REPP RESEARCH REPORT
Renewable Energy Policy Project
November 1998 • No. 6

EXPANDING WIND POWER:
Can Americans Afford It?[1]

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Wind energy may have a surprisingly modest cost. Deploying 3,050 megawatts of wind energy capacity in Texas, for example, could cost an average family as little as 75 cents per month. In addition to clean, climate-friendly electricity, large-scale development of wind power will also generate billions of dollars of local economic activity.

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A Message from the Staff of the Renewable Energy Policy Project

How much will a clean environment cost? That question dominates debate about renewable energy. Many environmentalists maintain that if we reckon the value of things that energy prices usually ignore — for instance, protection from fluctuations in the price of fossil fuel, cleaner air, less radioactive waste and a lower chance of catastrophic climate change — renewables may *save* us money. Equally important, communities that develop indigenous renewable energy resources and encourage renewable energy equipment manufacturing can create jobs and retain some of the money they would otherwise spend on imported coal, oil and gasoline. Skeptics dismiss such claims as malarkey, and warn that large-scale renewable energy development would cripple the economy.

The following analysis suggests that ambitious wind energy development could prove astoundingly cheap. To be specific, installation of 3,050 megawatts in Texas translates to seventy-five cents per month for an average household in the Lone Star State. That's the cost of a cup of coffee. It's less money than most families lose in between their couch cushions. *It's only nine dollars a year!*

Care should be taken with these numbers, of course. For example, the analysis does not discuss transmission costs for windpower in detail, due to current regulatory uncertainty and regional idiosyncrasies. Nevertheless, the calculations include very generous margins for error, and, in the case of the Texas example, the authors estimate that transmission might raise costs by around 15%. Yet, even if this study misses the mark on transmission costs by 100%, the resultant impact on electricity bills would still be "noise" in the average family budget. However you count it, it comes up cheap.

Not only is wind energy development cheap, but Texans — and presumably many other Americans — seem ready and willing to pay for it. According to *The Economist*, residents of Houston participating in a 1998 "deliberative poll" initially declined to spend a penny more on renewable energy. After spending a weekend questioning a panel of objective experts, the group said they would gladly pay an extra $6.50 per month. Similar surveys in Corpus Christi and Beaumont, TX generally echo these results.

The analysis presented in this paper demonstrates the crucial importance of group solutions to social problems. The authors' Texas case study assumes that regulators spread the cost of large-scale wind development among all customer classes and individual customers on a per-kilowatt-hour basis. For instance, policy makers might apply a systems benefit charge of the type adopted in California and other states as they restructure their electric systems. Given that the environmental and economic benefits of wind development accrue on a broad regional basis, this assumption of evenly distributed costs seems reasonable. If, on the other hand, the costs were borne only by altruistic families that cared enough about the environment to pay a premium to protect it, for example through a voluntary "green pricing" program of the type increasingly contemplated by utilities and regulators, the per-family costs would soar.

That's the message: Talk is cheap, but so is windpower. Everyone benefits — if everyone does their part.

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October 21, 1998

Executive Summary

Wind power represents an increasingly attractive option for generating electricity. Deploying wind turbines instead of conventional fossil-fired or nuclear plants can avoid numerous harmful environmental impacts. A strong wind energy sector can also bring substantial local economic benefits. Skeptics of wind power often assume that wind development costs too much to contemplate. In fact, using a conservative model that tends to overstate the cost, we estimate that a robust, ten-year program of wind power development would add only a few dollars per year to the electricity bill of a typical family — *in the case of those living in the state of Texas, perhaps 75 cents per month, or nine dollars per year.*

This paper describes a model to evaluate the impacts of adding 10,000 megawatts (MW) of wind-generated power to the national generating mix over ten years. The added capacity from wind-driven generators would be equivalent to 0.7 percent of the nation's 1996 electricity consumption. This would supplement the nation's 1,750 MW of existing wind-driven generating capacity, resulting in 11,750 total MW in place by the end of 2006.

Our model predicts appreciable economic gains from adding the new wind turbine capacity:

- *$7 billion in direct economic activity* from manufacturing wind turbines, constructing windfarms, and supplying parts and components over ten years. Most, but not all, of this activity would benefit the domestic economy.

In addition, revenue from three sources would flow to the local economy, rising during the installation period to the following levels in the year 2007, and continuing throughout the life of the windfarms:

- *$863 million in annual revenue* from the sale of 21.6 billion kilowatt-hours (kWh) of electricity, once all the turbines are installed.
- *$17 million per year in land-use easement payments* to the owners of the land on which the windfarms are situated, once all the turbines are installed.
- *$89 million per year from maintenance and operations,* once all the turbines are installed.

Although we do not calculate their economic value here, deployment of wind power has other benefits. Local governments may collect increased tax revenues. The incorporation of wind generating capacity can benefit utilities and other energy suppliers by, for example, mitigating fuel-price and regulatory risks; deferring new conventional capacity additions, and; reducing construction finance costs due to conventional capacity additions. In some cases, wind-powered generators may be deployed in distributed systems so as to defer the costs of line extension, reconductoring or voltage support. In addition, this added capacity may enable utilities and other energy suppliers to serve growing demand for environmentally clean electricity. To be sure, wind power development can have negative impacts (e.g., bird mortality) or subjectively judged ones (e.g., visual presence). Yet these can often be managed and limited. The public will certainly benefit from reductions in several negative environmental impacts of conventional electricity generation, including air pollution, emissions of greenhouse gases, production of radioactive waste, and land and water degradation from mining.

To illustrate the potential economic effects of investing in wind energy, we apply our model to the state of Texas. Based on Texas' very large wind resource — second best in the nation — and high electrical energy consumption, we assume that the state hosts 3,050 MW of new wind turbines, increasing the state's total electric energy generating capacity by nearly 5 percent. We assume the same gradual ten-year installation profile used in assessing the impacts of the 10,000-MW national wind-generation total. Upon installation of the state's full complement of 3,050 MW, we find that a Texas family using 1,000 kWh per month would pay *an additional 75 cents per month, or about 9 dollars annually,* to offset the investment in wind energy.

The model predicts four additional economic impacts for Texas:

- *$2.14 billion* in economic activity associated with manufacturing, construction, and supply of parts and components;
- *$263 million per year* in energy sales revenues after complete installation;
- *$5.2 million per year* in easement payments to landowners after complete installation, and;
- *$27 million per year* in maintenance and operations activities after complete installation.

In both the national analysis and the Texas example, we make some simplifying assumptions for the sake of clarity. Because the economic, environmental and employment benefits of wind power development accrue on a broad regional basis, we assume that regulators would spread the costs equally among all customer classes and individual customers, for example through a non-bypassable system-benefit charge on electricity sales levied on a per-kilowatt-hour basis. While several states have taken this approach to support renewable energy and other public benefits, it might not be the case universally.

In addition, we do not calculate transmission costs, which could increase the cost of incorporating wind energy into the electric system, particularly where such resources are far from population centers. On the other hand, we make a number of conservative assumptions that tend to overestimate the rate impact of deploying wind turbines, and probably offset the additional cost of transmitting wind energy, compared to the cost of transmitting energy from conventional non-wind resources. In our example, the average residential price of electricity is approximately 2.5 times the wholesale price. We use this multiplier to reckon the increase in retail rates should the wholesale price of wind exceed the conventional wholesale cost. Yet this multiplier likely overstates the effect of wind-generated electricity on retail rates, since many of the components of the retail rate are either fixed or would not rise as fast as the wholesale rate. In the case of Texas, we estimate that transmission costs calculated under current regulations could add about 15% to the cost of wind power. We stress that this figure results from a regulatory environment specific to Texas today, and might not be illustrative of other regions now or in the future. Still, we conclude that development of wind-powered electricity facilities might easily levy a more modest household cost than we estimate here.

In sum, our analysis supports the following points:

- The United States harbors more than enough windy land to boost wind generating capacity dramatically without interfering with other land uses;
- Wind development would likely bring substantial benefits to local economies, and;
- The cost per household of wind energy development is modest.

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I. INTRODUCTION: WIND ENERGY IN THE UNITED STATES

Recent Improvements to Wind Energy Systems

Large-scale, grid-connected wind energy installations used for generating electricity have made enormous strides over the last 15 years. By the end of 1996, the U.S. hosted approximately 1,750 megawatts (MW) of wind energy generating capacity; this compared with more than 4,500 MW of capacity operated in Europe, India, and other locations. Capital cost, reliability, and energy conversion efficiency have increased to the point where these renewable energy systems can compete economically under many circumstances with conventional generation technologies such as nuclear and modern coal-fired plants.

The installed capital costs of wind-driven generating systems decreased from more than $2,500 per kilowatt (kW) in the early 1980s, to $1,000 per kW or less for large scale installations in the mid-1990s. The costs of unscheduled and preventive maintenance also decreased in the same time period, from more than 5 cents to less than 1 cent per kilowatt-hour (kWh). These improvements have reduced the levelized cost of wind energy systems from more than 15 cents to less than 5 cents per kWh — not including the federal 1.5-cent/kWh tax credit now available. Design and manufacturing advances, the further results of ongoing research and development programs, and the realization of large production volumes promise to reduce these costs still further — to the range of 2.5 to 3.5 cents per kWh over the next ten years.[3]

Meanwhile, improvements in rotor aerodynamics and turbine operating modes along with increases in turbine size have boosted the efficiency of wind energy systems in converting energy. Under good wind conditions, modern wind energy systems typically achieve capacity factors of 28 percent or more.

