AC 2011-496: RESIDENTIAL RENEWABLE ENERGY SOURCES CASE STUDIES OF RETURN ON INVESTMENT

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Residential Renewable Energy Sources
Case Studies of Return on Investment

Renewable energy is a popular topic today because of concern over rising energy costs. Federal tax credits for renewable energy sources for principal residence are slated to last until 2016. For example, up to 30% of the cost to install a solar photovoltaic or small wind turbine qualify for federal tax credits. There are also state tax incentives and utility company rebates to promote the installation of residential-based renewable energy capture. This paper addresses the economic and engineering factors that determine the return on investment of two residential renewable energy sources: photovoltaic and small wind power. The technical and financial information presented in this paper provide enough data to serve as either case studies in engineering economy classes or as design problems for engineering students learning the fundamentals of renewable energy technology. Because there is much interest in the subject of renewable energy, the topic lends itself to be good case study material for college-aged students.

The analysis of return on investment begins by specifying the typical components used for each energy conversion technology. A brief but complete overview is presented on how climate data from the NASA Surface meteorology data and Solar Energy data set is used compute the electrical energy generated from photovoltaic and wind power systems. This study assumes a 2 kilowatt photovoltaic array and a 10 kilowatt faceplate power rated wind turbine are being used to provide supplemental electrical energy for a private residence. The return on investment calculation assumes the electrical energy generated by the systems is off-setting the cost of buying such energy at going consumer rates. The initial investment for each technology is based upon the retail purchase price of grid-tied power generation system, typical mounting hardware cost, and an estimated installation cost. Factors that offset the capital expense are the federal tax credits and rebates available through state programs. The expected life of the system and a nominal recurring maintenance cost complete the factors used to compute the internal rate of return. Some inputs have more uncertainty than others, thus variations in the installation cost, long term performance, and life expectancy are made to assess their effect on the rate of return.

Seven areas near well known cities with significantly different climates and tax incentives are used to illustrate the effect of location and tax policy on the economic justification of these systems. The climate and economic data show some areas in the country are well suited for solar photovoltaic but perhaps not wind power. Other areas in the country have sufficient sustained wind energy but lack adequate solar insolation to warrant photovoltaic panels. In summary, this paper provides the reader a single source for information about how climate data, technology, and economic factors interact in the field of renewable energy.

The analysis of the return on investment of two renewable electrical power generation platforms for residential use begins with identifying the components required. The solar photovoltaic (PV) and small wind systems have been selected to be grid-tied. This is the most economical approach because it allows the user to feed the power they generate back into the grid and get a credit through the net metering programs that have been established through electric utilities. The grid-tied system allows the user to draw power, for example at night when the PV system is not generating power, and then automatically meter out any excess power generated during the day. This can be profitable during high electrical energy demand times of the hot summer months.

The approach used in this paper for each mode of energy production, PV or wind, is to

1. outline the technology required for that mode, PV or wind,
2. comment on the costs associated for the components and installation,
3. show how to obtain meteorological data for that mode,
4. comment on some of the assumptions made with the data,
5. comment on the performance expectations for the system: losses and expected life,
6. summarize how to compute the captured energy from the system.

After the methods to compute energy are established, other key financial inputs needed to compute the internal rate of return are identified:

1. review the federal tax credits and state rebates available for residential PV and small wind systems that will offset the cost of installing the systems,
2. sources of electric utility rates that represent the value of the energy captured.

Finally, a thorough explanation is given on how to set-up and use a spreadsheet to compute the return on investment for the solar and wind systems specified.

Photovoltaic systems and costs

Photovoltaic systems convert sunlight into direct current. Typically a set of PV panels are wired in series to produce a relatively large voltage but small DC current. A schematic of typical grid-tied system is shown in Figure 1. The PV modules may be roof top mounted or pole mounted with appropriate mounting hardware. The maximum solar gain occurs when the panel is allowed to track the motion of the sun during the day. The tracking equipment is expensive and introduces additional uncertainty about the impact of maintenance. Thus, fixed position PV panels are used. A fixed position set of panels perform best when facing south and tilted at an angle equal to the geographic latitude of the site. The array is wired to a connector box and then to a DC disconnect box. The latter is done for servicing. The DC current is converted to AC in the inverter. The AC power passes through a dedicated meter that is used to track power that is generated and being fed back into the utility grid as part of a net metering program. The entire PV system and inverter must be able to be disconnected with an automated AC disconnect. This AC disconnect activates to take the PV system off the grid in the case of power outage outside the home to protect utility workers who may be working on the external power lines. The costs for the system used in this study is \$14,000 for a 2,000 watt PV system[1]. This equates to \$7 per watt DC installed which is a midrange cost rate for a 2kW system. Although a specific vendor is used in this study, the values are representative of current costs and available technology. The most expensive components of the system is the collection of PV modules, about 60%. A typical

200 watt module costs around $900. The other significant expense is the inverter, which for the 2 kW system costs around $1,500. Another 12% of the system cost will be the mounting hardware, disconnects, meters, and wiring. Finally, labor accounts for about 12% of the system costs.

