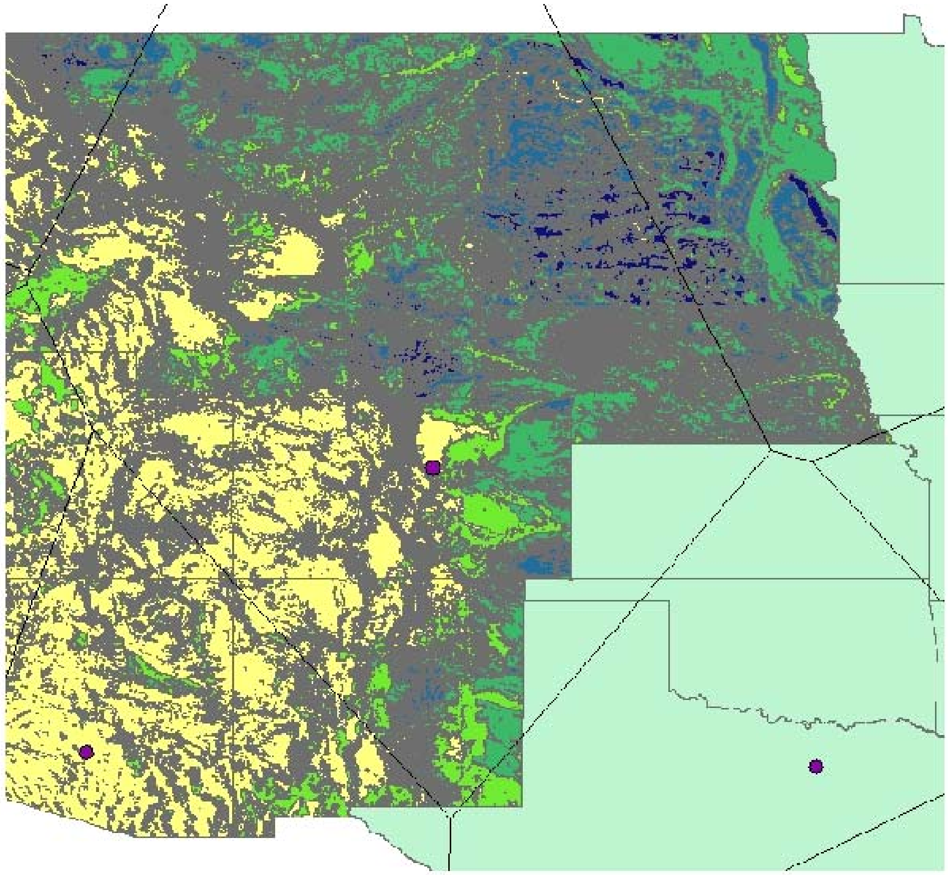
Minnesota, Iowa, Kansas, Oklahoma, and Texas. However, many of the states with the best wind resources were made available for analysis. These included North and South Dakota, Nebraska, Montana, Wyoming, and Colorado.

Electricity demand sites were selected as the top ٢٥ Metropolitan Statistical Areas, according to the ٢٠٠٧ estimates by the U.S. Census Bureau. The absence of city-level electricity consumption data makes it impossible to verify if population rank matches up with electricity consumption rank. However, we can be confident that each of the ٢٥ most populated MSA consume a large amount of electricity, and are therefore potential markets for remote wind-generated electricity.

Procedurally, we used ArcGIS software to calculate the centroid of each MSA. We then created a map layer of Thiessen polygons, polygons that contain exactly one MSA and all the points nearest to that MSA. All wind resources sites falling within a particular Thiessen polygon would transmit electricity to the MSA within the polygon, because that is the nearest major electricity demand site.

The two graphics below display the results of this analysis. The first show the Thiessen polygon projection for the top ٢٥ MSA in America. It is apparent from this projection that Denver, Colorado is the nearest MSA for the majority of suitable wind sites. We thus show a larger image of the Denver polygon.

