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Economic Evaluation of Wind Energy as an Alternative to Natural Gas Powered Irrigation

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High natural gas prices have agricultural producers searching for alternative energy sources for irrigation. The economic feasibility of electric and hybrid (electric/wind) systems are evaluated as alternatives to natural gas powered irrigation. Texas Panhandle and Southern Kansas farms are assessed with a quarter-mile sprinkler system, three crops, and two pumping lifts. Breakeven points identify the price at which conversion from a natural gas irrigation system to an electric or hybrid system is cost effective. Results indicate electricity is a more feasible energy source for irrigation and policy changes such as net metering are necessary to make hybrid systems viable.

Key Words: electricity, irrigation, natural gas, wind energy

JEL Classifications: Q12, Q20, Q42

Increasing natural gas prices have put a strain on the profitability of agriculture in states that have a significant number of natural gas powered irrigation systems. The price of natural gas was relatively stable at around $2 per thousand cubic feet (Mcf) during the 1990s. Since the summer of 2000, however, prices have been volatile and have averaged about $6.46 per Mcf. The average price in 2007 was $7.34, while the average price in 2008 was 22.6% higher at $9.00 (New York Mercantile Exchange, 2008). The increase in natural gas prices has caused many farmers to alter their cropping patterns by changing crop mix, abandoning irrigated acreage, and lowering the amount of irrigation water applied to crops (Guerrero et al., 2006).

Wind energy is an alternative energy source for powering irrigation wells, which producers can consider to mitigate the impact of increasing natural gas costs. Its popularity is increasing due to its renewable nature that increases energy security while reducing pollution. In addition, the cost of wind power has decreased approximately 90% over the past 20 years (American Wind Energy Association, 2005). Wind energy is expanding rapidly in the United States with 45% growth and more than 5,200 megawatts of wind energy generation capacity installed in 2007. The newly installed capacity alone is enough

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to provide annual power needs of 1.5 million American homes (American Wind Energy Association, 2008).

Farmland in the plains states has some of the best wind resources in the country (Union of Concerned Scientists, 2003). Thus, the thought of using wind energy for irrigation is natural for agricultural producers (Crummett, 2009). Texas Comptroller Susan Combs stated, “Investing in our communities through improved energy efficiency in farming operations is a win-win opportunity for state agriculture” (Texas State Energy Conservation Office, 2009). She recently premiered the Texas Agricultural Technical Assistance Program, which was formed to assist agricultural producers in making cost effective, energy efficient choices. Montana State University Extension developed a spreadsheet to help agricultural producers decide if wind energy is financially and economically feasible for their operation (Crummett, 2009). There is interest in wind energy among agricultural producers, however, because of substantial upfront investment costs, producers want to know if it will be economically feasible before making the conversion.

The objective of this study is to evaluate the feasibility of replacing natural gas powered irrigation systems with either electric or hybrid (electric/wind) systems in states that have significant natural gas powered irrigation systems, and furthermore, areas of those states that have sufficient wind to make wind energy possible. In this study, electric systems are powered only by electricity from the grid, while hybrid systems are powered from a combination of electricity generated from a wind turbine and electricity from the grid when wind generated electricity is not available. A feasibility analysis was conducted in order to compare the cost of implementing and maintaining electric and hybrid systems to existing natural gas powered systems. A number of combinations of independent variables such as delivery systems, pumping lifts, locations, crops, wind availability, electric buyback policies, energy balance, and natural gas and electric prices were parameterized. Results of the analysis estimated the points at which it was most cost effective to convert from a natural gas irrigation system to an electric or hybrid system in the case study context. In addition, results under two alternative net metering scenarios, in which wind energy producers can bank excess electricity, are compared with a baseline scenario to analyze the effect of net metering policy incentives.