Wind Energy in the United States

Most of the installed wind-energy generating capacity in the United States is located in three regions of California: Altamont Pass (about 60 miles east of San Francisco), San Gorgonio Pass (east of Los Angeles near Palm Springs), and Tehachapi Pass (between Bakersfield and Mojave to the northeast of Los Angeles). Much of this capacity was installed during the 1980s, and almost all was planned, financed, installed and operated by independent power producers (IPPs), entities not affiliated with utilities. Entrepreneurs installed most of the California capacity in response to federal and California state legislation that provided a market[4] and favorable tax incentives that attracted private capital.[5]

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[2] This paper grew out of research originally undertaken by Chapman with financial support from the Electric Power Research Institute in 1996. (For this reason our hypothetical examples take 1997 as the base year.) The authors thank Heather Rhoads and Ron Lehr for their invaluable assistance. They also thank reviewers Roby Roberts, Russell Smith, Tom “Smitty” Smith, Randy Swisher, Carl Weinberg and Jean Wilson. The content of this Research Report does not necessarily reflect the positions of the reviewers, the Renewable Energy Policy Project, or the REPP Board of Directors.

[3] For example, Princeton Economic Research Inc. estimates energy costs for 1998 wind technology at 4.66 cents/kWh at ridgeline sites with 6.7 meters per second (m/s) average wind speed at 10 meters elevation, and 6.51 cents/kWh for lowland sites with 5.2 m/s winds. PERI expects technology available between 2000 and 2002 to generate power at 3.25 cents/kWh and 4.53 cents/kWh, respectively. *Wind Energy Weekly* 814 (15 September 1998). These costs are based on and consistent with a recent authoritative source: Electric Power Research Institute and the U.S. Department of Energy, *Renewable Energy Technology Characterizations*, EPRI TR-109496 (December 1997).

[4] Notably the Public Utility Regulatory Policies Act of 1978 (PURPA). PURPA required utilities to purchase energy from certain independent power producers at their avoided (marginal) cost of producing electricity.

[5] Federal tax incentives included an energy tax credit of 15 percent and an investment tax credit of 10 percent, and expired at the end of 1985. California’s 25 percent credit against taxes of that state expired after 1986. These credits were on the total installed cost of a wind facility and could be taken in the year of initial operation.

California's wind industry development also occurred in an era of unusually high energy prices coupled with expectations of higher prices still to come.[6]

More recent installations tend to be smaller projects. For example, in 1996 the Sacramento Municipal Utility District (SMUD) completed installation of 5 MW of new wind-driven generating capacity. In general, most of the capacity has been installed as the result of either partially subsidized demonstration programs, or of mandated installations:

- Among the demonstration programs, the U.S. Department of Energy and the Electric Power Research Institute (EPRI) jointly support the Turbine Verification Program (TVP). Managed by EPRI, the TVP has resulted, as of 1998, in the installation of 6 MW of capacity by Central and South West Corporation in Texas, 6 MW by Green Mountain Power in Vermont, and 3.75 MW by utilities in Iowa and Nebraska.
- Another demonstration program, still in the planning stage, is the proposed CARES windfarm in Washington State. The consortium of utilities sponsoring CARES envision it as a 25-MW installation.
- Through a mandated agreement involving the storage of spent nuclear fuel, Northern States Power of Minnesota had installed 125 MW of wind generating capacity by mid 1998 as part of a commitment to install a total capacity of 425 MW by 2002. The agreement mandates installation of a further 400 MW, should wind energy be shown to be in the "public interest."

A few notable exceptions to demonstrations or mandated installations include:

- a 35-MW windfarm installed in west Texas as a joint venture between the Lower Colorado River Authority, the City of Austin, Texas, Kenetech Wind power and other parties;
- the 25-MW Vansycle Ridge project now under construction in eastern Oregon by Portland General Electric Company; and
- the 41.4-MW Wyoming Wind Energy Project by Pacificorp and the city of Eugene (Oregon) Water & Electric Board.

Together the wind-energy capacity owned by utilities or their related, non-regulated affiliates now totals about 400 MW, or about 23 percent of the total 1,750 MW of United States wind-driven generating capacity. While these utility installations are significant, they are small in comparison to the available wind resources in the United States, particularly in the Great Plains.

Benefits of Wind Energy

Development of wind energy generating capacity can assist utilities and other energy generators in complying with existing regulations and rulings regarding the pollution, emissions, or hazardous materials associated with operating fossil-fuel and nuclear power plants. Similarly, investments in wind energy can mitigate the risk of future taxes or other levies (e.g., a carbon tax) on the pollution, emissions, or hazardous materials associated with conventional generation sources — all measures which may confront energy producers in coming years.

Depending on the configuration of a given utility's transmission and distribution system, customer demands and available wind resource, wind energy also can provide substantial and quantifiable economic benefits to ratepayers and owners by deferring the need for additional investment to meet demand growth. For example, use of wind-driven generators may defer the need for line and service extension or the reconductoring of existing lines. In certain situations, these installations also may provide voltage support at the end of weak lines. In addition, wind energy can help mitigate fuel price risk and provide supply diversity.

Finally, and perhaps most compelling, wind energy enables utilities and other energy suppliers to tap the emerging market for green power — energy generated from renewable, non-polluting sources. It is important to note that green power need not be generated within a given service or market territory. One of the hallmarks of current efforts to restructure the nation's electric system through the substitution of market principles for state regulation is the increased access to and use of transmission systems by all energy suppliers and users.

[6] To relieve the cost to small power producers of negotiating a purchase contract with a utility, the California Public Utility Commission devised standardized Interim Standard Offer 4 (ISO4) power purchase agreements. These 30-year contracts specified the price (plus inflation) that independent generators would receive for their power during the facility's first ten years of operation, and pegged prices thereafter to the actual avoided cost. The contracts specified prices that reflected expectations in the early 1980s that oil prices would continue to soar. In 1985, as oil prices plummeted, the CEC discontinued ISO4. As the ten-year period expires and the ISO4 contracts revert to (much lower) actual avoided cost, many California wind developments find their revenue streams constrained.

Barriers to Industry Acceptance of Wind Energy

Despite continuing improvements in the cost and performance of wind turbines, the huge untapped wind resources that exist in many states, and the recognized environmental benefits of wind energy, most utilities have yet to incorporate wind energy systems into their generation mix. There are several reasons for this.

Conservative management culture: Electric utility managers generally take a conservative stance toward new technology, perhaps reflecting their desire to protect a complex system providing an important public service.[7] Structural and reliability problems encountered in the early 1980s with first-generation wind energy machines helped turn this institutional conservatism into skepticism. Technological advances, positive operating experience and a new generation of innovation-friendly management have altered this situation, but the initial impressions may linger.

Intermittency: The power output of a windfarm depends on the strength and time characteristics of the wind resource. For this reason, wind-powered generating plants behave differently from conventional power sources. Utilities are beginning to develop the experience to understand and manage the variable, yet predictable, nature of wind power systems in the same way they understand and manage unplanned outages and load changes of transmission lines and conventional power plants.

With some exceptions, the intermittent nature of the wind resource means that wind energy facilities cannot at present supply all of our electricity needs. There is a general perception among utility managers that wind power can provide 10 to 15 percent of available capacity in a given region with no significant modifications to the existing utility system. Surprisingly, we have found little or no hard analysis to justify this rough figure. In the absence of further research, it should not be taken as a ceiling on wind power penetration. In any case, the levels of wind-powered generating capacity considered in this study fall well below this range.

Surplus generating capacity: Most regions of the United States enjoy more than enough low-cost generating capacity (i.e., baseload plants) to meet anticipated demand over the next several years. During this period, the energy produced by new wind turbines would be worth only as much as the fuel, such as coal or natural gas, needed by an existing power plant. In other words, the existence of surplus generating capacity decreases the value of all proposed capacity, including wind. Yet energy prices do change, sometimes due to events beyond our control. Planned or unexpected load growth or power plant shutdowns may sop up the existing excess of baseload capacity, increasing the value of wind energy capacity substantially, and making it more attractive on a pure cost basis.

High capital costs: Wind-powered generators have high capital costs in comparison with some conventional generating technologies, notably gas-fired combustion turbines. However, operating costs are low, and there are no fuel costs (and therefore no fuel-cost risks) associated with wind-driven generators. In addition, capital costs for wind-energy installations are expected to continue to decline. Adding to the favorable picture, financing options now becoming available will help reduce the levelized cost of wind energy.

Restructuring: The United States electricity market changed dramatically in the 1990s, and it continues to evolve. The emergence of non-regulated, independent power producers (IPPs) and power marketing organizations has presented utilities with unexpected and unaccustomed competition. This has occurred in an era of low fuel prices and rapid development of relatively small, point-of-load generating systems that enjoy low capital and operating costs. The premier examples are gas-fired combustion turbine systems. In addition, some utilities are burdened with costly nuclear and aging fossil-fueled generation facilities. As a consequence of these factors, most utilities have not yet integrated or been inclined to consider meaningful amounts of a new, intermittent generation technology such as wind energy.

However, as part of their strategic redefinition, many utilities and other energy suppliers may begin to incorporate renewable energy generation options into their portfolios. This strategic shift will be driven under the increasingly attractive economics of wind and other renewable energy sources by emerging green market forces, and under an increasingly demanding regulatory environment.

Few economies of scale so far: While the U.S. hosts some 16,000 wind turbines today, most were installed prior to 1990 and half of those came from Europe, principally Denmark. The size of the United States turbine market has not been adequate to support domestic innovations in manufacturing and processes that would result in reduced wind turbine manufacturing costs. Thus the potential economic impact of improved manufacturing methods and material processes has yet to be realized.