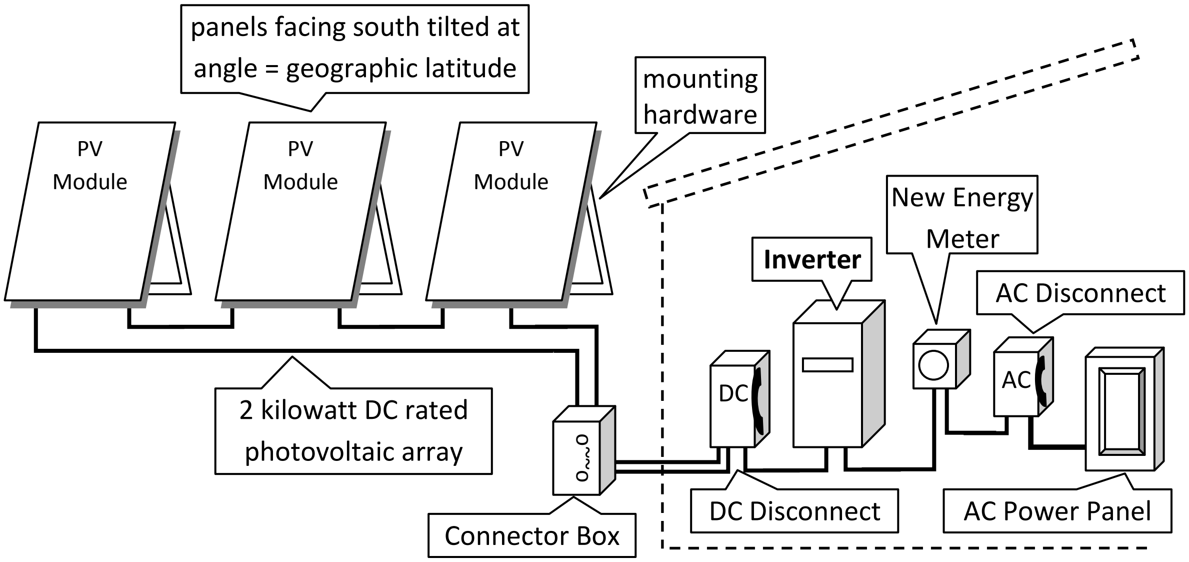


Figure 1. Schematic of a photovoltaic array system for a residence.

Solar Radiation Data

A typical PV module converts about 20% of the available incident solar radiation into direct current electric power. Figure 2 illustrates this fact with a power curve for a typical PV module. At 1,000 watts of incident solar radiation per meter squared, or "one sun" of radiation, the panel generates 200 watts of DC power. Thus, this panel is rated at "200 watts per sun". The solar radiation reaching the surface of the Earth varies dramatically across the United States due to local weather patterns and latitude and thus the income generating potential will vary greatly. A map of long term averaged daily solar radiation data expressed as kWh per square meter per day is shown in Figure 3. This data is also called sun-hours per day. One-thousand watts per square meter per day is called a sun-hour per day.