Study Area

The major agricultural irrigated areas of the United States powered by natural gas include the states of Arkansas, Colorado, Kansas, Nebraska, New Mexico, Oklahoma, and Texas. The total annual natural gas use for these seven states was estimated to be 61,360,000 Mcf with Kansas, Nebraska, and Texas comprising over 90% of the total energy use. Texas and Kansas were chosen for the analysis which account for 60% of natural gas powered irrigation in the seven states and a combined total of approximately 3,000,000 acres irrigated by natural gas powered wells (United States Department of Agriculture–National Agricultural Statistics Service (USDA–NASS), 2003). The study area for the analysis was narrowed further by overlaying state wind maps to determine which specific areas of each state have high quality wind speeds to make wind power generation possible in combination with irrigated agricultural production using primarily natural gas (Kansas Corporation Commission, 2004; Texas State Energy Conservation Office, 2006). The final study area consisted of 20 counties in the Northern Texas Panhandle and 12 counties in Southwest Kansas.

Data Sources and Methodology

There are several steps that were necessary to conduct a feasibility analysis comparing natural gas, electric, and hybrid irrigation systems. First, the well data (pumping lift and flow capacity) were needed to calculate horsepower requirements. The horsepower requirements were then used to calculate energy requirements per acre-inch of irrigation for both natural gas and electricity. Total energy use for irrigating wheat, sorghum, and corn were determined using the energy requirements per acre-inch of irrigation and monthly irrigation water applied. Wind energy production data for the wind turbine were needed for the analysis of the hybrid system. Natural gas and electric prices, as well as buy-back rates, were required to calculate the variable costs of irrigation for each system. Finally, it was necessary to identify the costs of owning and operating each type of irrigation system. The feasibility analysis evaluated the net costs associated with natural gas, electric, and hybrid powered irrigation systems over a 20 year time horizon at various natural gas prices to determine the breakeven price at which it is cost effective to convert from a natural gas irrigation system to an electric or hybrid system.

Well Data and Horsepower Requirements

Well size was determined by the depth from which irrigation water must be pumped (pumping lift) and flow capacity. These two parameters vary considerably across the study area. Two pumping lifts and one flow capacity were chosen to be analyzed for each state. From obtained well data (USDA–NASS, 2003), it was determined that pumping lifts of 200 feet and 500 feet would be reasonable comparatives for both states. However, the flow capacity was much higher for Kansas at 1,200 gallons per minute (GPM) compared with Texas at 600 GPM (Kansas Geological Survey, 2006; New, 2006).

Horsepower (HP) requirements, or the capacities needed for irrigation, were calculated in order to compile energy use for both natural gas and electric powered irrigation systems. Gearhead efficiency (E_{GH}), or the efficiency of the device that reduces motor speed and increases motor torque, was assumed to be 95% for the two states. A gearhead is not required for pumps driven by electric motors due to the use of a vertical hollow line shaft. This gives the irrigation pumps driven by electric motors a 5% gain in efficiency over those driven by natural gas engines. The pump efficiencies (E_P) used, or the degrees of the pumps' hydraulic and mechanical perfection, were 53% for a pumping lift of 200 feet and 66% for a pumping lift of 500 feet (New, 2005). Horsepower requirements were calculated using the following formula:

$$(1) \qquad HP = \frac{GPM \times H_T}{3960 \times E_P \times E_{GH}},$$

where H_T refers to total head, or the equivalent height that irrigation water is to be pumped, in feet. Total head (H_T) was calculated using the following formula:

$$(2) \qquad H_T = PL + \left(\frac{2.31ft}{psi} \times OP\right),$$

where PL is the pumping lift in feet and OP is the operating pressure, or the system pressure at which the pump is operating. A weighted average system operating pressure of 26 pounds per square inch (psi) for Texas and 30 psi for Kansas was determined (USDA–NASS, 2003). There was a large variation in horsepower requirements depending on depth and flow capacity. The calculated horsepower data were used to determine energy use per acre-inch of water pumped.