[7] On utility management culture, see Richard F. Hirsh, *Technology and Transformation in the American Electric Utility Industry* (Cambridge, England: Cambridge University Press, 1989), e.g. pp. 114-120.

Environmental impacts: Early wind enthusiasts hoped that the new technology would levy zero environmental cost. These hopes proved over-optimistic; early installations had unexpected problems concerning noise, land erosion, visual clutter and — a lingering problem — bird kills. Improved management practices and technology have largely addressed these problems. In particular, the National Wind Coordinating Committee has made progress toward resolving the technical and political issues surrounding avian mortality from windfarms.[8] Nevertheless, siting a new wind project can be a slow process.

II: THE IMPACTS OF ADDING WIND POWER IN THE UNITED STATES

This section describes a model for developing wind power in the United States during the ten-year period from 1997 through 2006. The model projects some important economic, energy-supply, and environmental impacts of adding 10,000 MW of new wind energy generating capacity to the 1,750 MW of existing capacity at the end of 1996. The model is designed not only to calculate the economic and other costs and benefits associated with the addition of this capacity, but also to analyze the feasibility of incorporating this additional capacity into the existing generating mix.

Methodology

This study uses a spreadsheet analysis and makes use of a number of general, technical and economic assumptions to arrive at its conclusions. These assumptions reflect our understanding of the wind power industry. For comparison, we provide in the footnotes the current estimates and projections of wind technology performance and cost published in the *Renewable Energy Technology Characterizations*, an authoritative source released jointly in 1997 by the Electric Power Research Institute and the U.S. Department of Energy.

We conduct our spreadsheet analysis in three steps. *First*, the model calculates the land use and wind resource requirements of the added wind capacity, and then compares these requirements to available land and documented wind resources. This step confirms that existing resources would suffice to achieve the 10,000-MW target. *Second*, the model calculates the costs associated with installing new wind turbines (i.e., capital costs) and maintaining existing turbines during each year. *Third*, the model calculates the annual electrical energy production and sales revenue that would arise from the installations.

Assumptions Used in the Model

General assumptions	Technical assumptions	Economic assumptions
• Amount of capacity added • Installation schedule	• Wind technology deployed • Capacity factor • Array and electrical losses • Land use requirements	• Capital costs • Operating costs • Wholesale energy prices • Land lease rates • Escalation rate

[8] See, for example, National Wind Coordinating Committee, *Wind Energy Environmental Issues*, Issue Paper No. 2 (January 1997), at http://nationalwind.org/pubs/wes/wes02.htm, accessed 14 October 1998. Also, *1995 National Avian-Wind Power Planning Meeting Proceedings* at http://nationalwind.org/pubs/avian95/TOC.htm, accessed 14 October 1998.

Our Assumptions

Wind capacity installed: The choice of 10,000 MW of added wind capacity reflects two estimated levels: that generally considered necessary to achieve economies of manufacturing volume, and that readily achievable with the anticipated manufacturing base. The chosen value also equates to 1.3% of the United States' total utility and non-utility generation capacity in 1997 of 783,125 MW,[9] safely below the perceived 10 to 15 percent limitation on wind capacity discussed above.

Installation schedule: The model assumes an installation schedule beginning with the addition of 100 MW of new wind turbine capacity during 1997 and culminating in the addition of 2,000 MW during the year 2006. The cumulative total capacity added over the ten-year study period is 10,000 MW. Including the 1,750 MW of capacity in place at the end of 1996, the total capacity at the end of 2006 is 11,750 MW. The lower line in Figure 1, below, graphically portrays the capacity added each year, while the upper line shows the cumulative total capacity, including the 1,750 MW existing at the end of 1996. The y-axes show the installed capacity in terms of megawatts and the number of 750-kW wind turbines added.

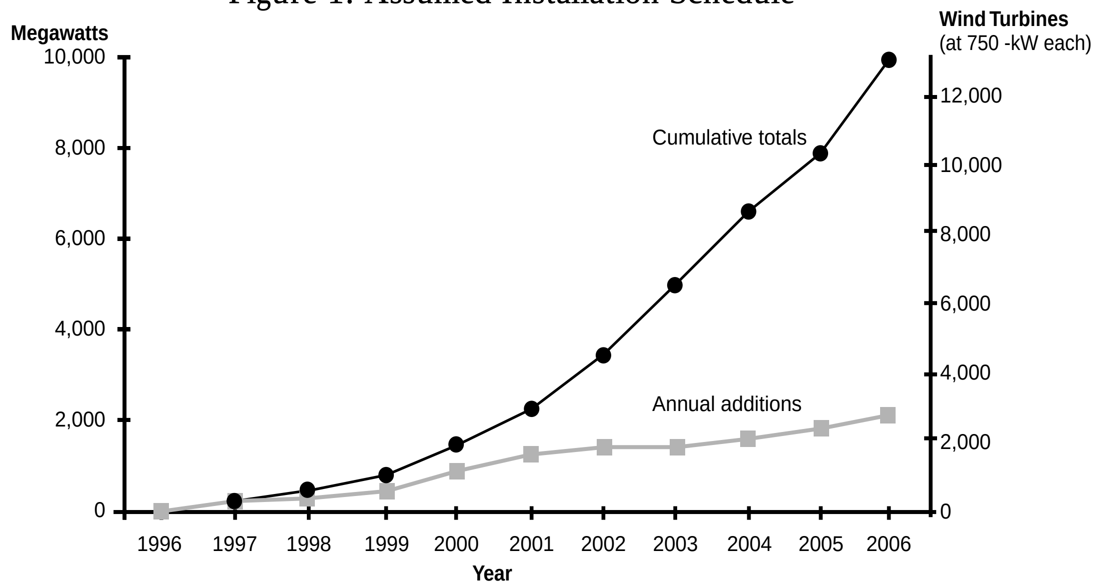
The accelerating pace of installations assumed in the profiles is important for two reasons. First, it will require time to organize and implement those actions needed for the installation of 10,000 MW of new wind-driven generating capacity over ten years. They cannot be negotiated and put in place overnight. Second, a certain amount of time is required for ramping up wind turbine manufacturing capacity and for installation. Thus the assumed installation schedule begins at a level consistent with recent rates of installation and then increases to a level of 2,000 MW per year by 2006.

We find the installation schedule, commencing with 100 MW installed in 1997, readily achievable, given the industry's past performance. Windfarm developers installed between 40 and 50 MW in the U.S. during 1995. Four-hundred and seventy MW went on line during 1985, the final year of the energy and investment tax credits, and a peak year for installations. Of this amount, one manufacturer alone installed slightly less than 100 MW, comprising almost a thousand wind turbines.

Wind technology deployed: Our model assumes the use of 750-kW wind turbines having a rotor diameter of 50 meters and a hub height of 50 meters. As shown in Figure 1, 13,333 new, 750-kW wind turbines can supply the 10,000 MW under consideration here.

Our specification of 750-kW turbines may be conservative. In Europe, high land costs and growing site restrictions are driving turbine sizes upward. According to Greenpeace International, all large Danish turbine manufacturers now offer machines with a capacity of one megawatt or more; the largest, from Vestas Wind Systems A/S, is rated at 1.65 MW. At the end of 1997, more than 130 megawatt-scale machines were operating in Europe.[10] The use of megawatt-scale ma-

Figure 1. Assumed Installation Schedule



9 Capacity data from U.S. Department of Energy, National Energy Information Center at (202) 586-8800.

10 *Wind Briefing 1: World Beaters — The Danish Wind Industry* (Amsterdam: Greenpeace International, 1998).

chines might lower the cost of the wind energy generated, for example, by reducing land-use requirements. On the other hand, as American land prices are much lower than those driving European developers toward larger turbines, turbine sizes here may cease their recent rise somewhere below a megawatt.

Capital and maintenance costs: As shown in Figure 2 and Figure 3 below, we assume that the installed cost of wind-driven generating capacity will decrease from $1,000 to $600 per kW,[11] while the cost of unscheduled and preventive maintenance (U & PM) decreases from 0.55 to 0.31 cents per kWh.[12]

The model for the costs of unscheduled and preventive maintenance assumes a two- or three-person crew with a truck, plus management and support. This led to a blended crew size of 4 persons (including management and support). A blended hourly direct labor rate of $22 with a direct labor markup factor of 3 led to a burdened hourly rate of $66. It was further assumed that the mean time to dispatch the crew, get to the wind turbine and make the repair was 6 hours. It was further assumed that each visit required parts and expendables costing $750, plus a General and Administrative ex-