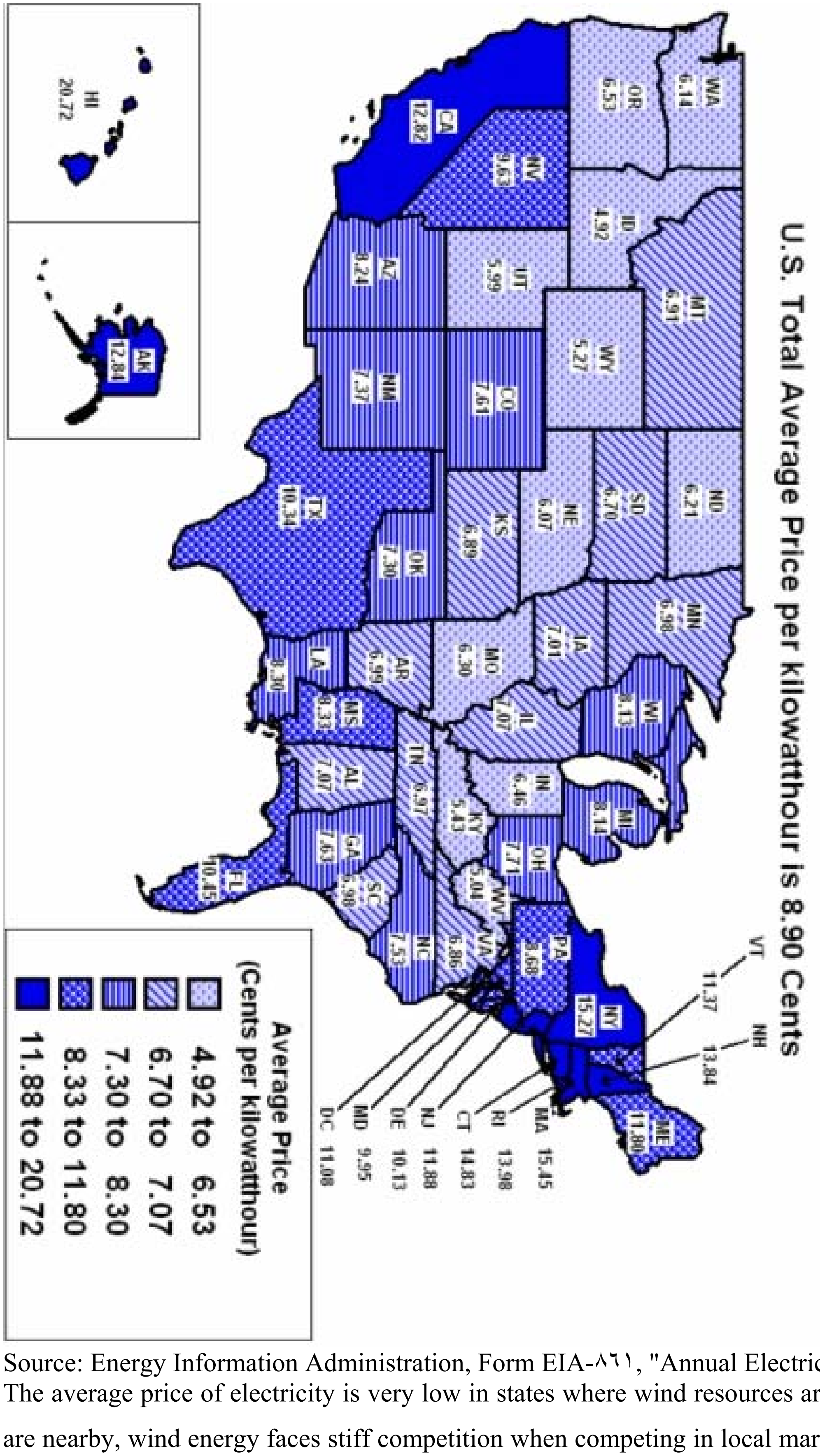




The Thiessen polygons allow us to determine the maximum distance from a wind resource site to the nearest MSA. For each MSA, the straight-line distance to the border of the Thiessen polygon is the longest distance wind-generated electricity would need to travel to reach a major consumption site. For Denver, ٥٠٠ miles is the maximum straight-line distance electricity would need to travel to reach a consumption site. Over these distances, an HVAC line is more competitive than an HVDC line. Therefore, we will use HVAC grid estimates in our cost analysis of this scenario.

Scenario B: Exploiting Price Variation

Our second scenario predicts that wind-generated electricity will be transmitted to consumption sites where it can exploit variation in prices. Electricity prices vary considerably across states, as is evident from the map on the following page of average ٢٠٠٦ prices:



Source: Energy Information Administration, Form EIA-٨٦١, "Annual Electric Power Industry Report." ٢٠٠٨.

The average price of electricity is very low in states where wind resources are sited. Thus, although these markets are nearby, wind energy faces stiff competition when competing in local markets (Wyoming, a state with abundant wind resources, had the third lowest average price of any state in ٢٠٠٦, at just ٥.٢٧ cents/kWh). However, a long-distance transmission line could carry wind-generated electricity to higher-price markets where it might prove more competitive. At ١٢.٨٢ cents/kWh, the Californian electricity market looks particularly appealing. Such a project would require transmission beyond the ٥٠٠ mile break-even point between HVAC and HVDC, leading policymakers to favor the use of an HVDC line.

In fact, proposals to build a long-distance HVDC transmission line are currently being heard. Western governors have formed a task group to research many transmission investments, including the Frontier Line, a high-voltage transmission line that would connect Wyoming energy supply to California loads. With energy demand increasing at ٢% a year, California must add ١,٠٠٠ MW of electric capacity every year to keep prices constant (WRTEP ٢٠٠٧). Apart from needing additional electricity, California also favors renewable energy. In ٢٠٠٢ the state established the Renewable Portfolio Standard Program, marking a commitment to achieve ٢٠% of electricity from renewable sources by ٢٠١٧. With just ١٠.٩% of electricity coming from renewables (EIA ٢٠٠٧a), there is significant room for expansion to meet this commitment. California is therefore an eager market for Wyoming wind-generated electricity.

The Frontier Line would address the two major disadvantages of wind energy. For one, an HVDC line minimizes transmission costs, thus addressing the issue of wind resource availability. Secondly, the Frontier Line is well-positioned to weather wind resource variability due to it's origin in Wyoming. Not only does Wyoming have abundant wind resources; it also houses the nation's largest supply of coal. When the wind is not blowing, coal plants can generate electricity to keep the transmitted supply constant at ١٠٠% of line capacity. Thus, wind-based electricity generation can be backed up by coal-based generation, in much the same way that the Danish wind energy system decreases variability by relying on the German coal-fired grid. Therefore, the Frontier Line may avoid the two major pitfalls of wind energy, availability and variability of wind resources.

Cost Analysis

We turn now to considerations of cost. Through our cost analysis we will determine the economic viability of wind power under our two scenarios. The cost analysis is organized as follows: Section ١ will cover assumptions concerning wind farm costs and output. Section ٢ addresses our assumptions about financing the transmission line in Scenarios A and B. Section ٣ presents a Cost Spreadsheet using the previously-described assumptions. After analyzing the findings of this spreadsheet, we compare wind-generated electricity costs to market electricity costs for both scenarios, thus forming our initial conclusion of the economic viability of wind energy. In Sections ٤ we consider variations in the policy environment, and the effect of such variations on our initial conclusion. Section ٥ concludes.

Section ١: Wind Farm Assumptions

Our analysis requires many assumptions, with the justifications from authoritative sources. The next two sections provide the logic behind our assumptions.

PROJECT SIZE: We assume the creation of a wind farm with ٣GW of generation capability. There are many sites in our data set with developable wind resources on this scale. Such a site would require ٢,٠٠٠ ١.٥MW Turbines, each requiring about ٩٠ acres, for a total land requirement of ١٨٠,٠٠٠ acres (or ٧٣٠ km٢) (source AWEA ٢٠٠٧).

PROJECT SITE: Project siting could occur at many locations in the interior US. However, Scenario B requires a site with adequate wind resources and nearby coal resources, to serve as back-up capacity for wind generation and so ensure that the Frontier Line remains at capacity. This leads us to choose the Hanna Basin in Carbon County, Wyoming as our wind farm location for Scenario B. To remain consistent, we use the same site for Scenario A.

CAPACITY FACTOR: The capacity factor of a wind farm refers to the percent of theoretical energy output that the wind farm in fact produces. This is dependent on a number of variables – turbine design, project siting, and weather – and so is difficult to predict with a great degree of certainty. We therefore follow the assumptions put out by Ryan Wiser and Mark Bolinger of Lawrence Berkeley National Laboratory, who calculated the average wind capacity in Mountain region wind farms to be ٤١% (Wiser and Bolinger ٢٠٠٧).

INSTALLED CAPITAL COSTS: Our assumption for initial costs of installed capital come from a recent large wind turbine deal. On May ١٥, ٢٠٠٨ Mesa Power LLP signed a $٢ Billion with GE to produce ٦٦٧ ١.٥ MW turbines. The proposed wind farm would therefore have a generating capacity of ١,٠٠٠ MW, leading to a ratio of $٢ Million/MW installed capacity. This ratio is higher than many estimates (Wiser and Bolinger ٢٠٠٧); we therefore consider it an upper-bound on installed capital costs. We do not anticipate economies of scale beyond ١,٠٠٠MW, and therefore assume this ratio to hold for a ٣,٠٠٠ MW wind farm.

