OPTIMUM NUMBER OF WIND TURBINES CUSTOMER-SIDE IN THE STATE OF KANSAS USING HOMER

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Michelle Lim

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The following faculty members have examined this final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Electrical Engineering.

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Ward Jewell, Committee Chair

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Asrat Teshome, Committee Member

____
Bayram Yildirim, Committee Member

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ABSTRACT

This research primarily is in finding the optimum number of wind turbines in the state of Kansas customer-side. Three different areas, with different annual average wind speeds in Kansas were studied: South Kansas, Wichita and Topeka, with decreasing annual wind speeds respectively. Various other factors such as different customer load demands, implementation of carbon taxes and a range of power prices were part of the study. Research was simulated using HOMER program, which was developed by the National Renewable Energy Laboratory. It was found that not only an increase in wind speed but size of load will increase the optimum number of wind turbines. The addition of carbon taxes prove very useful in determining the economic viability of having wind turbines in an optimal power system. A small study on the addition of battery storage in a wind system was confirmed to have no substantial effect on it.

This thesis ultimately provides concrete values on the economic viability of having wind turbines in small energy systems.

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LIST OF ABBREVIATIONS / NOMENCLATURE

WT	Wind Turbines
CO_2	Carbon Dioxide
NPC	Net Present Cost
COE	Cost of Energy
Avg	Average
V	Windspeed
CT	Carbon Tax (or Carbon Penalty)
CF	Capacity Factor

LIST OF SYMBOLS

°	Degree
#	Number

CHAPTER 1

INTRODUCTION

Without a doubt, there is a growing concern worldwide about global warming, which is primarily linked to the emissions of green house gases (GHG) such as carbon dioxide. GHG emission is a result of the combustion of fossil fuels that powers the steam-powered generators. The highest energy consumption comes from the United States and 92% of it comes from steam power generation [1].

From an effort to reduce the current emissions of GHG, many forms of sustainable and renewable forms of electric power generation were and still are being developed. One such form of generation stems from the wind. A wind turbine basically transforms the “kinetic energy of the wind into mechanical or electrical energy” [1].

Wind energy is a form of carbon-free electric power generator. Discounting the effects of manufacturing and transportation of a physical wind turbine, a wind turbine produces electricity without any GHG emission.

There is also increasing pressure for governments worldwide to install new energy and environmental policies that will help develop renewable and sustainable sources of energy. Also, fluctuations on the prices of fossil fuels on the global energy market led to much development and implementation of renewable energy [2]. The United States is an example of a country ready to advance its renewable energy portfolio.

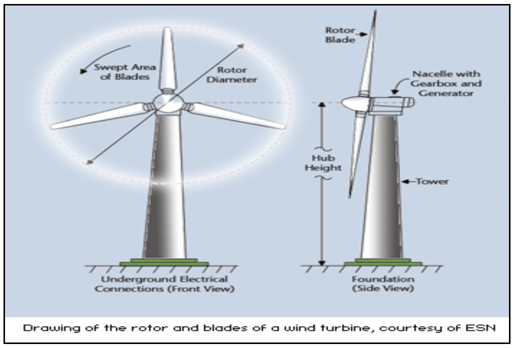
This leads us to the focus of this thesis. This project is mainly funded by a Department of Energy grant concentrating on sustainable energy (specifically wind energy) in the state of Kansas. This thesis primarily centers on the finding of the optimum number of wind turbines at three different geographic areas in the state of Kansas.

CHAPTER 2

LITERATURE REVIEW

The state of Kansas is ranked third (with a potential of $1{,}070\times10^9$ kWh of power by wind alone) amongst the list of top potential “wind-producing” states in the United States. It is also estimated that energy from the wind could supply up to 20% of the United States load demand [1]. However, as with all things too good to be true, this statement could be misleading. The variability of wind becomes a limit on the amount of electricity it could generate. Therefore, wind energy alone is not the sole alternative of energy. “Solution wedges” [3] comprised of a variety of methods (e.g. solar power plants, hydroelectric plants, biofuels, etc) used in conjunction with each other would help significantly in reducing the necessity of conventional steam-powered power plants.

The three-bladed wind turbine (see Figure 1) is the most common of wind turbines. It is made up of the rotor (blades and rotor hub), nacelle, tower and various electrical control equipment. The blades are designed (usually three) based on concepts similar to airfoils on aircrafts for aerodynamic efficiency. These blades then drive the shaft located in the nacelle. The shaft in turn drives the gearbox transmission and generator, which converts the “kinetic energy from the rotor into electrical energy.” [1, 2]



Drawing of the rotor and blades of a wind turbine, courtesy of ESN

Figure 1 Three-Bladed Horizontal Wind Turbine [4]

As stated in chapter 1, wind energy is variable and therefore poses possible problems “regarding its integration to the grid” [5]. However, it has been estimated that up to 10% of wind energy generation transmitted to the grid would not create any disruptions. Since, the wind turbine is dependent on so intermittent a source; it does not run at its full rated power output all the time. Therefore, the output of a wind turbine is described by its capacity factor (CF), which is the wind turbine’s average output generation divided by its nameplate capacity. The average CF of a wind turbine is between 30%-40% [3].

As attractive as it sounds to have a free source of energy such as the wind, the cost/kWh of a wind turbine is much higher than that of power prices generated from fossil-fueled generators. The investment costs (including capital cost and auxiliary costs for construction and grid connection) [6] are high.

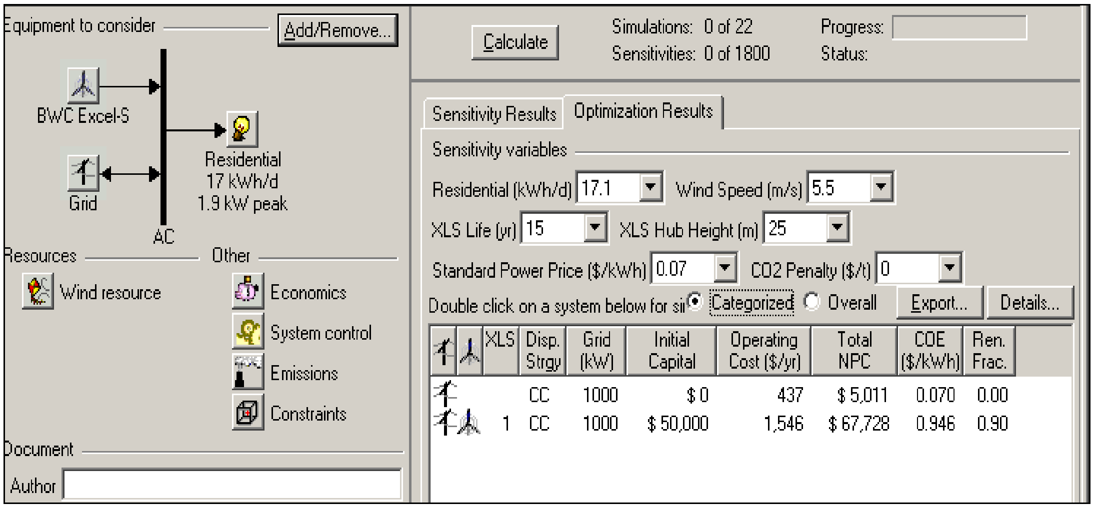
This leads us into the main substance of this research, which is finding out the factors that go into having an economically efficient power system with the optimal number of wind turbines.

CHAPTER 3

METHODOLOGY

3.1 HOMER Software

HOMER, from the National Renewable Energy Laboratory is the main software utilized in this research. It analyses specific power systems that includes both optimization and sensitivity values. Although HOMER is capable of simulating various power systems, this research concentrates only upon integrating an optimum number of wind turbines with an existing power grid. Three small cases are also simulated for systems with both wind turbines and battery storage.



Simulations: 0 of 22
Sensitivities: 0 of 1800

Residential (kWh/d) 17.1
Wind Speed (m/s) 5.5
XLS Life (yr) 15
XLS Hub Height (m) 25
Standard Power Price ($/kWh) 0.07
CO2 Penalty ($/t) 0

Double click on a system below for si ● Categorized ○ Overall

		XLS	Disp. Strgy	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
			CC	1000	$ 0	437	$ 5,011	0.070	0.00
		1	CC	1000	$ 50,000	1,546	$ 67,728	0.946	0.90

Figure 2 Screenshot of HOMER Program

Figure 2 shows a screenshot of the HOMER program with the optimization results for a sample scenario. Since analysis of this research centers mainly upon wind energy, the equipment for consideration are only wind turbines, the electric grid and in the case of battery storage, only one battery. All of these would supply an electrical load demand.

Another input resource is the average monthly wind speed values. HOMER would "synthesize" [1] monthly wind speed data into hourly values for a year. Various other factors or sensitivity variables can be introduced into the system using this program, such as fiscal carbon penalties, physical caps on emissions and other similar constraints. Simulation data for HOMER was taken from numerous sources. The information needed for simulating cases in this research came from different sources and is reported below.

3.2 Load Data

The electrical load demand data was taken from the New Hampshire Electric Co-Op website [7]. These are hourly load data for the year 1997 for three types of different customers: residential, large commercial and small business load data. Although these data are not recent and taken in another state, it is assumed to be relevant in 2007 and Kansas. The residential load is for one customer with an average of 17 kWh/day and 1.9 kW peak. For simulations done with HOMER, the residential load is done for one customer, fifty customers and a hundred customers. For fifty customers, the average load is just 855 kWh/day = 50 x 17 kWh and for a hundred customers, the average load is 1710 kWh/day: 100 x 17 kWh.

The large commercial load has an average load of 147 MWh/day with a 11MW peak. Small business has an average load of 413 MWh/day with a 41 MW peak. Two distinct systems of cost structure were simulated for large commercial and small business loads. One is for a standard cost regardless time of day. The other is to have two separate power prices for both peak and off-peak time of day. Specifically, peak hours were assumed to be from 7 am to 7 pm and peak hour power prices are higher than off-peak hour power prices.

3.3 Wind Speed Data

The annual wind speed data is taken from two sources and from three distinct geographic locations in the state of Kansas. The wind speed from an area in South Kansas [8] has an annual average speed of 6.42 m/s and has the highest wind speed amongst the three locations. Next is taken from the National Climatic Data Center (NDCD) website [9] for Wichita and Topeka. Wichita has an average annual wind speed of 5.45 m/s and Topeka is 4.31 m/s.

It is uncertain the height at which these wind speeds were measured but it is assumed that the wind speeds match those at wind turbine's hub height (40 m for Bergey wind turbines and 80 m for GE wind turbines). However, it is generally assumed that wind speeds are measured at 50 m [3]. It is also worth noting that at higher elevations wind speed increases, thus possibly increasing the amount of wind generated. According to NREL's wind classification scheme [3], South Kansas is a Class-3 wind (fair) whereas Wichita and Topeka fall into a Class-2 wind system (marginal). The implications of these classification data could be later seen in comparing the results between South Kansas and Wichita (or Topeka).

3.4 Wind Turbine Data

Two different wind turbines were used in the analysis. A preference was given to wind turbines that were manufactured or assembled in the United States. Although not a criteria stated by any guideline, this was done to reduce the carbon footprint (caused by transportation) of the wind turbine. For the smaller load demand of residential customers, Bergey wind turbines [6] with rated power of 10 kW (ac) are used. Table 1 below shows the division of cost of a Bergey wind turbine.

TABLE 1

BERGEY WIND TURBINE COST DIVISION

Model	**Rated Power (kW)**	**Height Tower (m)**	**Model ($)**	**Installation ($)**	**Tower ($)**	**TOTAL ($)**	**Approximate $/kW**
Bergey *BWC Excel S*	10	37	30,684	included in model cost	17,200	47,884	4,788.40

For a larger load demand, the GE wind turbine with a rated power of 1.5 MW (ac) is used. However, the cost of a GE wind turbine has not been determined and therefore has just been extrapolated from the costs of current wind turbines in the market. Below table 2 shows three different wind turbines with the respective costs.

TABLE 2

WIND TURBINES AND COST

Model	**Rated Power (kW)**	**Height Tower (m)**	**Model ($)**	**Installation ($)**	**Tower ($)**	**TOTAL ($)**	**Approx. $/kW**
Bergey *BWC Excel S*	10	37	30,684	17,200		47,884	4,788
Entegrity *eW15* (20 m tower)	50	20	135,000	80,000	62,500	277,500	5,550
Entegrity *eW15* (37 m tower)	50	37	135,000	55,000	16,000	206,000	4,120
NorthWind *Northwind 100*	100	37	330,000	200,000		530,000	5,300

As can be seen from table 2, the approximate average $/kW is $5,000/kW. Therefore, it is assumed that a GE 1.5 MW wind turbine would then cost $\frac{\$\ 5{,}000}{kW} \times 1{,}500\ kW = \$\ 7{,}500{,}000$ per turbine, with an assumed error margin of $\pm 7\%$.

3.5 Battery Storage

The battery storage used for the three simulations is a vented lead-acid, tubular-plate, deep-cycle battery model from Hoppecke (10 OPzS 1000 battery) [10]. It has a nominal capacity of 1,000 Ah, nominal voltage of 2 V and costs about $700. A converter is needed to connect the DC (direct current) battery to the AC (alternate current) load. It is assumed that the converter is running at 85% efficiency and at rated power of 1 kW. The lifetime of a converter is assumed to be 20 years.

3.6 Carbon Penalty

A penalty on carbon dioxide emissions has been included in the analysis. A range of five values from no tax (i.e. \$0/ton CO_2) up to \$150/ton CO_2 were simulated with the scenarios. These values were chosen to verify the effectiveness of a carbon tax upon the economic attractiveness of a wind turbine project.

