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ECONOMICS OF ON-SITE WIND POWER

MICHAEL EDESESS

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Solar Energy Research Institute

1536 Cole Boulevard
Golden, Colorado 80401

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Michael Edesess

Solar Energy Research Institute
Golden, Colorado
303-231-1008

INTRODUCTION

Wind power has a long recorded history, starting with water pumping machines in ancient Persia and China, continuing with wind-powered sailing ships and windmills for grinding grain in Europe, for pumping water in the American Midwest, and eventually for generating electricity [1]. Wind power, in terms of its percentage of contribution to total energy use, has been a very significant factor in economies of the past.

In the vast majority of its applications, wind power was used as an intermittent energy source without back-up power. Most of the users probably never thought about what their demand for energy was over time or whether wind power provided an adequate fit for their load profile. They thought not of their demand for energy but of their demand for bread, water, and transportation. Today, people have both the advantage and the disadvantage of being able to think in terms of that abstract concept: energy. Habits have been formed from the use of fossil fuels. People are accustomed to obtain energy on demand. They have come to believe that it is necessary for civilization to be able to obtain energy on demand. Perhaps some time in the future when alternative energy sources are in more widespread use, those applications will be determined that can use energy whenever it is available as easily as using energy on a preset schedule. This obviously will be the most economical way to use energy sources, such as wind power. However, for applications that require energy on a fixed schedule, either back-up or storage systems will continue to be needed.

Wind-electric power rapidly is becoming economical for on-site applications. It will soon be highly competitive with grid electricity or on-site diesel-electric power. The economic comparisons presented here are based on conventional, reasonably conservative assumptions about future increases in materials and energy costs. The energy costing methodology for Wind Energy Conversion Systems (WECS) is the author's simplification of somewhat more complex standard methods. These comparisons indicate that wind power is worth serious consideration for on-site power generation. They show it is worth taking the time required to give wind power detailed consideration, along with the other alternatives, for specific on-site power needs.

ECONOMIC ANALYSIS

Table 1 presents the cost assumptions to be used for the comparison. The costs are not absolutes but averages of prevailing costs. Some WECS currently sell for more than $1,500/kW and some for less.

When wind systems are interconnected with the utility grid, the user often will draw supplemental power from the grid. Charges will have to be levied by the utility for this back-up power. These charges will not necessarily be the same on a per kilowatt-hour basis as the charges for ordinary use. The utility will argue that, although the WECS owner may use less energy than other customers, the utility is still required to maintain substantial generating capacity to provide the WECS owner with reliable back-up power. Therefore, the utility may spread the same demand charge across a smaller energy use, resulting in a higher kilowatt-hour charge for the WECS user [2, Vol. 1].

On the other hand, the WECS user may at times feed surplus energy into the grid. The Public Utilities Regulatory and Policy Act has required that the utility pay for this surplus energy, which we shall call "buy-back." The buy-back rate is likely to be lower than the per kilowatt-hour rate which the utility charges to the average customer, in part because of additional metering and billing charges.

There is not enough experience as yet to identify typical utility rates for back-up and buy-back. Hence, an effort has been made to bracket the possibilities with two rate structure scenarios—one optimistic and one pessimistic. No relative likelihood of these scenarios is implied. The objective is only to bracket the possibilities and to test the sensitivity of WECS cost to utility rate structures. In the optimistic scenario, both back-up and buy-back are priced at 4.5¢/kWh, which is, at this time, roughly the national average price for electricity. In the pessimistic scenario, back-up costs 6¢/kWh while buy-back is priced at 2¢/kWh.

Of course, since average costs have been used, the results will apply to averages. If a potential user is in an area where utility-generated electricity costs much more than 4.5¢/kWh, or if a good wind turbine that costs much less than $1,500/kW can be found, wind power will be yet more favorable. If grid electricity costs less than 4.5¢/kWh, wind power will be less favorable.