PROJECT FINANCING: We assume a ٣٠-year mortgage agreement with annual payments and ٧% interest.

LAND COSTS: We require ١٨٠,٠٠٠ acres of Wyoming land to achieve a generation capacity of ٣,٠٠٠ MW. However, installed capital will only occupy a small portion of this land. Turbines, electrical facilities, and service roads average between ٠.٢٥ and ٠.٥ acres per turbine (NREL ٢٠٠٦). Taking the higher of these two estimates, we anticipate land needs of just ١,٠٠٠ acres. We then calculate the costs of purchasing this land. This oversimplifies the land negotiations for a large wind farm project; however, because farmland in Carbon County, Wyoming sells at less than $٢٠٠/acre, additional land expenditures will not significantly affect project viability. Property taxes are also negligible in the state of Wyoming.

GRID INTEGRATION COSTS: Due to its variable nature, wind places an extra burden on the grid. When the wind is not blowing (or is not blowing sufficiently strongly), other sources must generate additional electricity to ensure that demand for electricity does not outstrip supply. Therefore, extra electricity-generating capacity must be installed. In our case, the extra capacity will consist of mine-mouth coal plants that will share a high-voltage transmission line with the wind farm. The amount of extra capacity is determined by a number of factors – the capacity factor of the wind farm, the exposure of the destination market to wind power, the flexibility of the destination market, the presence of a smart grid, etc. We assume in our analysis that grid integration costs require an add-on of $٠.٠٠٦٢/kWh, the upper-bound of recent estimates (VTT ٢٠٠٧).

OPERATION AND MANAGEMENT COSTS: Operation and Management Costs are relatively small for a wind farm. We use the inflation-adjusted estimates of Wiser and Kahn, amounting to an add-on of $٠.٠٠٨٩/kWh (Wiser and Kahn ١٩٩٦).

INSURANCE COSTS: We similarly use Wiser and Kahn's estimates for property insurance, which are calculated as a percentage (٠.٠٠١٥%) of installed capital costs. This amounts to an add-on of less than nine-hundredths of a penny per kilowatt hour (Wiser and Kahn ١٩٩٦).

INFLATION: To get cost estimates in ٢٠٠٨ dollars, we adjust many of our figures for inflation. For all figures older than ٢٠٠٦, we assume that inflation matched CPI growth. We adjust ٢٠٠٦ figures according to recent CPI information specific to the electricity industry. Electricity prices grew at a year-over-year rate of ٥% in the ١٢ months prior to May ٢٠٠٨. Assuming that this trend held for the ١٧ months since December ٢٠٠٦, we adjust all ٢٠٠٦ figures with a ٧.٥% inflation rate.

Section ٢: Transmission Line Assumptions

SCENARIO A: We first consider moving electricity from wind resource sites to the nearest major metropolitan area. From our project site at the Hanna Basin Mine in Carbon County, Wyoming the nearest demand site is Denver, just ١٥٠ miles away. This distance makes HVAC transmission optimal. To model the costs of this line, we utilize the assumptions of the Western Regional Transmission Expansion Partnership for a similar-length HVAC line between Mona, Utah and Northeastern Nevada. This line had an estimated cost of $١ Billion.

Operation and Management fees are included in the initial estimate. Line losses are assumed to be ١٠% over the course of the line.

SCENARIO B: We next consider moving electricity from the Hanna Basin Mine in Carbon County, Wyoming to Los Angeles. This transmission line, spanning ٩٦٠ miles, has been modeled by ABB Grid Systems. Station costs of $٤٢٠ Million are added to transmission line costs of $١,٨٠٠,٠٠٠ per mile, leading to a project total of $٢.١ Billion. Operation and Management fees are calculated as a percentage of the total one-time grid payment. Line losses are estimated at ٨% over the course of the line (Bahrman ٢٠٠٦).

Section ٣: Cost Analysis and Interpretation

Given the above assumptions, we are able to perform the calculations found on the following page. These calculations lead to an estimate of the average total cost per kWh for wind-generated electricity (the standard pricing unit in the electricity industry). We find that in Scenario A, where wind energy is used to service local electricity demand, the average total cost is $٠.٠٧٤٥/kWh. In Scenario B, where wind-generated electricity is transported to distant loads, the average total cost is $٠.٠٨٢٥/kWh.

Wind Farm Costs

Capital Costs

Turbine Costs: Dollars/kW Generation Capacity	٢,٠٠٠
Targeted Generation Capacity (kW)	٣,٠٠٠,٠٠٠
Turbine Costs	$٦,٠٠٠,٠٠٠,٠٠٠
Land Costs: Dollars/Acre	٢٠٠
Acres needed	١٠٠٠
Land Cost	$٢٠٠,٠٠٠
One-Time Capital Costs	$٦,٠٠٠,٢٠٠,٠٠٠
Annual Capital Payment, ٣٠-year loan with ٧% interest	$٤٨٣,٥٣٤,٥٣٨

Variable Costs

Operation and Management	$٨٨,٢٢٤,٠٦٢
Insurance	$٩,٠١٦,٠٢٠

Grid Integration Costs		$٦١,٤٥٩,٤٥٩
Total Variable Costs		$١٥٨,٦٩٩,٥٤٢
Total Annual Generation Costs		$٦٤٢,٢٣٤,٠٨٠
	A	**B**
Grid Costs		
Distance (miles)	١٥٠	٩٦٠
Cost of Transmission Line, $/mile	Unavailable	$١,٨٠٠,٠٠٠
Transmission Line Cost	Unavailable	$١,٧٢٨,٤٣٩,٦١٠
Total One-time Cost	$١,٠٠٠,٠٠٠,٠٠٠	$٢,١٤٨,٤٣٩,٦١٠
Annual Grid Payment	$٨٠,٥٨٦,٤٠٤	$١٧٣,١٣٥,٠٢١
Operation and Management, Yearly	Unavailable	$١,٤٥٦,٥٦٩
Yearly Grid Cost	$٨٠,٥٨٦,٤٠٤	$١٧٤,٥٩١,٥٩١
Annual Payments, All Fixed Costs	$٥٦٤,١٢٠,٩٤٢	$٦٥٨,١٢٦,١٢٩
Total Annual Costs	$٧٢٢,٨٢٠,٤٨٣	$٨١٦,٨٢٥,٦٧١
Expected Electricity Generation		
Generation Capacity (kW)	٣,٠٠٠,٠٠٠	٣,٠٠٠,٠٠٠
Capacity Factor	٤١%	٤١%
Line Losses	١٠%	٨%
Total Electricity Generation (kWh/year)	٩,٦٩٧,٣٢٠,٠٠٠	٩,٩١٢,٨١٦,٠٠٠
Average Generation Cost ($/kWh)	$٠.٠٦٦٢	$٠.٠٦٤٨
Average Transmission Cost ($/kWh)	$٠.٠٠٨٣	$٠.٠١٧٥
Average Total Cost ($/kWh)	$٠.٠٧٤٥	$٠.٠٨٢٤