3.7 Power Prices

Power prices are done on a range of lower values, $0.07/kWh to higher values like $0.20/kWh. For residential loads, the power prices are kept at a standard constant that is the same price during peak and off-peak hours. For small business and large commercial loads, simulations are done for both a standard price and peak, off-peak hours.

3.8 Economic Model

The program HOMER performs “energy balance calculations” [10] for the many distinct simulated scenarios. In this research, the electrical system load demand would always be met because all simulated systems are integrated into the power grid (see Figure 1).

HOMER will calculate an estimate of the total cost of a configuration over a specified lifetime. It is assumed that all cases simulated have a lifetime of 20 years. The lifetime of a wind turbine is estimated to be 20 years [11] and since the actual lifetime of a power grid is uncertain, the both are made to be the same value.

This research will find the most economical system with the optimum number of wind turbines and in three select simulations, the optimal number combined with a battery storage system. The costs calculated by HOMER include the system's net present cost (NPC in \$), cost of energy (COE in \$/kWh) and an annual operating and maintenance cost (O&M, \$/year). The "cost-effectiveness" of a particular simulated scenario is based on its net present cost [10] on the basis that it is a "more trustworthy" number than that of the COE, which has a mathematical definition that is "arbitrary and disputable" [10]. The formula to find the NPC of a system is shown below [10]:

$$NPC = \frac{\sum annualized \cos t}{CRF(i,\ project\ lifetime)}$$

with CRF = Capital Recovery Factor, i = interest rate (assumed 6% by HOMER).

CHAPTER 4

RESULTS – RESIDENTIAL

4.1 South Kansas Residential

As stated above, the area in south Kansas has the highest average wind speed as compared to Wichita and Topeka. Therefore, this should reflect a power system with a higher number of wind turbines as compared to Wichita and Kansas.

4.1.1 Single Customer

The residential load results for the single customer with an average demand of 17 kWh/day are shown by the two tables (table 3 and 4) below. Table 3 will show results for simulations without a carbon penalty and table 4 is for simulations with a carbon penalty of \$100/ton CO2.

The **bold** font shows the optimum system with the optimum number of wind turbines (the case of zero WT is an optimum system that operates only with the grid). The *italic* font shows for comparison the costs associated with a system with one wind turbine.

TABLE 3

SOUTH KANSAS SINGLE RESIDENTIAL CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price (\$/kWh)	# WT	Operating Cost (\$/year)	NPC (\$)	COE (\$/kWh)	WT kWh Generation (%)
No CT	low wind speed	5.50	0.07	**0**	**437.00**	**5,011.00**	**0.070**	**-**
				1	*885.00*	*60,146.00*	*0.840*	*92%*
			0.20	**0**	**1,248.00**	**14,318.00**	**0.200**	**-**
				1	*1,099.00*	*62,607.00*	*0.875*	*92%*
	average wind speed	6.42	0.07	**0**	**437.00**	**5,011.00**	**0.070**	**-**
				1	*469.00*	*55,380.00*	*0.774*	*96%*
			0.20	**0**	**1,248.00**	**14,318.00**	**0.200**	**-**
				1	*631.00*	*57,235.00*	*0.799*	*96%*

TABLE 3 (continued)

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
No CT	high wind speed	7.00	0.07	**0**	**437.00**	**5,011.00**	**0.070**	**-**
				1	*212.00*	*52,430.00*	*0.732*	*97%*
			0.20	**0**	**1,248.00**	**14,318.00**	**0.200**	-
				1	*349.00*	*54,007.00*	*0.754*	97%

TABLE 4

SOUTH KANSAS SINGLE RESIDENTIAL CUSTOMER WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
With CT	low wind speed	5.50	0.07	**0**	**1,055.00**	**12,099.00**	**0.169**	**-**
				1	*-399.00*	*45,421.00*	*0.634*	*92%*
			0.20	**0**	**1,866.00**	**21,405.00**	**0.299**	**-**
				1	*-185.00*	*47,882.00*	*0.669*	*92%*
	average wind speed	6.42	0.07	**0**	**1,055.00**	**12,099.00**	**0.169**	**-**
				1	*-1,622.00*	*31,401.00*	*0.439*	*96%*
			0.20	**0**	**1,866.00**	**21,405.00**	**0.299**	**-**
				1	*-1,460.00*	*33,256.00*	*0.465*	*96%*
	high wind speed	7.00	0.07	**0**	**1,055.00**	**12,099.00**	**0.169**	**-**
				1	*-2,380.00*	*22,696.00*	*0.317*	*97%*
			0.20	**0**	**1,866.00**	**21,405.00**	**0.299**	-
				1	*-2,243.00*	*24,273.00*	*0.339*	97%

Tables 3 and 4 above are for a single residential load, with and without carbon taxes. It also shows that all optimum cases are without any wind turbine(s), regardless of wind speed and the inclusion of carbon taxes. This is because the initial capital cost of obtaining a wind turbine is approximately $50,000. The NPC value with a wind turbine far exceeds NPC values of one without. There are no capital costs for the grid, only operation and maintenance costs.

Also note that from table 4, the annual operating cost for a system with one wind turbine is a negative. This is because the wind turbine occasionally produces excess energy. And when there is no load demand but with excess energy, this excess electricity is sold back to the grid at a sellback rate of $0.05/kWh. Also, since the wind turbine reduces the carbon dioxide emitted by the system, the carbon penalty is now a carbon reward. Also with an increase in the carbon penalty, the cost of sustaining a system with the grid alone also increases (as the grid obtains its power from fossil fuel burning power plants).

Therefore, at a certain price of carbon tax, it becomes economically efficient to install a wind turbine. Figure 3 below indicates so:

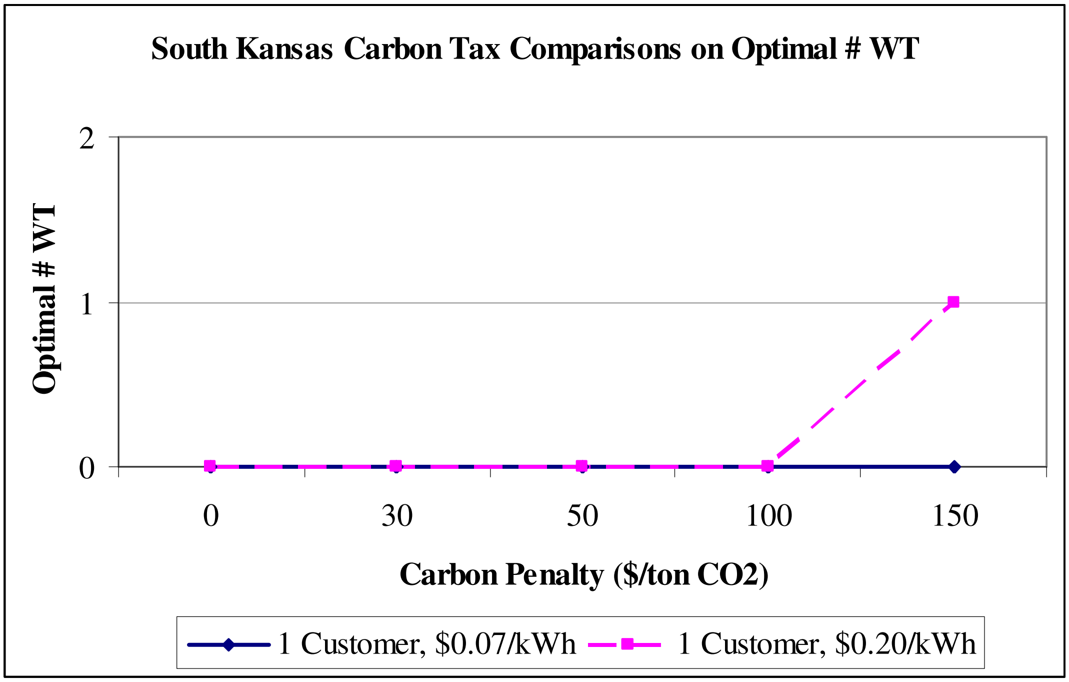


Figure 3 South Kansas Single Customer Carbon Tax Comparison

4.1.2 50 Customers on a Feeder

A feeder with 50 customers on it is now simulated with HOMER. The average load demand for this feeder is $50 \times 17\ kWh/day = 850\ kWh/day$, using the average load demand of a single customer of 17 kWh/day.

Bold font shows optimum system with the optimum number of wind turbines (the case of zero WT is an optimum system that operates only with the grid). The *italic* font shows for comparison the costs associated with a system with one wind turbine.

TABLE 5

SOUTH KANSAS FIFTY RESIDENTIAL CUSTOMERS WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
No CT	low wind speed	5.50	0.07	**0**	**21,845.00**	**250,563.00**	**0.070**	**-**
				1	*22,001.00*	*302,345.00*	*0.084*	*6%*
			0.20	**0**	**62,415.00**	**715,895.00**	**0.200**	**-**
				1	*60,073.00*	*739,034.00*	*0.206*	*6%*
	average wind speed	6.42	0.07	**0**	**21,845.00**	**250,563.00**	**0.070**	**-**
				1	*21,430.00*	*295,802.00*	*0.083*	*9%*
			0.20	**0**	**62,415.00**	**715,895.00**	**0.200**	**-**
				1	*58,443.00*	*720,341.00*	*0.201*	*9%*
	high wind speed	7.00	0.07	**0**	**21,845.00**	**250,563.00**	**0.070**	**-**
				1	*21,075.00*	*291,733.00*	*0.082*	*10%*
			0.20	**1**	**57,430.00**	**708,713.00**	**0.198**	**10%**
				0	*62,415.00*	*715,895.00*	*0.200*	-

TABLE 6

SOUTH KANSAS FIFTY RESIDENTIAL CUSTOMERS WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
With CT	low wind speed	5.50	0.07	**0**	**52,741.00**	**604,931.00**	**0.169**	**-**
				1	*50,994.00*	*634,901.00*	*0.177*	*6%*
			0.20	**0**	**93,310.00**	**1,070,263.00**	**0.299**	**-**
				1	*89,067.00*	*1,071,590.00*	*0.299*	*6%*
	average wind speed	6.42	0.07	**0**	**52,741.00**	**604,931.00**	**0.169**	**-**
				1	*49,617.00*	*619,105.00*	*0.173*	*9%*
			0.15	**5**	**52,890.00**	**856,642.00**	**0.239**	**42%**
				0	*77,707.00*	*891,290.00*	*0.249*	-
			0.20	**7**	**53,506.00**	**963,714.00**	**0.269**	**53%**
				0	*93,310.00*	*1,070,263.00*	*0.299*	-
	high wind speed	7.00	0.07	**0**	**52,741.00**	**604,931.00**	**0.169**	**-**
				1	*48,761.00*	*609,279.00*	*0.170*	*10%*
			0.15	**5**	**47,355.00**	**793,157.00**	**0.222**	**48%**
				0	*77,707.00*	*891,290.00*	*0.249*	-
			0.20	**10**	**31,852.00**	**865,339.00**	**0.242**	**72%**
				0	*93,310.00*	*1,070,263.00*	*0.299*	-

The load of this system is now for 50 customers. By looking at Table 5, it can be seen that only at a high wind speed of 7.00 m/s and high power price of $0.20/kWh, that the optimum system includes one wind turbine. The cost difference between with and without (wind turbine) is merely $715,895-$708,713 = $7,182.

Table 5 also shows that the annual operating cost for a system without any wind turbine(s) is generally higher than a system with wind turbine(s) (except at wind speeds of 5.00 m/s and power price of $0.07/kWh). The reason of the lower annual cost is because the installed wind turbine generates electricity that feeds the customer’s load, thus lowering the cost paid to buy electricity from the grid. At wind speeds of 5.00 m/s and power price of $0.07/kWh, the cost of electricity generated by the wind is higher than the power price to buy from the grid, hence the higher annual operating cost.

Table 6 shows configurations for systems with a carbon penalty of $100/ton CO_2. At low wind speeds (5.00 m/s) and at all simulated power prices, optimal systems would not include any wind turbines. However, at average wind speeds and power prices above $0.15/kWh, optimal systems start including wind turbine(s). Also note that as power prices increase, the optimum number of wind turbines also increase.

It is important too to find the optimum wind turbines corresponding to the different values of carbon taxes. Below is a graph illustrating the lowest and highest energy price with corresponding carbon penalties, ranging from $30/ton CO_2 to $150/ton CO_2. This graph is shown for systems at the average wind speed of 6.42 m/s.