Figure 2. Assumed Installed Costs

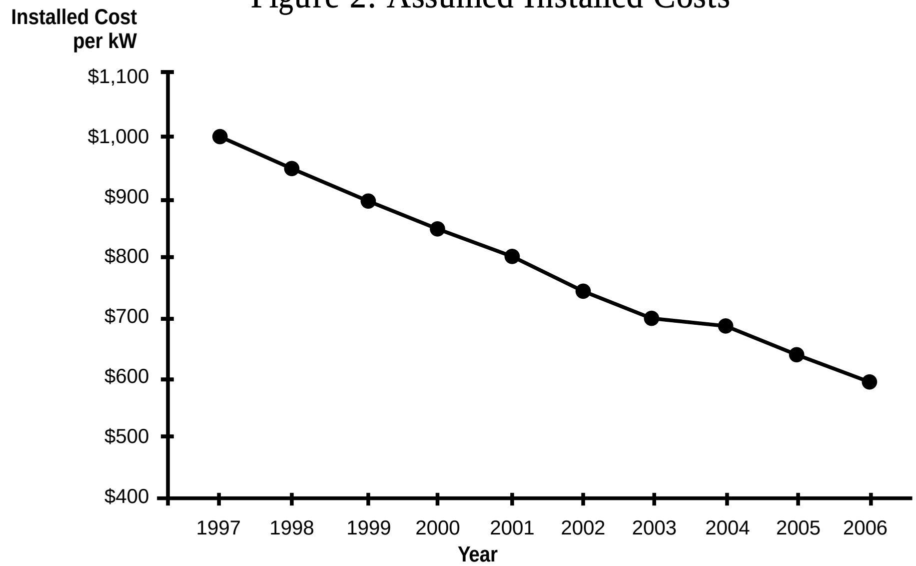
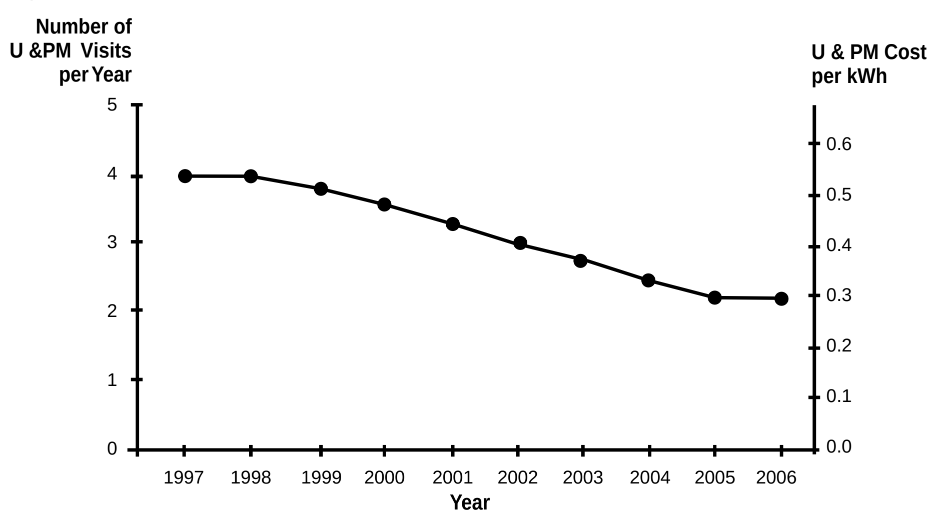


Figure 3. Assumed Unscheduled and Preventive Maintenance Costs



[11] For purposes of comparison, a recent authoritative source projects a drop in installed costs from $1000/kW in 1997 to $720/kW in 2005 (+10% or -20%). EPRI/DOE, *Energy Technology Characterizations*, p. 6-13.

[12] EPRI/DOE projects a drop in operation and maintenance costs from 1.0 cents/kWh in 1997 to 0.5 cents/kWh in 2005 (both figures +20% or -30%). EPRI/DOE, *Renewable Energy Technology Characterizations*, p. 6-13.

pense of 25 percent for a marked-up cost of $938. As with energy production (see below), we assumed that only half of the wind turbines contributed to maintenance costs during their year of installation.

Capacity factor: We assume a 28 percent annual capacity factor for all new wind turbine installations,[13] resulting in gross energy production of 1.84 million kWh per year for each 750-kW wind turbine, or 24.5 billion kWh per year for all the wind turbines. The assumed capacity factor may be conservative when applied to wind energy development in some areas. Planned windfarms in the upper Midwest, where wind resources are strong and consistent, are expected to achieve capacity factors of 30 percent or more.[14]

Windfarm losses: We assume total losses of 12 percent, resulting in the net generation of 21.6 billion kWh per year for the completed 10,000 MW of added capacity. The composite loss figure reflects three distinct categories:

- The model assumes that, due to malfunction, not all the wind turbines operate all the time. "Availability" defines the operational fraction at a given moment. We assume availability values of about 98 percent, or availability losses of about 2 percent.[15]
- There are electrical losses associated with the transfer of the electric power from the location of each wind turbine to the point of central interconnection with the balance of the utility system. While the magnitude of the electrical losses depends on the details of the power collection network and the interconnection, these losses may reduce the gross energy by 2 to 4 percent.[16]
- In a windfarm, energy production by turbines located downwind of the front row of turbines is reduced. This can arise from diminished energy content of the wind flow and the effects of turbulence generated by the front-row turbines. Such "array loss" depends strongly on the array's size and spacing of the individual turbines, the topography of the land, and the directional characteristics of the wind. Large installations can suffer array losses of 10 to 25 percent. As a consequence of the square and linear array configurations assumed for the Plains installations, together with an admixture of small clusters (having reduced wake interference and array losses), we have assumed a value between 7 percent to 8 percent.[17]

Wholesale wind-generated electricity prices: Revenues derived from wind-generated electricity production are calculated assuming a wholesale wind electricity price of 4 cents per kWh. Prices were not assumed to change over the study period. These prices do not account for the 1.5-cent/kWh production tax credit that is available through the federal government.

Land use: For estimating land use requirements, the model assumes a windfarm array resulting in the commitment of 30 acres per wind turbine.[18] This corresponds to flat terrain with an omnidirectional wind regime and wind turbine spacing of 350 meters.

System capacity constraints: Finally, we compare the assumed amount of added wind-powered generating capacity with the existing amount of conventional generation capacity to determine if the added capacity will be within the perceived 10 to 15 percent limitation on total system capacity described earlier. If the 10,000 MW is apportioned over the 12 windiest Great Plains states, the added wind-generated capacity would provide less than 5 percent of the 1996 electric energy consumption of these states, and less than 1 percent of the energy consumption for all 50 states.

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[13] For class 4 winds, EPRI/DOE predicts that capacity factors will rise from between 26.2% in 1997 to 35.1% in 2005 (all +5% or -15%). *Renewable Energy Technology Characterizations*, p. 6-13.

[14] Personal communication from Randall Swisher, Executive Director, American Wind Energy Association (1998).

[15] EPRI/DOE projects availability factors of 98% (+1% or -2%) for the entire period considered here. *Renewable Energy Technology Characteristics*, p. 6-12.

[16] EPRI/DOE projects electrical losses falling from 5% in 1997 to 4% in 2005. *Renewable Energy Technology Characteristics*, p. 6-19.

[17] EPRI/DOE projects array losses falling from 5.0% in 1997 to 4.5% in 2005. The EPRI/DOE analysis also considers losses due to rotor soiling, which they see falling from 7.5% in 1997 to 2.5% in 2005. Overall, EPRI/DOE predicts a fall in total losses (i.e., availability, array, rotor soiling, electrical, control and miscellaneous) from 19.5% in 1997 to 13% in 2005. *Renewable Energy Technology Characteristics*, p. 6-12, 6-19.

[18] The area of 30 acres per wind turbine is approximately $48D^2$, where D is the diameter of the turbine blade sweep: for example configurations of 7D x 7D, 4D x 12D, 5D x 10D and 3D x 16D. This is the methodology used by D.L. Elliott et al., *An Assessment of the Available Windy Land Area and Wind Energy Potential in the Contiguous United States*, Battelle Pacific Northwest Laboratory, PNL-7789/UC-261 (August, 1991).

Results

Land and wind resource availability: The first question to be considered when modeling a significant expansion of wind-driven generating capacity is whether sufficient land and wind resources exist to support the development of new windfarms. If comprised of units rated at 750 kW, the 10,000 MW of generating capacity would require 13,333 wind turbines. At 30 acres per wind turbine, the total land required would be 400,000 acres. This is equal to 625 square miles (1,619 square kilometers) or, if all of the wind turbines were concentrated in a single hypothetical square array, an area 25 miles (40 kilometers) on a side. Although wind turbine spacing, in order to avoid excessive energy loss and harmful turbulence, corresponds to land allocation of 30 acres per turbine, the turbines themselves and associated roads generally occupy less than 5% of this area. Consequently, wind development interferes with farming and grazing only minimally.

Table 1, below, shows the available windy area in each of the 12 states with the greatest wind resources, based on the authoritative survey of U.S. wind resources.[19] These 12 states are in the Great Plains and Midwest. The first column shows that each of these states harbors far more windy land area available than the 1,619 square kilometers needed to supply the entire national total of 10,000 MW. Further, the table shows that 27,702 of the 750-kW wind turbines considered here could supply 10 percent of the combined electricity demand of the 12 states (285 billion kWh). This is approximately double the 13,333 wind turbines assumed to be installed in this study.

Table 1. Wind Turbines and Land Area Required to Supply 10 Percent of Demand

State	Wind Capacity Potential[a] (MW)	Wind Energy Potential[a] (billion kWh)	Available Windy Land Area[a] (km^2)	% of Total Land Area in State[a]	Number of 750-kW Turbines Needed to Supply 10% of 1993 Demand[b]	Land Area Required (km^2)	% of Available Windy Land	% of Total Land Area
North Dakota	138,400	1,210	100,700	55.0	402	49	0.05	0.03
Texas	136,100	1,190	123,700	18.2	13,595	1,651	1.33	0.24
Kansas	121,900	1,070	108,700	51.3	1,859	226	0.21	0.11
South Dakota	117,200	1,030	93,700	47.6	255	31	0.03	0.02
Montana	116,000	1,020	97,300	25.8	701	85	0.09	0.02
Nebraska	99,100	868	90,100	45.4	1,017	123	0.14	0.06
Wyoming	85,200	747	63,400	25.2	647	79	0.12	0.03
Oklahoma	82,700	725	72,900	41.0	2,202	267	0.37	0.15
Minnesota	75,000	657	61,100	29.7	2,674	325	0.53	0.16
Iowa	62,900	551	56,700	39.1	1,745	212	0.37	0.15
Colorado	54,900	481	45,700	17.0	1,794	218	0.48	0.08
New Mexico	49,700	435	46,600	14.8	810	98	0.21	0.03
12-State Totals	1,139,100	9,984	960,600	29.9	27,702	3,363	0.35	0.10
48-State Totals	1,230,000	10,777	1,040,000	13.5	154,833	18,798	1.81	0.24

[a] Values taken from Elliott et al., *Assessment of Available Windy Land in the U.S.*, table B.1, pp. B.2-B.3. The values shown are for exclusion category 3, in this source's terminology.