To project future costs for the late 1980s, some rather conventional assumptions have been used. Standard capital items, such as diesel generators, are assumed to increase in cost at an inflation rate of 6% per year. The cost of grid electricity is assumed to increase 7.5% per year. The cost of diesel fuel is assumed to increase 9% per year. The time frame used for these increases is eight years, so we are in principle talking about late in the year 1987. The real costs of modern wind energy conversion systems will decline considerably. This is not merely a hope or a goal, but a likelihood. Much of the decrease can be foreseen with virtual certainty due to the economies of mass production. The rest will be due to learning effects in an emerging industry. The cost of storage batteries for WECS will decline as batteries designed specifically for this application are mass-produced.

The value of a wind energy conversion system is highly dependent upon the wind regime in which it is placed. The higher the wind speeds, the more power the turbine will produce. Since wind turbines are generally assigned a "rated power," the power output they produce can be expressed as a capacity factor. Table 2 shows the capacity factor for a WECS rated at a wind velocity of 10 m/s in different wind regimes [3, p. 30]. At a typical site in Florida or Virginia, a WECS rated at one kilowatt will produce about 900 kWh of electricity in a year. At Great Falls, Mont., or Dalhart, Tex., or Nantucket Shoals, Mass., the same wind turbine will produce about 4,600 kWh [4].

Table 3 shows the simple way in which we shall assess the cost of wind energy. It will be assumed that the cost of interest and depreciation, property taxes and liability insurance, operation and maintenance, all added together, will amount to 20% of the original capital cost each year. This annual cost can simply be divided by the number of kilowatt-hours generated in a year to get the per kilowatt-hour cost of energy. By assumption, this shall be the levelized cost of energy for WECS.

The first line of Table 4 gives the current cost of WECS-generated electricity under three different wind regimes. This does not include the cost of back-up or storage. If the WECS is used purely on a stand-alone basis (i.e., if the WECS power is used directly without back-up or storage), this is what it will cost. We shall look later at what happens to the costs when back-up energy is included. As for storage, suppose a battery is used (with no back-up generation). If one insists on 99.9% reliability (i.e., if it is necessary to be 99.9% sure of being able to draw power at any time), then quite a large battery is needed or maybe many batteries. Even at the projected price of the batteries, the cost becomes prohibitive. On the other hand, if one is willing to settle for what is, in effect, interruptible power, then a much smaller battery will suffice. Other varieties of storage that may be appropriate under some circumstances are pumped water storage and compressed air storage. The costs of these techniques are more difficult to estimate, but they of course include the cost of a second turbine.

WECS GENERATION COST COMPARED TO CONVENTIONAL ELECTRICITY COST

The current cost of grid electricity is, by assumption, 4.5¢/kWh. Hence, a wind turbine clearly will cost more in the first year of its life than if power were purchased from the utility. But consider the costs over the entire life of the WECS, assumed to be 20 years. Over that time, if grid electricity costs could be levelized so that the rate were always the same, then it would cost 8.1¢/kWh. (Recall that grid-electricity rates are assumed to increase 7.5% per year and diesel fuel costs increase 9% per year; a 12% discount rate was used.) The levelized cost is still less than the cost of energy for WECS, but getting closer.

The alternative of a diesel generator costs 7.5¢/kWh, which is still less than the WECS-generated power in the first year. If the cost of diesel-generated electricity is levelized, it will be 13.7¢/kWh over the next 20 years. Now it is seen that wind-generated electricity already costs less than diesel electricity at good wind sites. This suggests that wind power is already competitive in remote applications where diesel power is the alternative [5].

Now, something which is unconventional in the energy economics field but widely practiced in the investment field [6] is to "risk-adjust" the projected costs of grid and diesel electricity. The fact is that although the price of grid electricity is expected to rise at 7.5% per year, it might rise at any rate from 2% per year to 13% or more per year; 7.5% is merely in the middle of the range. When confronted with such a wide range of possible future costs, the customer is not likely to think of it as being "just like" a certain cost increase of 7.5% per year. In fact, customers might very well agree to a contract in which the utility guarantees an annual increase of 8%, rather than be subject to the risk that the increase might be 10-13%.