Energy use was calculated for both natural gas and electricity using the following formulas:

$$(3) \qquad \frac{Mcf}{Acre - Inch} = HP \times \frac{2{,}545BTU}{HP - HR} \times \frac{Mcf}{1{,}000{,}000BTU} \times \frac{1}{E_E} \times \frac{450}{GPM}$$

and

$$(4) \qquad \frac{kWh}{Acre - Inch} = HP \times \frac{2{,}545BTU}{HP - HR} \times \frac{kWh}{3{,}413BTU} \times \frac{1}{E_M} \times \frac{450}{GPM}.$$

Engine efficiency (E_E) was determined to be 19% for a 200 foot lift and 23% for a 500 foot lift, while electric motor efficiency (E_M) was determined to be 90% for both pumping lifts (New, 2005). The engine and motor efficiencies are the relationships between the total energy contained in natural gas and electricity, respectively, and the amount of energy used for irrigation. The amount of natural gas and electricity required for each acre-inch of pumping at the specific depths is shown in Table 1.

Estimated Energy Use and Wind Production by State and Crop

The months in which energy is required for irrigation pumping was based on the respective

Table 1. Energy Use per Acre-Inch for the Study Area

	Texas		Kansas	
Energy Source	200 ft Lift	500 ft Lift	200 ft Lift	500 ft Lift
Natural Gas (Mcf)	0.77	1.13	0.80	1.15
Electricity (kW)	46.52	80.24	48.22	81.60

growing season for each crop (Amosson et al., 2005; USDA–NASS, 2003). The three major crops grown in both Texas and Kansas that were chosen to be analyzed were corn, wheat, and grain sorghum. Texas operates irrigation systems from March to October and the month of December while Kansas irrigates these crops from March through the month of September.

The amount of energy used by state and crop was determined using the distribution of crop growing seasons. The amount of water applied throughout the growing season was calculated by taking the percentage of water applied during each month by the total amount of water applied. Energy use was evaluated for a quarter-mile center pivot irrigation system, which is equivalent to 120 acres. Energy use per acre-inch was multiplied by the total monthly water use for 120 acres to calculate the total energy use for both natural gas and electricity.

Wind production data for Texas and Kansas were calculated with the Hybrid Optimization Model for Electric Renewables (HOMER) software using a three step process (Jimenez, 2006). First, the hourly wind speed data for a reference location was adjusted to the hub height, or the distance from the ground to the center of the turbine rotor. For this study, the power law profile was used to determine the ratio of wind speeds at various heights with the following equation:

$$(5) \qquad \frac{v(z_{hub})}{v(z_{anem})} = \left(\frac{z_{hub}}{z_{anem}}\right)^{\alpha},$$

where z_{hub} is the height of the wind turbine in meters, z_{anem} is the height of the anemometer in meters, v represents the wind speed in meters per second, and α is the power law exponent. Next, the wind turbine's power curve under standard conditions of temperature and pressure was applied to calculate power output and which was adjusted using an air density ratio. The air density ratio is the actual air density (ρ) divided by the air density under standard conditions (ρ_0) shown in the following equation:

$$(6) \qquad \frac{\rho}{\rho_0} = \left(1 - \frac{Bz}{T_0}\right)^{\frac{g}{RB}} \left(\frac{T_0}{T_0 - Bz}\right),$$

where B is the lapse rate, z is the altitude, g is gravitational acceleration, R is the gas constant, and T_0 is standard temperature. Each variable on the right side of the equation is constant with the exception of altitude. Therefore, the air density ratio is a function of altitude alone. The E15 65 kW Wind Turbine™[1] was selected for use in the analysis, which is a popular turbine with a relatively small capacity used mainly for businesses, schools, and remote institutions. This turbine produces approximately 146,842 kilowatt-hours (kWh) per year in Texas and 151,143 kWh per year in Kansas with an average wind speed of seven meters per second (Jimenez, 2006). The difference in wind energy production between locations is attributed to variation in hourly wind speed data.

Monthly irrigation energy usage was plotted with monthly wind power generation for each crop and state to determine which crops had the best fit for being irrigated using wind energy. The wind generation more closely fit the peak power requirements for Texas wheat (spring & fall) than corn or sorghum. There is a spike in energy used for irrigation in Kansas during late June to mid July; whereas, there is a peak in the amount of energy used during August in Texas. Collectively, energy demand for irrigation in the study area peaks during June, July, and August.