To draw conclusions about the competitiveness of wind energy under each scenario, we must compare the average total cost to market prices. However, we must include a delivery charge to calculate the average total cost of electricity service. The average national delivery charge in ٢٠٠٦ amounted to $٠.٠٣٢١/kWh (EIA ٢٠٠٧b), or $٠.٠٣٤٥/kWh after adjusting for inflation. Adding this delivery cost to both outcomes, we find the average cost of electrical services to be $٠.١٠٩١/kWh in Scenario A and $٠.١١٦٩/kWh in Scenario B.

We are now prepared to consider the economic viability of both scenarios. In Scenario A, wind-generated electricity would compete in the Denver electricity market. Because no city-level data is available, we assume that Denver prices match average electricity prices across Colorado. This price is $٠.٠٨١٨/kWh after adjusting for inflation (EIA ٢٠٠٧c). At $٠.١٠٩١/kWh, wind-generated electricity is significantly more expensive. And while it is in the nature of averages to have some figures above and other figures below, a newly-installed electricity generating facility ought to be below the average cost, so that it can continue to compete as its technology becomes outdated. Therefore, wind-generated electricity is too costly to compete in the Denver electricity market, making Scenario A as economically infeasible.

In Scenario B, wind-generated electricity would compete in the Los Angeles electricity market. Again, assuming city-level prices to reflect state-level data, the observed market price for electricity is $٠.١٣٧٩/kWh (EIA ٢٠٠٧c). At $٠.١١٦٩/kWh, wind-generated electricity is competitive in the far-away Los Angeles market. Due to variations in average electricity prices across states, wind energy in Wyoming is economically viable in distant Californian markets.

Section ٤: Policy Variables

In this section we will consider the effect of policy variables on the economic viability of wind energy in local and distant markets. Specifically, we will consider the effect of the Producer Tax Credit within our model, and the potential effect of a cap-and-trade scheme for Carbon emissions.

The Producer Tax Credit

Our original model assumed a neutral policy stance with respect to wind energy. By using this approach, we observe that wind energy is viable in Scenario B even without the Producer Tax Credit (PTC). However, utilizing this credit might drive down the costs of wind-generated electricity, further increasing competitiveness and potentially opening up new markets. Therefore, we now consider the effect of the Producer Tax Credit.

The Renewable Electricity Producer Tax Credit (PTC) provides a ٢ cents/kWh tax credit to all wind farm projects. Though still not as large as tax credits for coal, oil, and natural gas, the PTC could significantly boost the profitability of wind energy. Unfortunately, the PTC is largely inaccessible to wind energy producers. Because it is a tax credit rather than a direct subsidy, the PTC is only worthwhile when companies have tax liabilities that they wish to eliminate. Corporate tax liabilities would occur when companies are generating profits. However, due to the high capital costs of wind farms, producers are not profitable until after their ٣٠-year loans are repaid. And because the PTC only lasts for ١٠ years, it cannot be accessed by wind energy producers. Thus, this policy is largely ineffectual at increasing the competitiveness of wind-generated electricity.

However, because these tax credits are so massive (over $١٨٠ million annually for our ٣GW project), creative producers will find clever ways to capture them. The simplest (and perhaps most common) method of utilizing the PTC is for producers to apply the tax credits to separate sources of profit. For example, a large ranching firm might decide to build a wind farm on a portion of their land (turbines and cows coexist quite well). The firm can then use the tax credits acquired from selling wind energy and apply them to their ranching income, which unlike the wind farm presents taxable near-term profits. This arrangement has the potential to create some odd bedfellows in the wind energy industry.

Overall, the Producer Tax Credit is poorly designed to increase the competitiveness of wind-generated electricity. Tax credits in general are ineffective tools for bringing new technologies to market, because they presume that the technology is already in the market and earning a taxable profit. A number of reforms could replace the PTC with a federal incentive that did increase the competitiveness of wind-generated electricity, the simplest of which would be a direct subsidy. We will next consider an indirect route to increasing the competitiveness of wind energy: a cap-and trade policy for carbon emissions.

Cap-and-Trade

The current policy environment could not be more favorable to a cap-and-trade system for carbon emissions. With all three major Presidential candidates advocating a cap-and-trade policy, carbon emissions will likely pose a financial liability in the near future. Such an outcome is particularly favorable to non-emitting sources of energy, including wind energy. Because operation costs for its competitors will rise, wind-generated electricity may become economically viable in new markets.

To analyze the impact of a cap-and-trade system, we assume that the price of carbon in America will be $٤٠/ton of carbon, a number derived from European prices (current as of June ١ ٢٠٠٨). We then look at annual carbon emissions in California and Colorado, focusing on the largest electricity source.

In California, the largest electricity source is natural gas, with ٤١.٥% of the market. Natural gas plants emit ٥١,٦٢٠,٠٠٠ metric tons of carbon annually. Multiplying this figure by the cost of carbon and dividing by industry output, we find that a cap-and-trade system would lead to a $٠.٠٢/kWh add-on to gas-generated electricity prices in

California. Assuming that gas-generated electricity prices are equal to average electricity prices, we find the new average price of electricity to be $٠.١٥٧٩/kWh. At $٠.١١٦٩/kWh, wind-generated electricity is significantly cheaper.

In Colorado, the largest electricity source is coal, with ٧١.٥% market share. Colorado coal plants emit ٣٦,٢٦٩,٤٢٥,٠٠٠ tons of carbon every year – a startlingly-high figure. Under a cap-and-trade system, these emissions would be priced at $٤٠/tonC, requiring $١.٤ billion in credit purchases. Averaged over output, this leads to a $٠.٠٤/kWh increase in the cost of coal-generated electricity. This would raise the average price of electricity to $٠.١٢١٨/kWh, well above the average cost of wind-generated electricity ($٠.١٠٩١/kWh). Therefore, under a cap-and-trade scheme wind energy is economically viable in the Denver market. Scenario A, in which wind-generated electricity was transported to local demand sites, is viable in the presence of cap-and-trade.