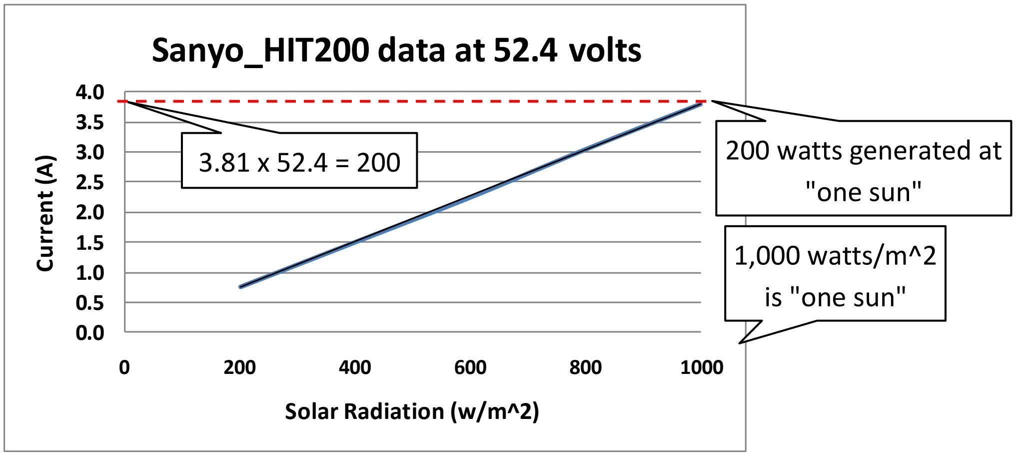
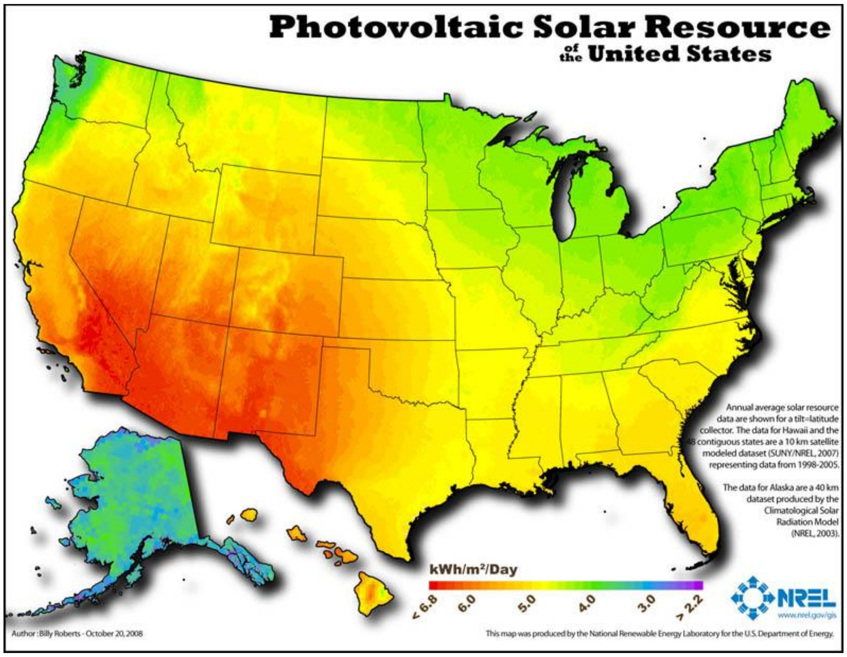


Figure 2. DC power output linearly proportional to solar radiation.



Photovoltaic Solar Resource of the United States

Annual average solar resource data are shown for a tilt=latitude collector. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

Author : Billy Roberts - October 20, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

http://www.nrel.gov/gis/images/map_pv_national_lo-res.jpg for tilt-latitude collectors

Figure 3. Annual average solar insolation or sun-hours per day across the United States

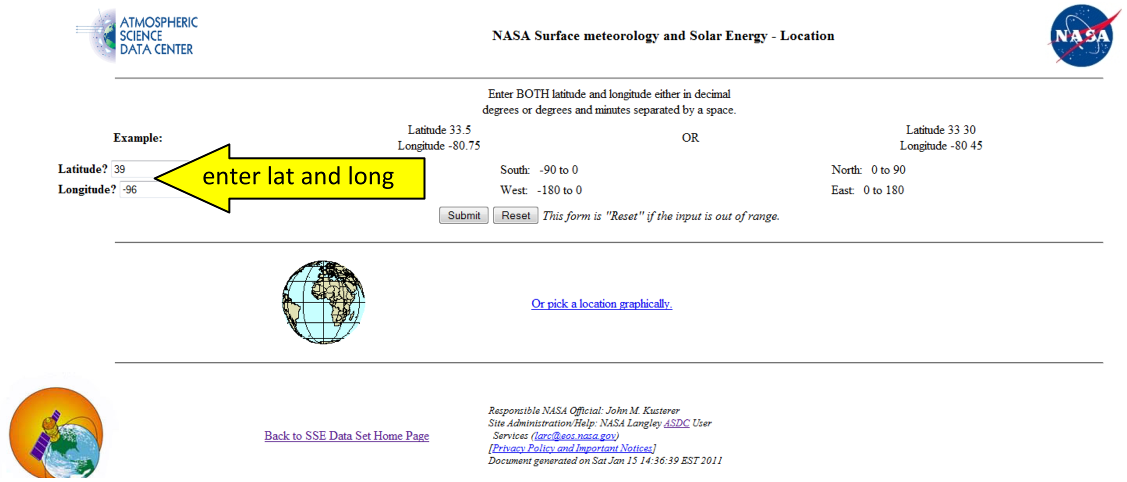
More detailed information can be downloaded from the internet and used to calculate energy captured by PV systems. The data set used in this study is the NASA Surface meteorology data and Solar Energy data set and can be accessed at this site: *http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?* Solar radiation data is obtained from this cite by inputting the latitude and longitude of the desired location. The following set of steps are used to obtain solar radiation data. The test case city is Manhattan, Kansas.

