



Sustainable Energy Solutions

**Estimating the Economic Benefits of Wind
Energy Projects using NREL's JEDI Model with
Monte Carlo Simulation:
Coconino and Navajo County, Arizona**

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Susan K. Williams

Assistant Professor
College of Business Administration

Tom Acker

Associate Professor
Department of Mechanical Engineering

Megan Greve

MBA Research Assistant

All of:

Northern Arizona University

Box 15066

Flagstaff, AZ 86011-5066

(928) 523-0940

Fax: (928) 523-7331

Susan.Williams@nau.edu

Estimating the Economic Benefits of Wind Energy Projects using the NREL's JEDI Model with Monte Carlo Simulation: Coconino and Navajo County, Arizona

Susan K. Williams, Tom Acker and Megan Greve

Introduction

A process to estimate the county-level economic benefits from constructing and operating a wind energy project was developed. The Jobs, Economic Development, and Impactsⁱ (JEDI) model developed for the National Renewable Energy Laboratory (NREL) was used in conjunction with Monte Carlo simulation. JEDI, an economic input/output model was used to estimate jobs, earnings, and output (economic activity) resulting from developing the wind energy project.

By using Monte Carlo simulation, the input parameters which are uncertain may be estimated by a range of values as opposed to a single estimate. This produces a frequency distribution for the output thus providing a range of output values instead of a single point estimate. In addition, the Monte Carlo simulation provides a means to perform a sensitivity analysis and determine which input parameters most affect the output.

This process was demonstrated using two counties in northern Arizona, Coconino and Navajo. Both of these counties are approximately 50% Indian Reservation. Electrification on Indian Reservation significantly lags the national average so there is a high need for distributed energy resources. In addition, these two counties contain some of the best wind resources in Arizona.

Methodology

In this study, the JEDI model performed the economic input/output (I/O) analysis with an Excel add-in, *@Risk* (Palisade Corp. 2005), used to perform the Monte Carlo simulation.

In I/O analysis, a project expenditure may have up to three impacts on the local economy:

- **Direct effects** – on-site effect created by expenditure (i.e., on-site jobs of contractors and crews, jobs at the turbine).
- **Indirect effects** – increase in economic activity that occurs when a contractor, vendor or manufacturer receives payment for goods or services and in turn is able to pay others who support their business.
- **Induced effects** – change in wealth and income that is induced by the spending of those persons directly and indirectly employed by the project (i.e., spending on food, clothes, utilities, transportation, insurance, medical, etc.).

The results of I/O analysis estimate these effects (direct, indirect, and induced) on the jobs, earnings, and economic output.

JEDI Model

JEDI is a spreadsheet economic input/output model that accepts wind energy project data and estimates the economic benefits derived from building and operating a wind energy project. The model separates a wind energy project into two distinct phases: construction phase and operations and maintenance (O&M) phase. The construction phase is approximately a year while the O&M phase is from the time the project is brought on-line until it is decommissioned. The JEDI model estimates the economic impact using six measures: jobs during construction phase, jobs during O&M phase, earnings during construction phase, earnings during O&M phase, output during construction phase and output during O&M phase.

JEDI was designed for users that have a variety of experience-levels in I/O analysis or with wind energy projects. To obtain results from JEDI, a user can input as little as the year of installation, the size of the project, and the state for which the economic impacts will be estimated. In this study, the inputs are the county multipliers, wind

ⁱ The JEDI model was designed by Marshall Goldberg, of MRG & Associates, under contract with NREL. The model is posted on the Wind Powering America website: http://www.eere.energy.gov/windandhydro/windpoweringamerica/filter_detail.asp?itemid=707 in June 2005.

energy project size, construction cost, O&M cost, property tax information, and local share percentages. The unspecified inputs have default values defined in JEDI. As the user gains additional experience or information about the project, additional details can be entered into the model (Goldberg et al 2004). If a user wants to perform an impact analysis for a smaller or larger region, the user enters direct, indirect and induced multipliers for employment, earnings and output, and personal consumption expenditures for the desired region.

Why Monte Carlo simulation?

Monte Carlo simulation is a statistical simulation technique which allows input parameters that are uncertain to be randomly varied over a specified range of values. Multiple trials of the Monte Carlo model allow the user to observe and average the results of the output (Winston and Albright 2001). @Risk by Palisade Corporation, an add-in to Microsoft Office Excel, was utilized for Monte Carlo simulation (Winston 2000). Using Monte Carlo simulation in conjunction with the I/O analysis provided three advantages over an analysis with JEDI only:

- 1) **Increased input flexibility** – cost estimates, tax rates, and local share percentages may be entered as a range of values instead of a single estimate.
- 2) **Increased output information** – a range of output values was obtained instead of a single value. This provides a measure of certainty or risk: the smaller the range, the more certainty in the results.
- 3) **Sensitivity analysis** – the most influential input parameters on the estimated economic impact. This is useful information because the input parameters that have the greatest effect on the model can be identified, and extra attention can be applied to estimate these parameters most carefully.