Natural Gas/Electric Prices and Buyback Rates

Natural gas prices analyzed in the study ranged from $2.00 per Mcf to $16.00 per Mcf. Electricity prices fluctuate somewhat with natural

[1] Mention of a trademark does not constitute any suitability or endorsement of the product for any purpose or application.

gas prices since natural gas is used a portion of the time in generating electricity, and thus, equivalent electric prices were calculated for each state in order to compare the economic feasibility of irrigating with natural gas versus electric or hybrid systems at each natural gas price level. In addition, the buyback rates were determined for each state.

In Texas, natural gas prices were converted to a base electric price by using a 6-month average natural gas settlement price for the summer months in 2006 of $7.521 per Mcf (New York Mercantile Exchange, 2008) to calculate the fuel factor, which is the charge an electric company adds in order to recover the cost for the fuel needed to generate electricity (Kauffman, 2006). The fuel factor, $0.036, was used to calculate the base retail electricity rate of $0.0835 per kWh. For this analysis, coal prices were held constant. Natural gas power plants account for 50% of electricity generation during the summer months and there are no peak demand charges (Kauffman, 2006). The equivalent electric prices for $2 to $16 per Mcf natural gas prices in Texas ranged from $0.06 to $0.12 per kWh. The buyback rate for electricity in Texas varies based on hourly surplus or shortage. For the purpose of this analysis, however, an average buyback rate of 65% of the electric price was used (Kauffman, 2006). Texas buyback rates ranged from $0.04 to $0.08 per kWh.

Kansas equivalent electric prices were calculated using the fixed and variable costs for generating electricity from natural gas and coal. The wholesale transmission costs are $0.01 per kWh for both natural gas and coal generated electricity. However, the fixed costs of generating electricity are $0.025 per kWh for coal and $0.015 per kWh for natural gas (Miller, 2006). The fuel cost of generating electricity from coal was held constant at $0.02 per kWh while the average natural gas price of $7.521 per Mcf equated to a $0.075 per kWh fuel cost.

Southwest Kansas uses very little natural gas generated electricity. The amount of natural gas generated electricity used in Kansas was calculated as follows. Sunflower Electric has 360 megawatts of coal generating capacity. The peak demand in the summer months was 449 megawatts. It is estimated that an average coal generation shortfall of 66.75 megawatts is experienced (Miller, 2006). Approximately 18.5% of the electricity is generated using natural gas during the summer months assuming all shortfalls are filled with natural gas generating capacity.

The average summer retail electricity rate was $0.08549 per kWh (Wiltze, 2006). Using the percentage of electricity generated from natural gas of 18.5%, the base wholesale cost of electricity was estimated at $0.0633 per kWh. The difference in the retail and estimated wholesale electricity cost was assumed to be the retail maintenance and transmission cost ($0.022). The wholesale cost is adjusted by varying the natural gas fuel cost by $0.01 per kWh for each $1.00 per Mcf change in natural gas price. The equivalent electric prices for $2 to $16 per Mcf natural gas prices in Kansas ranged from $0.08 to $0.10 per kWh. The buyback rate for Kansas is approximately $0.023 per kWh (Miller, 2006) or 150% of the company's voided cost. An average buyback rate of 27% of the electric price was used in this analysis. Kansas buyback rates ranged from $0.02 to $0.03 per kWh.

Fixed and Variable Irrigation Pumping Costs by System

It was necessary to identify the costs of owning and operating each type of irrigation system so that the economic costs of each system could be compared. Expenses related to investment and maintenance of a natural gas engine are shown in Table 2. Lubrication, maintenance, and repair costs increase with pumping depth due to increased horsepower needs and engine size. At a pumping lift of 200 feet in Texas, the investment engine costs are $3,600 and annual lubrication, maintenance, and repair costs are $8.18 per acre. The higher horsepower requirements from a higher flow rate of 1,200 GPM in Kansas versus 600 GPM in Texas necessitated investment in a larger engine. At a depth of 500 feet in Kansas, the investment engine costs are $43,416 and annual lubrication, maintenance, and repair costs are $16.67 per acre (New, 2006).