[b] Values are based on a 28 percent capacity factor, no losses, and 30 acres per wind turbine.

[19] *Ibid*.

The table also shows the land area associated with such an installation. Ten percent of the 1993 electricity demand could be met by developing just 0.35 percent of the adequately windy land area in the 12 states having the highest wind resources, or by developing just 1.81 percent of the adequately windy land in all 48 states. In each of the 12 states listed, the land area required to produce 10 percent of electricity demand with wind power is well under one percent of the total land area, and never more than two percent of the available windy land area. These estimates indicate that:

- The wind resource potential exceeds by significant margins the electrical energy usage in the United States;
- Adequate, available windy land exists;
- Only a small fraction of the available windy land (1.81 percent) would be required to supply 10 percent of the nation's electrical energy supply, and;
- An even smaller fraction (approximately 0.87 percent) would be required to supply the 10,000 MW of new wind energy generating capacity postulated in this study.

Capital costs: The direct economic impact resulting from installing 10,000 MW of added wind-driven generating capacity includes both immediate and continuing components. Below, Table 2 shows that over the ten-year period from 1997 through 2006, the cumulative installed capital cost of this capacity translates to $7.1 billion of economic activity in the manufacturing, construction, and electrical equipment sectors. (Note, however, that some of the capacity could represent equipment manufactured overseas.) This level of activity is associated only with the manufacture and installation of the added capacity, and not, for example, operating or servicing it.

Table 2. Capital Costs

Year	Capacity Added During Year (MW)	Total Installed Capacity at End of Year (MW)	Assumed Capital Cost (per kW)	Installed Capital Cost (in millions)	Cumulative Installed Capital Cost (in millions)
1996	-	1,750			
1997	100	1,850	$1,000	$100	$100
1998	200	2,050	$950	$190	$290
1999	350	2,400	$900	$315	$605
2000	600	3,000	$850	$510	$1,115
2001	1,000	4,000	$800	$800	$1,915
2002	1,250	5,250	$750	$938	$2,853
2003	1,250	6,500	$700	$875	$3,728
2004	1,500	8,000	$675	$1,013	$4,741
2005	1,750	9,750	$650	$1,138	$5,879
2006	2,000	11,750	$600	$1,200	$7,079

Maintenance costs: There is, in addition, a continuing stream of economic activity associated with the operations and maintenance of these facilities. This stream, shown below in Table 3, gradually increases in value to $89 million per year by 2007. Economic activity associated with maintenance of windfarms would continue throughout the 30-year life of the wind-energy-generating facilities.

Energy Production and Revenues: The values of energy production and revenue resulting from the added capacity appear in Table 4, below. We derived the energy generation values by assuming that all of the wind turbines installed during previous years contributed fully and that only half of the turbines installed during the current year contributed fully. Assuming that the equipment and wind regime yield a 28 percent capacity factor, the added capacity at completion would generate 21.6 billion kWh of electricity annually. At four cents per kWh, this would result in wind-electricity production revenues of $863 million per year continuing over the remaining portions of the 30-year equipment lifetime.

Table 3. Unscheduled and Preventive Maintenance Costs

Year	No. of U & PM Visits/Year	Burdened Labor Cost	Burdened Parts Cost	U & PM Cost/WT	U & PM Cost/WT (cents/kWh)	U & PM Cost for Fleet (in millions)
1997	4	$6,336	$3,750	$10,086	0.55	$0.7
1998	4	$6,336	$3,750	$10,086	0.55	$2.7
1999	3.75	$5,940	$3,516	$9,456	0.51	$6.2
2000	3.5	$5,544	$3,281	$8,825	0.48	$11.7
2001	3.25	$5,148	$3,047	$8,195	0.45	$20.5
2002	3	$4,752	$2,813	$7,565	0.41	$31.8
2003	2.75	$4,356	$2,578	$6,934	0.38	$43.4
2004	2.5	$3,960	$2,344	$6,304	0.34	$54.9
2005	2.25	$3,564	$2,109	$5,673	0.31	$67.2
2006	2.25	$3,564	$2,109	$5,673	0.31	$81.4
2007	-	-	-	-	-	$89.0

Table 4. Energy Production and Revenue

Year	Capacity Added During Year (MW)	Total Capacity End of Year (MW)	Energy from New Turbines (million kWh)	Energy Revenue @ 4 cents/kWh (in millions)
1996	-	1,750	-	
1997	100	1,850	108	$4.3
1998	200	2,050	432	$17.3
1999	350	2,400	1,025	$41.0
2000	600	3,000	2,051	$82.0
2001	1,000	4,000	3,777	$151.1
2002	1,250	5,250	6,206	$248.2
2003	1,250	6,500	8,904	$356.1
2004	1,500	8,000	11,872	$474.9
2005	1,750	9,750	15,379	$615.2
2006	2,000	11,750	19,426	$777.0
2007			21,585	$863.4

Land-use payments: The owners of the land on which the wind turbines are installed would receive a portion of this revenue in payment for the additional use of the land for wind turbines. At 2 percent of the energy production revenue, the land use easement payments would be $17 million per year. Assuming that 400,000 acres are in service, this equates to an average annual payment of $42.50 per acre.[20]

Environmental impacts: Calculating the clean air benefits of wind energy development precisely represents an extremely complex task; it requires matching wind regimes to local energy demand in order to figure the resources (e.g., a nuclear facility, a coal plant, etc.) displaced by the wind facility over time. Nevertheless, while these benefits are hard to calculate exactly, they are clearly large. The state of Texas, for example, emits more CO_2 than all but six foreign nations. Calculating very roughly on a per-kWh basis, we estimate that the added capacity of 10,000 MW would displace annually 15 million tons of CO_2, 140,000 tons of SO_2, and 56,000 tons of NO_X.[21] These represent pollutants that would otherwise have been generated from fossil fuel-fired power plants. In addition, there would be no radioactive or hazardous emissions associated with this renewable energy generating capacity. Finally, in some plausible policy scenarios, owners of low-NO_X or low-CO_2 generating facilities could earn credits that they could then sell to polluters on the open market.

Discussion

The following conclusions follow from this analysis:

- Wind resources in the United States more than suffice to power the 10,000 MW of new wind-energy generating capacity assumed in this study.
- A commitment to installing 10,000 MW of new wind-driven energy generating equipment over 10 years would result in the generation of nearly $8 billion in new economic activity. This could support the creation of thousands of new jobs, some or most of which would occur in the United States.
- Citizens, local and state governments, electric utilities, and other energy providers would receive other benefits not quantified in this study, such as cleaner air, higher tax revenues, and, in some cases, improved voltage support at the end of weak transmission and distribution lines.
- Finally, the added wind-energy generating capacity would produce approximately 21 billion kWh annually without the pollution associated with fossil-fueled power plants.

Of course, these conclusions are sensitive to the assumptions made in the analysis. As we noted before, the analysis in this study was kept as simple as possible in order to keep the analysis general and the methodology clear. In particular, three issues merit further discussion and analysis in future iterations of this study: transmission costs, stable wholesale energy prices, and wind energy import and export markets.

Transmission costs: This study does not consider the potential effects of transmission charges on the overall cost of generating electricity through the use of wind energy. In areas where available wind resources are located a great distance from population or load centers, the cost of building new transmission lines, or of wheeling the energy across existing lines, may be significant. These costs will tend to be higher when the transmission distances are longer. In Texas, for example, the major wind resources are located in the northern and far western parts of the state, while the major load centers of Dallas, San Antonio, Houston and Austin are located in the central, southern and eastern sections. If transmission costs were included in this analysis, they would have two effects. First, if new transmission lines were needed, the installed capital cost of the wind-driven energy generating facilities would increase. Second, if wheeling charges were incurred in delivering wind-generated energy to end users, the cost of that energy would increase in order to compensate for the extra delivery charge.

It should be noted that transmission costs are not unique to wind-generated energy. Any new generating facility, whether powered by fossil fuels, nuclear energy, or some other renewable energy source, must interconnect with the transmission system. Depending on the proximity of the generating unit to end users and on the capital cost of the interconnection, the transmission costs can vary significantly from one facility to another.

[20] EPRI/DOE assumes that land-use payments will fall from 3.0% (+ or -30%) in 1997 to 2.5% (+40% or -30%) in 2005. *Renewable Energy Technology Characterizations*, p. 6-13.