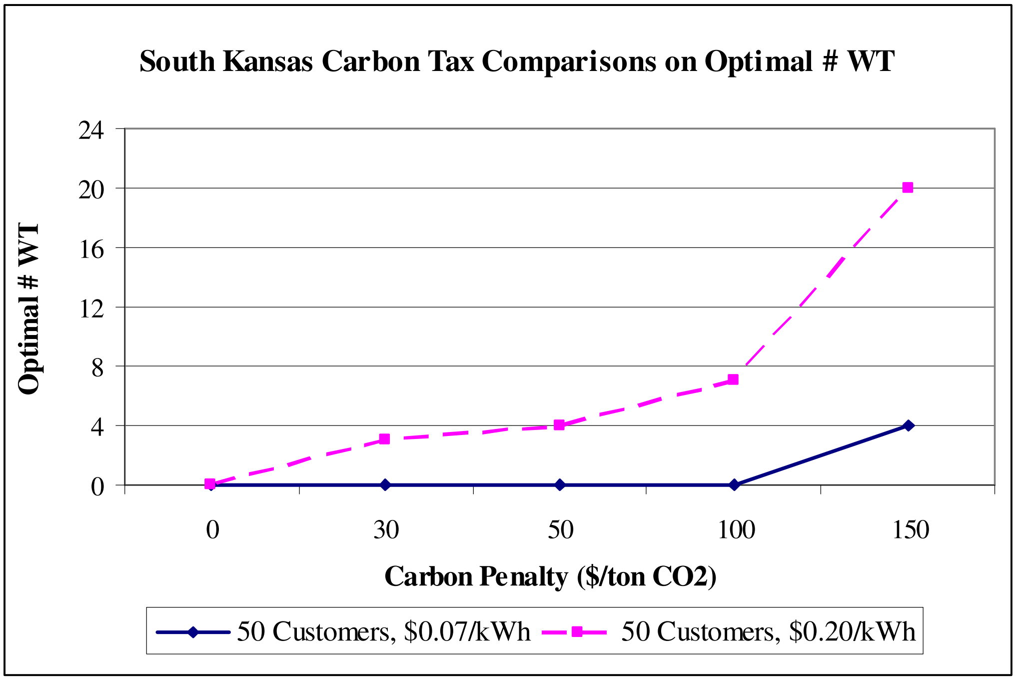


Figure 4 South Kansas Fifty (50) Customer Carbon Tax Comparison

4.1.3 100 Customers on a Feeder

Again, simulations are increased to a hundred customers on a feeder with an average load demand of $100 \times 17\ kWh/day = 1{,}710\ kWh/day$.

TABLE 7

SOUTH KANSAS HUNDRED RESIDENTIAL CUSTOMERS WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
No CT	low wind speed	5.50	0.07	**0**	**43,690.00**	**501,127.00**	**0.070**	**-**
				1	*43,846.00*	*552,909.00*	*0.077*	*3%*
			0.20	**0**	**124,830.00**	**1,431,791.00**	**0.200**	**-**
				1	*122,488.00*	*1,454,930.00*	*0.203*	*3%*
	average wind speed	6.42	0.07	**0**	**43,690.00**	**501,127.00**	**0.070**	**-**
				1	*43,275.00*	*546,366.00*	*0.076*	*4%*
			0.20	**0**	**124,830.00**	**1,431,791.00**	**0.200**	**-**
				1	*120,858.00*	*1,436,236.00*	*0.201*	*4%*
	high wind speed	7.00	0.07	**0**	**43,690.00**	**501,127.00**	**0.070**	**-**
				1	*42,921.00*	*542,296.00*	*0.076*	*5%*
			0.20	**5**	**100,189.00**	**1,399,156.00**	**0.195**	**26%**
				0	*124,830.00*	*1,431,791.00*	*0.200*	-

TABLE 8

SOUTH KANSAS HUNDRED RESIDENTIAL CUSTOMERS WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
With CT	low wind speed	5.50	0.07	**0**	**105,481.00**	**1,209,863.00**	**0.169**	**-**
				1	*103,735.00*	*1,239,833.00*	*0.173*	*3%*
			0.20	**0**	**186,621.00**	**2,140,527.00**	**0.299**	**-**
				1	*182,377.00*	*2,141,854.00*	*0.299*	*3%*
	average wind speed	6.42	0.07	**0**	**105,481.00**	**1,209,863.00**	**0.169**	**-**
				1	*102,358.00*	*1,224,036.00*	*0.171*	*4%*
			0.15	**10**	**105,780.00**	**1,713,284.00**	**0.239**	**42%**
				0	*155,413.00*	*1,782,579.00*	*0.249*	-

TABLE 8 (continued)

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
With CT		6.42	0.20	**15**	**102,912.00**	**1,930,394.00**	**0.270**	**56%**
				0	*186,621.00*	*2,140,527.00*	*0.299*	-
	high wind speed	7.00	0.07	**0**	**105,481.00**	**1,209,863.00**	**0.169**	**-**
				1	*101,501.00*	*1,214,211.00*	*0.170*	*5%*
			0.15	**15**	**71,853.00**	**1,574,143.00**	**0.220**	**63%**
				0	*155,413.00*	*1,782,579.00*	*0.249*	-
			0.20	**20**	**63,704.00**	**1,730,678.00**	**0.242**	**72%**
				0	*186,621.00*	*2,140,527.00*	*0.299*	-

Table 7 shows configurations without any carbon penalty. At the high wind speed of 7.00 m/s and power price of $0.20/kWh, the optimum system has five wind turbines. Due to the increase in load from that of 50 customers, the optimum number of wind turbines also increase to accommodate the increase in load.

Table 8 shows an equivalent of Table 7 with an added carbon penalty of $100/ton CO_2. At average wind speed of 6.42 m/s and power price of $0.15/kWh, optimal systems start including wind turbines. Note also that with a larger load demand, the annual operating cost of systems without wind turbine(s) is much higher than that of systems with wind turbine(s). For example, take the system at average wind speed of 6.42 m/s and at low power price of $0.07/kW. Although that optimal system is one without any wind turbine(s), its annual operating cost is higher than that of one with a single wind turbine. This is due to the fact of the addition of the carbon penalty of $100/ton CO_2, which penalizes the carbon dioxide emitted by the system.

Like the abovementioned scenarios (single customer and 50 customers), it is important to know at what price of carbon penalty would an optimum system include wind turbine(s). The figure below shows for 100 customers, a graph plotting the carbon tax vs. optimum number of wind turbines.

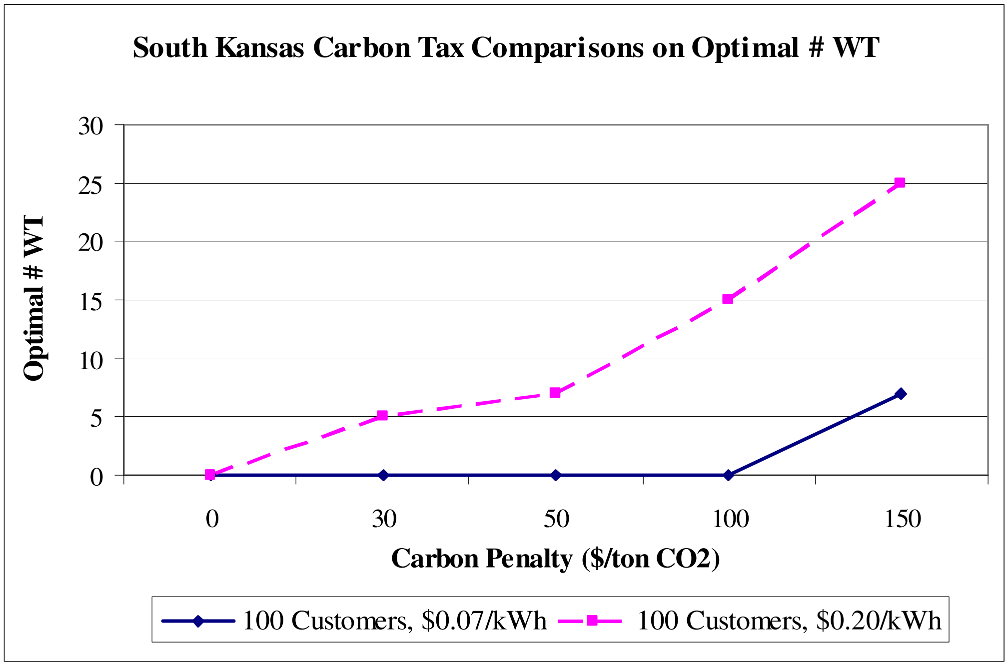


Figure 5 South Kansas 100 Customers Carbon Tax Comparison

4.1.4 Optimum Number of WT with Varying Carbon Taxes

Below are two graphs showing the corresponding optimum number of wind turbines with respect to varying power prices and carbon taxes. Note that only two scenarios are taken into account: one at high wind speed and one at average wind speed. Configurations for a single customer are not plotted because even at high wind speeds and power prices, the optimum system would not include any wind turbines (see Tables 3 and 4).

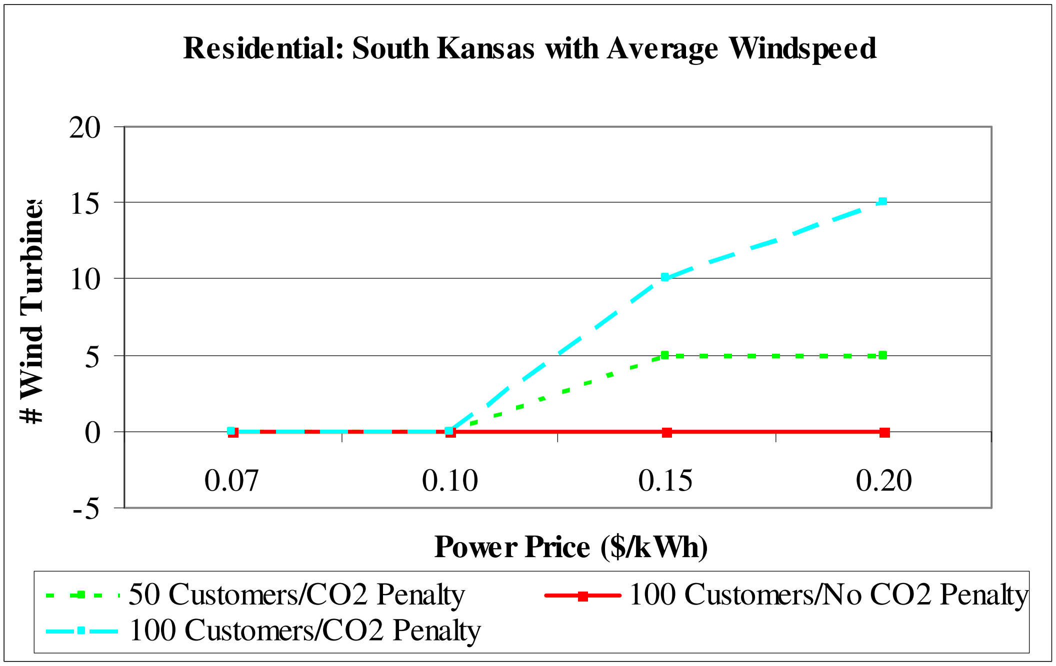


Figure 6 South Kansas Optimum # WT vs. Power Price Varying Carbon Taxes (Avg. V.)

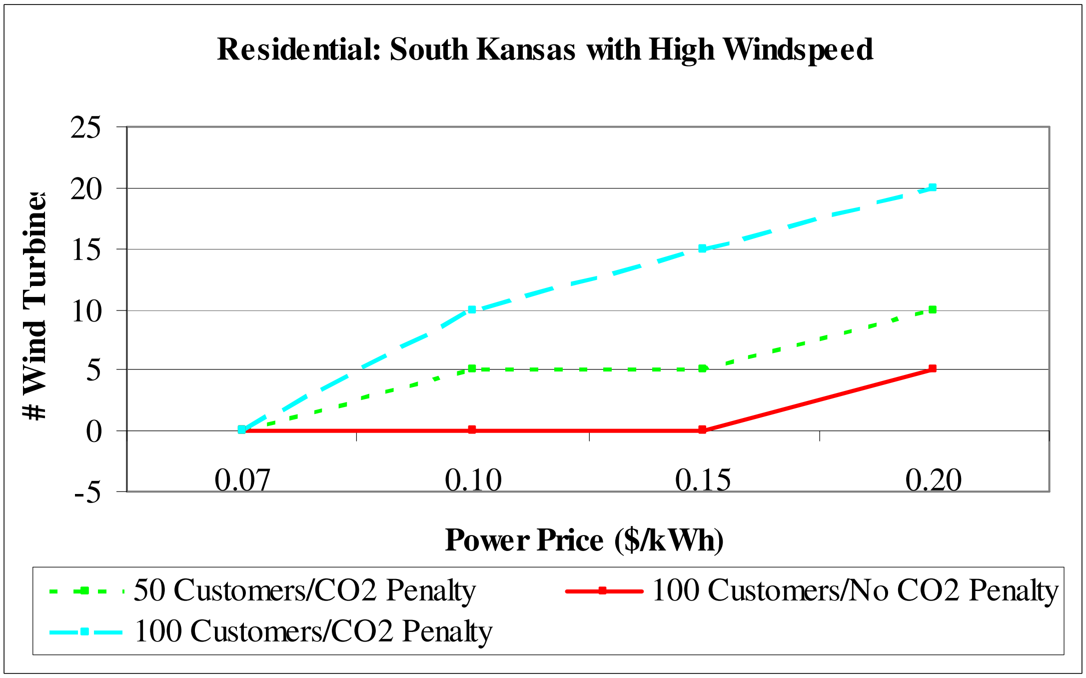


Figure 7 South Kansas Optimum # WT vs. Power Price Varying Carbon Taxes (High V.)

4.2 Wichita Residential

Wichita has a lower average wind speed compared to the area in South Kansas. Simulations were done and it was found that for the simulated configurations, most optimal systems did not include any wind turbine(s). Therefore, results shown below are only for the single customer and 100 customers on a feeder.

4.2.1 Single Customer

The residential load results for a single customer with an average demand of 17 kWh/day are shown by the two tables (table 9 and 10) below. The **bold** font shows the optimum system with the optimum number of wind turbine (the case of zero WT is an optimum system that operates only with the grid). The *italic* font shows for comparison the costs associated with a system with one wind turbine.

