CALCULATING EMISSIONS REDUCTIONS FROM RENEWABLE ENERGY PROGRAMS AND ITS APPLICATION TO THE WIND FARMS IN THE TEXAS ERCOT REGION

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ABSTRACT

In August 2008 the Texas State Legislature required adding 5,880 MW of generating capacity from renewable energy technologies by 2015, and 500 MW from non-wind renewables. This legislation also required the Public Utility Commission (PUC) to establish a target of 10,000 MW of installed renewable capacity by 2025, and required the Texas Commission on Environmental Quality (TCEQ) to develop a methodology for computing emission reductions from renewable energy initiatives and the associated credits. In this legislation the Energy Systems Laboratory is required to assist the TCEQ to quantify emission reduction credits from energy efficiency and renewable energy programs. To satisfy these requirements the ESL has been developing and refining a method to calculate annually creditable emissions reductions from wind and other renewable energy resources for the TCEQ. This paper provides a detailed description of an improved methodology developed to calculate the emissions reductions from electricity provided by a wind farm. Details are presented for the wind farm Sweetwater I (Abilene) as well as results from the application of this procedure to all the wind energy providers in the Texas ERCOT region in 2006.

INTRODUCTION

Texas is now the largest producer of electricity from wind energy in the United States. The 2005 79th Texas legislature created legislative requirements for wind and renewable generation through Senate Bill 20, House Bill 2481, House Bill 2129 and amended Senate Bill 5. Wind developers are attracted to Texas by the many windy sites suitable for wind power development here.

As of November 2007 the capacity of installed wind turbines totaled 4,112 MW with another 1,478 MW under construction (Figure 1)[1]. The capacity announced for new projects is 8,012 MW by 2011. Electricity produced by wind farms in Texas reduces emission of pollutants from conventional power plants. As new wind farms come online and older turbines are retired, creditable accounting of pollution credits for wind energy requires normalization of the power generation to the base year used for State Implementation Plan (SIP) credits. This paper presents an improved methodology that was developed to assist the Texas Commission on Environmental Quality (TCEQ) for calculating the electricity savings and emissions reductions from wind energy within the Electrical Reliability Council of Texas (ERCOT) region for the state's SIP credits[2]. In the proposed method, the ASHRAE Inverse Model Toolkit (Kissock et al. 2003; Haberl et al. 2003) is used for weather normalization of the daily wind power generation to the base year selected by TCEQ (i.e., 1999). The US EPA's Emissions and Generations Resource Integrated Database (eGRID) is then used for calculating annual and Ozone Season Day's NOx emissions reductions from the wind energy programs[3].

METHODOLOGY

To determine the performance of a wind farm in the 1999 base year, at least one year of hourly wind power generation data from a wind farm and the corresponding hourly on-site wind speed for the same period and the base year need to be collected.

[1] Wind project information obtained from Public Utility Commission of Texas (www.puc.state.tx.us) and Electric Reliability Council of Texas (ERCOT).
[2] In the paper published in 2007 (Liu, Z., et al. 2007), the annual daily regression models had been used to calculate the electricity savings and emissions reductions.
[3] Currently, the TCEQ is using a special version of eGRID that projects emissions to 2007 using a 1999 base year.