Expenses related to investment, conversion, and maintenance of an electric motor are shown

Table 2. Fixed and Variable Costs for a Natural Gas Irrigation Engine

	Engine Costs		Useful Life	Salvage Value	LMR	
Lift	Investment ($)	$/acre/ year	Years	% of Investment	Annual ($)	$/acre/ year
Texas						
200′	3,600	7.50	4	10%	982	8.18
500′	20,111	13.97	12	10%	1,340	11.17
Kansas						
200′	20,111	13.97	12	10%	1,340	11.17
500′	43,416	30.15	12	10%	2,000	16.67

LMR = Lubrication, Maintenance, and Repair.

in Table 3. At a pumping lift of 200 feet in Texas, the investment motor costs are $3,594 and annual lubrication, maintenance, and repair costs are $3.13 per acre. At a pumping depth of 500 feet in Kansas, the investment motor costs are $9,538 and annual lubrication, maintenance, and repair costs are $9.83 per acre. The cost to convert from a natural gas powered irrigation system to electric includes the fuse, control panel, pump conversion, and labor and installation and ranges from $6,485 to $18,340 (New, 2006).

Turbine costs were gathered for the E15 65 kW wind turbine. The initial investment for the turbine is $110,000 with a life of 20 years based on equipment wear and no salvage value. Lubrication, maintenance, and repair costs were estimated at $1,700 per year (Jimenez, 2006). Turbine costs were combined with electric motor costs to determine the total fixed and variable costs for a hybrid system. Expenses related to investment, conversion, and maintenance of the system are shown in Table 4. At a pumping lift of 200 feet in Texas, investment costs total $120,080 and annual lubrication, maintenance, and repair costs are $17.29 per acre. At a pumping depth of 500 feet in Kansas, investment costs are $137,878 and annual lubrication, maintenance, and repair costs are $24.00 per acre.

Feasibility Analysis

The net costs associated with natural gas, electric and hybrid powered irrigation systems were evaluated over a 20-year time horizon. The time horizon corresponds to the estimated useful life of the wind turbine used in the hybrid system. The analysis was conducted for two geographic areas, the Northern Texas Panhandle and Southwestern Kansas, where wind speeds appeared to be the most promising for hybrid systems. In each area, two pumping lifts (200 and 500 feet) and three crops (corn, wheat, and grain sorghum) were evaluated. Based on pumpage records, a flow capacity of

Table 3. Fixed, Variable, and Conversion Costs for an Electric Irrigation Motor

	Motor Costs			Useful Life	Salvage Value	LMR	
Lift	Investment ($)	Conversion ($)	$/acre/ year	Years	% of Investment	Annual ($)	$/acre/ year
Texas							
200′	3,594	6,485	5.60	15	10%	375	3.13
500′	6,599	9,421	8.90	15	10%	645	5.38
Kansas							
200′	6,599	9,421	8.90	15	10%	775	6.46
500′	9,538	18,340	15.49	15	10%	1,180	9.83

LMR = Lubrication, Maintenance, and Repair.

Table 4. Fixed and Variable Costs for a Hybrid Irrigation System

	Investment Costs		Useful Life	Salvage Value	LMR	
Lift	Turbine, Motor, and Conversion ($)	$/acre/ year	Years (motor/turbine)	% of Investment (motor/turbine)	Annual ($)	$/acre/ year
Texas						
200′	120,080	51.43	15/20	10%/0%	2,075	17.29
500′	126,020	54.73	15/20	10%/0%	2,345	19.54
Kansas						
200′	126,020	54.73	15/20	10%/0%	2,475	20.63
500′	137,878	61.32	15/20	10%/0%	2,880	24.00

LMR = Lubrication, Maintenance, and Repair.