The data required by the JEDI model to estimate the economic impact of constructing and operating a wind energy project can be difficult to accurately estimate. Some input parameters are specific to the site and design. However, estimates for economic impacts are often desired before a site and design have been selected. In addition some of this data is proprietary and industry norms must be relied on to estimate the parameters.

The approach in other work (Costanti 2004), (Tegen 2004), has been to use a single estimate representing the most likely value or industry average. For each of the outputs, the JEDI model then produced a single value. Using Monte Carlo simulation, for each of these input parameters, three estimates were determined: (1) the most likely estimate, (2) the minimum estimate, and (3) the maximum estimate.

Case Study: Coconino and Navajo counties

For this study, Coconino County and Navajo County were selected not only because of the need for distributed energy resources in these counties, but in addition these two counties contain some of the better wind energy resource sites in Arizona. A GIS study (Williams et al 2005) of the wind energy potential for these two counties determined that the potential installed capacity of wind energy in Coconino County was an estimated 7500 MW and for Navajo County was 5000 MW. Of the developable windy land in Coconino County 91.8% is Class 3, 5.3% is Class 4, 2.1% is Class 5, and 0.9% is Class 6 and above. Of the developable windy land in Navajo County 96.7% is Class 3, 2.2% is Class 4, 0.6% is Class 5, and 0.4% is Class 6 and above. A map of the developable windy land and wind class definitions is in Figure 1.

Coconino County is the largest county in Arizona with 18,661 square miles and a sparse 2003 population of 122,770. The area is known for many scenic sites, such as the Grand Canyon, Oak Creek Canyon, the San Francisco Peaks, and Lake Powell. (Arizona Dept. of Commerce 2004).

Navajo County is 9,959 square miles and is divided by the Mogollon Rim, an escarpment that defines the southwestern edge of the Colorado Plateau. The population in 2003 for Navajo County was 101,615. (Arizona Dept. of Commerce 2004).

The largest land ownership category in both Coconino and Navajo counties, approximately 46% and 55%, respectively, is Indian Reservation (Arizona Dept. of Commerce 2004). These lands are home to Navajo, Hopi, Paiute, Havasupai, and Hualapai tribes. In 1990, 14.2% of reservation households had no access to electricity as compared to 1.2% of all households nationally. On the Navajo Reservation the percentage of households with no access to electricity is as large as 38% (Conner 2005). Thus there is a need for electricity in these two counties.