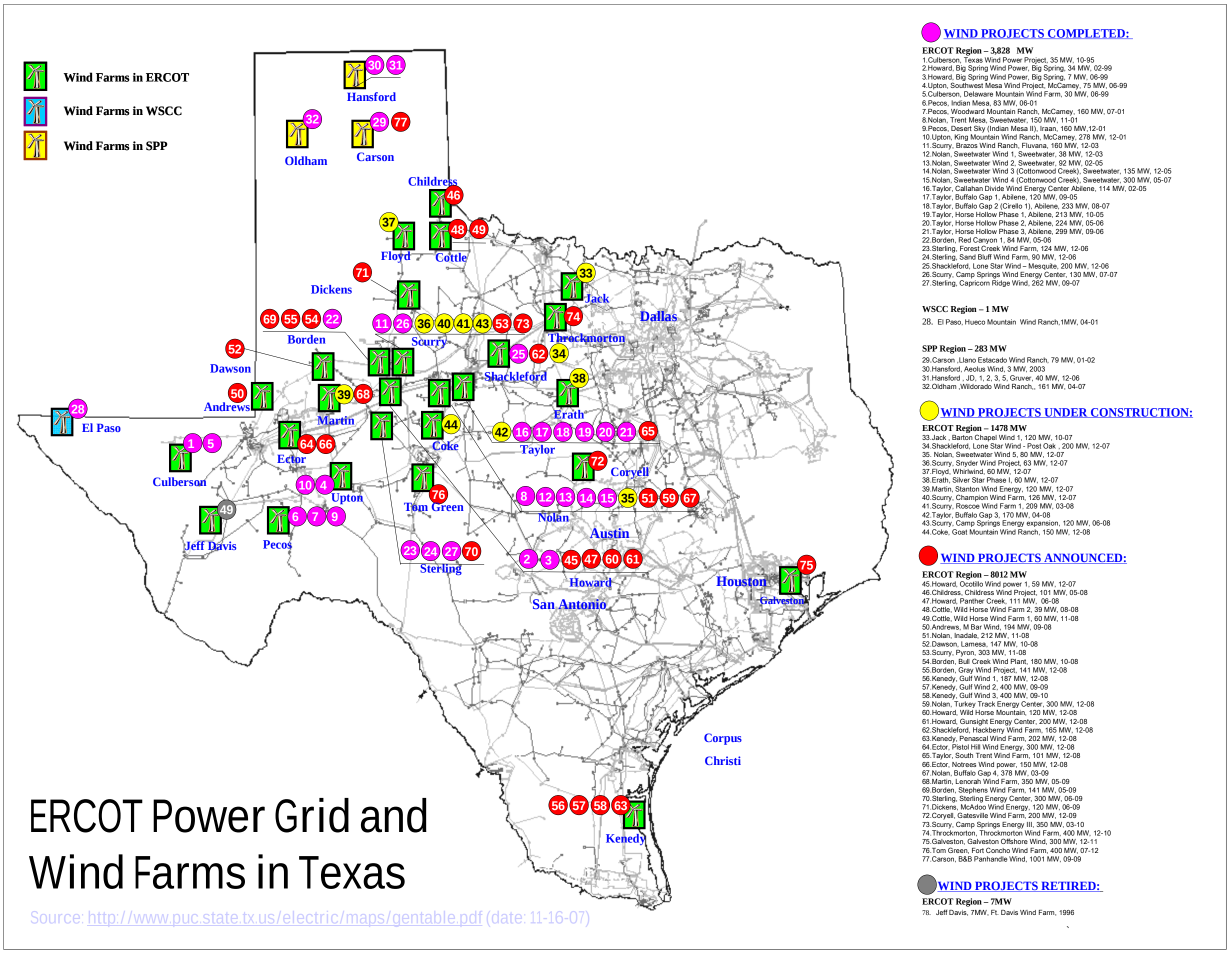

Figure 1: Completed and Announced Wind Projects in Texas by November 2007

Unfortunately, it is difficult to obtain wind data at the site of the farm in 1999 because most wind farms did not exist at that time. In fact, even for an operating wind farm, on-site wind data may not be available on a long-term basis. On the other hand, the National Oceanic and Atmospheric Administration (NOAA), has a network of weather stations that provide ongoing as well as archived data on wind speeds at a 10 meter high tower as well as a number of other meteorological variables. Therefore, it was decided that the wind speed from the nearest NOAA weather station to be used in the weather normalization procedure. Accordingly, the hourly measured electric power generation data was obtained from ERCOT for each wind farm installed since September 6, 2001.

Description of the Daily Modeling Procedure

In a paper published in 2007 (Liu, Z. et al. 2007), an annual daily regression model was developed for predicting both annual wind power production and the average daily wind power production in the Ozone Season Days (OSD) period in base year 1999. Figure 2 illustrates this method by plotting the daily wind power from a wind farm against the average daily wind speed from the nearest NOAA weather station. The daily regression model developed using the entire year's data was imposed on top of the measured data. The green data points show the measured daily wind power data in Ozone Season Period (OSP)[4] while the orange data points are the measured daily wind power in Non-Ozone Season Period. It is noted that most of the data points in the Ozone Season Days were clustered below the regression model. Due to the reason that wind speed and other related weather conditions in summer could be different from other seasons for this site which may have an impact on the operation of the wind farm, it shows that the annual model could not represent the reality of the wind power production in the summer season very well.

[4] Ozone Season Period used in this work was determined by the Texas Commission on Environmental Quality, i.e., from July 15 to September 15.

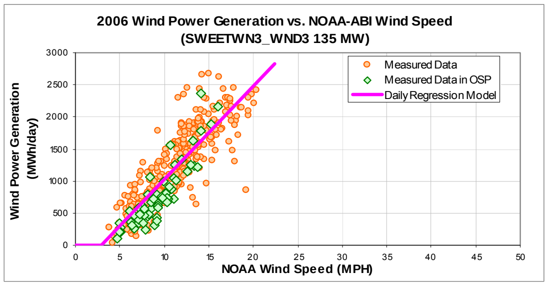

Figure 2: Daily Wind Power vs. NOAA-ABI Wind Speed Using Annual Model.

To improve the accuracy of the prediction in Ozone Season Days the previous method was enhanced to include two models. One method was developed for the Ozone Season Period (07/15/06 - 09/15/06) and the other is for the Non-Ozone Season Period.

In this improved method the measured hourly electric power production from a wind farm for the study year 2006, the corresponding hourly wind speed data from the nearest NOAA weather station in 2006, and the hourly NOAA wind speed for the base year 1999 were collected for a given site. Next, the hourly data for Ozone Season Days and Non-Ozone Season Days, respectively, were converted to daily data and a daily performance curve of the specific facility was developed by regressing the daily electricity production from the wind farm against the daily average wind data at the selected NOAA weather station..

Finally, the coefficients from the OSP and Non-OSP linear regression models and the 1999 average daily NOAA wind speed data were used to calculate the daily electricity the wind farm would have produced in 1999.

Analysis on Sweetwater I Wind Farm

In this section, the Sweetwater I wind farm is used as an example to illustrate the development of the methodology in detail. The Sweetwater I wind farm was completed and commenced operation in late December 2003. It is a 37.5 MW project that has 25 GE Wind turbines, located in Nolan County, Texas. The project characteristics are listed in Table 1.

1. Weather and Power Data:

In Figure 3, the 2006 hourly electric power data were plotted against 2006 hourly NOAA wind measurements at Abilene (ABI) for the Sweetwater wind farm. The data shows scatter and discretization (i.e. patterning) due to precision of measurements. It is also found that using an hourly model to predict wind power generation in the base year was impractical because of the significantly different profiles of on-site wind versus the NOAA wind.

Table 1: Project Characteristics

Wind Turbine	GE 1.5s 1500 kW
Tower Height	80 m
Rotor Diameter	70.5 m
Rotor Speed	11-22 rpm
Number of Turbines	25
Generating Capacity	37.5 MW
Projected Annual Output	141,748 MWh

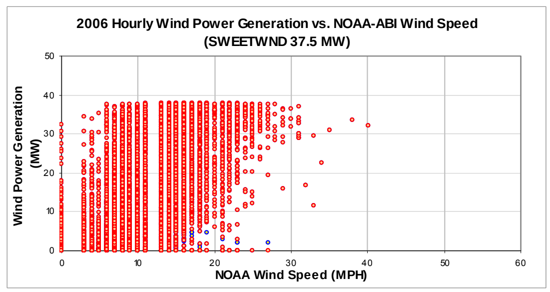

Figure 3: Hourly Wind Power vs. NOAA-ABI Wind Speed (2006)

2. Modeling of Turbine Power vs. Wind Speed

In Figure 4, the hourly electricity produced by the wind farm, except for Ozone Season Days, were summed to daily totals and plotted against the daily average NOAA wind speed. Figure 5 shows the daily electricity produced by the wind farm plotted against the daily average NOAA wind speed only for the Ozone Season Days.

The summary of the regression model coefficients from the NON-OSP and OSP daily models are listed in Table 2. These coefficients show that these two daily models are well described with root-mean-squared error (RMSE) of 104.24 MWh/day (Non-OSP Model) and 69.4526 MWh/day (OSP model) for the 2006 data.

In Table 3 the predicted monthly electricity production using the 3-parameter, change-point linear daily NON-OSP and OSP models is shown for 2006 to compare against the measured monthly electricity for the same period. The largest discrepancy of 11.42% between the measured and predicted value happened in November. In this month, the data can be seen to be unevenly distributed around the model predictions (Figure 6), which shows significant discrepancies during the first and final week of the month. In the middle of the month, the model shows good agreement with measured values.