TABLE 9

WICHITA SINGLE RESIDENTIAL CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
No CT	low	5.00	0.20	**0**	**1,248.00**	**14,318.00**	**0.200**	**-**
				1	*1,354.00*	*65,530.00*	*0.915*	*88%*
	average	5.45	0.20	**0**	**1,248.00**	**14,318.00**	**0.200**	**-**
				1	*1,124.00*	*62,892.00*	*0.879*	*92%*
	high	6.00	0.20	**0**	**1,248.00**	**14,318.00**	**0.200**	**-**
				1	*846.00*	*59,709.00*	*0.834*	*94%*

TABLE 10

WICHITA SINGLE RESIDENTIAL CUSTOMER WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
With CT	low	5.00	0.20	**0**	**1,242.00**	**14,246.00**	**0.199**	**-**
				1	*-322.00*	*46,307.00*	*0.647*	*88%*
	average	5.45	0.20	**0**	**1,866.00**	**21,405.00**	**0.299**	**-**
				1	*-145.00*	*48,334.00*	*0.675*	*92%*
	high	6.00	0.20	**0**	**1,866.00**	**21,405.00**	**0.299**	**-**
				1	*-893.00*	*39,760.00*	*0.555*	*94%*

Tables 9 show that at all scenarios simulated, all optimum systems are without wind turbine(s). Table 10 is for simulations with an added carbon tax of $100/ton CO2. However, optimum systems also do not include any wind turbine(s). This example serves to show the importance of wind turbine (or wind farm) siting.

Looking at table 10, it can be seen that the operating cost for all three simulations are negative. This is again due to the carbon tax implemented. This tax increases annual cost on a system without a wind turbine because the electricity generated from fossil-fueled power plants. Meanwhile, the yearly operating cost from a system with a wind turbine decreases not only because it saves the cost of utilizing energy from the grid but also it circumvents the carbon tax.

4.2.2 100 Customers on a Feeder

Again, simulations are increased to a hundred customers on a feeder with an average load demand of $100 \times 17\ kWh / day = 1{,}710\ kWh / day$.

TABLE 11

WICHITA HUNDRED RESIDENTIAL CUSTOMERS WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
No CT	low	5.00	0.20	**0**	**124,830.00**	**1,431,791.00**	**0.200**	**-**
				1	*123,270.00*	*1,463,895.00*	*0.204*	*2%*
	average	5.45	0.20	**0**	**124,830.00**	**1,431,791.00**	**0.200**	**-**
				1	*122,518.00*	*1,455,267.00*	*0.203*	*3%*
	high	6.00	0.20	**0**	**124,830.00**	**1,431,791.00**	**0.200**	**-**
				1	*121,568.00*	*1,444,378.00*	*0.202*	*4%*

TABLE 12

WICHITA HUNDRED RESIDENTIAL CUSTOMERS WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
With CT	low	5.00	0.20	**0**	**186,621.00**	**2,140,527.00**	**0.299**	**-**
				1	*183,546.00*	*2,155,256.00*	*0.301*	*2%*
	average	5.45	0.20	**0**	**186,621.00**	**2,140,527.00**	**0.299**	**-**
				1	*182,421.00*	*2,142,358.00*	*0.299*	*3%*
	high	6.00	0.20	**10**	**134,980.00**	**2,048,208.00**	**0.286**	**36%**
				0	*186,621.00*	*2,140,527.00*	*0.299*	*0%*

It can be seen from table 11 that all simulations show no optimal system that includes wind turbine(s). However looking at table 12, at highest wind speed of 6.00 m/s and power price of $0.20/kWh, the optimal system includes 10 wind turbines. It can be implied from observing simulations for a single customer and a hundred that optimal systems for a feeder with fifty customers would yield no optimal systems with any wind turbine(s).

4.3 Topeka Residential

Topeka has the lowest average wind speed (4.31 m/s) of the three different areas studied in Kansas. Simulations were done for similar configurations for South Kansas and Wichita and it is found that all optimal systems did not include any wind turbines. Therefore, only two resulting tables are shown, one at the lowest load and without a carbon penalty. The other is the opposite with the highest residential load of 100 customers and with a carbon penalty.

4.3.1 All Configurations

TABLE 13

TOPEKA SINGLE RESIDENTIAL CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
No CT	low	4.00	0.20	**0**	**124,830.00**	**1,431,791.00**	**0.200**	**-**
				1	*124,719.00*	*1,480,519.00*	*0.207*	*1%*
	average	4.31	0.20	**0**	**124,830.00**	**1,431,791.00**	**0.200**	**-**
				1	*124,323.00*	*1,475,981.00*	*0.206*	*2%*
	high	4.50	0.20	**0**	**124,830.00**	**1,431,791.00**	**0.200**	**-**
				1	*124,066.00*	*1,473,022.00*	*0.206*	*2%*

TABLE 14

TOPEKA HUNDRED RESIDENTIAL CUSTOMERS WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh Generation (%)
With CT	low	4.00	0.20	**0**	**186,621.00**	**2,140,527.00**	**0.299**	**-**
				1	*185,713.00*	*2,180,110.00*	*0.305*	*1%*
	average	4.31	0.20	**0**	**186,621.00**	**2,140,527.00**	**0.299**	**-**
				1	*185,121.00*	*2,173,325.00*	*0.304*	*2%*
	high	4.50	0.20	**0**	**186,621.00**	**2,140,527.00**	**0.299**	**-**
				1	*184,736.00*	*2,168,902.00*	*0.303*	*2%*

Tables above show that all systems regardless of wind speed and power prices do not include any wind turbine. The annual average wind speed at Topeka is too low to generate electricity required for a system with a hundred residential customers.

CHAPTER 5

RESULTS - LARGE COMMERCIAL

5.1 South Kansas Large Commercial

South Kansas has the highest average wind speed compared to Wichita and Topeka. Therefore, this would reflect a power system with a higher number of wind turbines compared to Wichita and Topeka. This has been shown true for the previous residential cases.

Also, the load for a large commercial customer is much larger compared to residential cases with an average daily load of 147 MWh/day with 11MW peak. This would also reflect a larger number of wind turbines compared to the residential cases. As mentioned in 3.7, two different cost structures were simulated for commercial customers. One is a standard power price regardless time of day. The other is for two separate power prices for peak and off-peak hours.

5.1.1 Standard Rates

The rates for this part of the simulation range from \$.07/kWh to \$0.20/kWh. Table 15 shows results for simulations without carbon penalties and table 16 shows results with a carbon tax of \$100/ton CO_2.

TABLE 15

S. KANSAS STANDARD RATE LARGE COMMERCIAL CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	low wind speed	5.50	0.07	**0**	**4,328,764**	**49,650,584**	**0.081**	**-**
				1	*4,189,755*	*55,056,156*	*0.090*	*9%*
			0.20	**5**	**7,911,318**	**125,742,192**	**0.205**	**43%**
				0	*11,291,709*	*129,515,016*	*0.211*	-

TABLE 15 (continued)

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	avg wind speed	6.42	0.07	**0**	**4,328,764**	**49,650,584**	**0.081**	**-**
				1	*4,088,826*	*53,898,508*	*0.088*	*12%*
			0.15	**5**	**5,407,491**	**97,023,488**	**0.158**	**54%**
				0	*8,613,653*	*98,797,920*	*0.161*	-
			0.20	**5**	**6,743,172**	**112,343,648**	**0.183**	**54%**
				0	*11,291,709*	*129,515,016*	*0.211*	-
	high wind speed	7.00	0.07	**0**	**4,328,764**	**49,650,584**	**0.081**	**-**
				1	*4,034,471*	*53,275,060*	*0.087*	*13%*
			0.15	**5**	**4,935,137**	**91,605,632**	**0.149**	**59%**
				0	*8,613,653*	*98,797,920*	*0.161*	-
			0.20	**5**	**6,129,579**	**105,305,784**	**0.171**	**59%**
				0	*11,291,709*	*129,515,016*	*0.211*	-

TABLE 16

S. KANSAS STANDARD RATE LARGE COMMERCIAL CUSTOMER WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
With CT	low wind speed	5.50	0.07	**1**	**9,018,046**	**110,436,280**	**0.180**	**9%**
				0	*9,631,314*	*110,470,416*	*0.180*	-
			0.10	**5**	**7,627,505**	**122,486,880**	**0.199**	**43%**
				0	*11,238,148*	*128,900,672*	*0.210*	-
			0.20	**10**	**7,099,775**	**151,433,856**	**0.246**	**67%**
				0	*16,594,260*	*190,334,864*	*0.310*	-
	avg wind speed	6.42	0.07	**10**	**1,793,724**	**90,573,872**	**0.147**	**77%**
				0	*9,631,314*	*110,470,416*	*0.180*	-
			0.15	**10**	**3,300,357**	**107,854,840**	**0.176**	**77%**
				0	*13,916,204*	*159,617,760*	*0.260*	-
			0.20	**10**	**4,242,002**	**118,655,432**	**0.193**	**77%**
				0	*16,594,260*	*190,334,864*	*0.310*	-

TABLE 15 (continued)

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
With CT	high wind speed	7.00	0.07	**10**	**625,804**	**77,177,920**	**0.126**	**81%**
				0	*9,631,314*	*110,470,416*	*0.180*	-
			0.15	**10**	**1,932,619**	**92,166,984**	**0.150**	**81%**
				0	*13,916,204*	*159,617,760*	*0.260*	-
			0.20	**10**	**2,749,378**	**101,535,152**	**0.165**	**81%**
				0	*16,594,260*	*190,334,864*	*0.310*	-

For table 15, note that at low wind speed of 5.50 m/s and high power price of $0.20/kWh, the optimum number of wind turbines for the system is five wind turbines. However, at wind speeds higher than 6.42 m/s and power price above $0.15/kWh, optimum systems include wind turbine(s). This shows that power prices play a role equally as important as wind speed. Observe also that annual operating costs for systems with wind turbine(s) are lower than that of systems without any turbine(s), which was also shown for residential cases in the residential section. Table 16 shows results for a similar system with an added carbon tax of $100/ton CO_2. Results show that all the optimum systems include wind turbine(s).

Overall, the optimum number wind turbines increases as the load demand also increases, as can be seen from comparing results from the residential and large commercial customers.

5.1.2 Peak & Off-Peak Rates

The rates for this part of the simulation are divided into two periods of the 24-hour day. The peak hours are from 7 am – 7 pm with a power price range of $0.10/kWh - $0.20/kWh. The off-peak power price range is from $0.05/kWh - $0.10/kWh. It is worth noting that when both the power prices for peak and off-peak hours are the same (e.g. $0.10/kWh), it is no different from having a standard constant power rate of $0.10/kWh.

However, simulation results show that the NPC and COE of a constant rate of \$0.10/kWh is different from a peak and off-peak rate of \$0.10/kWh. This discrepancy is not a large one (less than 1%), is an artifact of the optimization technique and therefore neglected. Table 17 shows results for simulations without carbon penalties and table 18 for a carbon tax of \$100/ton CO_2.

TABLE 17

S. KANSAS PEAK RATE LARGE COMMERCIAL CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Peak Price (\$/kWh)	Off-Peak Price (\$/kWh)	# WT	Operating Cost (\$/year)	NPC (\$)	COE (\$/kWh)	WT kWh (%)
No CT	low wind speed	5.50	0.200	0.05	**0**	**6,721,059**	**77,090,016**	**0.125**	**-**
					1	*6,361,763*	*79,968,920*	*0.130*	*9%*
				0.10	**0**	**8,243,114**	**94,547,864**	**0.154**	**-**
					1	*7,749,622*	*95,887,552*	*0.156*	*9%*
	avg wind speed	6.42	0.100	0.05	**0**	**4,409,058**	**50,571,548**	**0.082**	**-**
					1	*4,161,084*	*54,727,300*	*0.089*	*12%*
				0.10	**0**	***5,931,113***	***68,029,392***	***0.111***	**-**
					1	*5,506,322*	*70,157,080*	*0.114*	*12%*
			0.200	0.05	**0**	**6,721,059**	**77,090,016**	**0.125**	**-**
					1	*6,208,909*	*78,215,696*	*0.127*	*12%*
				0.10	**1**	**7,554,148**	**93,645,488**	**0.152**	**12%**
					0	*8,243,114*	*94,547,864*	*0.154*	-
	high wind speed	7.00	0.100	0.05	**0**	**4,409,058**	**50,571,548**	**0.082**	**-**
					1	*4,107,712*	*54,115,128*	*0.088*	*13%*
				0.10	**0**	**5,931,113**	**68,029,392**	**0.111**	**-**
					1	*5,429,157*	*69,272,000*	*0.113*	*13%*
			0.150	0.05	**0**	**5,565,059**	**63,830,788**	**0.104**	**-**
					1	*5,117,723*	*65,699,876*	*0.107*	*13%*
				0.10	**1**	**6,439,168**	**80,856,744**	**0.132**	**13%**
					0	*7,087,114*	*81,288,632*	*0.132*	-
			0.200	0.05	**0**	**6,721,059**	**77,090,016**	**0.125**	**-**
					1	*6,127,733*	*77,284,608*	*0.126*	*13%*
				0.10	**5**	**4,743,029**	**89,402,168**	**0.146**	**59%**
					0	*8,243,114*	*94,547,864*	*0.154*	-

TABLE 18

S. KANSAS PEAK RATE LARGE COMMERCIAL CUSTOMER WITH CARBON PENALTY

		Wind speed (m/s)	Peak Price ($/kWh)	Off-Peak Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
With CT	low wind speed	5.50	0.100	0.05	**1**	**9,088,710**	**111,246,792**	**0.181**	**9%**
					0	*9,711,607*	*111,391,368*	*0.181*	-
				0.10	**5**	**7,621,537**	**122,418,424**	**0.199**	**43%**
					0	*11,233,662*	*128,849,216*	*0.210*	-
			0.200	0.05	**10**	**4,973,773**	**127,048,784**	**0.207**	**67%**
					0	*12,023,608*	*137,909,840*	*0.224*	-
				0.10	**10**	**5,679,850**	**135,147,440**	**0.220**	**67%**
					0	*13,545,662*	*155,367,680*	*0.253*	-
	avg wind speed	6.42	0.100	0.05	**10**	**1,805,199**	**90,705,488**	**0.148**	**77%**
					0	*9,711,607*	*111,391,368*	*0.181*	-
				0.10	**10**	**2,360,322**	**97,072,712**	**0.158**	**77%**
					0	*11,233,662*	*128,849,216*	*0.210*	-
			0.200	0.05	**10**	**2,580,196**	**99,594,648**	**0.162**	**77%**
					0	*12,023,608*	*137,909,840*	*0.224*	-
				0.10	**10**	**3,135,318**	**105,961,848**	**0.172**	**77%**
					0	*13,545,662*	*155,367,680*	*0.253*	-
	high wind speed	7.00	0.100	0.05	**10**	**625,674**	**77,176,432**	**0.126**	**81%**
					0	*9,711,607*	*111,391,368*	*0.181*	-
				0.10	**10**	**1,107,269**	**82,700,288**	**0.135**	**81%**
					0	*11,233,662*	*128,849,216*	*0.210*	-
			0.200	0.05	**10**	**1,296,003**	**84,865,048**	**0.138**	**81%**
					0	*12,023,608*	*137,909,840*	*0.224*	-
				0.10	**10**	**1,777,597**	**90,388,896**	**0.147**	**81%**
					0	*13,545,662*	*155,367,680*	*0.253*	-

Table 17 shows that at wind speeds higher than 6.42 m/s and at peak power price of $0.20/kWh and off peak rate of $0.10/kWh; optimal systems include wind turbine(s). However, table 18 shows that for all configurations, all optimal systems include wind turbines. Comparing both tables 17 and 18 it is obvious that with the addition of a carbon penalty, it becomes more economically viable to include more wind turbine(s) into the system.