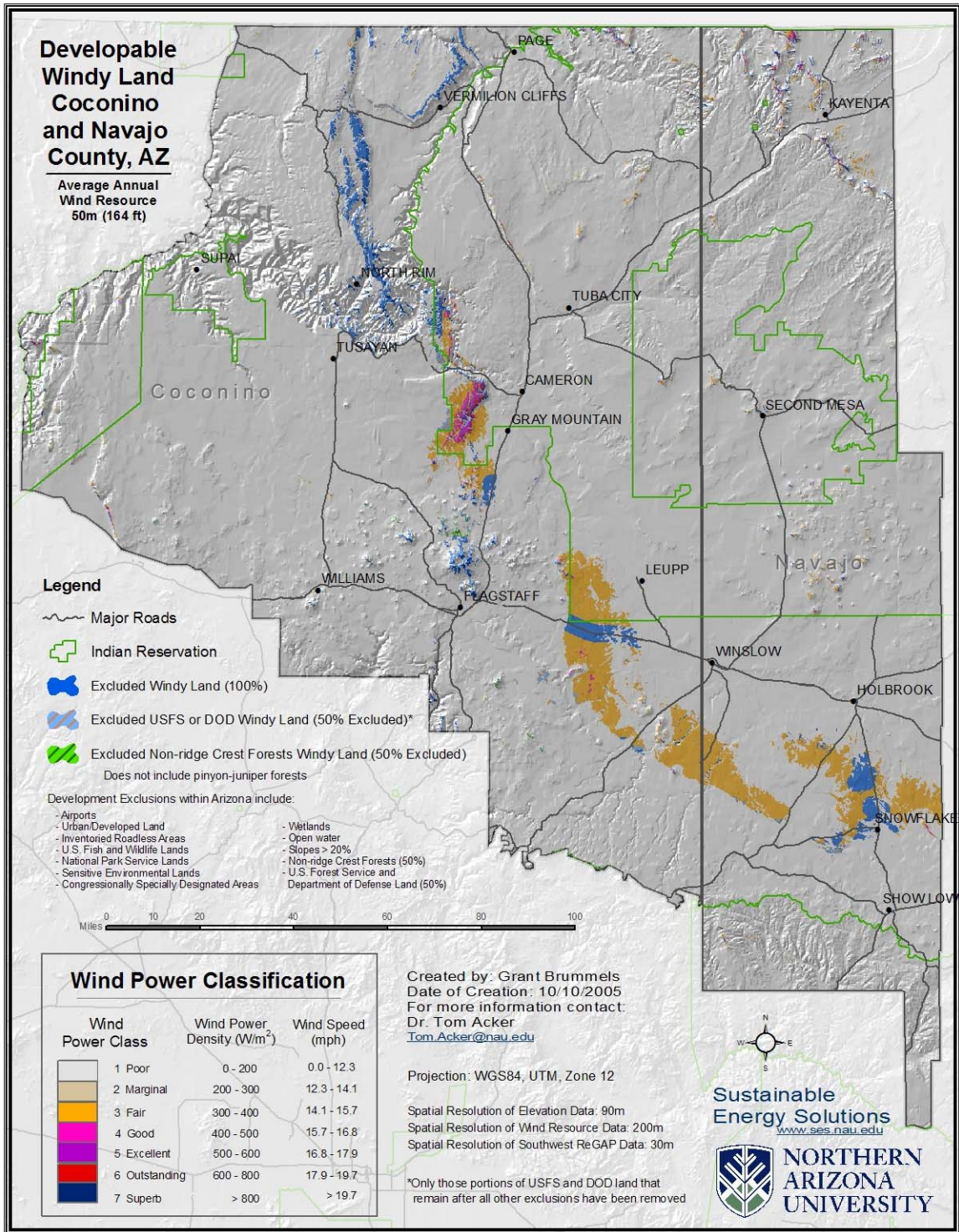


Figure 1 Map of Developable Windy Land for Coconino and Navajo Counties

Input Data

A variety of input parameters were required to run JEDI with a Monte Carlo simulation. For the JEDI model the county multipliers, wind energy project size, construction cost, O&M cost, property tax information, and local share percentages were all estimated. In addition, several simulation parameters are required and discussed below.

County Multipliers

In order to utilize JEDI for county-level analysis, appropriate multipliers for Coconino and Navajo counties were obtained from Marshal Goldberg via NREL (Goldberg et al 2004). Specifically, the direct, indirect and induced multipliers for employment, earnings and output (per million dollars change in final demand) and personal consumption expenditures (i.e., average consumer expenditures on goods for the counties) were obtained (Goldberg 2004).

Wind Energy Project Size

Three wind energy project sizes were selected for the economic impact analysis, 10.5 MW, 60 MW, and 180 MW. The sizes that were selected were based on discussions with wind energy experts and professionals, examination of the results of the developable windy land analysis (Williams et al 2005) and surveying the southwest projects that came on-line in 2003-2004. For all analysis, 1.5 MW wind turbines were assumed since this is currently the typical size for utility-sized wind projects.

Construction Cost and Operations & Maintenance Cost

Construction cost and O&M cost depend on site and design specific data. Since the site and design were not known, these costs were estimated by a range of values. The estimates used for construction cost and O&M cost are given in Table 1. Estimates for these costs are based on several sources including conversation with a wind developer (Costanti 2004), (Tegen 2004), (EWEA 2003), (Poore 2005).

Table 1 Input Parameter Estimates

Input Parameter	Minimum	Most Likely	Maximum
Construction Cost (\$/kw)	\$1,000	\$1,200	\$1,500
Annual Operating Cost (\$/kw)	\$9.50	\$12.50	\$25.00
Property Tax Rate	5.0%	7.6%	11.0%

Both construction cost and O&M cost were uncertain input parameters and were therefore simulated. The triangular distribution was used to generate these costs. The triangular distribution is often used in practice because it is uni-modal and may be non-symmetrical. In addition, there are fixed endpoints for the range of values. Finally, the triangular distribution is a good distribution to use in the absence of data. In the absence of data, experts can be surveyed and industry data consulted for averages. Experts can be asked for their subjective estimates of the minimum, most likely, and maximum values (Law and Kelton 1982).

Property tax information

To calculate the property tax in Arizona the construction cost which includes the cost of the equipment (wind turbines), building and installation costs, must first be determined. Typically, the *full-cost value* is 80% of the construction cost. Property taxes are based on the *assessed value* which is 25% of the full-cost value. The *property tax* is the tax rate multiplied by the assessed value.

The tax rate varies significantly depending on the location within the counties. The tax rate for the Sunshine Wind Park that is planned for eastern Coconino county will be 7.6%. This rate was used as the most likely estimate for both Coconino and Navajo counties. Examining the tax tables, it was determined that the range of tax rates vary from a minimum of 5% to a maximum 11%, in both Coconino and Navajo counties. (Arizona Dept. of Commerce 2004), (Coconino County Tax Assessor 2005), (Navajo County Tax Assessor 2005). The property tax rate was simulated using a triangular distribution.

Local Share

Local share is the percentage of expenditures spent in the analysis region where the wind energy project is constructed. For this work, it represents the percentage of expenditures spent in the county. Currently, the JEDI model provides default values for local share percentages that are estimated at the state-level (See Table 2). Upon review, some of the default local share percentages were determined to be too high for a county-level analysis. Based upon discussions with a wind developer and an economist, the decision was made to use the JEDI model default values as maximum values. Minimum values were established for the local share percentages and are also

shown in Table 2 (Costanti 2004). The local share percentages were simulated using a uniform distribution which implies that all values between the minimum and maximum (default) are equally likely.