Figure 7 shows the predicted electricity production from the wind farm as a time-series trace for the Ozone Season Period, from July 15 to September 15, using the OSP daily model. For most of days, the predicted power production matches very well the measured values, demonstrating a good performance of this OSP model.

Table 2: Model Coefficients

IMT Coefficients	NON-OSP Daily Model	OSP Daily Model
Ycp (MWh/day)	-191.15	-272.0612
Left Slope (MWh/mph-day)	50.87	55.622
RMSE (MWh/day)	104.24	69.4526
R2	0.77	0.824
CV-RMSE	27.12%	28.70%

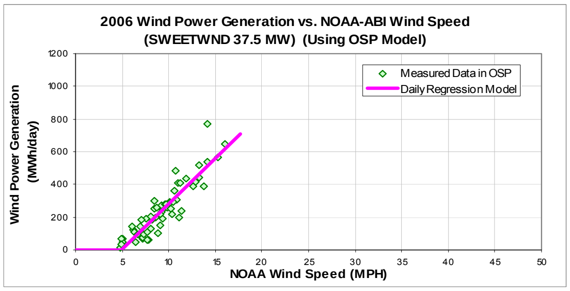

Figure 4: Daily Wind Power vs. NOAA-ABI Wind Speed for Non-OSD period

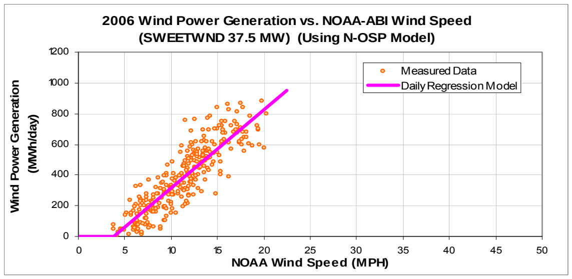

Figure 5: Daily Wind Power vs. NOAA-ABI Wind speed for the OSD Period

Table 3: Predicted Wind Power Using Daily Models

Month	No. Of Days	Average Daily Wind Speed (MPH) NOAA	Measured Power Generation (MWh) NOAA	Predicted Power Generation Using Daily Model (MWh) NOAA	Diff. NOAA	CV-RMSE
Jan-06	31	11.88	13,257	12,809	3.38%	21.29%
Feb-06	28	11.14	10,678	10,512	1.55%	26.75%
Mar-06	31	12.60	12,929	13,943	-7.84%	28.89%
Apr-06	29	12.19	12,045	12,437	-3.26%	27.47%
May-06	31	12.32	12,444	13,499	-8.48%	25.83%
Jun-06	30	9.83	8,793	9,260	-5.31%	26.02%
Jul-06	31	10.15	9,338	9,530	-2.06%	16.31%
Aug-06	28	9.33	6,383	6,914	-8.31%	27.60%
Sep-06	30	9.46	8,668	8,065	6.95%	32.98%
Oct-06	31	10.68	11,139	10,923	1.94%	34.90%
Nov-06	27	10.79	10,896	9,652	11.42%	33.78%
Dec-06	26	11.03	10,580	9,614	9.13%	24.02%
Total	353	10.95	127,149	127,158	-0.01%	27.45%
Total in OSP (07/15-09/15)	60	9.24	14,515	14,523	-0.06%	28.45%

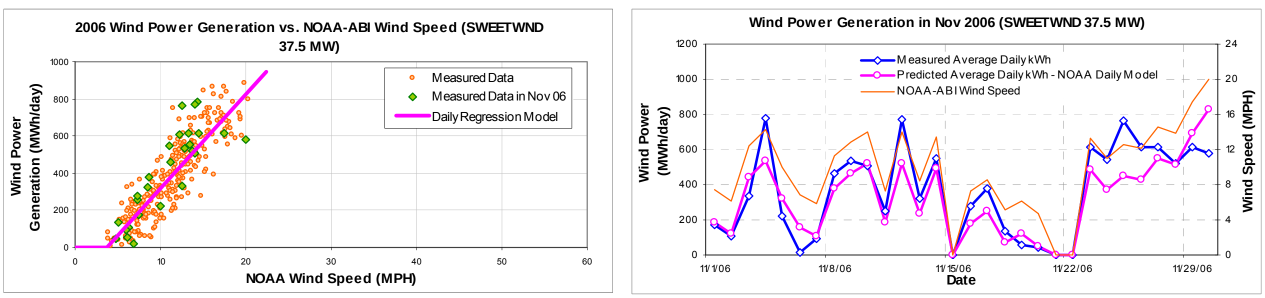

Figure 6: Measured Power Production in November 2006

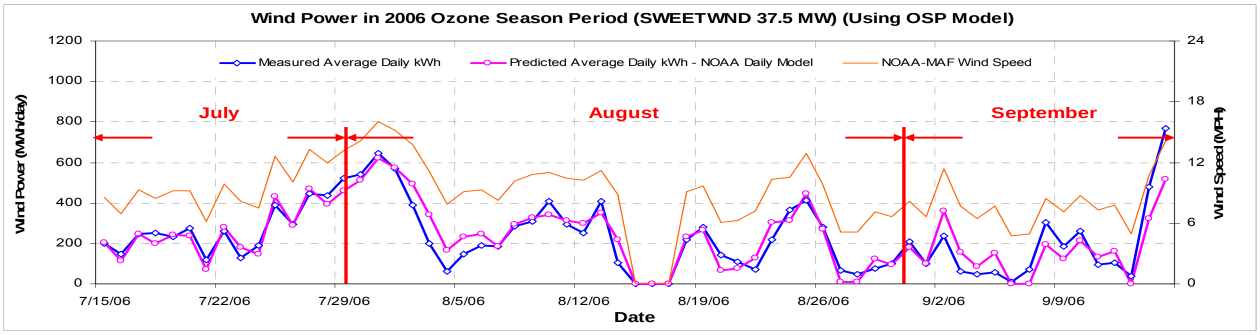

Figure 7: Predicted Wind Power in OSP Using NOAA-ABI Wind Speed (2006)

3. Testing of the Model

To test the performance of the OSP and NON-OSP daily models, the model coefficients were applied to the 2005 NOAA daily wind speed to predict the daily wind power that would have been generated in 2005. The predicted daily wind power was then summed monthly to compare with the monthly measurements in 2005 from ERCOT, as shown in Table 4.