What guaranteed annual increase the customer will accept depends on his aversion to risk. The more risk averse he is, the higher the guaranteed rate increase he will settle for. A risk-adjusted, levelized electricity cost, bypassing an assessment of the risk averseness of the typical utility customer, can be approximated in the following manner. Suppose that annual increase rates may range from 2% to 13%. At the 2% increase, the levelized cost will be 5.2¢/kWh. At the 13% increase, the levelized cost will be 13.2¢/kWh. An average of the high and low levelized costs is 9.2¢/kWh. This estimate of risk-adjusted, levelized cost could easily have been justified differently by assuming an appropriate level of risk aversion on the part of the customer.

The WECS levelized energy cost should really be risk-adjusted, too, but that risk-adjustment has been neglected here. There is comparatively little uncertainty in the future costs of a WECS, once it is bought. The costs of amortizing the capital expenditure are fixed, and the only uncertainties lie in the WECS performance and in the operation and maintenance costs. These uncertainties may be substantial, but they are considerably less for a well-designed WECS than the uncertainties about the future price of fossil fuels. This is what people mean who speak of the "economic independence" they can gain by purchasing a WECS; the WECS will, at least partially, insulate them from the uncertainties in the prices of conventional fuels and central generation capacity. When comparing the 9.2¢ for grid electricity with the 8.4¢ for wind power in good wind regimes, it appears that wind power can be competitive with grid electricity even now. By applying the same risk adjustment technique to the cost of diesel electricity, we obtain a levelized, risk-adjusted cost of 15.2¢/kWh, making wind power at good sites appear superior to that alternative.

To assess the costs of wind power properly when used with back-up, add the costs of back-up and subtract the revenue received from the utility for buy-back. Table 4 provides the costs for wind power with back-up and buy-back. In the poorer wind regimes, these costs are lower than for wind alone because the back-up power is cheaper than the wind power. In the good wind regime, these costs are still close to being competitive with the alternative of grid power only, especially under the optimistic scenario for back-up and buy-back rates. The costs of WECS with diesel back-up simply reiterate the fact that WECS is competitive with diesel in high wind regimes.

The cost comparisons projected about eight years into the future are presented in Table 5. Remember that these costs are stated in terms of future inflated dollars. The cost of WECS generation has decreased in accordance with the decrease in the capital cost. The first-year cost of grid electricity is 8¢/kWh which is greater than the energy cost of WECS in moderate to good wind regimes. Diesel generation is even less competitive. Looking at levelized and risk-adjusted costs for grid electricity and diesel, one notices that wind power apparently has become a viable energy alternative. Even when the cost of WECS with back-up is considered, it is generally significantly less than the conventional alternative. The arrows pointing downward occur whenever the price for buy-back is greater than the cost of WECS generation. In these cases the WECS user could in theory increase his WECS generating power indefinitely, making a profit on the excess, and thereby decreasing his power costs until they become negative.

CONCLUSION

The analyses presented here have included numbers, which many people associate with precision and certainty. Therefore, it is necessary to reiterate that they are no more than rough projections. Different assumptions or ways of looking at things may lead to other conclusions. The chief qualitative conclusion is likely to stand, however: namely, that wind power is fast becoming economically viable and is worth giving serious consideration for on-site power generation.*

Wind power is good for the U.S. economy because the technology imports no oil. It is good for the environment because it burns no dirty fuels. It now appears that wind power also may be good for the pocketbook.