600 gallons per minute was used in the Northern Texas Panhandle while a flow capacity of 1,200 gallons per minute was used in the Southwest Kansas analysis. All irrigation was assumed to occur with a quarter-mile center pivot sprinkler system.

The costs associated with each system over the 20-year horizon were estimated in 2006 dollars for each scenario (combinations of geographic area, crop, and pumping lift). These costs included: the net expense of converting a natural gas system to electric or hybrid system, irrigation fuel, repairs, and any necessary replacement costs to the systems. The cost stream was modified to reflect the tax benefits associated with depreciation of the equipment. Under the Modified Accelerated Cost-Recovery System (MACRS), businesses can recover investments in certain property through depreciation deductions. The MACRS establishes a set of class lives for various types of property over which the property may be depreciated. Currently, wind property placed in service after 1986 has a property class of 5 years (Database of State Incentives for Renewables & Efficiency, 2007). A tax credit was approximated utilizing the MACRS over 5 years at a 15% marginal tax rate. In addition, the net cost stream was adjusted to account for the credit received from selling electricity back from the hybrid system during periods of the year where excess electricity was generated. These rates corresponded to the current buyback rates existing in the areas studied. Costs incurred after year one of the analysis were inflated 3% annually. The net cost stream was placed in 2006 dollars utilizing a 6% discount rate[2] to allow comparison between systems. Net costs were calculated on a per acre basis and aggregated over 20 years using the following formula:

$$NC = IC + \sum_{t=1}^{20} \Big[\big(LMR_t + T_t + INS_t + REP_t\big)\big(1.03^{t-1}\big) - TS_t + EC_t - R_t \Big] \left(\frac{1}{1.06^t}\right), \tag{7}$$

where NC is the net costs per acre over 20 years, IC is the net investment costs (investment minus the salvage value of the existing system), LMR is lubrication, maintenance, and repair, T is taxes (calculated at 1% of the assessed value using a tax assessment ratio of 0.20), INS is insurance costs (calculated at 0.6% of the investment cost), REP is replacement costs, TS is tax savings from depreciation, EC is energy costs, and R is the revenue from the electricity generated from the turbine and sold to the electric company.

A sensitivity analysis was conducted to estimate the levels of natural gas prices at which changing to electric or hybrid systems became economically feasible. Natural gas prices were parameterized from $2.00/Mcf to $16.00/Mcf, in $2.00 increments. At each natural gas price point, a corresponding price of electricity and buyback rates were estimated based on the

[2] A sensitivity analysis of the discount rate was conducted for rates of 3%, 6%, and 10%. Breakeven prices increase as the discount rate increases. However, the overall conclusions of the analysis are not affected.

electric power generation balance (the percentage of natural gas versus coal used to generate the electricity) within the region. Costs were reestimated for the systems at each pricing point for all scenarios analyzed.

Results under two alternative net metering scenarios are compared with a baseline scenario to analyze the effect of net metering. Net metering is an incentive, which allows consumers to offset their cost of consuming electricity by banking, or essentially storing, excess energy produced until needed for consumption. The baseline scenario projects the prices at which the electric and hybrid systems become more economically feasible with all current incentives considered. The first alternative scenario projects the breakeven prices of natural gas and electricity between the three systems with monthly net metering. Under the monthly net metering scenario, producers are allowed to bank excess electricity generated for a month at a time with the electric company. During that month, the producer is only charged for the net amount of electricity used. The other alternative scenario projects breakeven prices between systems under annual net metering. With the annual net metering alternative, producers can bank excess electricity generated for a full year and are only charged for the net amount of electricity used during that time. Annual net metering provides additional flexibility to the producer as to when they can use their excess of electricity generated with the turbine. Net metering is used as an incentive for the production of wind energy in many states; however, not all electric companies currently participate in net metering.