Section ٥: Conclusion

Our cost analysis shows that wind-generated electricity is competitive under a variety of scenarios. Under our current policy environment, we find that wind-generated electricity is not competitive in local markets, but is competitive when transmitted to distant markets to exploit regional price variations. If a cap-and-trade system were adopted, we predict that wind-generated electricity would be competitive in both near and distant markets.

<u>Works Cited</u>

ABB, "ABB HVDC," <http://www.abb.co.uk/industries/us/٩AAC٧٥١٠٦٨.aspx>.

AWEA (American Wind Energy Association) ٢٠٠٧. "Wind Web Tutorial" <http://www.awea.org/faq/wwt_environment.html#How%٢٠much%٢٠land%٢٠is%٢٠needed%٢٠for%٢٠a%٢٠utility-scale%٢٠wind%٢٠plant>.

Bahrman, Michael, ABB Grid Systems ٢٠٠٦. "Economics of Mine-Mouth Generations with HVDC Transmission Relative to Coal Transport".

Bahrman, Michael and Brian K. Johnson ٢٠٠٧. "The ABCs of HVDC Transmission Technology." *IEEE Power & Energy Magazine* March/April ٢٠٠٧ Vol. ٥ No. ٢

BTM Consult. ٢٠٠٥. "١٠ Years Review of the Wind Power Industry Forecast and scenarios ٢٠٠٥ through ٢٠٢٥."

Crosset et. al ٢٠٠٤. "Population Trends along the Coastal United States: ١٩٨٠-٢٠٠٨." <http://oceanservice.noaa.gov/programs/mb/pdfs/coastal_pop_trends_complete.pdf>.

DOE ٢٠٠٧. "Wind Energy Multiyear Program Plan For ٢٠٠٧–٢٠١٢."

DOE ٢٠٠٨. "Annual Report on U.S. Wind Power Installation, Cost, and Performance."

EIA (Energy Information Administration) ٢٠٠٧a. "Table ٥. Electric Power Industry Generation by Primary Energy Source, ١٩٩٠ Through ٢٠٠٦." *California Electricity Profile*. <http://www.eia.doe.gov/cneaf/electricity/st_profiles/california.html>.

EIA ٢٠٠٧b. "Table ٧.٤. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, ١٩٩٥ through ٢٠٠٦ (Cents per kilowatt-hour)." *Annual Electric Power Industry Report.* <http://www.eia.doe.gov/cneaf/electricity/epa/epat٧p٤.html>.

EIA ٢٠٠٧c. "State Electricity Profiles ٢٠٠٦ Edition". DOE/EIA-٠٣٤٨. <http://www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html>.

Ek, Kristina ٢٠٠٦. "Quantifying the environmental impacts of renewable energy: the case of Swedish wind power," "Environmental Valuation in Developed Countries," Endward Elgar Publishing Limited

Energy Information Administration, Form EIA-٨٦١, "Annual Electric Power Industry Report." ٢٠٠٨.

European Commission . ١٩٩٧. " Energy for the future: Renewable sources of energy – White Paper for a Community strategy and action plan." <http://europa.eu/documents/comm/white_papers/>.

EWEA. ٢٠٠٦. "EWEA ٢٠٠٦ Annual Report." <http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/>.

Gijs van Kuik, Bart Ummels, Ralph Hendriks, Kluyverweg. ٢٠٠٦. "Perspectives of Wind Energy". IUC Conference in Dubrovnik: Advances in New and Sustainable Energy Conversion and Storage Technologies.

Gipe, Paul. ٢٠٠٤. "Wind Power: Renewable Energy for Homes, Farms and Business".

Keith, David et al. ٢٠٠٥. Presentation of "NREL Site Visit Overview". <http://cdmc.epp.cmu.edu/SEMINARS.htm>

Makhijani, Arjun. ٢٠٠٧. "Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy" < http://www.ieer.org/carbonfree/>.

NREL. See http://www.nrel.gov/.

NREL ٢٠٠٤. "Model State Implementation Plan."

NREL (National Renewable Energy Laboratory) ٢٠٠٦, "Wind Farm Area Calculator", *Power Technologies Energy Data Book.* <http://www.nrel.gov/analysis/power_databook/calc_wind.php>.

NREL ٢٠٠٨. "Wind Energy and Air Emission Reduction Benefits: A Primer."

ODPM. ٢٠٠٤. "Planning for Renewable Energy – a companion guide to PPS٢٢." <http://www.communities.gov.uk/publications/planningandbuilding/planningrenewable>

Rudervall, Roberto et. al. "High Voltage Direct Current (HVDC) Transmission Systems

Technology Review Paper" World Bank Technology Series, <http://www.worldbank.org/html/fpd/em/transmission/technology_abb.pdf>.

Sesto, Ezio, Lipman, Norman H. ١٩٩٢. "Wind energy in Europe". Wind Engineering.Vol.١٦, no. ١.

Siemens, Inc. "High Voltage Direct Current Transmission: The Proven Technology for Power Exchange."

Szarka, Joseph. ٢٠٠٧. “Wind Power in Europe.”

VTT ٢٠٠٧, “Design and Operation of Power Systems with Large Amounts of Power”. <http://www.vtt.fi/inf/pdf/workingpapers/٢٠٠٧/W٨٢.pdf>. Page ٣.

WRTEP (Western Regional Transmission Expansion Partnership) ٢٠٠٧. “The Frontier Line Feasibility Study” <http://www.ftloutreach.com/>.

Wiser, Mark and Mark Bolinger ٢٠٠٧. “Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: ٢٠٠٦.” <http://www.nrel.gov/docs/fy٠٧osti/٤١٤٣٥.pdf>. Pages ١٥-١٨

Wiser, Ryan and Edward Kahn ١٩٩٦. “Alternative Wind Power Ownership Structures: Financing Terms and Project Costs.” <http://eetd.lbl.gov/EA/EMP/reports/٣٨٩٢١.pdf>.

Wizelius, Tore. ٢٠٠٧. "Developing Wind Power Projects: Theory and Practice"

APPENDIX TO

Wind Energy: A Thorough Examination of Economic Viability

Energy and Energy Policy

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Appendix Explanation

During our research we have ran into many policies and examples of Wind Power and/or energy transmission obstacles. Since not all of these can be directly used in our research paper, the appendix is an additional source of information one may want to know about the subject.

Overview of the Problematic and Challenges

Wind Power Energy has become more and more popular to the investors, government, and general public since the ١٩٧٠s. The awakening of higher investments in wind energy was caused by growing need for energy security. There are, however, numerous problems and challenges, both short and long term, with developing wind power generation.