1. Find the latitude and longitude of a city by accessing http://itouchmap.com/latlong.html and enter the city and state information in the address field. The screen updates to show a call out with the decimal latitude and longitude: 39.183608,-96.571669. Round this to 39 and -96.

2. Latitude and Longitude retrieval of wind data: http://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi? *Need to login and provide email to retrieve data.* Upon logging in the user sees the screen shown in Figure 4.

3. Enter values for Latitude and Longitude of desired location.
   For example for Manhattan, KS: 39, -96

4. After submitting the location information, the parameter selection screen appears like that shown in Figure 5. Select the parameters to download by choosing the *Parameters for Tilted Solar Panels*/Radiation on equator-pointed tilted panels. Then submit.


ATMOSPHERIC SCIENCE DATA CENTER

NASA Surface meteorology and Solar Energy - Location

Enter BOTH latitude and longitude either in decimal degrees or degrees and minutes separated by a space.

Example:	Latitude 33.5 Longitude -80.75	OR	Latitude 33 30 Longitude -80 45
Latitude? 39		South: -90 to 0	North: 0 to 90
Longitude? -96		West: -180 to 0	East: 0 to 180

This form is "Reset" if the input is out of range.

enter lat and long

Or pick a location graphically.

Back to SSE Data Set Home Page

Responsible NASA Official: John M. Kusterer
Site Administration/Help: NASA Langley ASDC User Services (larc@eos.nasa.gov)
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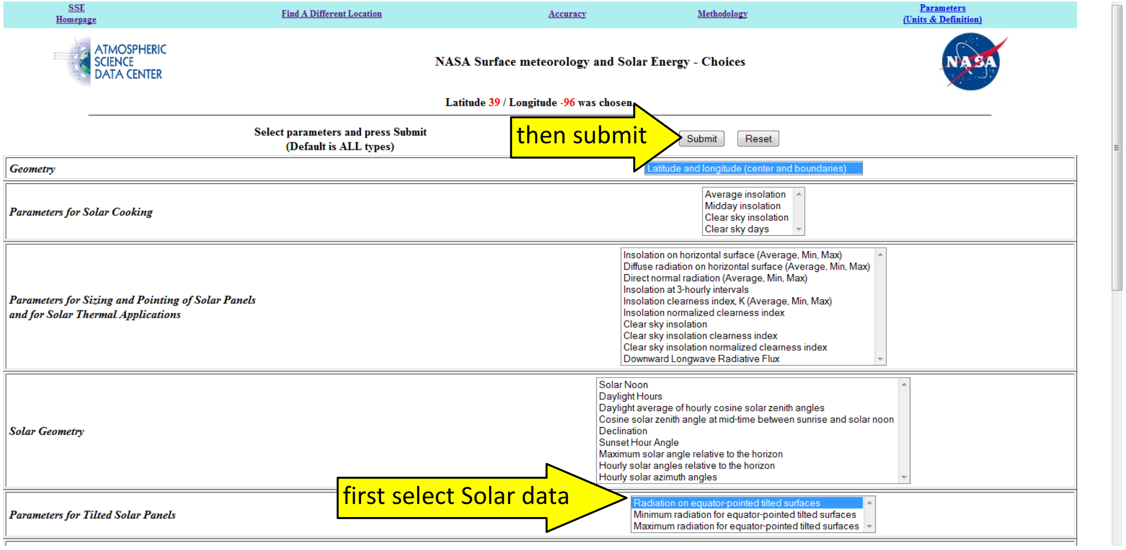
Document generated on Sat Jan 15 14:36:39 EST 2011

Figure 4. Latitude and Longitude entry screen for NASA meteorological dataset


SSE Homepage | Find A Different Location | Accuracy | Methodology | Parameters (Units & Definition)

ATMOSPHERIC SCIENCE DATA CENTER

NASA Surface meteorology and Solar Energy - Choices

Latitude 39 / Longitude -96 was chosen.