The test results show that both the OSP and NON-OSP models are sufficiently robust to allow for its use in projecting wind production into other weather base years. The largest error of 25.7% was observed in August 2005 in OSP model (Figure 8) and the largest error of 12.7% for the Non-OSP model (Figure 9) was observed in December 2005.

4. Prediction of Wind Power in the 1999 Base Year

The resultant coefficients (Table 2) from the 3-parameter models were next applied to the 1999 average daily NOAA-ABI wind speed to predict the electricity the wind farm would have produced in 1999 (Table 5). In Table 5 the estimated annual and Ozone Season Day values are compared against the measured 2006 values to illustrate the error that would result if one were to simply use the 2006 values without normalization. Table 5 shows that the estimated annual power production increased 4.8% when compared against 2006. The average daily power production during the Ozone Season Period increased 10.7% as well. This may be because 1999 (an average of 11.3 mph) is had a stronger average wind than 2006 (an average of 10.9 mph).

Table 4: Predicted vs. Measured Wind Power in 2005

Month	2005 Predicted MWh- OSP & Non-OSP Daily Models	2005 Measured-ERCOT MWh	2005 Diff. Daily Model
Jan	10384.1	11,105	6.5%
Feb	7412.4	7,130	-4.0%
Mar	12267.8	11,611	-5.7%
Apr	14054.9	13,597	-3.4%
May	11100.3	10,930	-1.6%
Jun	12361.4	13,323	7.2%
Jul	9250.0	8,465	-9.3%
Aug	5859.5	7,882	25.7%
Sep	7918.3	9,062	12.6%
Oct	8720.3	9,068	3.8%
Nov	10033.6	11,094	9.6%
Dec	9879.1	11,322	12.7%
OSD	14467.7	18,131	20.2%
Total	119,242	124,589	4.3%

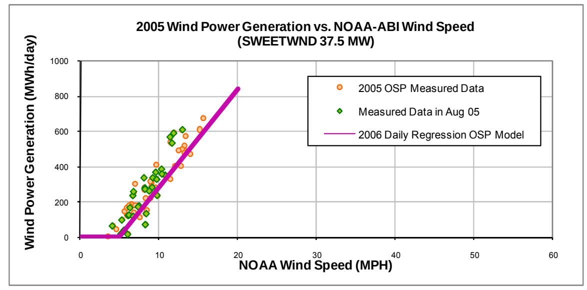

Figure 8: Measured and predicted Power Production in August 2005 using the OSP Model

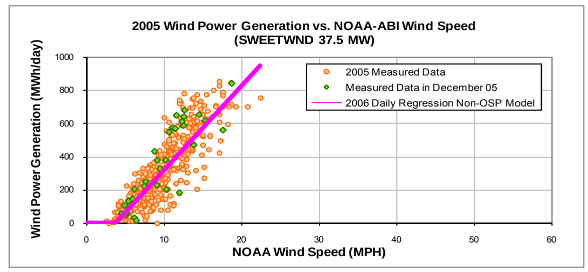

Figure 9: Measured and Predicted Power Production in December 2005 Using the Non-OSP Model.

Table 5: Predicted Power Production in 1999

1999 Estimated MWh/yr	2006 Measured MWh/yr
137,761	131,472
1999 OSP Estimated MWh/day	2006 OSP Measured MWh/day
268	242

<u>Capacity Factor Analysis</u>

Capacity factor is one element in measuring the productivity of a wind turbine or any other power production facility. It compares the plant's actual production over a given period of time with the amount of power the plant would have produced if it had run at full capacity for the same amount of time. The predicted monthly capacity factors for 2006 using the daily model and the measured monthly capacity factors for the same period are shown in Figure 10. Figure 11 shows the predicted capacity factors using the NOAA model from January to December for the periods 1999 through 2006. Figure 11 also shows the measured monthly capacity factor in 2006 and the average monthly capacity factors for these eight years, using the daily NOAA model. In Figure 10, the model shows good agreement tracking the measured capacity factor. In comparison, Figure 11 shows there is more variation in the year to year wind speeds than the uncertainty from the model. Figure 11 also shows the importance of weather normalizing the wind speeds back to the base year.

As seen in Table 6 the annual capacity factors for these years vary from 36.4% to 43% with an average of 39.8% if predicted with the NOAA daily model. Analysis also shows that the highest electricity production occurs in the spring months (Figure 11).

It is interesting to note that the variation across the same month of these years can be more than 20% due to the significantly different wind conditions, e.g. March and May.

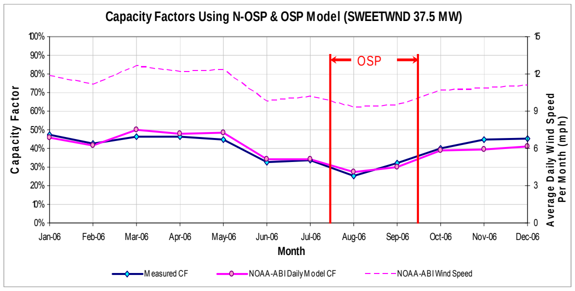

Figure 10: Predicted Capacity Factors Using Daily Models (2006)

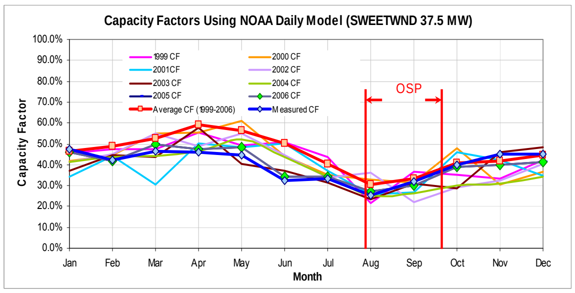

Figure 11: Predicted Capacity Factors Using Daily Models (1999-2006)

Table 6: Summary of Predicted Capacity Factors (1999-2006)

	NOAA Annual Average Wind Speed (MPH)	Annual Predicted Capacity Factor NOAA Daily Model	Predicted Capacity Factor in OSP-NOAA Daily Model
1999	11.3	42.30%	29.80%
2000	11.5	43.00%	28.90%
2001	10.8	39.30%	28.10%
2002	11	40.30%	28.20%
2003	10.8	39.00%	28.00%
2004	10.7	37.80%	28.50%
2005	10.3	36.40%	28.80%
2006	11	39.90%	28.50%
Average (1999-2006)	10.9	0.398	0.286

APPLICATION TO ALL WIND FARMS

The methodology presented in the previous section was applied to all the wind farms within the Texas ERCOT region to calculate the total energy savings from wind power programs for the NOx emissions credits. Table 7shows the summary of this application.