Figures 8 and 9 will illustrate the impact of implementing carbon taxes versus the optimum number of wind turbines in South Kansas.

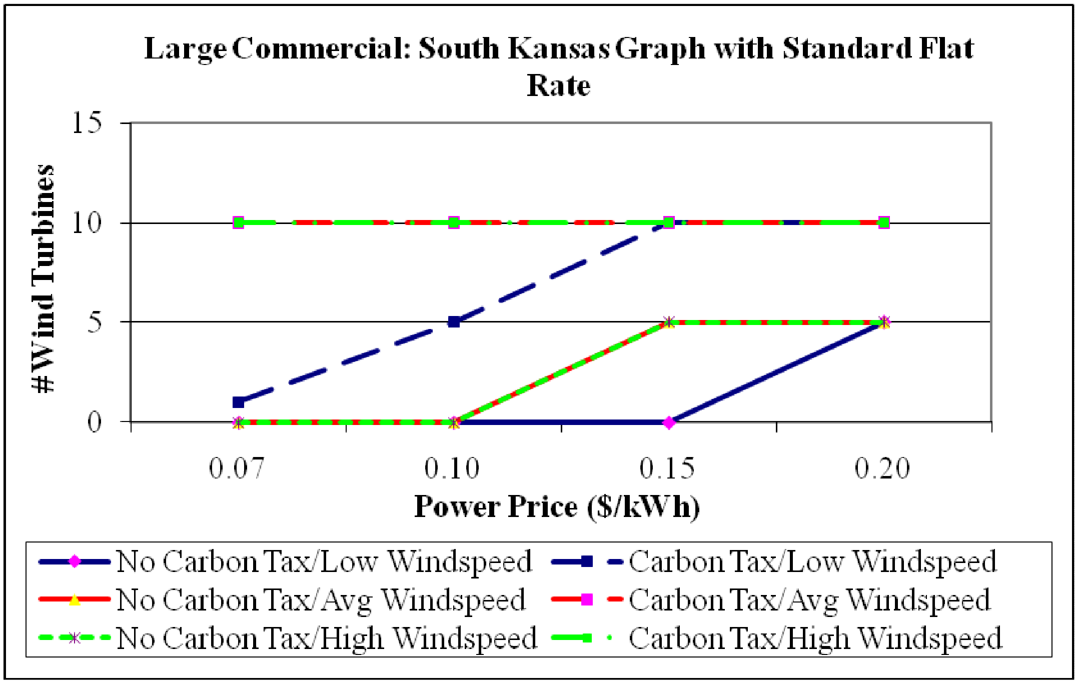


Figure 8 S. Kansas Large Commercial Standard Rate Carbon Tax Comparison

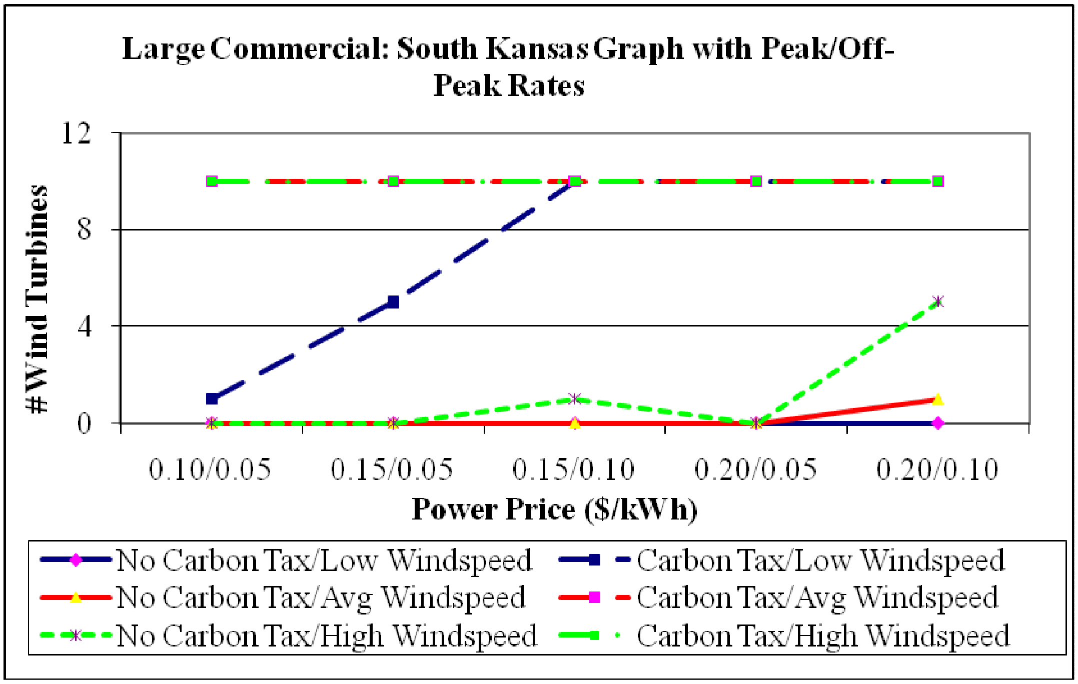


Figure 9 S. Kansas Large Commercial Peak Rate Carbon Tax Comparison

5.2 Wichita Large Commercial

Simulations done for the city of Wichita are only for standard constant power prices. As shown in Section 3.1 above, there is little variation between the NPC and COE values of the standard and peak/off-peak power rates.

5.2.1 Standard Rates

TABLE 19

WICHITA LARGE COMMERCIAL CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	low wind speed	5.00	0.07	**0**	**2,721,930**	**31,220,326**	**0.051**	**-**
				1	*2,796,988*	*39,081,228*	*0.064*	*6%*
			0.20	**0**	**11,291,709**	**129,515,016**	**0.211**	**-**
				1	*10,861,961*	*131,585,840*	*0.214*	*6%*

TABLE 19 (continued)

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	avg wind speed	5.45	0.07	**0**	**4,328,764**	**49,650,584**	**0.081**	**-**
				1	*4,196,130*	*55,129,276*	*0.090*	*9%*
			0.20	**5**	**7,974,315**	**126,464,760**	**0.206**	**42%**
				0	*11,291,709*	*129,515,016*	*0.211*	-
	high wind speed	6.00	0.07	**0**	**4,328,764**	**49,650,584**	**0.081**	**-**
				1	*4,136,272*	*54,442,712*	*0.089*	*10%*
			0.15	**1**	**7,975,003**	**98,472,656**	**0.160**	**10%**
				0	*8,613,653*	*98,797,920*	*0.161*	-
			0.20	**5**	**7,266,699**	**118,348,464**	**0.193**	**49%**
				0	*11,291,709*	*129,515,016*	*0.211*	-

TABLE 20

WICHITA LARGE COMMERCIAL CUSTOMER WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
With CT	low wind speed	5.00	0.10	**0**	**11,238,148**	**128,900,672**	**0.210**	**-**
				1	*10,643,434*	*129,079,352*	*0.210*	*7%*
			0.20	**10**	**8,826,888**	**171,243,712**	**0.279**	**59%**
				0	*16,594,260*	*190,334,864*	*0.310*	-
	avg wind speed	5.45	0.07	**0**	**9,631,314**	**110,470,416**	**0.180**	**-**
				1	*9,029,645*	*110,569,320*	*0.180*	*9%*
			0.15	**10**	**6,020,926**	**139,059,552**	**0.226**	**66%**
				0	*13,916,204*	*159,617,760*	*0.260*	-
			0.20	**10**	**7,241,412**	**153,058,432**	**0.249**	**66%**
				0	*16,594,260*	*190,334,864*	*0.310*	-
	high wind speed	6.00	0.07	**10**	**2,748,571**	**101,525,896**	**0.165**	**72%**
				0	*9,631,314*	*110,470,416*	*0.180*	-
			0.15	**10**	**4,441,955**	**120,948,872**	**0.197**	**72%**
				0	*13,916,204*	*159,617,760*	*0.260*	-
			0.20	**10**	**5,500,321**	**133,088,248**	**0.217**	**72%**
				0	*16,594,260*	*190,334,864*	*0.310*	-

Table 19 shows simulations done for a large commercial customer in Wichita without any carbon penalties. At average wind speed of 5.45 m/s and highest power price $0.20/kWh, the system will have an optimum number of wind turbines at five. However, at high wind speed (6.00 m/s) and power prices below $0.10/kWh, the optimum system is without any wind turbine(s). Again, all annual operating costs of system without any wind turbine(s) is lower that that of systems with wind turbine(s).

Table 20 shows simulations with an added carbon penalty of $100/ton CO_2. Due to this carbon penalty, optimum systems start including wind turbine(s) to incur a lower annual operating cost. Only at low wind speed of 5.00 m/s and power prices below $0.15/kWh, will there be no wind turbines in an optimum system.

Figure 10 below shows the impact of implementing carbon taxes with regards to the optimum number of wind turbines in Wichita.

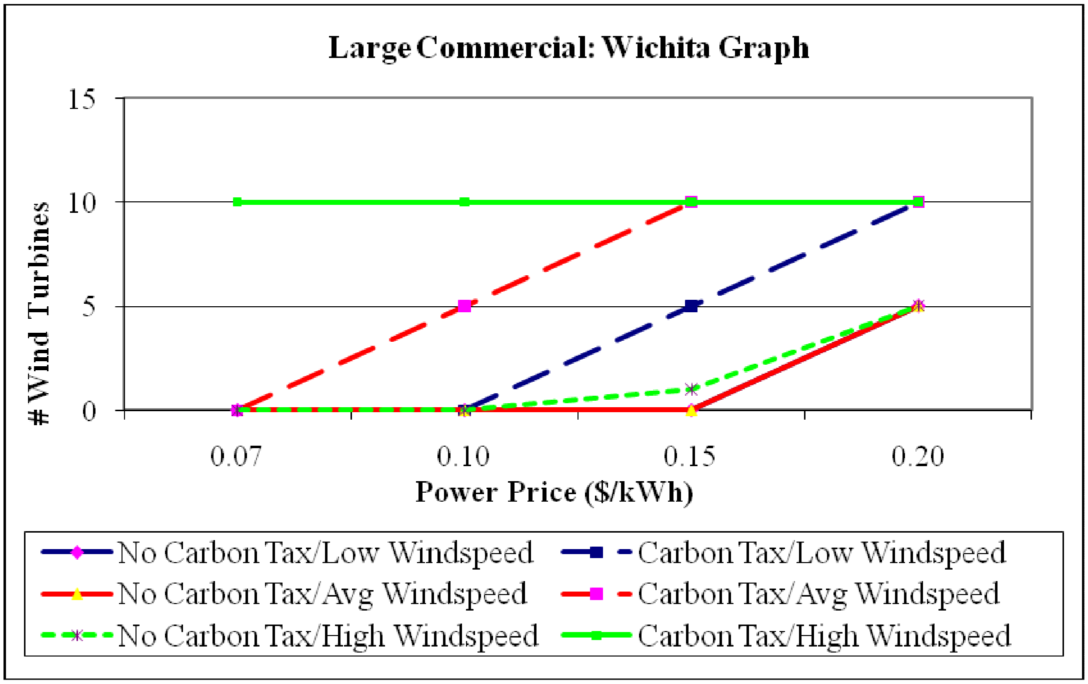


Figure 10 Wichita Large Commercial Carbon Tax Comparison

5.3 Topeka Large Commercial

As previously mentioned, the annual average wind speed for the city of Topeka is the lowest as compared to the other areas simulated in this research.

Therefore, simulations done for Topeka are only for standard constant power prices.