The U.S. Department of Energy identifies several key challenges in wind power energy development: risk perception, the transmission and grid limits, the low competitiveness of wind energy, low speed wind location usage, lack of infrastructure for transmission, regulatory policy, environmental policy, environmentalists, and general public opinion (DOE ٢٠٠٧, ٨, ١٨).

Risk perception is a challenge since wind energy is perceived risky since it depends on the presence of wind. For example, globally agriculture too depends on whether (rain and sunny days), but for agriculture we have a long history and large data sample from which to estimate the risk. Even though the technology for installing wind energy at better locations is cost efficient compared to other technologies, the market has a high risk perception of the availability of new technologies (DOE ٢٠٠٧, ٨, ١٩).

Transmission channels operate under strict regulations and operational policies. These transmission restraints and the lack of knowledge of wind generated energy's impact on the grid suspend wind energy development (DOE ٢٠٠٧, ٨, ١٩). Therefore, developing wind energy without the development and research of transmission is inefficient.

The wind energy itself is still costly. The cost of wind energy is competitive to the latest conventional[٧] technologies; nonetheless, the system cost of wind energy's technical development is still too high (DOE ٢٠٠٧, ٨, ١٩). Reduction of these costs will enable the wind energy to be used at an even more competitive rate.

[٧] Conventional refers to all non-renewable energy resources, primarily: Coal, Natural Gas, and Nuclear

The low speed wind locations are economically not as risk-safe as high speed wind locations due to perception of higher wind location yielding more energy than lower wind location. Nonetheless, they too are a resource and while the excellent wind locations are being used and attached to grids there is a need to prepare cost-effective access to low wind generating areas (DOE ٢٠٠٧, ٨, ١٩).

The existing transmission network is limited (DOE ٢٠٠٧, ٨, ١٩). The network needs to be expanded to reach out to the distant locations at which often renewable energy resources are located.

The regulatory agency has set up regulations previously adjusted to non-renewable energy resources and now they need to be adjusted for the renewable energy sources. The regulatory energy approvals are confound to unclear predispositions; even more so, the separate regulatory procedures exist across local, state, and federal levels increasing costs of wind energy farm installation(DOE ٢٠٠٧, ٨, ١٩).

One can therefore conclude that Wind energy and Transmission development are closely related. The fall in cost of wind energy yields only a limited result if such energy may not reach its consumers cost-efficiently (DOE ٢٠٠٧, ٤٤). Transmission development is encouraged by Wind Power Energy growth which cannot develop without cost-efficient transmission. Developing domestic Energy production will ultimately help "secure [the US] energy economy" (DOE ٢٠٠٧, ٢٢).

Governmental incentives and programs

There are multiple incentives, monetary and logistical, that government provides to foster growth of Wind Power Energy development: research, development, and deployment co-operation (RD&D), production tax-credit (PTC), Wind Energy Program (WEP), Wind Powering America (WPA), Distributed Wind Technologies (DWT), Energy Policy Act ٢٠٠٥ (EPA), Energy and Policy Conservation Act (EPCA), Federal Energy Management Program (FEMP), Renewable Portfolio Standards (RPS), Advanced Energy Initiative (AEI), Advanced Wind Turbine Program (AWTP), and Clean Renewable Energy Bonds (CREB).

The RD&D programs are fostered to develop new technologies in a manner that would help investors manage Wind Power farms that are economically feasible. This is achieved by conducting research that reduces the technology cost (DOE ٢٠٠٧, ٢٢). The Department of Energy aims to also conduct basic research in high-risk energy sources in order to long term make them more attractive to investors (DOE ٢٠٠٧, ٢٣). Therefore what would be fixed preliminary costs in research for Wind Power investors is now conducted by the governmental agency, resulting in lower cost of research; more so, companies can now re-allocate research money for more concrete research. Any such governmental research is the public access of that information, reduces competitive advantage of investors in Wind Power.

Some research requires high risk heavy capital investment where in current government needs to step in the market economy. There are turbine testing projects that require such facilities and infrastructure (DOE ٢٠٠٧, ٢٣). The program helps the government develop data to estimate national standard parameters while reducing the commercial risk for investors (DOE ٢٠٠٧, ٢٣). Such projects are usually run either by the Federal agencies or in public-private partnerships (DOE ٢٠٠٧, ٢٣). Since the project has benefits for the government and significantly reduces risk of sink cost in preliminary research for investors, the public-private testing projects may be economically justified.

WEP is part of the Wind and Hydropower Technologies Program, and concentrates on research that would develop the reliability of Wind technology, cost-efficiency of Wind Production, and small-scale wind technology to ultimately show the feasibility of investing in wind (DOE ٢٠٠٧, ١١). Aware of importance of the grid to Wind energy distribution, WEP also concentrates on researching the challenges behind the integration of the power grid, transmission and technological compatibility with energy from Wind production farms (DOE ٢٠٠٧, ١٢). There are four main sub programs of WEP. One program is a technological Viability research of large-scale wind turbines: Large Wind Technologies (LWT) (DOE ٢٠٠٧, ٣٣). Second program addresses the research of "smaller distributed wind technology" (٣٣). Third program conducts technology application research addressing the research in transmission and system integration (SI) (٣٣). Fourth program is technology acceptance seeks the outreach activities with different groups such as state-based organizations, environmental studies, and utility partnerships (٣٣). Ultimately WEP explores solutions to natural variability of Wind energy production, the interconnection of such volatile energy source with the grid, and transmission of the energy to appropriate load centers (٣١).

The LWT in addition to mentioned activities specifically works on low wind speed technologies as well as the off-shore wind turbines (٣٤). The strong wind areas are becoming more interesting, yet the low wind speed areas are actually also usable yet more research needs to be conducted. DWT also examines low speed areas but that is because the research in DWT examines possibilities of local usage of Wind Turbines that would release burden on the grid (٦٩). By local one means schools, farms, factories, and general public and private facilities (٦٩). Also DWT can help some secluded, isolated, remote, and/or rural areas (٣٥, ٥١, ٦٩). The research of energy supply in remote areas on small scale can save huge costs of developing a power line to the national transmission grid. On the other hand, developing small scale remote wind power generators can have immense costs; after all, ١MW turbine has an approximate cost of ١ million dollars. System integration part of WEP serves mostly the government through collecting data from wind farms, analyses the grid operations, develops grid regulations, and plans transmission and grids (٣٤). Through SI, researches are encouraging transmission industries to have more wind power clean energy passing through the power lines to final consumer, the federal and states' officials to implement more policies favoring this action by transmission firms (٨٦). A mentioned previously the perception of high risk is a 'red light' in wind energy, and SI works on educating the energy industry of real state of development of wind energy.