Table 2 Local Shares Values

Project Cost Data	Minimum Local Share	Maximum Local Share (JEDI default)
Construction Costs		
Materials		
Construction (concrete, rebar, equip, roads and site prep)	10%	90%
Transformer	0%	0%
Electrical (drop cable, wire,)	10%	100%
HV line extension	10%	100%
Materials Subtotal		
Labor		
Foundation	25%	100%
Erection	25%	75%
Electrical	10%	75%
Management/supervision	0%	0%
Labor Subtotal		
Construction Subtotal		
Equipment Costs		
Turbines (excluding blades and towers)	0%	0%
Blades	0%	0%
Towers	0%	0%
Equipment Subtotal		
Other Costs		
HV Sub/Interconnection	10%	100%
Engineering	0%	0%
Legal Services	10%	100%
Land Easements	100%	100%
Site Certificate/Permitting	100%	100%
Other Subtotal		
Total		
Wind Plant Annual Operating and Maintenance Costs		
	Local Share	Local Share
Personnel		
Field Salaries	50%	100%
Administrative	50%	100%
Management	50%	100%
Personnel Subtotal		
Materials and Services		
Vehicles	10%	100%
Misc. Services	10%	80%
Fees, Permits, Licenses	100%	100%
Utilities	100%	100%
Insurance	0%	0%
Fuel (motor vehicle gasoline)	100%	100%
Tools and Misc. Supplies	50%	100%
Spare Parts Inventory	2%	2%

Simulation Parameters

For each county and wind project size, a simulation was run. For each simulation, the number of trials was determined by observing the convergence of the distribution statistics for the output variables (construction phase: jobs, earnings, output; O&M phase: jobs, earnings, output). When the measured statistics changed no more than 1%, the output distribution was considered ‘stable’ and the simulation was considered to have converged. The number of trials in each simulation varied between 900 and 1100. The output distribution statistics measured are the average percent change of the percentiles, the mean, and the standard deviation.

Results

All economic outputs from JEDI are divided into benefits that occur during the construction phase (usually less than a year) and annual benefits that occur during the operational life of the wind project. For each phase, the model estimates:

- Jobs – the number of full-time equivalent employment for a year.
- Earnings - wage and salary compensation paid to workers.
- Output - economic activity or the value of production in the county economy.

Overall, there were slight variations in the results of the two counties because their economies are linked differently. For example, in 2003, the unemployment rate for Navajo county, 10.2%, was almost twice as high as the unemployment rate for Coconino, 5.5%. This reduces the induced economic benefits that Navajo County would receive from a wind energy project as compared to Coconino County.

Jobs

Results pertaining to job creation for each wind energy project size, project phase, and county are given in Figure 2, and Figure 3. Based on simulation, there is a 90% likelihood that the number of jobs created during the construction phase in Coconino County will be between 59 and 149 for a 60 MW wind energy project. During the O&M phase, there is a 90% likelihood that the number of jobs created in Coconino County will be between 26 and 42.

When compared to Navajo County, Coconino County has approximately 5% more jobs created during the construction phase and approximately 11% more jobs created during the O&M phase. During the construction phase, the difference between the two counties is primarily in the construction sector where Coconino County has a larger induced jobs multiplier due to its more strongly linked economy. During the O&M phase, the induced jobs multiplier in the government sector produces the difference between Coconino and Navajo counties.