As seen in Table 7, the estimated power production in 1999 (6,919,353 MWh/yr) increased about 2% when compared to what was measured in 2006 (6,760,687 MWh/yr). For the Ozone Season Period, the estimated average daily power production is 15,468 MWh/day, a 15% increase from that measured in 2006 (13,488 MWh/day). This is because for all the four NOAA weather stations involved in the modeling, 1999 has a stronger average wind than 2006 (Figure 13).

Table 7 also presents the modeling results for each wind farm. For the wind farms Horse Hollow 2, 3 and 4 and Red Canyon, which started operation in the mid of 2006, the power production during the testing period (mostly from January to June 2006) was low and was excluded in the analysis. Therefore, only certain months of data (mostly from July 2006 to December 2006) were used in the modeling.

For Brazos Wind Ranch (BRAZ_WND_WND1 and BRAZ_WND_WND2) and Red Canyon Wind Farm, it shows that measured power in 2006 was much higher than the estimated power production in 1999 (Figure 12). This is because some metering problems were identified from the ERCOT measured data during the analysis, which resulted in almost doubled maximum capacity in certain months. Those data were excluded in the analysis for the modeling purpose but were still included in the total measured MWh from ERCOT before confirmation from ERCOT about the possible metering problem is received. This may also explain the difference between 1999 estimated MWh and 2006 measured MWh as being much smaller (2%) for annual totals than the OSD period (15%).

From this analysis it can be concluded that the use of the improved weather normalization procedure for predicting 1999 base year production based on 2006 measured power production is more accurate than simply using the measured 2006 power production as the base year power production.

Table 7: Summary of Power Production for All Wind Farms

Wind Unit Name	County	NOAA Weather Station	PCA	Capacity (MW)	2006 Measured (MWh/yr) (ERCOT Original Data)	1999 Estimated Using Daily Model (MWh/yr)	2006 OSP Measured (MWh/day)	1999 OSP Estimated (MWh/day)
BRAZ_WND_WND1	SCURRY	ABI	AEP-West	99	423,823	348,113	566	637
BRAZ_WND_WND2	SCURRY	ABI	AEP-West	61	249,970	198,702	331	371
BUFFALO_GAP_1	TAYLOR	ABI	AEP-West	120	372,954	390,430	719	813
CALLAHAN_WND1	TAYLOR	ABI	AEP-West	114	410,497	428,993	789	885
*DELAWARE_WIND_NWP**	*CULBERSON*	*GDP*	*TXU*	*30*	*67,288*	*67,452*	*97*	*93*
H_HOLLOW_WND1	TAYLOR	ABI	AEP-West	213	684,543	728,851	1,211	1,363
HHOLLOW2_WIND1**	TAYLOR	ABI	AEP-West	224	191,471	198,696	626	1,029
HHOLLOW3_WND_1**	TAYLOR	ABI	AEP-West	299	338,374	351,472	1,116	1,246
HHOLLOW4_WND_1**	TAYLOR	ABI	AEP-West	115	165,572	195,070	583	657
INDNENR_INDNENR	PECOS	FST	AEP-West	80	257,297	270,994	506	595
INDNENR_INDNENR_2	PECOS	FST	AEP-West	80	230,780	246,042	455	537
*INDNNWP_INDNNWP**	*PECOS*	*FST*	*AEP-West*	*82.5*	*235,758*	*251,397*	*487*	*569*
KING_NE_KINGNE	UPTON	MAF	AEP-West	79.3	186,937	201,259	322	365
KING_NW_KINGNW	UPTON	MAF	AEP-West	79.3	217,652	231,449	408	455
KING_SE_KINGSE	UPTON	MAF	AEP-West	40.3	91,151	98,462	161	184
KING_SW_KINGSW	UPTON	MAF	AEP-West	79.3	196,732	210,137	369	415
*KUNITZ_WIND_LGE**	*CULBERSON*	*GDP*	*LCRA*	*35*	*57,562*	*57,072*	*64*	*61*
RDCANYON_RDCNY1**	BORDEN	ABI	AEP-West	124	323,018	250,818	787	787
*SGMTN_SIGNALMT**	*HOWARD*	*MAF*	*TXU*	*41*	*101,218*	*106,777*	*178*	*198*
*SW_MESA_SW_MESA**	*UPTON*	*MAF*	*AEP-West*	*75*	*210,316*	*224,262*	*424*	*476*
SWEETWN2_WND2	NOLAN	ABI	LCRA	92	332,222	354,718	606	669
SWEETWN3_WND3	NOLAN	ABI	LCRA	135	416,803	442,506	767	843
SWEETWND_WND1	NOLAN	ABI	LCRA	37.5	126,379	137,761	242	268
TRENT_TRENT	NOLAN	ABI	TXU	150	508,398	534,218	933	1,054
*WOODWRD1_WOODWRD1**	*PECOS*	*FST*	*AEP-West*	*80*	*185,586*	*200,746*	*379*	*459*
*WOODWRD2_WOODWRD2**	*PECOS*	*FST*	*AEP-West*	*80*	*178,385*	*192,956*	*362*	*439*
TOTAL				2,645	6,760,687	6,919,353	13,488	15,468