The WPA project that started in ١٩٩٩ concentrated on the 'America' aspect: the project encouraged a higher federal involvement to encourage national not just regional development (١٧). Prior to the program California and Minnesota were most advanced wind power developers due to state initiatives (١٧). This information from DOE does not however back-up WPA's direct impact on the development of wind power.

There are programs that DOE claims to have had significant impact in attracting wind power capacity expansion. Renewable Portfolio Standards (RPS) are state-based initiatives helping the development of wind energy (٢٢). The percentage of wind power capacity built in ١٩٩٩ was around ٥٥% for that to rise to ٧٥% by ٢٠٠٧ (DOE Annual ٢٠٠٧, ٢٨). The data shows that states without state-based policies dropped their percentage from ٤٥% to ٢٥%. However, the information does not take into account that states have significantly different levels of maximum possible wind power capacity and that in between ١٩٩٩ and ٢٠٠٧ more states might have started RPS policies. Nevertheless, a jump from ٥٥% to ٧٥% is a sign that more wind power capacity facilities have been built. Knowing that wind energy growth is so recent that we have risk of perception problems due to lack of data, the growth could have been impacted by other policies.

The Production Tax Credit (PTC) on the other hand has left behind some interesting effects that show how after its first implementation it had significant impact of wind power capacity growth. The PTC was founded in ١٩٩٢ and since had a few modifications; PTC supports energy generated through renewable energy sources by allocating a ٢ cents per kWh (٢٠٠٧) for first ١٠ years of operation (٢٨). The program was not active every year and was suspended in years ٢٠٠٠, ٢٠٠٢, and ٢٠٠٤. The years the PTC was not enacted there was a significantly strong drop in wind capacity growth, while all the other years ١٩٩٩, ٢٠٠١, ٢٠٠٣, ٢٠٠٥, and ٢٠٠٦ there was a much higher capacity growth (DOE ٢٠). Therefore the PTC is highly stimulating federal incentive. The DOE estimates that PTC stimulated the production of nearly ١٢GW of wind power (٢٠).

The PTC data gave much encouraging data to officials but resulted in a disaster for the turbine industry. The swings in wind power growth have made the demand for turbines very volatile, which then resulted in higher costs and shift of consumption of turbines to foreign based companies (٢٠). What is interesting is that this negative effect could have been predicted. In the ١٩٨٦s in California there was a cut of tax credits and other incentives resulting in bankruptcies of turbine manufacturers (١٤). The negative effects the tax credit incentive can cause are thus very dangerous. The effort tax credit allocates to increase the growth of wind energy capacity can be economically diminished by the risk of wind infrastructure productivity drops.

In the aftermath of the bankruptcies in the turbine manufacturing industry, Advanced Wind Turbine Program (AWTP) was launched in ١٩٩٠. The program induced the corporations to have their wind turbine designs include newer technologies that the program recognizes as necessary for maintaining competitiveness on the market (١٥). In the second phase, the program provided logistics in testing turbines for Class ٤ wind which targeted the gap sector in turbine development: between earlier and future-new-generation turbines (١٦). The AWT efforts might be able to be a good way of encouraging domestic industry to develop innovations without directly affecting their cash flow with direct financial incentives.

Local, State, Regional, Federal organization and regulation

The administration however in some situations causes problems, challenges, and disruption to the incentives producing a counter effect. One regulatory problem is that incentives may not be same across state borders. While some states are favorable to RPS other states have no advanced initiative towards wind power generation; meanwhile, in all states the PTC is available. What is worse, certain areas of the country may be underdeveloped in terms of technology and logistics in planning and helping transmission companies that help the distant wind power plants transmit wind power generated electricity to other states.

The DOE realizes that a federal support is necessary in encouraging developing the wind technologies across states (٢٤) (DOC ٢٠٠٧, ٨٢). So state-by-state expands to be region-by-region, according to SI, aware that each region in US has different grid networks with different expectations, regulations, scheduling, reserves, and line voltage (٧٩, ٨٧). In recent years the problem was approached both on regional and national level. Energy Policy Act of ٢٠٠٥ (EPA) assigned Federal Energy Regulatory Commission (FERC) to "approve proposed new transmission facilities in [corridors reported by the National Electric Transmission Compression Report (NETCR)] if the states fail to do so within one year" (DOE Annual ٢٠٠٧, ٢٧). These corridors are the Southwest Area National Interest Electric Transmission Corridor and the Mid-Atlantic Area National Interest Electric Transmission Corridor.

On the other hand regulation charges across states is different where in some states the wind power operator needs to pay the regulation charges in some states and regions "[regulation is a service provided] by the power system or regional transmission organization (RTO)…with costs paid by the load-serving entities" (DOC ٢٠٠٧, ٨٣). Therefore creating a corridor does not mean that wind operators or load-services can feasibly build these networks when regulation and policy changes state-by-state.

Another regulation that is wind power specific is height limit. Some counties and/or local authorities limit the height of the turbine (٧٣). The technological development resulted in greater energy yield in new wind turbines that are higher, and therefore more economically feasible than the older lower turbines. Therefore, wind energy faces legislation that blocks the possibility of technological development in such areas, slowing down the competitiveness to conventional and other renewable energy generators.

Transmission

FERC also adjusted the Order ٨٨٨ penalties to costs for energy imbalance that was a burden for wind energy (DOC Annual, ٢٧) (DOC ٢٠٠٧, ٨٢). The transmission companies too are affected by the same, ٨٩٠, FERC order. Transmission companies are required to undergo "open transmission planning" with regional and local authorities; furthermore, if a firm tries to use point-to-point transmission and that service cannot be provided by the transmission company, the transmission company needs to examine alternative transmission possibilities (DOC Annual, ٢٧). The 'examine' definition does not imply an 'obligation.' The FERC order might downturn the possibility of investment in transmission due to uncertainty the transmission companies of costs in alternative transmission requirement in case of lack of extra capacity.

The transmission lines have to be capable of directing energy from different energy producers to specific consumers. This is true in Sweden where consumers have the possibility of choosing their electricity provider based on whether or not the provider's electricity has some "green"[٨] or all "green" energy (Ek, ١٨١). In the case of electricity from "green" providers there was a premium consumers had to pay (١٨١). Such measures may be effective in areas where the public has a strong positive attitude towards renewable energy, but previous research shows that one cannot expect the number of those willing to pay more for "green" to be high (١٨٣). Treating "green" energy as a slightly different product with a different price may be justified yet such action does not help the wind power energy becoming more cost-effective. People are free to choose their providers in such markets and can therefore shift back to lower-cost energy providers in hardship; such price policy makes "green" power more of a luxury good.

Institutions

[٨] "Green" refers to electricity generated from a renewable energy source.