5.3.1 Standard Rates

TABLE 21

TOPEKA LARGE COMMERCIAL CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	avg wind speed	4.31	0.07	**0**	**4,328,764**	**55,336,132**	**0.081**	**-**
				1	*4,243,279*	*61,243,348*	*0.089*	*5%*
			0.20	**0**	**11,291,709**	**144,345,936**	**0.211**	**-**
				1	*10,842,312*	*145,601,136*	*0.213*	*5%*
	high wind speed	4.50	0.07	**0**	**4,328,764**	**55,336,132**	**0.081**	**-**
				1	*4,220,599*	*60,953,416*	*0.089*	*6%*
			0.20	**0**	**11,291,709**	**144,345,936**	**0.211**	**-**
				1	*10,778,804*	*144,789,296*	*0.211*	*6%*

TABLE 22

TOPEKA LARGE COMMERCIAL CUSTOMER WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
With CT	avg wind speed	4.31	0.07	**0**	**9,631,314**	**123,120,520**	**0.180**	**-**
				1	*9,268,696*	*125,485,048*	*0.183*	*5%*
			0.20	**5**	**13,124,853**	**202,779,680**	**0.296**	**26%**
				0	*16,594,260*	*212,130,336*	*0.310*	*-*
	high	4.50	0.07	**0**	**9,631,314**	**123,120,520**	**0.180**	**-**
				1	*9,214,924*	*124,797,656*	*0.182*	*6%*

TABLE 22 (continued)

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
	wind speed	4.50	0.20	**10**	**9,824,448**	**195,589,424**	**0.286**	**50%**
				0	*16,594,260*	*212,130,336*	*0.310*	-

Table 21 shows that for all simulations the optimal systems without any carbon penalties would not include any wind turbine(s). Table 22 shows the same configurations as table 21 except with a carbon penalty of $100/ton CO_2. However, only at wind speed higher than 4.31 m/s and at highest power price at $0.20/kWh, would the optimum system include wind turbines. These results show that Topeka is a poor candidate for wind turbine siting.

CHAPTER 6

RESULTS - SMALL BUSINESS

6.1 South Kansas Small Business

Small businesses have the largest load as compared of the residential, large commercials and small business. A small business customer has an average daily load demand of 413 MWh with a 41 MW peak. It is predicted that small business would have a larger number of optimum wind turbines as compared to the rest. As mentioned in Section 1.3.1, two different cost structures were simulated.

6.1.1 Standard Rates

The rates for this part of the simulation range from $.07/kWh to $0.20/kWh. Table 23 shows results for simulations without carbon penalties and table 24 for a carbon tax of $50/ton CO_2. The carbon tax is lower here because at $100/ton CO_2, the number of optimal wind turbines becomes too large to be practical (i.e. above 100). Comparing tables 23 and 24, the number of optimal wind turbines increase with the added CO_2 penalty of $50/ton CO_2.

TABLE 23

SOUTH KANSAS SMALL BUSINESS CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	low wind speed	5.50	0.07	**0**	**12,377,435**	**141,968,208**	**0.082**	**-**
				1	*12,226,302*	*147,234,720*	*0.085*	*3%*
			0.20	**10**	**24,702,292**	**353,333,344**	**0.205**	**31%**
				0	*31,959,286*	*366,570,496*	*0.212*	-

TABLE 23 (continued)

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	avg wind speed	6.42	0.07	**0**	**12,377,435**	**141,968,208**	**0.082**	**-**
				1	*12,117,528*	*145,987,088*	*0.084*	*4%*
			0.15	**10**	**17,496,964**	**270,688,800**	**0.157**	**40%**
				0	*24,427,804*	*280,184,992*	*0.162*	-
			0.20	**15**	**18,833,172**	**321,015,008**	**0.186**	**56%**
				0	*31,959,286*	*366,570,496*	*0.212*	-
	high wind speed	7.00	0.07	**0**	**12,377,435**	**141,968,208**	**0.082**	**-**
				1	*12,058,169*	*145,306,256*	*0.084*	*5%*
			0.15	**10**	**16,460,881**	**258,805,008**	**0.150**	**45%**
				0	*24,427,804*	*280,184,992*	*0.162*	-
			0.20	**15**	**17,116,092**	**301,320,224**	**0.174**	**61%**
				0	*31,959,286*	*366,570,496*	*0.212*	-

TABLE 24

SOUTH KANSAS SMALL BUSINESS CUSTOMER WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
With CT ($50/ton CO_2)	low wind speed	5.50	0.07	**0**	**19,833,600**	**227,489,840**	**0.132**	**-**
				1	*19,445,340*	*230,036,528*	*0.133*	*3%*
			0.20	**15**	**26,040,638**	**403,684,064**	**0.234**	**45%**
				0	*39,415,452*	*452,092,128*	*0.262*	-
	avg wind speed	6.42	0.07	**0**	**19,833,600**	**227,489,840**	**0.132**	**-**
				1	*19,267,600*	*227,997,856*	*0.132*	*4%*
			0.15	**20**	**14,893,962**	**310,832,576**	**0.180**	**66%**
				0	*31,883,970*	*365,706,624*	*0.212*	-
			0.20	**20**	**18,040,290**	**346,920,704**	**0.201**	**66%**
				0	*39,415,452*	*452,092,128*	*0.262*	-
	high wind speed	7.00	0.07	**7**	**15,411,161**	**225,764,800**	**0.131**	**32%**
				0	*19,833,600*	*227,489,840*	*0.132*	-
			0.15	**20**	**12,638,718**	**284,965,088**	**0.165**	**71%**
				0	*31,883,970*	*365,706,624*	*0.212*	-

TABLE 24 (continued)

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
		7.00	0.20	**35**	**6,112,628**	**315,111,360**	**0.182**	**85%**
				0	*39,415,452*	*452,092,128*	*0.262*	-

6.1.2 Peak and Off-Peak Rates

The rates for this part of the simulation are divided into two periods of the 24-hour day. The peak hours are from 7 am – 7 pm with a power price range of $0.10/kWh - $0.20/kWh. The off-peak power price range is from $0.05/kWh - $0.10/kWh. This is the same principle utilized in the previous simulation for a large commercial customer.

Table 25 shows results for simulations without carbon penalties and table 26 for a carbon tax of $50/ton CO_2.

TABLE 25

S. KANSAS PEAK RATE SMALL BUSINESS CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Peak Price ($/kWh)	Off-Peak Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	low wind speed	5.50	0.200	0.05	**0**	**19,801,716**	**227,124,128**	**0.131**	**-**
					1	*19,435,370*	*229,922,160*	*0.133*	*3%*
				0.10	**0**	**23,846,388**	**273,516,192**	**0.158**	**-**
					1	*23,345,848*	*274,775,040*	*0.159*	*3%*
	avg wind speed	6.42	0.100	0.05	**0**	**12,828,098**	**147,137,280**	**0.085**	**-**
					1	*12,566,941*	*151,141,824*	*0.087*	*4%*
				0.10	**0**	**16,872,770**	**193,529,344**	**0.112**	**-**
					1	*16,434,796*	*195,505,824*	*0.113*	*4%*

TABLE 25 (continued)

		Wind speed (m/s)	Peak Price ($/kWh)	Off-Peak Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT		6.42	0.200	0.05	**0**	**19,801,716**	**227,124,128**	**0.131**	**-**
					1	*19,276,382*	*228,098,592*	*0.132*	*4%*
				0.10	**10**	**17,237,648**	**267,714,480**	**0.155**	**40%**
					0	*23,846,388*	*273,516,192*	*0.158*	-
	high wind speed	7.00	0.100	0.05	**0**	**12,828,098**	**147,137,280**	**0.085**	**-**
					1	*12,509,454*	*150,482,448*	*0.087*	*5%*
				0.10	**0**	**16,872,770**	**193,529,344**	**0.112**	**-**
					1	*16,353,514*	*194,573,520*	*0.113*	*5%*
			0.200	0.05	**1**	**19,191,092**	**227,120,320**	**0.131**	**5%**
					0	*19,801,716*	*227,124,128*	*0.131*	-
				0.10	**10**	**16,253,303**	**256,424,112**	**0.148**	**45%**
					0	*23,846,388*	*273,516,192*	*0.158*	-

TABLE 26

S. KANSAS PEAK RATE SMALL BUSINESS CUSTOMER WITH CARBON PENALTY

		Wind speed (m/s)	Peak Price ($/kWh)	Off-Peak Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
With CT ($50/ton CO_2)	low wind speed	5.50	0.200	0.05	**15**	**22,048,948**	**357,899,680**	**0.207**	**45%**
					0	*32,117,734*	*368,387,872*	*0.213*	-
				0.10	**15**	**23,379,512**	**373,161,152**	**0.216**	**45%**
					0	*34,550,308*	*396,289,312*	*0.229*	-
	avg wind speed	6.42	0.100	0.05	**1**	**21,297,714**	**251,283,104**	**0.145**	**4%**
					0	*21,919,920*	*251,419,760*	*0.146*	-
				0.10	**10**	**17,285,788**	**268,266,640**	**0.155**	**40%**
					0	*24,352,492*	*279,321,184*	*0.162*	-
			0.200	0.05	**20**	**15,237,610**	**314,774,176**	**0.182**	**66%**
					0	*32,117,734*	*368,387,872*	*0.213*	-
				0.10	**20**	**16,178,506**	**325,566,208**	**0.188**	**66%**

					0	*34,550,308*	*396,289,312*	*0.229*	-

TABLE 26 (continued)

		Wind speed (m/s)	Peak Price ($/kWh)	Off-Peak Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
With CT ($50/ton CO_2)	high wind speed	7.00	0.100	0.05	**15**	**11,875,032**	**241,205,680**	**0.140**	**61%**
					0	*21,919,920*	*251,419,760*	*0.146*	-
				0.10	**15**	**12,817,012**	**252,010,112**	**0.146**	**61%**
					0	*24,352,492*	*279,321,184*	*0.162*	-
			0.200	0.05	**25**	**9,868,831**	**288,194,720**	**0.167**	**78%**
					0	*32,117,734*	*368,387,872*	*0.213*	-
				0.10	**25**	**10,602,849**	**296,613,856**	**0.172**	**78%**
					0	*34,550,308*	*396,289,312*	*0.229*	-

For simulations without carbon penalties and at low wind speeds, optimal systems would not include any wind turbines. Comparing results for South Kansas with carbon penalties, there are no optimal systems with wind turbines. Figures 11 and 12 below show the impact of carbon taxes upon the optimum number of wind turbines in South Kansas for a small business customer.

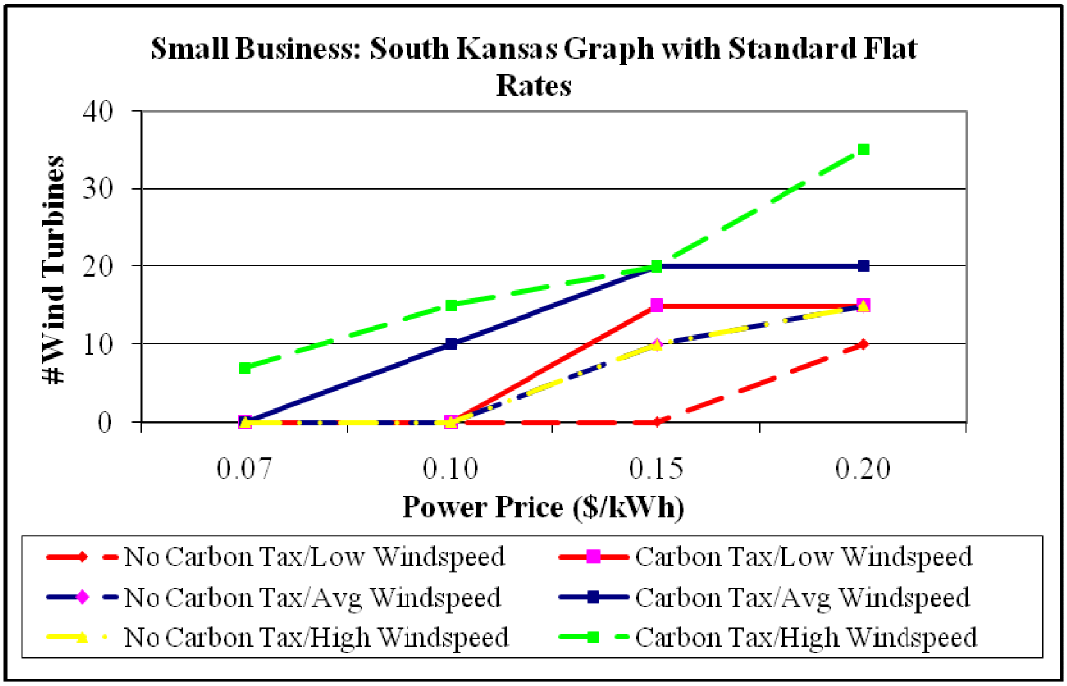


Figure 11 S. Kansas Small Business Standard Rate Carbon Tax Comparison

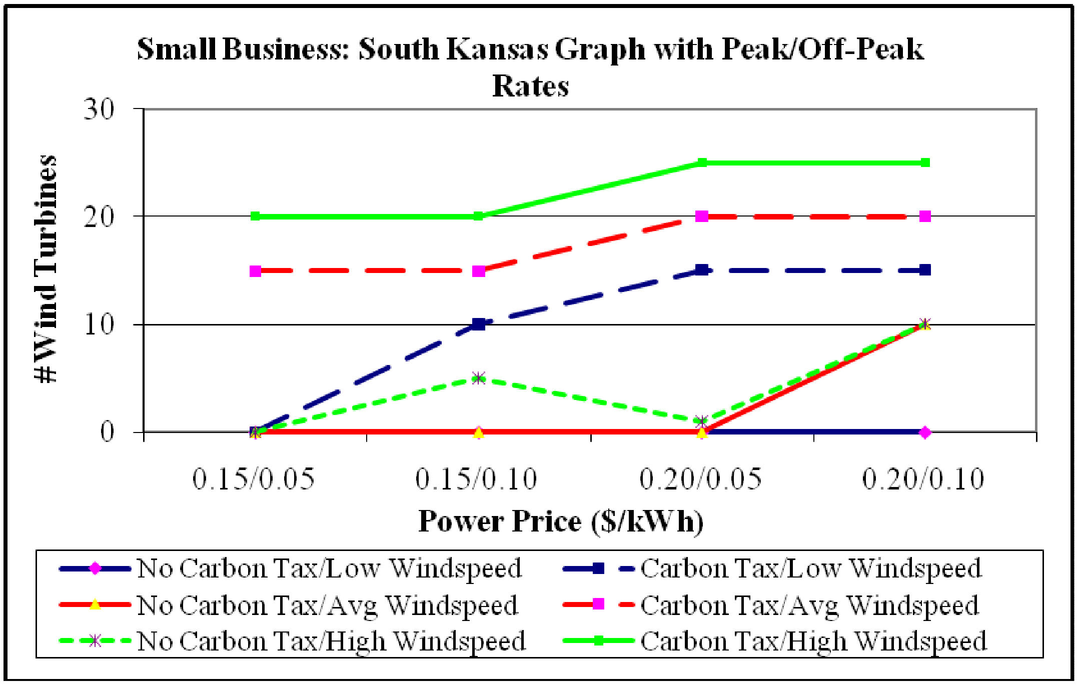


Figure 12 S. Kansas Small Business Peak Rate Carbon Tax Comparison

6.2 Wichita Small Business

Simulations done for the city of Wichita are for standard constant power prices only. As shown in Section 4.1 above, there is little variation between the NPC and COE values of the standard and peak/off-peak power rates.