Results

Cost curves for each system (C1, C2, and C3) for Texas wheat at a pumping lift of 200 feet are presented in Figure 1. C1 represents the cost stream for utilizing natural gas, which is assumed to be the system currently in use. Net costs for converting to electric and associated costs for operating that system over a 20-year time horizon are represented by cost curve C2. C3 corresponds to the expense of converting the natural gas system to a hybrid system including operational costs over the 20-year life of the turbine. Each cost stream was evaluated for the different combinations of natural gas prices and corresponding electric prices. Points where the cost curves cross indicate the level of natural gas and corresponding electric prices where conversion to the electric or hybrid powered systems becomes economically feasible. Prices at which cost streams intersect for the baseline and two alternative net metering scenarios are given in Table 5.

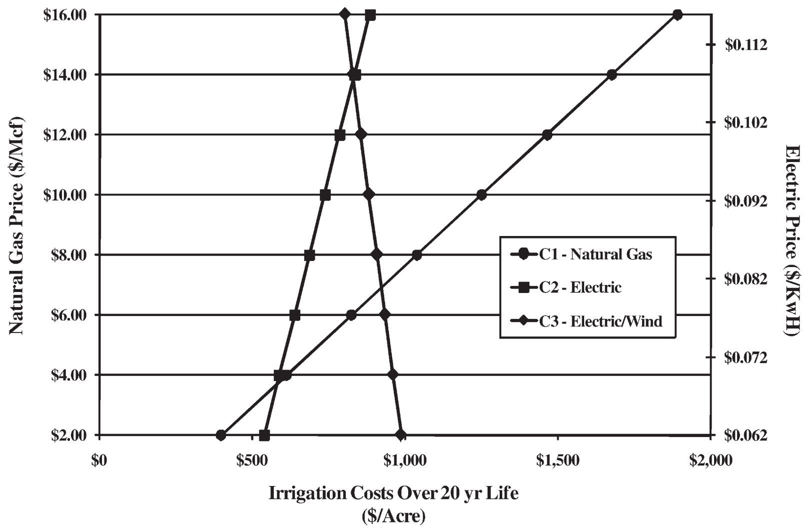

Figure 1. Natural Gas, Electric, and Hybrid Irrigation Costs for Texas Wheat at a 200 Foot Lift

Table 5. Breakeven Prices for Conversion to an Alternative Energy Irrigation System

	Texas			Kansas		
	Natural Gas to Electric	Electric to Hybrid	Natural Gas to Hybrid	Natural Gas to Electric	Electric to Hybrid	Natural Gas to Hybrid
	$/Mcf	$/kWh	$/Mcf	$/Mcf	$/kWh	$/Mcf
	Baseline Scenario					
200′						
Corn	3.9130	0.1073	6.1289	4.6867	0.1860	8.4873
Wheat	3.6986	0.1079	6.9097	4.6695	0.1894	8.9143
Sorghum	3.6986	0.1095	7.0105	4.6695	0.1927	8.9760
500′						
Corn	5.0720	0.1073	6.5724	5.4601	0.1860	8.1744
Wheat	4.9352	0.1079	7.1609	5.4212	0.1894	8.4601
Sorghum	4.9352	0.1095	7.2413	5.4212	0.1927	8.5044
	Monthly Net Metering					
200′						
Corn	3.9130	0.1017	5.8778	4.6867	0.1530	7.7817
Wheat	3.6986	0.0959	6.1102	4.6695	0.1449	7.8284
Sorghum	3.6986	0.1013	6.4858	4.6695	0.1549	8.1177
500′						
Corn	5.0720	0.1013	6.3605	5.4601	0.1513	7.6328
Wheat	4.9352	0.0926	6.3182	5.4212	0.1379	7.5130
Sorghum	4.9352	0.1013	6.8210	5.4212	0.1520	7.8280
	Annual Net Metering					
200′						
Corn	3.9130	0.0837	4.9086	4.6867	0.0889	5.2542
Wheat	3.6986	0.0935	5.9265	4.6695	0.0948	5.6691
Sorghum	3.6986	0.0935	5.9265	4.6695	0.0948	5.6691
500′						
Corn	5.0720	0.0757	5.1639	5.4601	0.0735	4.9975
Wheat	4.9352	0.0818	5.5829	5.4212	0.0735	4.9194
Sorghum	4.9352	0.0818	5.5829	5.4212	0.0735	4.9194

Overall, the crop grown did not affect results significantly regardless of region under the base scenario. In general, wind generation patterns for corn and sorghum did not match irrigation energy needs. Peak irrigation demand for these crops occurs during the summer and far exceeded the wind energy generated during that time period. Wind generation more closely fit the peak power requirements for wheat (spring and fall).