Select parameters and press Submit
(Default is ALL types)

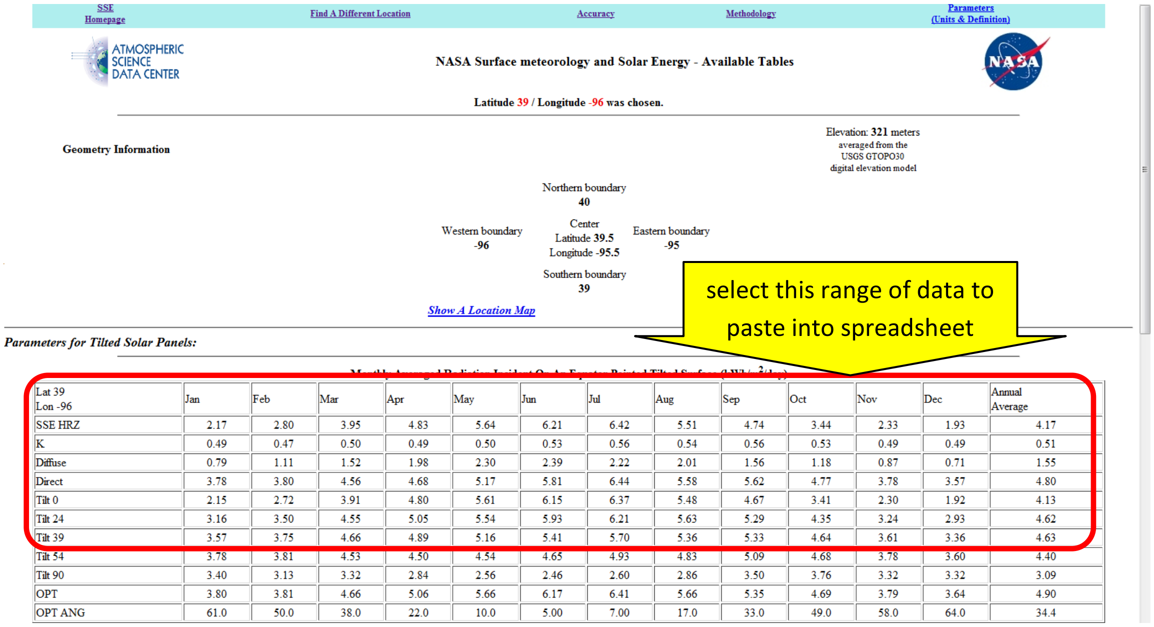
then submit

Geometry	Latitude and longitude (center and boundaries)
Parameters for Solar Cooking	Average insolation Midday insolation Clear sky insolation Clear sky days
Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications	Insolation on horizontal surface (Average, Min, Max) Diffuse radiation on horizontal surface (Average, Min, Max) Direct normal radiation (Average, Min, Max) Insolation at 3-hourly intervals Insolation clearness index, K (Average, Min, Max) Insolation normalized clearness index Clear sky insolation Clear sky insolation clearness index Clear sky insolation normalized clearness index Downward Longwave Radiative Flux
Solar Geometry	Solar Noon Daylight Hours Daylight average of hourly cosine solar zenith angles Cosine solar zenith angle at mid-time between sunrise and solar noon Declination Sunset Hour Angle Maximum solar angle relative to the horizon Hourly solar angles relative to the horizon Hourly solar azimuth angles
Parameters for Tilted Solar Panels	Radiation on equator-pointed tilted surfaces Minimum radiation for equator-pointed tilted surfaces Maximum radiation for equator-pointed tilted surfaces

first select Solar data

Figure 5. Parameter selection screen for desired location.

5. The next screen will display the data, see Figure 6. Only one row of the data is needed for the analysis: the "tilt 39" row which represents the radiation for a panel tilted at the geographic latitude for this location. However, to keep track of the header information, select the range of data shown in Figure 6 using a mouse. Copy the highlighted field and then paste into a M/S Excel worksheet. When performing the pasting it is important to "paste special/unicode text" to create a nice set of column delimited data as shown in Figure 7.



NASA Surface meteorology and Solar Energy - Available Tables

Latitude 39 / Longitude -96 was chosen.