[21] For purposes of comparison, the American Wind Energy Association calculates that installing 30,000 MW of wind nationally by 2010 would avoid the emission of 100 million metric tons of CO_2. AWEA, *Wind Energy and Climate Change* (1997). The U.S. DOE's "Five Lab Study" considers future energy and policy scenarios, and states that "it is probably reasonable to estimate that additional wind capacity will be 8-23 GW [8,000 to 23,000 MW] in 2010. This translates into reductions of carbon emissions of 6-20 MtC [million tons of carbon] relative to the BAU [business-as-usual] forecast for 2010." The study notes that wind penetration and carbon reduction could be much higher (50,000 MW and 28 MtC by 2010) given strong carbon-reduction policies. Interlaboratory Working Group on Energy-Efficient and Low Carbon Technologies, *Scenarios of U.S. Carbon Reductions: Potential Impacts of EnergyTechnolgies by 2010 and Beyond* (1997), pp. 7.19-7.20.

Moreover, the question of transmission charges concerns not so much cost contributions as prices, which vary according to regulatory practice. The principal reason for not considering transmission in this report is that it remains unclear how transmission will be priced in the emerging restructured electric system, and what relationship those prices will bear to the actual cost of transmission. Nevertheless, for purposes of illustration, we do consider in the Texas case study that follows the cost of transmission, given current regulations; our analysis yields transmission prices that add 10 to 15% to the cost of wind power. We stress, however, that actual prices will depend on decisions taken at the federal and individual state level in coming years, and may vary substantially from region to region.

Stable wholesale energy prices: Another of this study's assumptions, that of a constant wholesale wind-electricity price of 4 cents per kWh throughout the 10-year study period, may not be realistic, given the increasing market orientation of the electric utility industry. While it is possible that utilities may still desire to enter into fixed-price contracts for wind-generated power for a variety of reasons, the trends toward more competitive electricity supply markets make this possibility less likely in the next ten years. Rather, wind energy may be required to compete with other power supply options in competitive spot markets. To the extent that wind energy resources are coincident with peak demand periods, wind power may actually be bought and sold in spot markets at rates higher than that assumed in this study. At other times, however, it may be sold for less. In any case, the assumed 4 cents per kWh wholesale market price can be interpreted as an average price, recognizing that market conditions may change rapidly in the future.

Wind equipment import and export markets: Finally, this model does not consider the level of economic activity in import markets that could follow from production of 10,000 MW of new wind energy generating capacity. To provide some perspective on the import volumes possible, Danish sales of wind equipment to the United States during the period of 1981 through 1990 totaled more than $4 billion. Of the 1,400 MW of wind capacity installed in the United States through 1990, about half was of Danish manufacture. This was comprised principally of wind turbine nacelles and blades. Many of the towers were fabricated domestically. At $600/kW for the imported nacelles and blades, this equaled a total export market of $4.2 billion for Denmark.

Some of the equipment needed to generate the 10,000 MW we have described will likely come from foreign firms. However, the manufacturing volumes required may revive dormant interest among U.S. firms, and it will certainly require the deployment by foreign firms of domestic production facilities. Hence, a large fraction of the manufacturing jobs and all of the construction, operation and maintenance jobs will be in the U.S.

III. CASE STUDY: ADDING WIND POWER IN TEXAS

The previous section described the economic and environmental benefits that could be realized through the addition of 10,000 MW of wind-powered electricity generating capacity in the 12 states having the greatest wind generation potential of the contiguous 48 states. These benefits, while positive and attractive, do not consider the impact of adding wind power on customers' electricity bills. In this section, we more carefully consider the rate impact by means of a Texas case study. We focus on Texas because that state has the second most energetic wind resource (only slightly less than North Dakota) and the highest energy consumption among the 12 windiest states. In addition, Texas has been active in assessing the renewable energy resources within the state.[22]

[22] The Texas Sustainable Energy Development Council, organized by Governor Ann Richards in 1993, sponsored research evaluating the characteristics and distribution of wind, solar, biomass, water, and geothermal energy resources in Texas. The analysis also considered the application of distributed energy systems and the capabilities of the electric transmission system. Virtus Energy Research Associates, *Texas Renewable Energy Resource Assessment* (Austin, TX: Virtus, 1995). This document is in two forms, a *Project Summary* and the larger *Survey, Overview and Recommendations.*

Methodology

The method for studying the benefits and rate impacts of adding new wind-energy-generating capacity in Texas resembles that used in the national study in the previous section. Like the national analysis, the Texas study uses a spreadsheet to model the impacts of adding new wind-energy-generating capacity in the state. The Texas model proceeds from a similar set of assumptions as before, but with a few additional economic assumptions that relate to the calculation of ratepayer impacts:

Additional Assumptions in the Texas Case Study

General assumptions	Economic assumptions
• Amount of capacity allocated to Texas	• Average energy selling price • Costs other than generation • Average cost of energy • Energy usage escalation rate • Cost of energy from added wind

The approach begins by dividing Texas' annual electrical energy sales revenues by the total annual consumption to arrive at a selling price averaged over all sources and all rates. We then assume a representative value for wholesale conventional electricity costs in Texas consistent with wholesale market clearing prices and busbar generation costs reported in public references. Then we calculate the ratio of average selling price to representative wholesale cost. The resulting multiplier is applied consistently to wholesale energy from conventional and wind sources. As discussed below, this approach tends to overstate the impact of wind on average rates, but we have chosen to add a measure of conservatism to the analysis. Next, we calculate the difference in retail rates with and without the added wind capacity. On this basis, we arrive at a single illustrative value for the impact on the average rates.

Assumptions

All assumptions from the previous analysis are used in the Texas analysis, with the following exceptions and additions.

Amount of new capacity installed in Texas: We allocate to Texas 3,050 of the 10,000 MW of wind-powered generating capacity assumed to be added in the United States. We arrive at this allocation by taking the average ratio of Texas' wind resource potential and electrical energy consumption compared to the 12 state totals. Among the 12 states with the greatest wind energy potential, 12 percent of that potential exists in Texas. In addition, 49 percent of the energy consumption of these 12 states occurs in Texas. The average of these percentages, 30.5 percent, was the basis for the amount of new wind energy generating capacity installed in Texas: 3,050 MW, or, for purposes of comparison, about 4.1% of Texas' 1996 combined utility and non-utility generating capacity of 74,645 MW.[23] (A total of 4,067 wind turbines rated at 750 kW would provide the required capacity.) While this procedure is indeed somewhat arbitrary, our purpose here is to estimate the rate impact of a large but roughly plausible capacity addition, rather than to predict what size addition would meet future conditions.

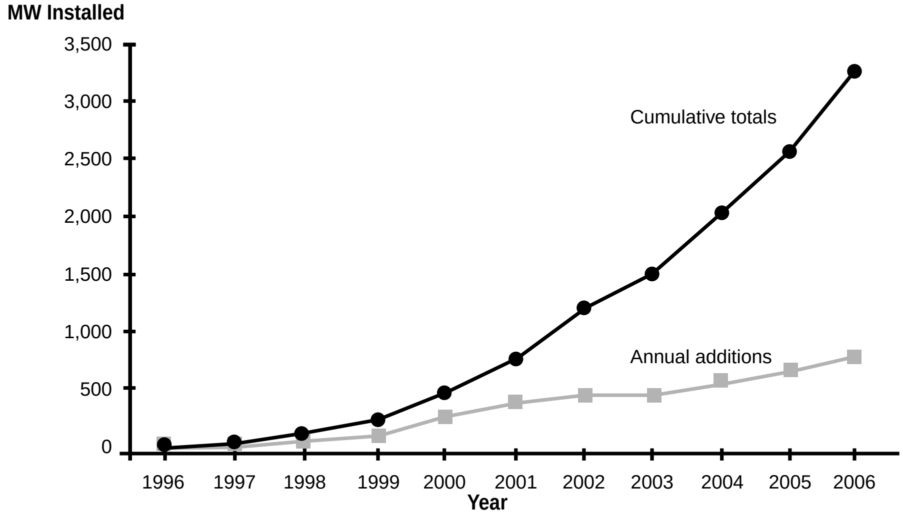
We assume the same installation schedule used in the national analysis, but scaled down for Texas, as shown in Figure 4 on page 16.

Average retail electricity price: We use in our analysis an average retail electricity price in Texas of 6.2552 cents per kWh. We derive this price from state-reported electricity usage, and expense values documented by the Energy Information Administration.[24] By dividing the annual electricity revenues by the annual consumption of kWh statewide, we calculated an average retail electricity price. This price is averaged over all sources, rates, and electric utilities in Texas. The average retail electricity price was held constant over the ten-year study period.

[23] Texas capacity from U.S. Department of Energy, National Energy Information Center at (202) 586-8800.

[24] U.S. Department of Energy, Energy Information Administration, *State Energy Data Report 1993: Consumption Estimates*, DOE/EIA-0214(93)/UC-950 (July 1995); *State Energy Price and Expenditure Report 1993*, DOE/EIA-0376(93)/UC-950 (December 1995). More recent retail figures are somewhat lower: a retail rate of 5.76 cents/kWh for Central Power & Light Co.; 5.69 cents/kWh for Houston Lighting and Power Co.; and 6.10 cents/kWh for Texas Utilities Electric Co. "Wholesale Market Watch March 1998 Profile," *Public Utilities Fortnightly* 136 (15 September 1998), p. 13.

Figure 4. Assumed Installation Schedule for Texas



Average wholesale cost of electricity: We assume for this analysis that the added wind-generated power is interconnected at the transmission-system level, and thus is a source of wholesale electricity. We have assumed a value of 2.5 cents per kWh for the latter, based on current typical market clearing prices in states with open transmission access (such as California). This results in a multiplier (i.e., the ratio of retail to wholesale price) of 2.502, or approximately 2.5. We apply this same multiplier to wind energy costs in calculating retail rate impacts.[25]

The average cost of electricity was assumed to remain constant over the ten-year study period.