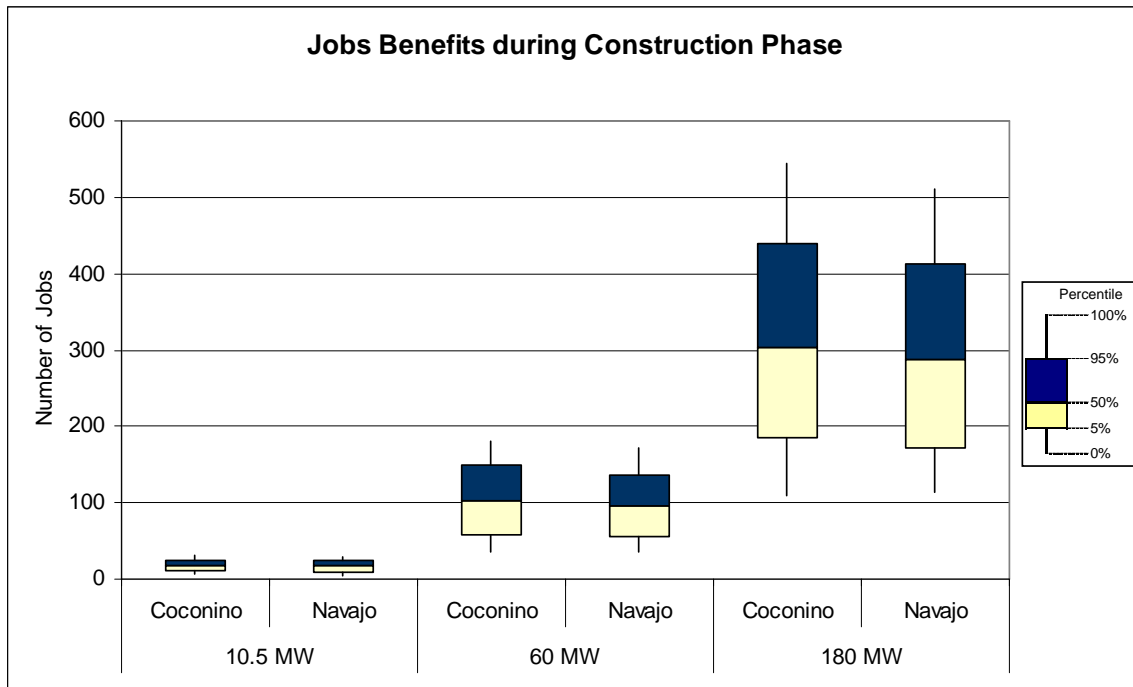


Figure 2 Wind Energy Project Impact on JOBS during Construction Phase

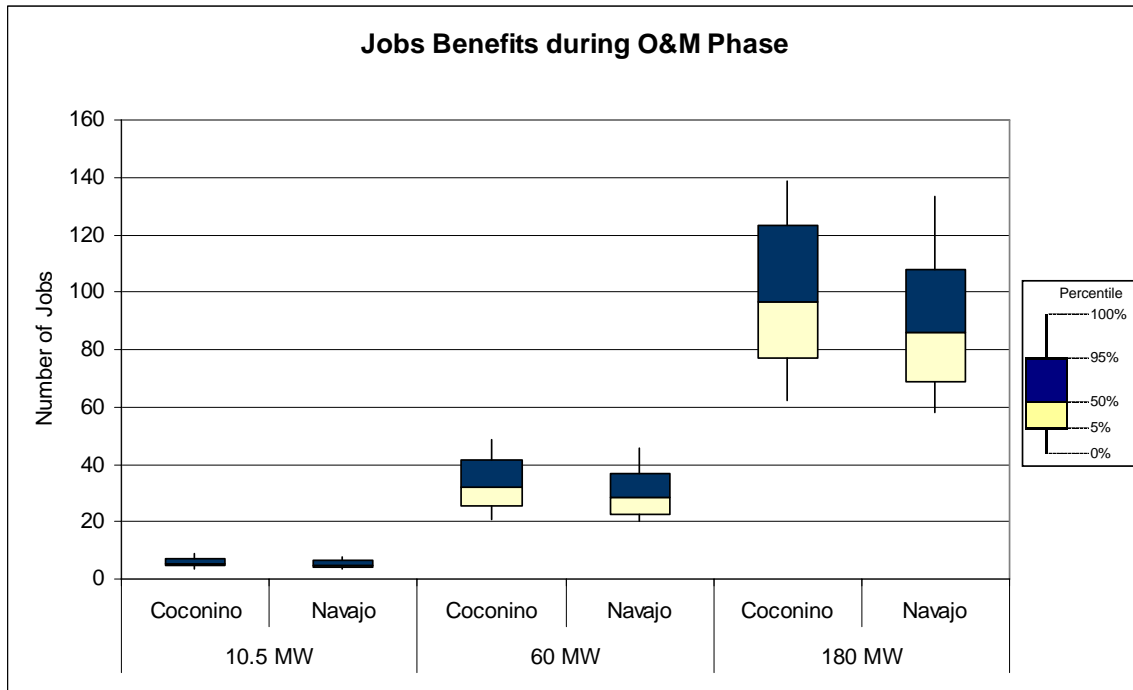


Figure 3 Wind Energy Project Impact on JOBS during O&M Phase

Earnings

Earnings refer to millions of dollars in wages and salary paid to workers. Results for earning for all wind energy project sizes, phases, and counties are given in Figure 4 and Figure 5. Based on simulation, there is a 90% likelihood that the earnings paid during the construction phase in Coconino County will be between \$1.40 and \$3.54 million annually for a 60 MW wind energy project (in 2005 dollars). During the O&M phase, there is a 90% likelihood that the earnings in Coconino County will be between \$0.64 and \$1.06 million.

Coconino County has 19% more earnings during the construction phase and approximately 15% more earnings during the O&M phase than Navajo County. Again during the construction phase, the difference between the two counties is due to the larger induced multipliers in Coconino County. The four most influential sectors in which this occurs (in decreasing order) are government, manufacturing, professional services, and construction. During the O&M phase, the sectors with the largest differences are government and manufacturing due to higher induced and indirect effects in Coconino County.