*** Wind farms in Italic were built before 9/2001.**

**** Only certain months of data available for modeling**

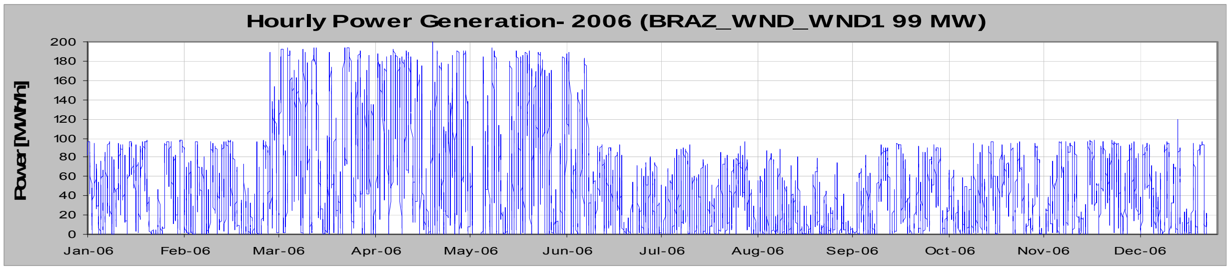

Figure 12: Data Metering Problem Identified in Brazos Wind Branch Wind Farm

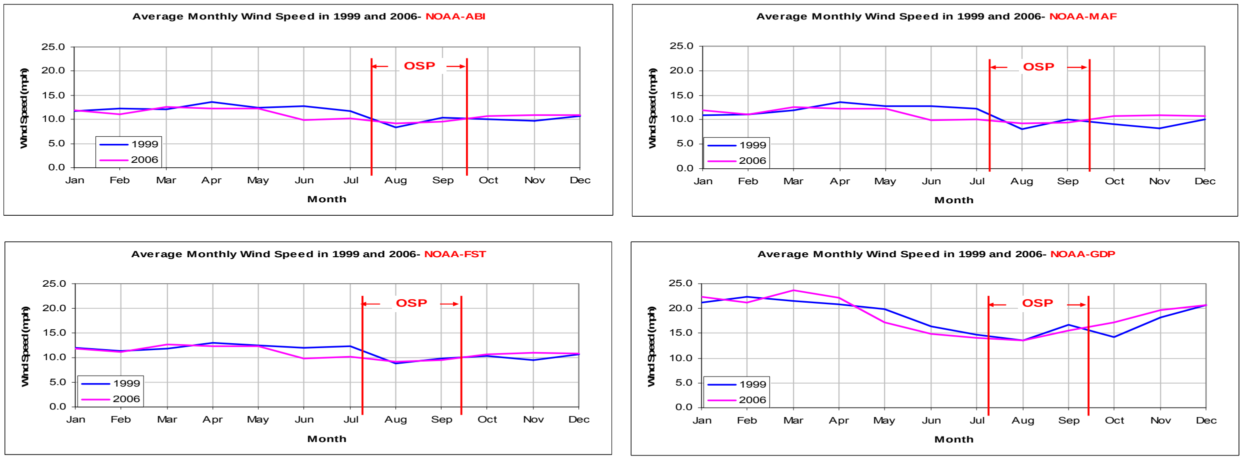

Figure 13: 1999 and 2006 Monthly Average Wind Speed for Four NOAA Weather Stations

UNCERTAINTY ANALYSIS

To calculate the uncertainty, a prediction uncertainty, $\sigma^2\left(\hat{E}_{pred,j}\right)$ was used assuming no autocorrelation effects in the data used to generate the linear model. Use of such a model, for a particular observation, *j*, during any time at a particular condition can be represented as follows (Reddy, et al. 1992):

$$\sigma^2\left(\hat{E}_{pred,j}\right) = MSE\left(\hat{E}_i\right)\cdot\left[1+\frac{1}{n}+\frac{\left(V_j-\bar{V}_n\right)^2}{\sum_{i=1}^{n}\left(V_i-\bar{V}_n\right)^2}\right] \quad (1)$$

The mean square error, $MSE\left(\hat{E}_i\right)$, during the period of the development of the linear model can be calculated by

$$MSE\left(\hat{E}_i\right) = \left[\frac{1}{n-(k+1)}\right]\sum_{i=1}^{n}\left(E_i-\hat{E}_i\right)^2 \quad (2)$$

Where *n* is the number of days in the period used for the developed model, *k* is the number of regression variables in the linear model, and $\bar{V}_n$ is the mean value of the velocity on the modeling period.

The last term in the brackets of the equation 2, accounts for the increase in the variance of the energy prediction for any particular observation, *j*, which is different of the centroid of the modeling data. On the other hand, the second term accounts for the variance in predicting the mean energy predicted for the observation *j*.

The total uncertainty for a period of interest, of *m* days, is the sum of all the wind energy predicted $\hat{E}_{pred,j}$ in each individual observation.

This can be calculated assuming that

$$\sum_{j=1}^{m}\sigma^2\left(\hat{E}_{pred,j}\right) = \sigma^2\left(\sum_{j=1}^{m}\left(\hat{E}_{pred,j}\right)\right) = \sigma^2\left(\hat{E}_{pred,total}\right) \quad (3)$$

with the total prediction variance –uncertainty, obtained through

$$\sigma^2\left(\hat{E}_{pred,total}\right) = MSE\left(\hat{E}_i\right)\cdot m\cdot\left[1+\frac{1}{n}+\frac{\sum_{j=1}^{m}\left(V_j-\bar{V}_n\right)^2}{m\sum_{i=1}^{n}\left(V_i-\bar{V}_n\right)^2}\right] \quad (4)$$

Note that the last equation is affected by the number of days that the wind energy will be predicted, the number of days used for the modeling development and the uncertainty due to the distances between the data predicted and the centroid of the modeling data. Therefore, increasing *n* and *m* yields an effective relative decrease in the uncertainty which is expected.

Table 8 presents the statistics parameters of the daily linear models for all the wind farms in the ERCOT region. Table 9 shows the uncertainty of applying the linear models to predict the energy generation that they would have had in the year 1999, ranging from 2.3% to 5.4%. The results indicate that the daily models are reasonably reliable for predicting the performance of the wind farm in the base year within the same range of wind conditions.

Also, in the same table the uncertainty related to the predicted wind generated for the same wind farms in the 1999 Ozone Season Period using the OSP model, which considers the period of July 15 though Sep 15, or about 63 days. The uncertainty of using OSP models for predicting wind power in the 1999 OSD varies from 5% to 11% for all the wind farms.

EMISSIONS REDUCTION

The Energy Systems Laboratory (ESL) has worked closely with the TCEQ and EPA to develop creditable procedures for calculating NO_x reductions from electricity savings using the EPA's Emissions and Generation Resource Integrated Database (eGRID[5]).

Calculating NOx emissions from wind power to counties within the ERCOT region encounters some major complications. First, electricity can be generated from different primary energy sources which results in very different NOx emissions. Second, the combination of generation resources used to meet loads may vary during each day or different seasons. Third, electricity is transported over long distances by complex, interconnected transmission and distribution systems. Therefore, the generation source related to electricity usage can be difficult to trace and may occur far from the jurisdiction in which that energy is consumed.

[5] This 2007 eGRID table for Texas, was provided by Art Diem at the USEPA, and includes emissions values for AEP, Austin Energy, Brownsville Public Utility, LCRA, Reliant, San Antonio Public Service, South Texas Coop, TMPP, TNMP, and TXU.