Geometry Information

Elevation: **321** meters
averaged from the
USGS GTOPO30
digital elevation model

Northern boundary
40

Western boundary
-96

Center
Latitude **39.5**
Longitude **-95.5**

Eastern boundary
-95

Southern boundary
39

Show A Location Map

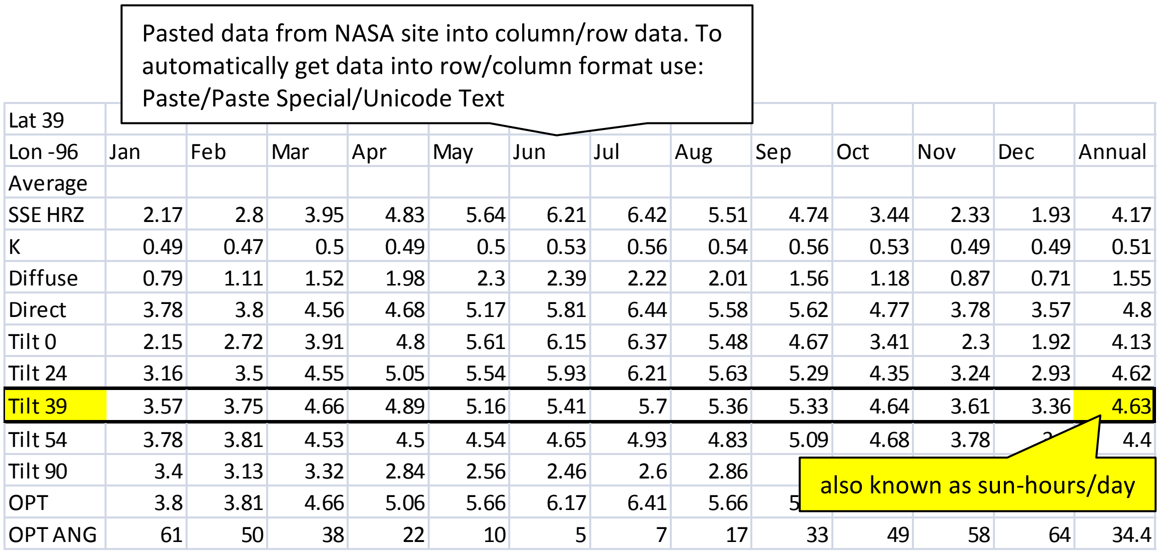
Parameters for Tilted Solar Panels:

Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface (kWh/m^2/day)

Lat 39 Lon -96	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
SSE HRZ	2.17	2.80	3.95	4.83	5.64	6.21	6.42	5.51	4.74	3.44	2.33	1.93	4.17
K	0.49	0.47	0.50	0.49	0.50	0.53	0.56	0.54	0.56	0.53	0.49	0.49	0.51
Diffuse	0.79	1.11	1.52	1.98	2.30	2.39	2.22	2.01	1.56	1.18	0.87	0.71	1.55
Direct	3.78	3.80	4.56	4.68	5.17	5.81	6.44	5.58	5.62	4.77	3.78	3.57	4.80
Tilt 0	2.15	2.72	3.91	4.80	5.61	6.15	6.37	5.48	4.67	3.41	2.30	1.92	4.13
Tilt 24	3.16	3.50	4.55	5.05	5.54	5.93	6.21	5.63	5.29	4.35	3.24	2.93	4.62
Tilt 39	3.57	3.75	4.66	4.89	5.16	5.41	5.70	5.36	5.33	4.64	3.61	3.36	4.63
Tilt 54	3.78	3.81	4.53	4.50	4.54	4.65	4.93	4.83	5.09	4.68	3.78	3.60	4.40
Tilt 90	3.40	3.13	3.32	2.84	2.56	2.46	2.60	2.86	3.50	3.76	3.32	3.32	3.09
OPT	3.80	3.81	4.66	5.06	5.66	6.17	6.41	5.66	5.35	4.69	3.79	3.64	4.90
OPT ANG	61.0	50.0	38.0	22.0	10.0	5.00	7.00	17.0	33.0	49.0	58.0	64.0	34.4

select this range of data to paste into spreadsheet

Figure 6. Data returned after selecting solar data.



Pasted data from NASA site into column/row data. To automatically get data into row/column format use: Paste/Paste Special/Unicode Text

Lat 39													
Lon -96	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average													
SSE HRZ	2.17	2.8	3.95	4.83	5.64	6.21	6.42	5.51	4.74	3.44	2.33	1.93	4.17
K	0.49	0.47	0.5	0.49	0.5	0.53	0.56	0.54	0.56	0.53	0.49	0.49	0.51
Diffuse	0.79	1.11	1.52	1.98	2.3	2.39	2.22	2.01	1.56	1.18	0.87	0.71	1.55
Direct	3.78	3.8	4.56	4.68	5.17	5.81	6.44	5.58	5.62	4.77	3.78	3.57	4.8
Tilt 0	2.15	2.72	3.91	4.8	5.61	6.15	6.37	5.48	4.67	3.41	2.3	1.92	4.13
Tilt 24	3.16	3.5	4.55	5.05	5.54	5.93	6.21	5.63	5.29	4.35	3.24	2.93	4.62
Tilt 39	3.57	3.75	4.66	4.89	5.16	5.41	5.7	5.36	5.33	4.64	3.61	3.36	4.63
Tilt 54	3.78	3.81	4.53	4.5	4.54	4.65	4.93	4.83	5.09	4.68	3.78		4.4
Tilt 90	3.4	3.13	3.32	2.84	2.56	2.46	2.6	2.86					
OPT	3.8	3.81	4.66	5.06	5.66	6.17	6.41	5.66	5				
OPT ANG	61	50	38	22	10	5	7	17	33	49	58	64	34.4