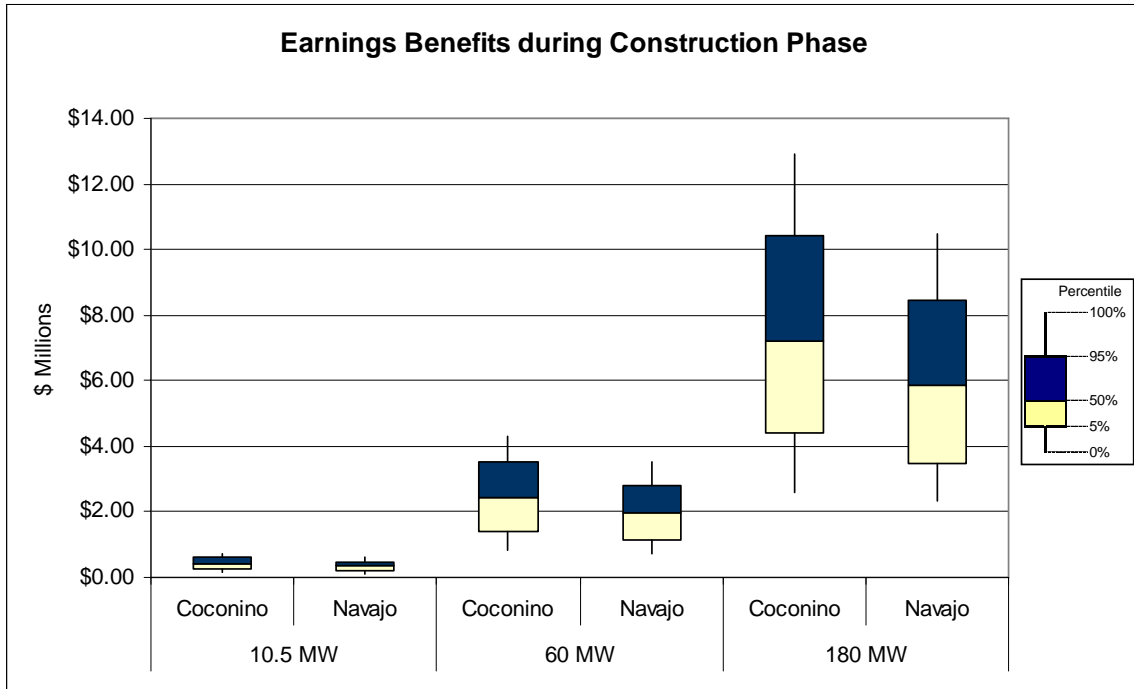


Figure 4 Wind Energy Project Impact on EARNINGS during Construction

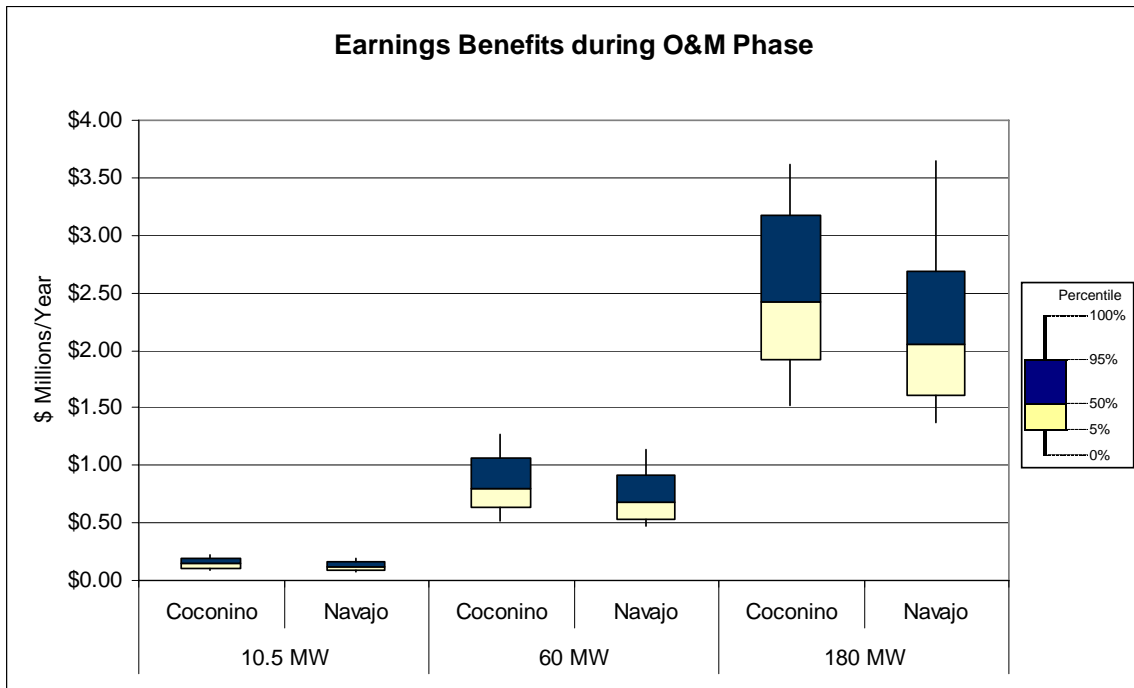


Figure 5 Wind Energy Project Impact on EARNINGS during O&M Phase

Output

Figure 6 and Figure 7 show a summary of output results for all wind energy project sizes, phases, and counties. Output refers to economic activity or the value of production in the county and is also in millions of 2005 dollars. Based on the simulation results there is a 90% likelihood that the output will be between \$4.3 and \$11.2 million annually for Coconino County. During the O&M phase, there is a 90% likelihood that the earnings in Coconino County will be between \$0.78 and \$1.32 million.