Table 8: Statistical Parameters of the Determined 2006 Daily Power Production Linear Models

Wind Farm	1999 Non Ozone Season Period				1999 Ozone Season Period (OSP)			
	Predicted days	Total Variance	Total Estimated	Relative Uncertainty	Predicted Days	Total Variance	Total Estimated	Relative uncertainty
BRAZ_WND_WND1	302	12,185.29	348,113	3.50%	63	4,118.86	40,126.0	10.26%
BRAZ_WND_WND2	302	6,661.64	198,702	3.35%	63	2,533.57	23,359.2	10.85%
BUFF_GAP_UNIT1	302	12,002.67	390,430	3.07%	63	2,581.97	51,220.5	5.04%
CALLAHAN_WND1	302	10,363.27	428,993	2.42%	63	3,024.06	55,744.0	5.42%
H_HOLLOW_WND1 *	302	18,207.82	728,851	2.50%	63	4,698.90	85,843.4	5.47%
HHOLLOW2_WIND1*	302	18,721.64	594,059	3.15%	63	3,868.09	64,797.2	5.97%
HHOLLOW3_WND_1*	302	20,218.32	676,954	2.99%	63	4,162.25	78,508.2	5.30%
HHOLLOW4_WND_1*	302	12,024.82	375,919	3.20%	63	2,467.58	41,391.8	5.96%
INDNENR_INDNENR	300	10,916.04	270,994	4.03%	63	3,608.18	37,496.0	9.62%
INDNENR_INDNENR_2	300	10,715.44	246,042	4.36%	63	3,426.89	33,853.0	10.12%
KING_NE_KINGNE	302	7,238.95	201,259	3.60%	62	2,409.18	23,011.5	10.47%
KING_NW_KINGNW	302	9,816.87	231,449	4.24%	63	2,773.74	28,689.7	9.67%
KING_SE_KINGSE	302	3,750.40	98,462	3.81%	62	1,297.03	11,637.8	11.14%
KING_SW_KINGSW	302	8,215.73	210,137	3.91%	63	2,453.26	26,137.6	9.39%
RDCANYON_RDCNY1*	302	10,807.65	341,043	3.17%	63	N/A	31,686.1	N/A
SWEETWN2_WND2	302	8,279.10	354,718	2.33%	63	2,917.40	42,136.9	6.92%
SWEETWN3_WND3	302	11,061.84	442,506	2.50%	63	3,510.20	53,119.1	6.61%
SWEETWND_WND1	302	3,557.81	137,761	2.58%	63	1,088.08	16,883.3	6.44%
TRENT_TRENT	302	14,829.57	534,218	2.78%	63	3,950.67	66,409.9	5.95%
DELAWARE_WIND_NWP	*302*	*2,281.84*	*67,452*	*3.38%*	*61*	*557.45*	*5,869.6*	*9.50%*
INDNNWP_INDNNWP	*300*	*11,423.87*	*251,397*	*4.54%*	*63*	*3,344.82*	*35,822.5*	*9.34%*
KUNITZ_WIND	*302*	*2,499.70*	*57,072*	*4.38%*	*59*	*395.74*	*3,910.0*	*10.12%*
SGMTN_SIGNALMT	*302*	*4,486.56*	*106,777*	*4.20%*	*63*	*1,393.76*	*12,475.1*	*11.17%*
SW_MESA_SW_MESA	*302*	*9,587.13*	*224,262*	*4.27%*	*63*	*3,171.62*	*29,990.7*	*10.58%*
WOODWRD1_WOODWRD1	*300*	*7,506.38*	*200,746*	*3.74%*	*63*	*2,231.27*	*28,942.8*	*7.71%*
WOODWRD2_WOODWRD2	*300*	*6,717.90*	*192,956*	*3.48%*	*63*	*2,139.50*	*27,638.9*	*7.74%*

Table 9: 1999 Annual and OSP Uncertainty of the Power Generation Prediction Using the Linear Daily Models

Wind Farm	Statistical Parameters of 2006 Non-OSP Daily Models						Statistical Parameters of 2006 OSP Daily Models					
	c_0	c_1	AdjR^2	RMSE	CV-RMSE	# Days	c_0	c_1	AdjR^2	RMSE	CV-RMSE	# Days
BRAZ_WND_WND1	-383.05	120.68	0.62	356.72	38.2%	196	-620.49	129.51	0.63	262.97	46.5%	63
BRAZ_WND_WND2	-189.84	66.28	0.61	194.99	37.8%	230	-337.22	72.92	0.59	161.75	48.9%	63
BUFF_GAP_UNIT1	-383.30	129.61	0.65	351.67	32.5%	301	-844.94	170.76	0.88	164.84	22.9%	63
CALLAHAN_WND1	-460.55	145.94	0.76	303.64	25.5%	301	-799.83	173.51	0.85	193.07	24.5%	63
H_HOLLOW_WND1	-620.45	236.58	0.73	533.46	25.9%	293	-1305.16	274.76	0.85	300.00	24.8%	63
HHOLLOW2_WIND1*	-379.61	183.45	0.59	546.01	33.9%	106	-1134.77	222.81	0.85	241.00	38.5%	15
HHOLLOW3_WND_1*	-572.24	219.73	0.63	590.85	33.8%	150	-1049.85	236.48	0.85	265.73	23.8%	63
HHOLLOW4_WND_1*	-213.14	113.65	0.55	350.86	34.8%	120	-640.13	133.60	0.83	157.54	27.0%	63
INDNENR_INDNENR	-400.67	102.57	0.46	320.70	43.4%	298	-579.80	117.98	0.53	229.95	45.5%	63
INDNENR_INDNENR_2	-397.37	96.11	0.44	314.81	46.9%	300	-544.64	108.64	0.52	218.40	48.0%	63
KING_NE_KINGNE	-278.17	77.47	0.57	212.00	38.4%	302	-356.88	76.23	0.50	154.77	48.1%	63
KING_NW_KINGNW	-151.36	73.45	0.40	287.50	45.2%	302	-329.15	82.83	0.47	176.80	43.3%	63
KING_SE_KINGSE	-146.33	38.70	0.56	109.84	40.9%	302	-209.60	41.60	0.51	83.33	51.9%	63
KING_SW_KINGSW	-188.12	71.18	0.47	240.61	41.9%	302	-348.37	80.58	0.52	156.37	42.4%	63
RDCANYON_RDCNY1*	-116.87	93.10	0.52	315.20	35.2%	99	-116.87	93.10	0.52	315.20	35.2%	99
SWEETWN2_WND2	-343.07	118.56	0.77	242.57	24.3%	294	-624.95	133.25	0.79	186.22	30.7%	60
SWEETWN3_WND3	-321.41	138.59	0.72	324.10	26.0%	296	-735.99	162.64	0.79	224.06	29.2%	60
SWEETWND_WND1	-191.15	50.87	0.77	104.24	27.1%	293	-272.06	55.62	0.82	69.45	28.7%	60
TRENT_TRENT	-758.44	198.46	0.74	434.50	29.2%	301	-1087.80	220.61	0.84	252.23	27.0%	63
DELAWARE_WIND_NWP	*-93.97*	*15.46*	*0.72*	*66.88*	*32.3%*	*294*	*-101.89*	*14.04*	*0.68*	*35.94*	*37.1%*	*61*
INDNNWP_INDNNWP	*-392.43*	*96.66*	*0.41*	*335.62*	*49.2%*	*300*	*-508.36*	*108.14*	*0.53*	*213.17*	*43.8%*	*63*
KUNITZ_WIND	*-137.73*	*16.28*	*0.70*	*73.27*	*41.0%*	*296*	*-104.59*	*11.95*	*0.75*	*25.93*	*40.2%*	*61*
SGMTN_SIGNALMT	*-13.39*	*29.07*	*0.33*	*131.40*	*44.1%*	*302*	*-138.39*	*35.52*	*0.40*	*88.84*	*50.0%*	*63*
SW_MESA_SW_MESA	*-170.20*	*72.62*	*0.40*	*280.77*	*0.46*	*302*	*-378.94*	*90.26*	*0.45*	*202.16*	*0.48*	*63*
WOODWRD1_WOODWRD1	*-471.94*	*90.83*	*0.59*	*220.53*	*41.0%*	*300*	*-602.03*	*106.58*	*0.71*	*142.20*	*37.6%*	*63*
WOODWRD2_WOODWRD2	*-457.84*	*87.73*	*0.63*	*197.36*	*38.1%*	*300*	*-572.38*	*101.52*	*0.71*	*136.35*	*37.7%*	*63*