6.2.1 Standard Rates

TABLE 27

WICHITA SMALL BUSINESS CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	low wind speed	5.00	0.07	**0**	**12,377,435**	**141,968,208**	**0.082**	**-**
				1	*12,278,395*	*147,832,224*	*0.086*	*3%*
			0.20	**1**	**31,341,032**	**366,479,168**	**0.212**	**3%**
				0	*31,959,286*	*366,570,496*	*0.212*	-

TABLE 27 (continued)

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	average wind speed	5.45	0.07	**0**	**12,377,435**	**141,968,208**	**0.082**	**-**
				1	*12,222,161*	*147,187,232*	*0.085*	*3%*
			0.15	**0**	**24,427,804**	**280,184,992**	**0.162**	**-**
				1	*23,893,512*	*281,056,704*	*0.163*	*3%*
			0.20	**10**	**24,864,320**	**355,191,808**	**0.206**	**31%**
				0	*31,959,286*	*366,570,496*	*0.212*	-
	high wind speed	6.00	0.07	**0**	**12,377,435**	**141,968,208**	**0.082**	**-**
				1	*12,158,983*	*146,462,576*	*0.085*	*4%*
			0.20	**10**	**23,308,788**	**337,349,984**	**0.195**	**36%**
				0	*31,959,286*	*366,570,496*	*0.212*	-

TABLE 28

WICHITA SMALL BUSINESS CUSTOMER WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
With CT ($50/ton CO$_2$)	low wind speed	5.00	0.07	**0**	**19,833,600**	**227,489,840**	**0.132**	**-**
				1	*19,536,862*	*231,086,272*	*0.134*	*3%*
			0.20	**20**	**31,741,340**	**434,070,688**	**0.251**	**26%**
				0	*39,415,452*	*452,092,128*	*0.262*	-
	average wind speed	5.45	0.07	**0**	**19,833,600**	**227,489,840**	**0.132**	**-**
				1	*19,443,808*	*230,018,944*	*0.133*	*3%*
			0.15	**10**	**24,695,676**	**353,257,472**	**0.204**	**31%**
				0	*31,883,970*	*365,706,624*	*0.212*	-
			0.20	**15**	**26,323,370**	**406,926,976**	**0.236**	**44%**
				0	*39,415,452*	*452,092,128*	*0.262*	-
	high wind speed	6.00	0.07	**0**	**19,833,600**	**227,489,840**	**0.132**	**-**
				1	*19,339,058*	*228,817,472*	*0.132*	*4%*
			0.20	**20**	**20,345,646**	**373,362,976**	**0.216**	**61%**
				0	*39,415,452*	*452,092,128*	*0.262*	-

Table 27 shows results for simulations done without any carbon penalties in Wichita and table 28 shows results for simulations done with a carbon penalty of $50/ton CO$_2$. At low wind speeds, for both simulations done with and without carbon penalties, at energy price above $0.20/kWh the optimal system would include wind turbine(s). There is an increase in the number of optimal wind turbines from simulations done with carbon penalties as compared to those without carbon penalties. Figure 13 shows the optimal number of wind turbines with the corresponding power price in $/kWh for both simulations with and without carbon penalties.

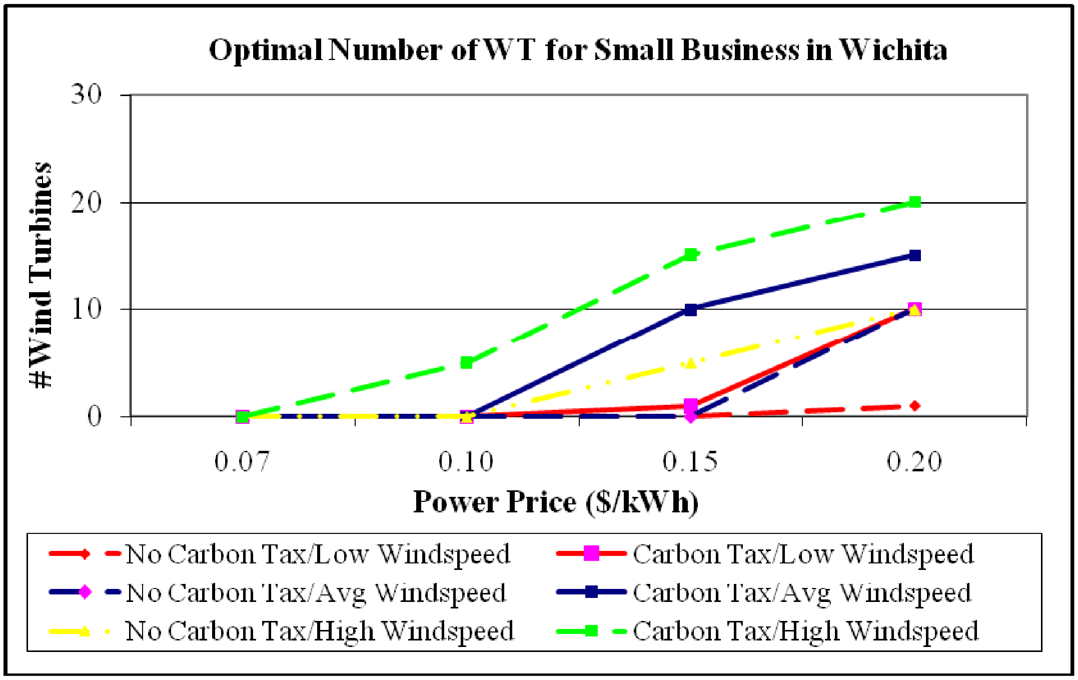


Figure 13 Wichita Small Business Standard Rate Carbon Tax Comparison

6.3 Topeka Small Business

Topeka has the lowest average yearly wind speed as compared to the other two cases in Kansas, with a wind speed of 4.31 m/s. It is expected that with a low wind speed; the optimum number of wind turbine(s) would decrease or even in some cases, would not include any. Simulations for Topeka are only done for two standard energy prices, one at a low energy price of $0.07/kWh and one at a high energy price at $0.20/kWh. Tables 29 and 30 show that even with a carbon penalty of $100/ton CO_2 (table 30) and at all energy prices, that the optimum systems would not include any wind turbines.

6.3.1 Standard Rates

TABLE 29

TOPEKA SMALL BUSINESS CUSTOMER WITHOUT CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
No CT	average wind speed	4.31	0.07	**0**	**12,377,435**	**141,968,208**	**0.082**	**-**
				1	*12,376,420*	*148,956,560*	*0.086*	*2%*
			0.20	**0**	**31,959,286**	**366,570,496**	**0.212**	**-**
				1	*31,594,362*	*369,384,864*	*0.214*	*2%*
	high wind speed	4.50	0.07	**0**	**12,377,435**	**141,968,208**	**0.082**	**-**
				1	*12,353,189*	*148,690,112*	*0.086*	*2%*
			0.20	**0**	**31,959,286**	**366,570,496**	**0.212**	**-**
				1	*31,530,308*	*368,650,144*	*0.213*	*2%*

TABLE 30

TOPEKA SMALL BUSINESS CUSTOMER WITH CARBON PENALTY

		Wind speed (m/s)	Power Price ($/kWh)	# WT	Operating Cost ($/year)	NPC ($)	COE ($/kWh)	WT kWh (%)
With CT	average wind speed	4.31	0.07	**0**	**27,289,766**	**313,011,456**	**0.181**	**-**
				1	*27,011,622*	*316,821,184*	*0.183*	*2%*
			0.20	**5**	**43,697,384**	**536,205,568**	**0.310**	**9%**
				0	*46,871,616*	*537,613,760*	*0.311*	-
	high wind speed	4.50	0.07	**0**	**27,289,766**	**313,011,456**	**0.181**	**-**
				1	*26,957,300*	*316,198,112*	*0.183*	*2%*
			0.20	**10**	**39,733,256**	**525,737,344**	**0.304**	**21%**
				0	*46,871,616*	*537,613,760*	*0.311*	-

CHAPTER 7

WIND SYSTEM AND BATTERY STORAGE

It is worth noting that adding a battery to the system does not increase its efficiency as the wind energy system is attached to the grid and is not a stand-alone system. With a connection to the grid, the battery serves as a “spinning reserve” [12] which could replace regular spinning reserves like fuel-generated (natural gas) power plants. However, the aim in adding the lone battery storage in the system is to show its effect or impact (or lack of) in the system. Also for all simulations with battery storage, it is assumed net metering is allowed in order to make it more competitive for power generated from the wind during off-peak times to be stored and then sold during more expensive peak times.

7.1 Residential Customer

The load for the residential case with storage was taken for a hundred customers with a daily load of 1,710 kWh. For simplification purposes, only scenarios at the average wind speed in South Kansas (6.42 m/s) and at off-peak rates of $0.10/kWh were taken.

TABLE 31

RESIDENTIAL 100 CUSTOMERS BATTERY STORAGE

	#WT	Battery	Operating Cost ($/yr)	NPC ($)	COE ($/kWh)	CO_2 Emitted (kg/year)
Peak Rate ($0.15/kWh) Carbon Tax ($100/ton CO_2)	15	0	77,260	1,636,162	0.229	211,638
	15	1	77,294	1,657,762	0.232	211,645
Peak Rate ($0.20/kWh) Carbon Tax ($100/ton CO_2)	20	0	58,838	1,674,871	0.234	76,214
	20	1	58,873	1,696,465	0.237	76,221

Table 31 shows adding battery storage to the system hardly affects the system. Note however that the optimum battery always remain at one and at a smaller size (only 1,000 Ah) compared to the overall system.

System Architecture: 1,000 kW Grid
20 BWC Excel-S
1 Hoppecke 16 OPzS 200
1 kW Inverter
1 kW Rectifier

Total NPC: $ 1,696,465
Levelized COE: $ 0.237/kWh
Operating Cost: $ 58,873/yr

Quantity	Value
String size	1
Strings in parallel	1
Batteries	1
Bus voltage (V)	2

Quantity	Value	Units
Nominal capacity	4.00	kWh
Usable nominal capacity	2.80	kWh
Autonomy	0.0393	hr
Lifetime throughput	6,801	kWh
Battery wear cost	0.190	$/kWh
Average energy cost	0.000	$/kWh

Quantity	Value	Units
Energy in	15	kWh/yr
Energy out	13	kWh/yr
Storage depletion	0	kWh/yr
Losses	2	kWh/yr
Annual throughput	14	kWh/yr
Expected life	20.0	yr

Figure 14 Residential (Peak Rate - $0.20/kWh & CT $100/ton CO_2) Screenshot

Figure 14 shows the resulting screenshot for a residential scenario. Note the table on the upper right corner showing the quantity of energy flow of the battery. It shows an annual throughput of only 14 kWh/yr, which is tiny when compared to a daily load of 1,710 kWh for the system. This shows that a battery serves only to increase the cost of a system without adding any significant benefits to it.