Navajo County will have 4% less output during the construction phase than Coconino County. The differences between the two counties during the construction phase are quite mixed. In most sectors, Coconino had a larger indirect or induced multiplier. However, Navajo had a particularly large induced benefit from the government sector. During the O&M phase, there will be 61% more output in Navajo County than Coconino. Again the differences are mixed but the large overall difference is due to a high induced effect in the government sector.

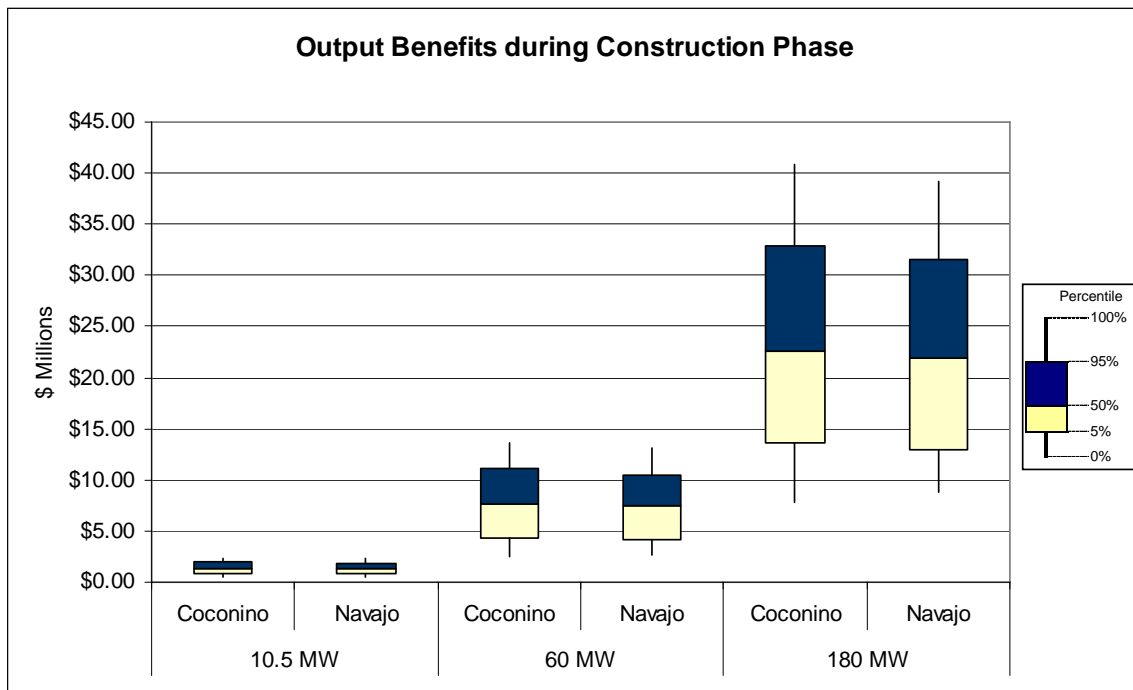


Figure 6 Wind Energy Project Impact on OUTPUT during Construction Phase

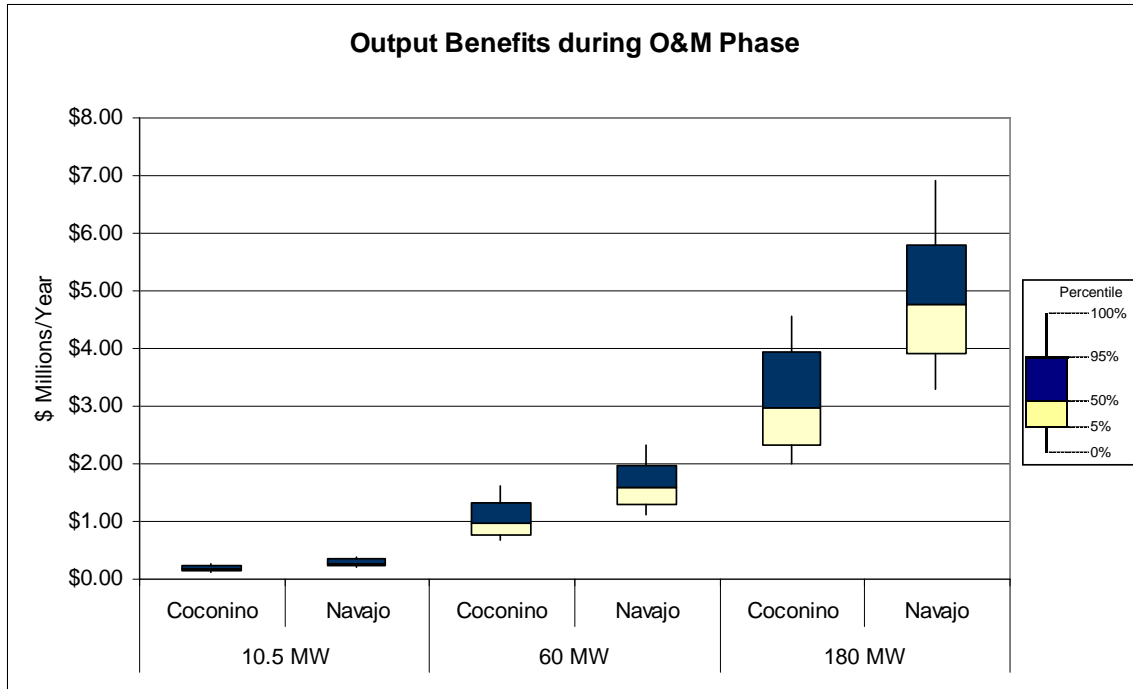


Figure 7 Wind Energy Project Impact on OUTPUT during O&M Phase

Sensitivity Analysis

As discussed earlier, one of the advantages of using Monte Carlo simulation in conjunction with the JEDI model is that we can examine the sensitivity of the six outputs (jobs, earnings, and output for both phases) to the input parameters. Those input parameters which have the most influence on the outputs should be carefully estimated. The more closely the input parameters can be estimated, the smaller the variation in the output variables. To assess the relationship between an input parameter and the output variables the correlation coefficient is used.

When ranges were entered for only construction cost, O&M cost, and tax rate, construction cost is the only one of the three that has a significant effect on the construction phase outputs. Similarly, for the O&M phase, only the O&M cost has a significant influence.

By entering ranges for the local share percentages in addition to the construction cost, O&M cost, and tax rate, it is possible to examine if the local share percentages are significant in affecting the results. Results for all wind energy projects sizes in both counties are similar.

For the construction phase, two local share percentages affected the output results more than construction cost:

- 1) Construction Local Share Percentage which is essentially site preparation, concrete, rebar, roads
- 2) High Voltage Substation and Interconnection Local Share Percentage

For the O&M phase, only the O&M cost significantly affects the economic impact. Tax rate and the local share field salary, have some effect but not as significant as the O&M cost.

Conclusions

The objective of this work was to develop a process to estimate the economic impact of constructing and operating wind energy projects. A Monte Carlo simulation was conducted in conjunction with the JEDI model and provided a range of outputs corresponding to a range of estimated input parameters. Coconino and Navajo County in Arizona were used to demonstrate the process. The economic benefits in the two counties are similar.