Due to the limited availability of public data and the fact that the eGRID database aggregates the emissions on the basis of PCA's (Power Control Areas)[6], the decision was made to calculate and assign emissions, according to the PCA where it was generated. A similar decision has been used in California (Marnay et al. 2002). This assumption does not address the deregulation of generation, but provides a good estimation of the emissions reduction from wind power electric production for the base year of 1999, which is currently in use by the TCEQ using the EPA's eGRID.

To calculate the NOx emissions reduction from the wind projects within the ERCOT region, the total MWh wind power for each Power Control Area are summarized in Table 10. The total MWh production in each PCA was input in the corresponding cells in the eGRID table to calculate the total annual and OSD emissions reduction for the entire ERCOT region (Figure 14 and Figure 15).

According to the developed models, the total MWh savings in the base year 1999 for the wind farms within the ERCOT region is 6,919,352 MWh and 15,269 MWh/day in the Ozone Season Period. The total NOx emissions reductions across all the counties amount to 4,059 tons/yr and 9 tons/day for the Ozone Season Period.

SUMMARY

In this paper, a methodology for predicting wind power the wind farms would have produced in the 1999 base year using 2006 measured wind power generation for each wind farm and the wind speed data from the nearest NOAA weather stations is discussed. The total wind power production in the base year (1999) and the corresponding emissions reduction from all the wind farms in the ERCOT region using this procedure is then presented to show the improved accuracy of using this weather normalization procedure compared to the non-weather normalization procedure. The uncertainty analysis performed on all the daily regression models shows that the developed daily regression models are sufficiently reliable to allow for their use in projecting wind production into other weather base years.

[6] A Power Control Area (PCA) is defined as one grid region for which one utility controls the dispatch of electricity. Some smaller utilities are embedded in the power control areas of larger utilities. The corresponding PCA for wind farms was obtained from PUCT.

Table 10: Wind Power Production Assigned to Each PCA in the ERCOT Region

PCA	Annual Wind Power (MWh/yr)	OSD Wind Power (MWh/ day)
AEP-WEST	5,218,849	12,082
TXU	708,447	1,345
LCRA	992,057	1,842
Total	6919352	15269

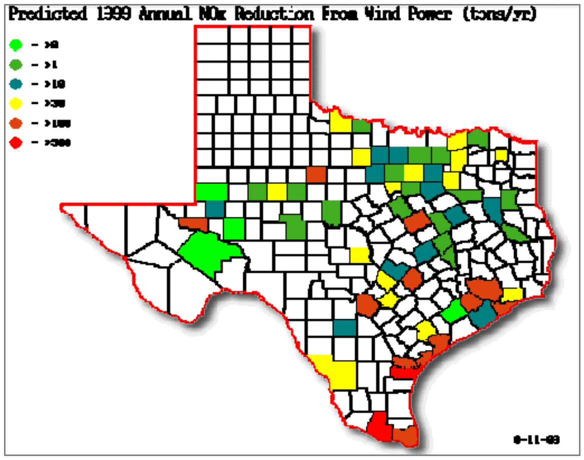

Figure 14: 1999 Predicted Annual NOx Reductions from Wind Power in Texas Map.

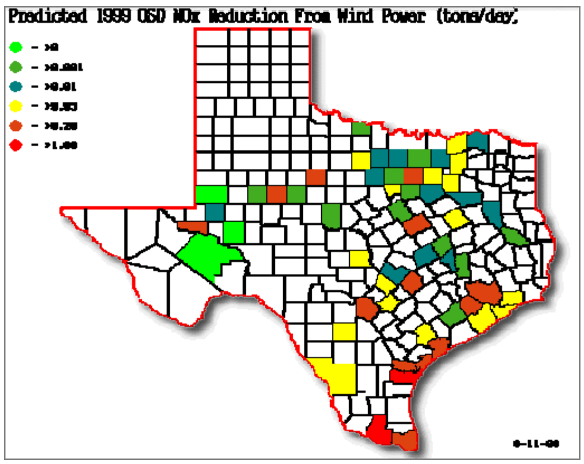

Figure 15: 1999 Predicted OSD NOx Reductions from Wind Power in Texas Map.

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