Energy consumption: Estimates of the total electrical energy consumption in Texas are derived by escalating the state's 1993 reported energy consumption at 2 percent per year throughout the study period. This is an extremely conservative projection: due to heat and economic growth, electricity consumption in Texas has increased at 3.2% in 1995, 3.7% in 1996, and 5.9% in 1997.[26] The projected energy consumption in Texas is given below in Table 5. The values shown are used in the analysis of price impact.

Table 5. Projected Energy Consumption in Texas

Year	Projected Total Energy Usage (million kWh)
1996	-
1997	270,716
1998	276,131
1999	281,653
2000	287,286
2001	293,032
2002	298,893
2003	304,871
2004	310,968
2005	317,187
2006	323,531
2007	330,002

Note: Based on 1993 Texas electricity consumption of 250,100 million kWh, escalated at 2 percent annually.

[25] Actually, the difference between retail and wholesale rates consists primarily of additive components such as transmission and distribution costs, wheeling charges and administrative costs. Hence if the cost of wind energy exceeds the wholesale cost of conventional sources, then the use of a multiplier will likely overstate the rate impact of wind, because some of those additive costs will either remain constant, or not rise as fast. We have chosen to apply this generous multiplier to the wind increment as a measure of conservatism. Our approach allows for (and may overstate) extra transmission and wheeling costs, which have otherwise been excluded from this analysis. For example, if wind energy were 1 cent/kWh more costly than conventional energy, the multiplier of 2.5 would add 2.5 cents/kWh to the retail rate for wind. In many cases, we expect that 1.5 cents/kWh would be a generous allowance for incremental transmission and/or wheeling costs.

[26] Demand continues to grow at 5.9% in 1998. Personal communication to Wiese from Tom Smith, Public Citizen, Austin, TX (1998).

Cost of new wind-generated energy: The cost of energy from added wind power in Texas is assumed to be 4 cents/kWh. This value is held constant throughout the ten-year study period. The assumed average cost of wind-generated electricity does not account for the 1.5-cent/kWh production tax credit currently available for wind facilities from the federal government.

Results

Land and wind resource availability: Texas would require approximately 190 square miles, or 486 square kilometers, for the addition of 3,050 MW of new wind-energy generating capacity. From Table 1 on page 10 we can see that Texas has 123,700 square kilometers of available windy land area. Developing this capacity would require the use of only 0.39 percent of the available windy land area in the state. Table 1 also shows that the available wind capacity potential in Texas is 136,100 MW. The 3,050 MW of new wind energy capacity assumed to be installed in Texas amounts to just 2.24 percent of this potential.

Capital costs: As shown below in Table 6, the cumulative capital cost of the 3,050 MW in Texas is approximately $2.16 billion.

Maintenance costs: At completion of the installation of the 3,050 MW of wind-turbine capacity in Texas, the ongoing labor and material expenditures for unscheduled and preventive maintenance would be approximately $28 million per year, held constant over the remaining twenty years of the project's life. Table 7, below, shows the year-by-year calculation of maintenance expenses.

Table 6. Capital Costs in Texas Example

Year	Capacity Added During Year (MW)	Total Installed Capacity at End of Year (MW)	Assumed Cost (per kW)	Installed Capital Cost (in millions)	Cumulative Installed Capital Cost (in millions)
1996	10	40			
1997	31	71	$1,000	$30.5	$30.5
1998	61	132	$950	$58.0	$88.5
1999	107	238	$900	$96.1	184.5
2000	183	421	$850	$155.6	$340.1
2001	305	726	$800	$244.0	$584.1
2002	381	1,108	$750	$285.9	$870.0
2003	381	1,489	$700	$266.9	$1,136.9
2004	458	1,946	$675	$308.8	$1,445.7
2005	534	2,480	$650	$346.9	$1,792.6
2006	610	3,090	$600	$366.0	$2,158.6

Table 7. Maintenance Costs in Texas Example

Year	Number of PM Visits per Year	Burdened Labor Cost ($)	Burdened Parts Cost ($)	U & PM Cost per Wind Turbine ($)	U & PM Cost per Wind Turbine (cents/kWh)	U & PM Cost for Fleet ($ million)
1996	4	$6,336	$3,752	$10,088	0.62	$0.2
1997	4	$6,336	$3,752	$10,088	0.62	$0.8
1998	3.75	$5,940	$3,518	$9,458	0.58	$1.9
1999	3.5	$5,544	$3,283	$8,827	0.55	$3.6
2000	3.25	$5,148	$3,049	$8,197	0.51	$6.2
2001	3	$4,752	$2,814	$7,566	0.47	$9.7
2002	2.75	$4,356	$2,580	$6,936	0.43	$13.2
2003	2.5	$3,960	$2,345	$6,305	0.39	$16.8
2004	2.5	$3,960	$2,345	$6,305	0.39	$20.9
2005	2.5	$3,960	$2,345	$6,305	0.39	$25.7
2006						$28.3

Energy production and revenue: As shown below in Table 8, the energy production from the new wind energy generating capacity in Texas reaches 6.6 billion kWh annually. Assuming a sales price of 4 cents/kWh for wind energy, revenues reach $263 million annually when all of the capacity has been installed. The analysis is based on the assumption that only half of the capacity installed in a given year is functional during the year of installation. The remainder is assumed to come on line in the following year.

Land-use payments: At two percent of the wind energy production revenue, land-use easement payments to landowners in Texas would be approximately $5.3 million per year.

Environmental benefits: As explained above, precise calculation of the environmental benefits of wind power lies beyond the scope of this study. However, we estimate that the added wind-driven generating capacity in Texas would displace approximately 4.6 million tons of CO_2, 43,000 tons of SO_2, and 17,000 tons of NO_x.[27] In addition, there would be no radioactive or hazardous emissions associated with this renewable energy generation capacity. In some plausible policy hypotheses, owners of wind capacity could earn credits from avoiding the emission of NO_x and CO_2.

As a further benefit, this capacity would add to the diversity of energy supplies in Texas and would help mitigate the effects of fossil fuel price changes.

Impact on average retail electricity prices in Texas: After full installation of the 3,050 MW of added wind power capacity, using the above assumptions and the values summarized later, and with no economic recognition given to the environmental and employment benefits of wind power to energy providers or ratepayers, the impact on the average rate is 0.075 cents per kWh. For a Texas ratepayer using 12,000 kWh per year, this would amount to an added 75 cents per monthly bill or about 9 dollars annually. Table 9, on page 19, shows the calculations leading to this result.

Table 8. Energy Production and Revenue in Texas Example

Year	Capacity Added During Year (MW)	Total Installed Capacity at End of Year (MW)	Energy Produced by New Wind Turbines (million kWh)	Energy Revenues (in millions)	Projected Total Energy Usage (million kWh)
1996	10	40			
1997	31	71	33	$1.3	270,716
1998	61	132	132	$5.3	276,131
1999	107	238	313	$12.5	281,653
2000	183	421	625	$25.0	287,286
2001	305	726	1,152	$46.1	293,032
2002	381	1,108	1,893	$75.7	298,893
2003	381	1,489	2,716	$108.6	304,871
2004	458	1,946	3,621	$144.8	310,968
2005	534	2,480	4,691	$187.6	317,187
2006	610	3,090	5,925	$237.0	323,531
2007			6,583	$263.3	330,002

[27] Emissions benefits are calculated on the basis of average, not marginal, emissions.

Table 9. Impact on Average Rates in Texas

Year (1)	Wind Capacity Added During Year (MW) (2)	Total Installed Wind Capacity at End of Year (MW) (3)	Energy Produced by New Wind Turbines (million kWh) (4)	Cost of Wind Energy (in millions) (5)	Projected Total Energy Usage (million kWh) (6)	Energy Supply from Conventional Sources (million kWh) (7)	Cost of Energy from Conventional Sources (in millions) (8)	Composite Cost of Energy (cents/kWh) (9)	Average Retail Energy Price With Added Wind (cents/kWh) (10)	Impact on Average Rates (cents/kWh) (11)
1996	10.0	40.0	-	$0.0	-	-	$0		0.0000	0.0000
1997	30.5	70.5	32.9	$1.3	270,716	270,683	$6,767	2.5003	6.2557	0.0005
1998	61.0	131.5	131.7	$5.3	276,131	275,999	$6,900	2.5008	6.2570	0.0018
1999	106.8	238.3	312.7	$12.5	281,653	281,341	$7,034	2.5018	6.2594	0.0042
2000	183.0	421.3	625.4	$25.0	287,286	286,661	$7,167	2.5034	6.2634	0.0082
2001	305.0	726.3	1,152.1	$46.1	293,032	291,880	$7,297	2.5060	6.2700	0.0148
2002	381.3	1,107.5	1,892.7	$75.7	298,893	297,000	$7,425	2.5096	6.2790	0.0238
2003	381.3	1,488.8	2,715.6	$108.6	304,871	302,155	$7,554	2.5134	6.2886	0.0334
2004	457.5	1,946.3	3,620.8	$144.8	310,968	307,347	$7,684	2.5176	6.2989	0.0437
2005	533.8	2,480.0	4,690.6	$187.6	317,187	312,497	$7,813	2.5223	6.3107	0.0555
2006	610.0	3,090.0	5,925.0	$237.0	323,531	317,606	$7,940	2.5276	6.3239	0.0687
2007	0.0	3,090.0	6,583.3	$263.3	330,002	323,418	$8,086	2.5300	6.3301	0.0749

The calculations and data shown in Table 9 result from the following procedure:

Step 1
The procedure begins by projecting the total energy usage in Texas for each year (column 6). These values were shown previously in Table 5, Projected Energy Consumption in Texas. This total annual energy usage is assumed to be supplied by a mixture of conventional and wind sources.