also known as sun-hours/day

Figure 7. The sun-hours per day data is reformatted in a worksheet for analysis.

The data captured contains the month by month average solar insolation as well as the annual average. Only the annual average value from the "tilt 39" row is required to compute the yearly energy collected by the PV array. This is true because the electrical power generated by a PV array is linearly proportional to the incident solar radiation.

Assumptions for the solar data and PV panel performance

The long term averaged data from NASA data set takes into account local weather patterns and cloud cover that would otherwise diminish available solar radiation during day time hours. Optimal electrical power output from a PV array depends upon the avoidance of any shading due to trees or structures. Further, soiling of the PV panel surface from dust and snow or ice coverage will diminish performance. In addition, PV modules are known to age with long term exposure to the weather and lose power generation potential. Sanyo, a major manufacturer of PV modules, states in its warranty literature[2], Figure 8, that their modules may exhibit two types of derating. First, the actual power output is warranted to be 95% of the maximum rated value. Further, there may be a 10% reduction in performance during the first 10 years of use and a 20% reduction in performance may occur between years 10 and 20 of use. They warranty their panels for 20 years. Kyocera has a similar warranty disclaimer about long term performance[3]. These aging reductions will be used to derate the energy capture over time when a detailed internal rate of return analysis is performed.

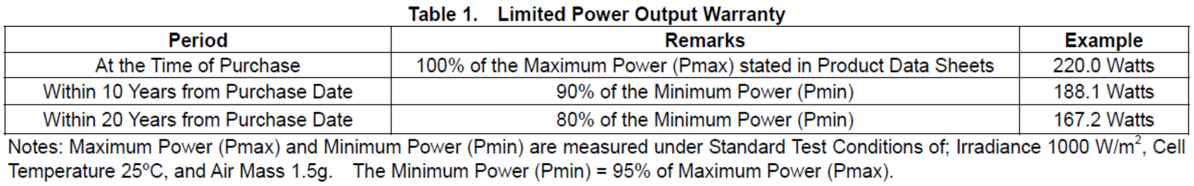


Table 1. Limited Power Output Warranty

Period	Remarks	Example
At the Time of Purchase	100% of the Maximum Power (Pmax) stated in Product Data Sheets	220.0 Watts
Within 10 Years from Purchase Date	90% of the Minimum Power (Pmin)	188.1 Watts
Within 20 Years from Purchase Date	80% of the Minimum Power (Pmin)	167.2 Watts

Notes: Maximum Power (Pmax) and Minimum Power (Pmin) are measured under Standard Test Conditions of; Irradiance 1000 W/m^2, Cell Temperature 25°C, and Air Mass 1.5g. The Minimum Power (Pmin) = 95% of Maximum Power (Pmax).

Figure 8. Sanyo HIT® Power Module Limited Warranty

The power rating for a PV panel is established for a single panel under ideal conditions. However, when panels are wired in series in the field there is a degradation of the system performance due to wiring losses. Studies have shown[4] these losses may approach 10%. Finally, the conversion from DC current to AC current through the inverter typically involves a another 5 to 10% loss in available power. The inverter is a component that is recommended to change out after 15 years in service. However, for this study, the inverter will not be replaced due to the diminishing effect of single cash flows made in the future on an IRR calculation.

In summary, the useful AC power coming out of a grid-tied system is derated by the product of the three loss factors addressed: name plate reduction x wiring losses x inverter efficiency. Thus, the typical AC power output may only be 82% of the nameplate power rating of a PV panel array at the beginning of the system life in the field as shown in equation 1. This initial derating factor is termed Delivery % in this paper:

Delivery % = face plate reduction x wiring losses x inverter efficiency (1a)

82% = 95% x 91% x 95% (1b)

This value would be lower if soiling and long term aging are factored. The effect of soiling will not be considered in this study but the reduction in performance due to aging as specified by a solar panel manufacturer, reference Figure 8, will be considered. For example, during the eighth year of service it is reasonable to assume the panel will have an aging related derating of 92% of the available power output. During the 18th year of service, the age-related derating may be 82%. The net derating factor is the product of the age-related derating factor times the initial derating factor as shown in Equation 2.