Estimates for Coconino County predict jobs and earnings benefits that are slightly higher than Navajo County for both the construction phase and the O&M phase. However, during the O&M phase, Navajo County would experience a greater economic output benefits than Coconino County.

In addition to the results mentioned above, it was shown that the construction cost had the greatest influence on the construction phase economic benefits. The O&M cost has the greatest influence on the O&M phase economic impacts. However, if the local share percentages are varied, the local share for construction and the local share for high voltage substation interconnection can also significantly affect the estimated construction phase economic impacts. Less variation in the input parameters will cause less variation in the estimated economic impacts. During the O&M phase, the influence of the local share percentages is not as significant as the O&M cost.

Acknowledgement

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References

- American Wind Energy Association, <http://www.awea.org/projects/index.html>, accessed 2/4/05.
- Arizona Department of Commerce. *Profile: Coconino County*.
http://www.azcommerce.com/communities/county_profiles.asp. 2004.
- Arizona Department of Commerce. *Profile: Navajo County*.
http://www.azcommerce.com/communities/county_profiles.asp. 2004.
- Coconino County Tax Assessor, <http://co.coconino.az.us/assessor/taxarea.asp>, accessed April, 13, 2005.
- Conner, Michael, presentation at the Governor's Tribal Energy Meeting, August 2005
- Costanti M. Quantifying the Economic Development Impacts of Wind Power in Six Rural Counties Using NREL's JEDI Model. NREL/SR-500-36414, September 2004.
- EWEA, *Wind Energy: The Facts Volume 2 Cost*, eds P.E. Morthorst, H. Jacobsen, 2003,
http://www.ewea.org/06projects_events/proj_WEfacts.htm.
- Goldberg M, K Sinclair, M. Milligan. Job and Economic Development Impact (JEDI) Model: A User-Friendly Tool to Calculate Economic Impacts from Wind Projects. NREL/CP-500-35953. March 2004.
- Goldberg M, personal communication, September 26, 2004.
- Law, AM, WD Kelton, *Simulation Modeling and Analysis*, McGraw-Hill, NY, 1982.
- Navajo County Tax Assessor, http://www.co.navajo.az.us/GenInfo_Src.aspx, accessed April 13, 2005.
- Palisade Corporation, www.palisade.com, 2005.
- Poore, RZ, "Wind 101: Wind Technology Overview", AWEA Fall Educational Symposium, 2005.
- Tegen, S., *Statewide Economic Impacts of Wind Energy Compared with Coal and Natural Gas*, NREL draft, 2004.
- Williams, SK, Acker T, Brummel G, Greve M, Wind Energy Potential in Coconino and Navajo Counties, Arizona: Economic Analysis using NREL's JEDI Model with Monte Carlo Simulation and Windy Land Analysis using GIS, submitted to NREL, November 2005.
- Winston, WL, *Simulation Modeling using @Risk*, Duxbury Press, 2000.
- Winston, WL, SC Albright, *Practical Management Science*, Duxbury Thomson Learning, p. 563-613, 2001.