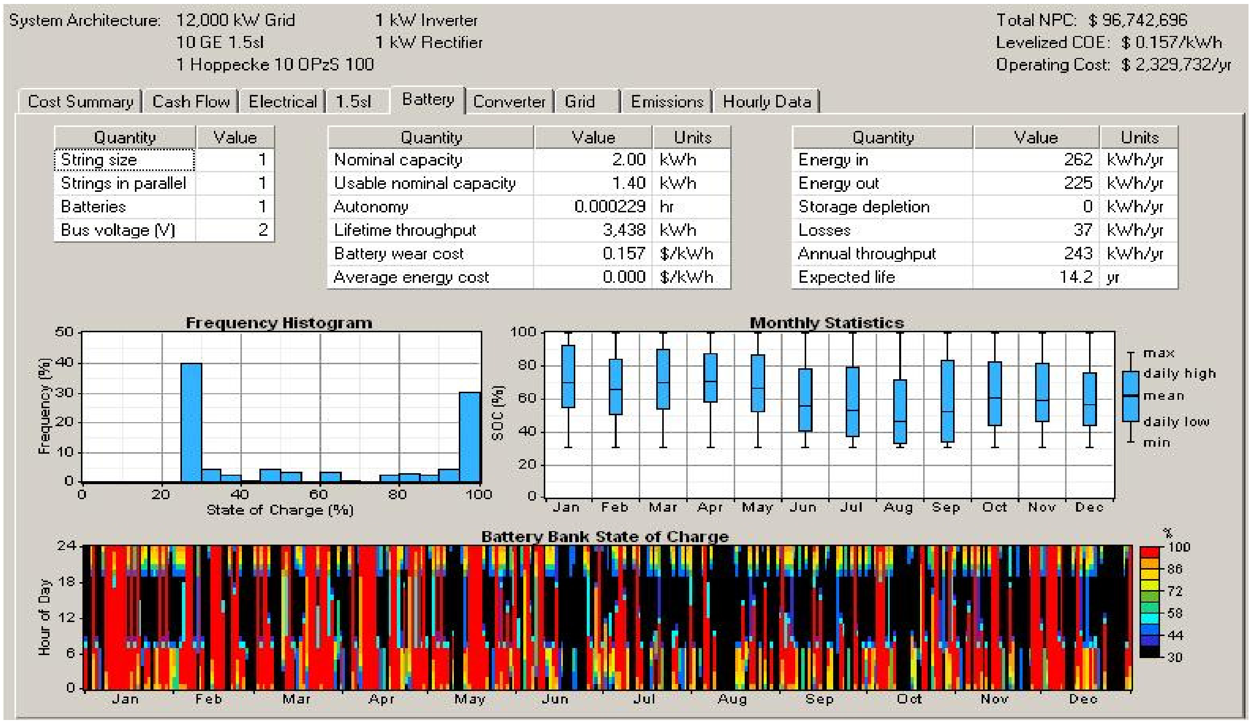
7.2 Large Commercial

Again, only cases at South Kansas (average wind speed of 6.42 m/s) and off peak rate of $0.10/kWh were taken into account. Table 32 shows that a battery in the system is not a vast change from a system without.

TABLE 32

LARGE COMMERCIAL BATTERY STORAGE

	#WT	Battery	Operating Cost ($/yr)	NPC ($)	COE ($/kWh)	CO_2 Emitted (kg/year)
Peak Rate ($0.15/kWh) Carbon Tax ($30/ton CO_2)	5	0	5,277,567	95,533,280	0.156	22,416,100
	5	1	5,277,491	95,553,256	0.156	22,416,100
Peak Rate ($0.20/kWh) Carbon Tax ($50/ton CO_2)	10	0	2,329,802	96,722,648	0.157	-8,193,300
	10	1	2,329,732	96,742,696	0.157	-8,193,185



System Architecture: 12,000 kW Grid
10 GE 1.5sl
1 Hoppecke 10 OPzS 100
1 kW Inverter
1 kW Rectifier

Total NPC: $ 96,742,696
Levelized COE: $ 0.157/kWh
Operating Cost: $ 2,329,732/yr

Quantity	Value
String size	1
Strings in parallel	1
Batteries	1
Bus voltage (V)	2

Quantity	Value	Units
Nominal capacity	2.00	kWh
Usable nominal capacity	1.40	kWh
Autonomy	0.000229	hr
Lifetime throughput	3,438	kWh
Battery wear cost	0.157	$/kWh
Average energy cost	0.000	$/kWh

Quantity	Value	Units
Energy in	262	kWh/yr
Energy out	225	kWh/yr
Storage depletion	0	kWh/yr
Losses	37	kWh/yr
Annual throughput	243	kWh/yr
Expected life	14.2	yr

Figure 15 Large Commercial (Peak Rate $0.20/kWh & CT $50/ton CO_2) Screenshot

Figure 15 shows slightly more interesting results. Note the battery bank state of charge graph that the battery tends to discharge (black spots <30% state of charge) at times between 7 am and 7 pm (i.e. peak hours) and charge during off-peak hours. The annual throughput of 243 kWh/year is still considerably smaller than the daily load demand of 147 MWh/day.

7.3 Small Business

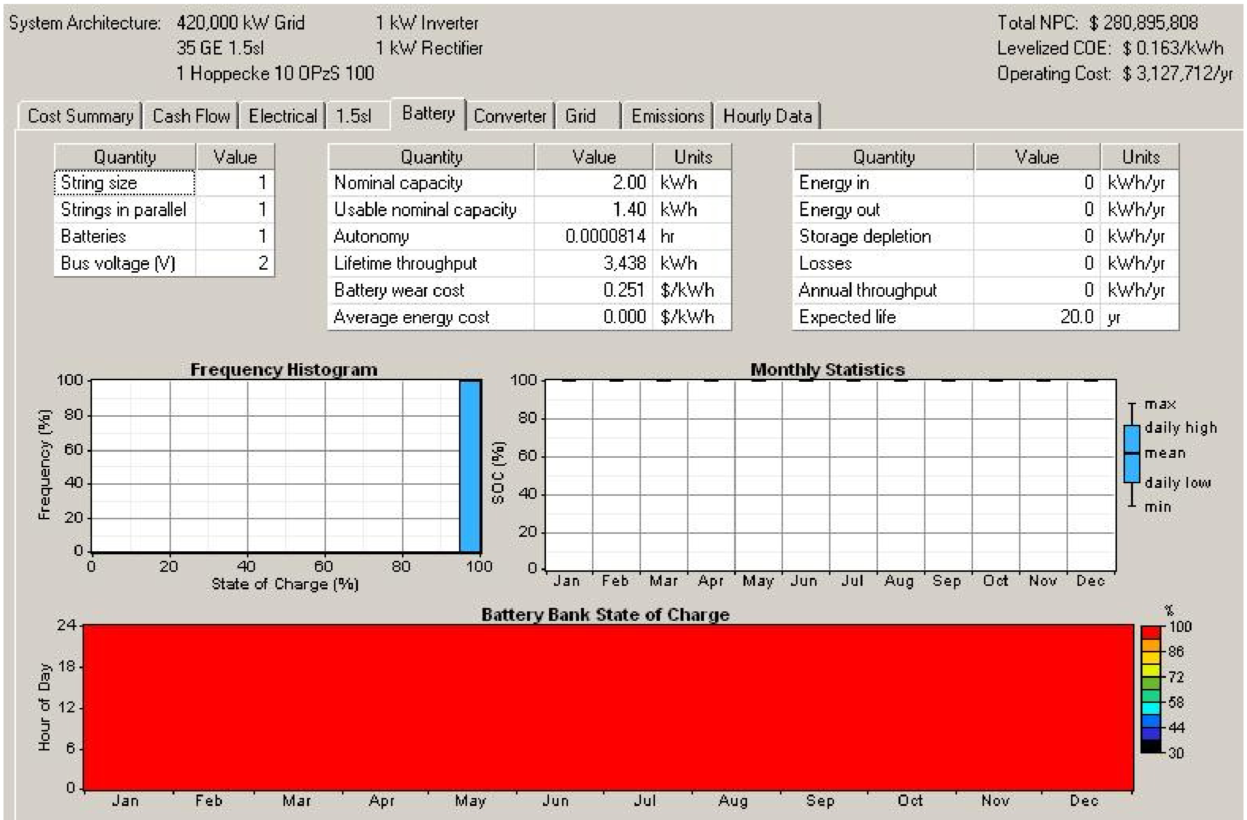
Simulations for a small business customer were done at South Kansas at average wind speed of 6.42 m/s and with off-peak price of $0.10/kWh. Table 33 show that having one battery does not affect the overall wind system.

TABLE 33

SMALL BUSINESS BATTERY STORAGE

	#WT	Battery	Operating Cost ($/yr)	NPC ($)	COE ($/kWh)	CO_2 Emitted (kg/year)
Peak Rate ($0.15/kWh) Carbon Tax ($30/ton CO_2)	20	0	11,157,062	267,970,624	0.155	26,685,728
	20	1	11,156,988	267,990,976	0.155	26,685,728
Peak Rate ($0.20/kWh) Carbon Tax ($50/ton CO_2)	35	0	3,127,788	280,875,488	0.163	-65,142,464
	35	1	3,127,712	280,895,808	0.163	-65,142,464

Figure 16 shows that the battery is not being utilized in the system. One of the reasons could be that with net metering, it is more cost-efficient to sell excess energy back to the grid instead of storing the energy.



System Architecture: 420,000 kW Grid
35 GE 1.5sl
1 Hoppecke 10 OPzS 100
1 kW Inverter
1 kW Rectifier

Total NPC: $ 280,895,808
Levelized COE: $ 0.163/kWh
Operating Cost: $ 3,127,712/yr

Quantity	Value
String size	1
Strings in parallel	1
Batteries	1
Bus voltage (V)	2

Quantity	Value	Units
Nominal capacity	2.00	kWh
Usable nominal capacity	1.40	kWh
Autonomy	0.0000814	hr
Lifetime throughput	3,438	kWh
Battery wear cost	0.251	$/kWh
Average energy cost	0.000	$/kWh

Quantity	Value	Units
Energy in	0	kWh/yr
Energy out	0	kWh/yr
Storage depletion	0	kWh/yr
Losses	0	kWh/yr
Annual throughput	0	kWh/yr
Expected life	20.0	yr

Figure 16 Small Business (Peak Rate $0.20/kWh & CT $50/ton CO_2) Screenshot

CHAPTER 8

CONCLUSIONS

8.1 Residential

For a single residential customer, the load of 17 kWh/day is much too low to cover the initial capital cost of installing a wind turbine without net metering. This is true regardless of wind speeds from the windier areas in South Kansas to areas with lower speeds like Topeka. For a single residential customer, only carbon tax higher than $150/ton CO_2 would make it an effective incentive to install a wind turbine.

Fifty residential customers increases the daily load to 855 kWh. However, only at very high wind speed of 7.00 m/s at South Kansas and power price ($0.20/kWh) would the optimal system have a single wind turbine. With the much lower wind speeds at Wichita and Topeka, all systems are more cost-efficient without any wind turbines. However with a carbon tax of $100/ton CO_2 at wind speeds above the average 6.42 m/s and at high power price of $0.20/kWh, the number of optimal wind turbines increase.

A hundred residential customers have a daily load of 1,710 kWh. In South Kansas, wind speed of 7.00 m/s and power price of $0.20/kWh is the only scenario at which the optimum number of wind turbines becomes five. With a carbon tax of $100/ton CO_2 added onto the system, two optimal cases at wind speeds 6.42 m/s & 7.00 m/s and power price of $0.20/kWh have 10 and 20 wind turbines respectively. Wichita would only have 10 wind turbines in its optimal system at a wind speed of 6.00 m/s, power price of $0.20/kWh and a carbon tax of $100/ton CO_2. Topeka remains without any wind turbines.

8.2 Large Commercial

A large commercial customer has a daily load of 147 MWh/day. At South Kansas, only at power prices below $0.07/kWh will the optimal system be without any wind turbines. However, with a carbon tax of $100/ton CO_2 at all wind speeds and power prices, the optimal system include wind turbines.

This increase in load made wind turbines more economically viable in areas with lower wind speeds like Wichita. Again, only at power prices below $0.07/kWh it is not commercially viable to have any wind turbines in the system. With an added carbon tax of $100/ton CO_2, only at wind speeds below the average of 5.45 m/s and power price of $0.07/kWh, would there not be any wind turbines.

Topeka with its low annual average wind speed would not have any wind turbines in its optimal system below a tax of $100/ton CO_2, power price above $0.20/kWh and above average wind speed (4.31 m/s).

8.3 Small Business

The small business customer has the highest load of 413 MWh/day with almost triple that of a large commercial customer. At South Kansas, power prices below $0.07/kWh would still yield an optimal system without any wind turbines. However; as wind speed increases above the average of 6.42 m/s, at power prices above $0.15/kWh the optimal system would include wind turbines. With an added carbon tax of $50/ton CO_2, only at wind speeds below 6.42 m/s and power price of $0.07/kWh and less, would there be no wind turbines in an optimum case.

With areas with lower wind speed like Wichita, only at high power prices of $0.20/kWh and above would there be wind turbines in the optimal case. The carbon tax of $50/ton CO_2 would help increase the number of wind turbines. Topeka, which has the lowest of all wind speed, would only have wind turbines with a carbon tax of $100/ton CO_2.

8.4 Wind Systems and Battery Storage

The only conclusion from the small simulation of wind systems with battery storage is that it is not cost effective to include any batteries. Adding a battery increases the NPC of a system without increasing the system's ability to provide power and has shown also that it does not decrease the amount of CO_2 emitted by the system. However, the battery has a much smaller capacity when compared to the overall larger system and thus would not be able to affect the system in a significant way.

8.5 Overall Conclusions

Without any form of government intervention or incentives (in the form of cap-and-trade or carbon taxes), the initial capital cost of small wind energy systems could prove overwhelming to customers or investors looking to install in wind turbines.

CHAPTER 9

FUTURE RESEARCH

This research shows that HOMER is capable of producing precise and definite data regarding the optimization of several renewable energy sources. However, the accuracy of these results could be increased with further research in several areas.

The monthly average wind speed data of the various areas in Kansas was accurate to a certain degree. Wind speeds are usually measured from airports instead of wind farm sites [12] and thus accuracy of results could be increased with new and more exact wind maps. The issue of variability of wind is a main source of contention from both critics and advocates [13,14] and therefore wind forecasting and characteristics is of utmost importance.

Load forecasting is also an important factor in this research. Although it is impossible to predict fully the load demand of customers, with more precise probability and statistic methods, the forecast results could be more accurate.

Another important area of further research could be incorporating photovoltaic cells (solar energy) together with the wind turbines. The optimization of the cells with wind turbines could be done using HOMER. Results about the interaction between the two components could be potentially important as each component could complement each other.

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