Some governmental institutions have a problem with turbines being set up in their neighborhood. One difficulty is that turbines may inflict with the radar systems (DOC ٢٠٠٧, ٩٩-١٠٠). As a result of an Interim Policy by the Department of Defense and the Department Homeland Security there were hundreds of projects that had to be stopped (١٠٠). These events are important as they send negative signals to investors that there are policies that might be implemented on a trial-error basis. Meaning, there are now higher variable future costs that companies might use in calculating the cost of investment that might turn down their interest in wind energy. The DOE mentions that there is a “lack of understanding of wind turbine technology, dynamics, available resources” resulting in lack of information for both the public and investors (١٠٠). Lack of information for investors increases risk, and higher risk results in less investors.

The environmentalists too are concerned in turbines affecting the nature in the nearby areas. Nonetheless, the lack of concrete knowledge of the environmental impacts complicates additionally the approval of projects due to incapability of the authorities to predict the environmental effects (١٠٠). These uncertainties increase time and expenses so that firms cannot predict well the economic feasibility of the projects they want to invest in. Moreover, the local and state officials to lose data with which to justify their support in wind energy development support in areas where the public might be reluctant towards wind power generation (١٠٠).

The wind power does however generate zero-emissions that can encourage the states to encourage the development of wind power energy generation in order to lower the air pollution levels (NREL, ١) (NREL Wind, ٩). The states have to comply to federal limitations on nitrogen oxide (٤). The NO_x cap encourages investment in wind power as investors do not have to incur present and future possible taxations, fees and cap policies for air pollution.

There are Supplemental Environmental Projects that let companies redirect their penalty for air pollution into investment of renewable energy development, future pollution prevention and/or community environmental projects. [٩][١٠] The policy does not affect the cost-efficiency of specific wind power companies, yet promotes clean air power generation.

The uncertainties may be the explanation why no top Fortune ١٠٠ companies invest in wind energy, while there are companies in solar energy generation field. The DOE goes further and uses this information to state that lack of Fortune ١٠٠ companies is why wind does not get as much publicity necessary to raise public awareness (DOC ٢٠٠٧, ٧٢). Such a conclusion does not have any more significant statistical backup.

The Market

Wind Power market also depends on the transmission market. Therefore the transmission development and cost-efficiency also comes afloat. The time needed for an investor to develop the wind farm is often shorter than the lengthier time necessary for new transmission lines to be set-up (DOE Annual ٢٧). One to three million USD is the DOE estimate of one mile of new transmission line for wind power generated electricity (٨٣). Furthermore, once the transmission line is built there is a possibility of not reaching optimal capacity usage due to low wind yield (٢٧). So for companies that have to develop their own transmission network, the wind energy itself might be extracted cost-efficiently yet the transportation may increase the costs to a non efficient level. Similarly, the more cost efficient the wind capacity the greater the space for the cost of transmission in maintaining the cost-efficiency (٥١). One way measure DOE suggests is to reduce current average distance between ٥٠ national load centers from ٥٠٠ miles to ١٠٠ miles, reducing the transmission cost upper bracket and lowering the risk of transmission blockage of next generation wind development (٥١). These problems are addressed in EPA where there DOE is in charge of developing a dialogue among all levels of elected authority (local through Federal) and other groups that will result in consensus decision on development of transmission infrastructure (٨١).

Wind as a renewable energy source that constantly becomes more and more can be effected not only by policies concerning the wind and/or other renewable energy resources but also by policies in conventional energy

[٩] United States Environmental Protection Agency, "Supplemental Environmental Projects," http://www.epa.gov/compliance/resources/policies/civil/seps/sepguide-mem.pdf, ٢٠٠٢

[١٠] National Renewable Energy Laboratory, "Supplemental Environmental Projects Using Renewable Energy: A New Approach to Addressing Air Quality Violation Penalties, " http://www.nrel.gov/docs/fy٠١osti/٢٩٦٦١.pdf, ٢٠٠١ resources. The fact that the wind energy is not a constant source of electricity, being open to variability levels, supports wind energy facing different challenges than other energy sources (٥٢). Federal plans for future energy development allot ٥٠% of the ١٠ billion budget to coal and ٢٠% to nuclear energy industry alone (٢٢). These industries have a competitive advantage of being close to the utility grid and have the ability to comply with current market rules (٨٠). What DOE refers to is the fact that most wind power farms are distant from load centers and final users and have to develop whole networks of transmission. The current market rules have costs for instable supply of electricity. The wind energy produces very unstable quantities of electricity while the conventional energy resources supply a stable level of electricity. Regulation exists, as mentioned, where stability of supply is essential or else the operator has to pay charges.

Nonetheless, some of these problems can be avoided or worked around. The offshore turbines yield at the right locations the most wind power electricity. The offshore wind power farms are often close to the mainland and the load centers, shortening the costs of transmission (٣٠). Offshore turbines may be greater in diameter and yield comparatively more energy than mainland turbines at same wind speeds. Due to high initial expenses in the offshore projects, the US might have to wait another decade for this project to develop (٣٠). However, experience in Europe has shown that the 'shallow-water' projects cost ١.٣ to ١.٥ times as much due to maritime environmental costs; not to mention, the accessibility of land and turbines themselves at the sea is more expensive than mainland construction and operations (٥٢).

In order to receive a permit to build a wind turbine one needs to conduct preliminary work and higher whole staff that will develop a proper application. The offshore sites in the USA have a greater chance of being refused than mainland sites (٥٤). The risk of applying to offshore becomes an economical problem for the companies will prefer to apply to less energy yielding energy generating power farm locations in order to avoid sunk costs from an offshore turbine project rejection.

Wind power energy generation has significantly risen since ١٩٩٩, and lacks historical development conventional energy generators had experienced. Lack of data causes low reliability of turbines; nonetheless, being a young energy industry, wind power lacks maintenance and logistical support (٧٤). In addition to previous gaps in information, the risk level was such that the investors willing to invest in wind energy are the ones that in ٢٠٠٧ have been affected by the credit crisis (DOE Annual, ١٤)

Co-operation

One proposal DOE exemplifies might solve quite some problems. There is a possibility of cooperation between the wind power and hydroelectric power plants. The two could be united into one group where when wind would generate electricity the hydropower plant could fill the reservoir and then when wind power is not generating enough electricity, the hydro power could fill in the gap (DOE ٢٠٠٧, ٨٩). Such a project could help the investor make a more reliable estimate of daily electricity production, enabling him/her to make a clearer estimate of income for kWh supplied. Nonetheless, there is real possibility that the now the hydropower plant would not operate at its optimal level. Also, hydropower plants are very demanding and heavy fix cost power plants requiring much space and water resources.