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Table 1. FIXED AND VARIABLE COSTS OF ELECTRICITY ALTERNATIVES

	Now	Later (Late '80s?) (Inflated $)
Wind Energy Conversion System (WECS)[ab]	$1,500/kW	$1,000/kW
Storage Battery	$ 100/kWh	$ 80/kWh
Diesel Generator[a]	$ 250/kW	$ 400/kW
Diesel Fuel	6¢/kWh	12¢/kWh
Electricity from Grid	4.5¢/kWh	8¢/kWh
WECS/Grid Interconnect Scenario 1 (Pessimistic)		
Utility Back-up	6¢/kWh	10.5¢/kWh
Utility Buy-back	2¢/kWh	3.5¢/kWh
WECS/Grid Interconnect Scenario 2 (Optimistic)		
Utility Back-up	4.5¢/kWh	8¢/kWh
Utility Buy-back	4.5¢/kWh	8¢/kWh

[a]Including Installation

[b]Approx. rated wind speed 10 m/sec (22.4 mph)

Table 2. WECS CAPACITY FACTORS

For WECS rated wind speed = 10 m/sec (22.4 mph)

Average Wind Speed m/s (mph)	Typical Locations	Capacity Factor	kWh Generated per kW Rated
4 (8.9)	Florida, Virginia State Averages	10.3%	902
5 (11.2)	Connecticut, Ohio State Averages	18.8%	1,647
6 (13.4)	Nebraska, Iowa State Averages	29.4%	2,575
7 (15.7)	Wyoming State Average; Boston, MA San Francisco, CA	41.0%	3,592
8 (17.9)	Great Falls, MT Dalhart, TX Nantucket Shoals, MA	52.3%	4,581

*This subject and the above analysis will be treated in greater detail in a forthcoming 1979 SERI report [7].

Table 3. SIMPLE WECS COST OF ENERGY CALCULATION

Example		
Given:		
WECS capital cost	=	\$ 1,500/kW
Annual fixed charge rate (includes O&M, taxes, and insurance)	=	20%
Capacity factor	=	25%
Number of hours in one year	=	8,760 h
Then:		

$$\text{Cost of energy} = \frac{100 \times 1{,}500 \times 0.20}{8{,}760 \times 0.25} = 13.7¢/\text{kWh}$$

Table 4. ELECTRICITY ALTERNATIVES:
CURRENT COST COMPARISONS
(¢/kWh)

	Average Wind Speed (m/s)		
	5	6	7
Cost of WECS Generation	18.2	11.6	8.4
Cost of Grid Electricity (First Year)		4.5	
Cost of Diesel Generation (First Year)		7.5	
Cost of Grid Electricity (20-Year Levelized)		8.1	
Cost of Diesel Generation (20-Year Levelized)		13.7	
Cost of Grid Electricity (Levelized, Risk-Adjusted)		9.2	
Cost of Diesel Generation (Levelized, Risk-Adjusted)		15.2	
WECS Interconnected with Grid (Pessimistic Scenario)	12.0	10.8	9.7
WECS Interconnected with Grid (Optimistic Scenario)	10.9	9.9	8.9
WECS with Diesel Back-up	16.5	15.0	13.4

Table 5. ELECTRICITY ALTERNATIVES:
LATER COST COMPARISONS
(¢/kWh)

(Late '80s?)
(Inflated \$)

	Average Wind Speed (m/s)		
	5	6	7
Cost of WECS Generation	12.1	7.8	5.6
Cost of Grid Electricity (First Year)		8.0	
Cost of Diesel Generation (First Year)		14.3	
Cost of Grid Electricity (20-Year Levelized)		14.4	
Cost of Diesel Generation (20-Year Levelized)		26.7	
Cost of Grid Electricity (Levelized, Risk-Adjusted)		16.4	
Cost of Diesel Generation (Levelized, Risk-Adjusted)		29.8	
WECS Interconnected with Grid (Pessimistic Scenario)	17.1	13.8	↓5.6
WECS Interconnected with Grid (Optimistic Scenario)	↓12.1↓	↓7.8↓	↓5.6↓
WECS with Diesel Back-up	24.1	21.5	18.7