In Texas at the 200 foot lift, it becomes economically feasible to switch from natural gas to electricity at rates above $3.70 per Mcf (Table 5). Conversion to electricity becomes beneficial at natural gas prices above $4.94 per Mcf at the deeper 500 foot lift. In Kansas, conversion to electricity becomes feasible at $4.67 per Mcf and $5.42 per Mcf at the 200 and 500 foot lifts, respectively. The hybrid system becomes cost effective in replacing natural gas powered systems between $6.13 and $8.98 per Mcf depending on crop, pumping lift, and region. It was difficult for the hybrid system to recapture the investment in the wind turbine to become economically feasible relative to a conversion to electric only. In Texas, the price of electricity must exceed 10.7 cents per kWh before the hybrid system becomes economically advantageous as only an average of about 15% of the electricity generated from wind could be used for crop irrigation. In Kansas, the hybrid system never becomes feasible compared with electric given the price range considered under the base scenario because the electric buyback rates are not high enough to overcome the initial investment cost. In addition, an average of only about 10% of the electricity generated from wind could be used for crop irrigation.

A monthly net metering policy improves the economic viability of hybrid systems. Wheat has an advantage compared with the other crops grown due to the irrigation pattern closely following wind production. In Texas, the hybrid system becomes feasible compared with the electric system at 9.6 cents per kWh at the 200 foot lift and 9.3 cents per kWh at the 500 foot lift. The hybrid system still does not become feasible compared with electricity in Kansas given the prior analyzed scenario. The average percentage of electricity generated from wind that could be used toward crop irrigation increased under the monthly net metering scenario to 34% and 27% for Texas and Kansas, respectively.

An annual net metering policy further improves the economic viability of hybrid systems. Corn is the optimal crop under this scenario because it requires the greatest amount of irrigation. In Texas, the hybrid system becomes feasible compared with the electric system at 8.4 cents per kWh at the 200 foot lift and 7.6 cents per kWh at the 500 foot lift. However, at the 500 foot lift for corn in Texas, both the electric and hybrid systems become feasible relative to natural gas at approximately the same point. The electric system becomes preferred to natural gas at $5.07 per Mcf while the hybrid system becomes feasible at $5.16 per Mcf. There are negligible differences in price intersections of the cost curves for the two regions under the annual net metering scenario. In Kansas, the hybrid system becomes feasible compared with electric at 8.9 cents per kWh at the 200 foot lift. At the 500 foot pumping lift in Kansas, the hybrid system is preferred to the electric system at all price levels for all crops grown. The hybrid system becomes optimal at natural gas prices above $4.92 per Mcf. The average percentage of electricity generated from wind that could be used toward crop irrigation increased greatly under annual net metering scenario to 75% and 86% for Texas and Kansas, respectively.

Conclusions

The results of the analysis indicate that switching from natural gas irrigation systems to electric powered irrigation systems is currently the best energy strategy for agricultural producers to enhance profits in the context of the study. Policy incentives such as monthly or annual net metering are needed to make hybrid systems a realistic alternative to natural gas powered irrigation. In addition, the advancements in technology could help to reduce the costs of wind power, and specifically the investment cost for wind power, even further.

Further research is needed to identify alternative scenarios where hybrid systems are economically viable. Different combinations of buyback rates and government assistance programs, as well as the impact of the power generation balance should be evaluated. Further analysis of these factors will provide a better projection for which additional wind energy scenarios could be economically desirable options for the irrigation market.

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