Step 2
Calculated next is the contribution to the total annual energy usage from the increasing capacity of wind turbines added annually during the study period, with full operational capability achieved in 2007 (column 4). These values are the same as those shown previously in Table 8, Energy Production and Revenue in Texas Example, above. Two uses are made of these wind energy contributions.

Step 3
For the first use, the wind energy contribution (column 4) is subtracted from the total annual energy usage values (column 6) to arrive at the contribution each year from the conventional sources (column 7). The total cost of the conventional source contribution (column 8) is then calculated using the assumed constant cost of energy value 2.50 cents per kWh.

Step 4
In the second use, the total cost of the wind energy contribution (column 5) is calculated from the wind energy contribution (column 4), assuming a constant cost of 4.0 cents per kWh.

Step 5
The cost of energy from conventional (column 8) and wind (column 5) sources are then summed to arrive at a total cost of energy for each year. When divided by the total annual energy usage (column 6), we arrive at the composite cost of energy in cents per kWh (column 9).

Step 6
Then, the composite cost of energy (column 9) is marked up by the multiplier of 2.502. We thus arrive at the composite retail energy price (REP) for each year (column 10).

Step 7
Finally, the assumed conventional retail energy price of 6.2552 cents per kWh is subtracted from the composite retail energy price (column 10) to derive the annual impact on average rates (column 11). Forming the difference completes the comparison.

Composite REP - Conventional REP = Impact on average rates

From the last entry in column 11 of Table 9, we see that *the impact on the average electricity rate of adding the full 3,050 MW of wind in Texas is 0.0749 cents per kWh*. For a Texas ratepayer using 1,000 kWh per month, or 12,000 kWh per year, this would add *75 cents to the monthly bill or about 9 dollars annually*.

Sensitivity to variations in wind and conventional energy costs: The above illustrative example estimates retail electricity rate impacts in the case where wholesale costs are 2.5 and 4.0 cents per kWh for conventional and wind energy, respectively. If the cost differential were 3 cents rather than 1.5 cents, then the rate impact would simply be doubled. However, in that case, the degree of conservatism, as discussed above in Footnote 25, would be even greater; so the actual rate impact would likely be less than double. If the wind and wholesale energy costs become equal, either because conventional costs rise, wind costs drop, or some combination of the two, then our analysis approach would predict a zero impact on average retail rates. To the extent that wind generation incurs incremental transmission and/or wheeling charges, the analysis would understate the retail-rate impact in this case. However the actual impact would almost certainly be less than that calculated in our Table 9 base case.

Discussion

The following conclusions follow from the analysis of our Texas hypothesis:

- Wind resources in Texas are more than adequate to power the 3,050 MW of new wind-energy-based generating capacity assumed in this study.
- The addition of 3,050 MW of new wind turbines in Texas over ten years would result in the creation of over $2 billion in new economic activity, even apart from the activity generated by servicing the wind units.
- The impact on retail electricity prices of such an addition in Texas would be small if the additional costs of the use of wind energy were spread evenly among all energy consumers.

Again, these conclusions are sensitive to the assumptions made in the analysis. As noted previously, the analysis in this study was kept as simple as possible in order to keep the analysis general and the methodology clear. Several issues merit further discussion and analysis in future iterations of this study.

Transmission costs: The issue of transmission costs discussed above in the analysis of the 10,000 MW total greatly pertains to Texas, where the bulk of the wind resource blows far from existing load centers. Texas calculates transmission fees on the basis of a complex formula adopted by the Public Utility Commission of Texas and implemented by the Electric Reliability Council of Texas (ERCOT). Only about 30 percent of the transmission fee reflects the transmission distance; factors determining the remaining 70 percent include the size of the load and scheduling constraints. On average, these transmission fees currently are assessed at about $13,500 per MW annually. Adding these transmission fees to the cost of wind-generated energy calculated for Texas would result in a 15 to 16 percent increase in the cost of wind energy on a per-kWh basis. This is equivalent to increasing the assumed levelized cost of 4 cents/kWh for wind energy to approximately 4.6 cents.

It is currently unclear whether new wind generating capacity in Texas would be subject to transmission fees at all, and if so, what the amount would be. Relative to the average transmission cost of approximately $13,500 per MW per year, the state might actually assess lower transmission costs for new wind-driven, energy-generating facilities. Much of the transmission fee reflects load size, and since windfarms tend to be small and dispersed relative to conventional generation facilities, these costs may tend to be low.

These estimates of transmission costs are based on planned or scheduled loads. Currently, unplanned loads in ERCOT do not pay any scheduling fees. To the extent that wind power facilities qualify as unplanned loads, the issue of transmission fees may be eliminated entirely.

A more likely scenario is that windfarms will qualify for reduced fees under new dynamic scheduling through ERCOT. With dynamic scheduling, facilities schedule an upper and lower load limit for any given time, but do not schedule for transmission of firm loads. The dynamic schedule may be most appropriate for wind facilities.[28]

Again, transmission costs are not unique to wind power. Any new generating facility, regardless of fuel type, must interconnect with the transmission system. The cost of this interconnection can be highly variable, and can increase the total cost of energy from the facility significantly. For these reasons, we do not include transmission costs in our model. Nevertheless, even at 15%, the impact on rates of adding wind capacity remains relatively modest. And, as discussed above in footnote #25, our base case analysis implicitly includes an increment in excess of this amount.

Use of average electricity rates: The result of this model's use of average rates is that the costs of added electric power generated by wind-driven turbines are distributed equally among all kilowatt-hours sold in Texas. The use of average rates has the effect of distributing the cost of new wind energy generating capacity as widely as possible, and with the lowest possible impact on a per-kWh basis. Our rationale for this decision is straightforward: that policy makers' likely rationale for encouraging wind development will be its environmental and economic benefits. Because these benefits will accrue to all Texans, we presume that policy makers will find it appropriate to spread the modest cost as evenly as possible.

Nevertheless, our treatment here has sacrificed some detail for the sake of clarity. Different utilities sell kilowatt-hours at different prices to different customers in different customer groups within the state. The outcomes of complex regulatory and other ratemaking processes determine the allocation of costs among residential, commercial and industrial customer groups. Although an equal distribution of costs among all kWh sold may be a policy goal of these ratemaking processes, it is rarely the only goal, and it is even more rarely the result.

In the future, as the electric utility industry becomes more competitive, regulatory processes to determine rates may become less common, or at least less stringent, allowing utility and energy supply companies more flexibility in assigning specific costs to specific customer groups. Some utilities may choose to recover the costs of renewable energy from voluntary "green power" customers, customers who agree to pay a premium rate for energy derived from renewable sources.

Permitting costs: This analysis did not consider permitting costs. The process of obtaining permits for large-scale installations of wind energy generating capacity in Texas or nationwide may be costly and time consuming, unless streamlined processes can be developed. A consensus-building exercise involving environmental constituent groups could speed the permitting process and decrease costs. Were wind development an important policy goal or even an increasingly important economic activity, it is possible that state policy makers would help organize such a process. Of course, permitting difficulties may be equally severe for proposed powerplants using conventional resources.

[28] Personal communication from Karl Donahue, Electric Reliability Council of Texas (August 1998).

Recommendations for Future Study

The analysis given in this section for expansion of wind-driven electric power generation in the state of Texas illustrates an important point of this paper: the incorporation of substantial numbers of wind turbines presents few significant land use, technical, or economic problems. Indeed, the analysis illuminates the direct economic benefits and shows that the impact on average rates can be small. With further assumptions about the variability of forward fuel prices, recognition of indirect economic impacts (the multiplier effect of the direct economic impacts), and recognition of the environmental benefits, the integration of large amounts of wind-generated power may be shown to result in reduced energy costs. On the other hand, it is possible that, for a particular region, there may exist significant short-term constraints, such as inadequate or inaccessible transmission capacity or an abundance of clean, low-cost fossil fuel sources.

While these and other further assumptions and refinements were not incorporated into the analysis and model presented here, we recognize that they are important and should be included in a more comprehensive analysis. They were omitted because, in any given state or region, there are particular circumstances that do not appear in other locales. Thus to include a more extensive list of factors would complicate the analysis and possibly reduce its general applicability.

In applying variations of this model or others to assess the impact of incorporating large amounts of wind power in a particular state or region, analysts should consider the following refinements:

1. The analysis should integrate the properties, locations and costs of transmission capacity relative to the prospective windfarm locations.
2. The use of averaged rates, as done initially to develop and illustrate the method, is overly simplistic. While analyses can be performed to examine the sensitivity of price impacts to changes in the average costs of energy, a more comprehensive description of sector energy usage and rates within a state, region, or utility service territory may be appropriate.
3. Similarly, the costs of wind power should be compared with those of other generation sources available during the period of comparison.
4. The distinction between cost and price should be maintained with a more comprehensive description of their ratio for electricity suppliers.
5. Since projections of future cost for almost any commodity or product are fraught with uncertainty, a sensitivity analysis should take into account projections of fuel prices, efficiencies of fossil-fueled generation sources and costs of both renewable and conventional generation sources.
6. Some economic consideration should be given to the possibility of more stringent environmental regulations.
7. The availability of energy production, financing and other incentives should be incorporated into the methodology, both for conventional and renewable sources.

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REPP receives generous support from the U.S. Department of Energy, The Energy Foundation, the Joyce Mertz-Gilmore Foundation, and the U.S. Environmental Protection Agency.

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