Net Derating (yrs 2 to 10) = 75% = 92% x Delivery % (initial derating factor) (2a)

Net Derating (yrs 11 to 25) = 67% = 82% x Delivery % (initial derating factor) (2b)

With some of these loss factors in mind, the basic calculations required to determine the AC energy generation from a PV array follows.

Computing energy from PV panels

1. First lookup the sun-hours/day (kWhr/m^2/day) from a map or a data set. Call this value S sun-hours/day.
2. Next multiply the S sun-hours/day by the maximum power rating of the PV array. Call the maximum power rating of the entire PV array (all modules), PMAX (kW/sun). The result is (S x PMAX) kWhr/day.
3. A yearly energy output (kWhr/yr) can be computed by multiplying S x PMAX by 365.
4. The final net energy output would be adjusted by any derating factors. As previously mentioned, an intial derating multiplier of 0.82 may be appropriate.

Using the example of the data from Manhattan, KS a in Figure 7 and the 2 kilowatt PV array specified for this study, the ideal DC amount of DC energy generated per year would be

$$\text{DC energy per year (kWhr/yr)} = \text{S sun-hrs/day} \times \text{PMAX kW/sun} \times \text{days/yr} \tag{3a}$$
$$= 4.63 \text{ sun-hours/day} \times 2 \text{ kW/sun} \times 365 \text{ day/yr} \tag{3b}$$
$$= 3{,}380 \text{ DC kWhr/yr} \tag{3c}$$

This calculation does not factor any losses due to soiling, wiring, inverter, or aging. If one factors only the initial derating due to nameplate reduction, the wiring losses, and the inverter efficiency, then the AC power output each year would be

$$\text{Net AC energy per year (kWhr/yr)} = 3{,}380 \text{ DC kWhr/yr} \times 0.82 = 2{,}772 \text{ AC kWhr/yr} \tag{4}$$

Small wind systems and cost

The other residential-based renewable energy technology addressed in this study is small wind. Small wind turbines are sized to provide either back-up using batteries or grid-tied power for home and small businesses. As with the PV array, a better economical model for a small wind turbine is a grid-tied system. A 10 kW faceplate rated turbine used in this study is a Bergey Excel-S. Such a turbine is typically installed at a moderate height of 30 meters and can provide significant power for a large home if located in an ideal wind area. Again, a specific vendor is used to obtain representative cost and performance data for a contemporary small wind system. The methodology presented in this paper is independent of specific hardware suppliers. A schematic of the small wind components used in this study are shown in Figure 9. It is placed on a guy-wired 30 meter tower. The small wind turbines generate DC power and must be converted to AC. Thus, other critical components include the inverter. A dedicated renewable energy meter is used to track production for net metering.

Cost data is obtained from a representative manufacturer[5]. The turbine with inverter lists at $31,770. A 30 meter (100 ft) guyed lattice tower costs $14,145. A wiring tower wiring kit costs $1,615. Thus, the costs for this 10kW wind turbine is $47,350. Additional costs will include permits, tower foundation and anchoring, and labor for electrical hook-up. The manufacturer[5], based upon experience with hundreds on installations, estimates these additional costs will range from $6,000 to $15,000 depending upon the level of customer involvement. Using an average value of $10,000 this brings the total installed cost of a 10 kW wind turbine to approximately $57,000.

Wind Energy Data

The wind energy data to be used is long term average wind speed data from the NASA Surface meteorology data set from the Atmospheric Science Data Center. This data is based upon satellite-derived data over a 22-year period. The data is compiled for each degree of latitude and longitude (each degree represents about 69 ground miles). Figure 10 depicts the annual average wind speed for the United States measured at 80 meters. It is important to note the wind energy resource is highly localized and driven in great part by large scale geographic topology. As with the solar radiation data, data set used in this study is sponsored by NASA and can be accessed at this site: http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi? As before, the location is specified by entering the latitude and longitude. For Manhattan, KS enter: 39, -96. When the parameter selection screen appears, refer to Figure 11, select from Meteorology (Wind) and then specify three items:

Meteorology (Wind) and

a. Wind Speed at 50 meters and specify the following two adjustments
b. Gipe Power Law rule with "Airport" flat roughness, and
c. a Height of 30 meters. The tower height used in this study is 30 meters. The on-line database converts the wind data from 50 meters to 30 meters to facilitate the wind energy calculations in this study.

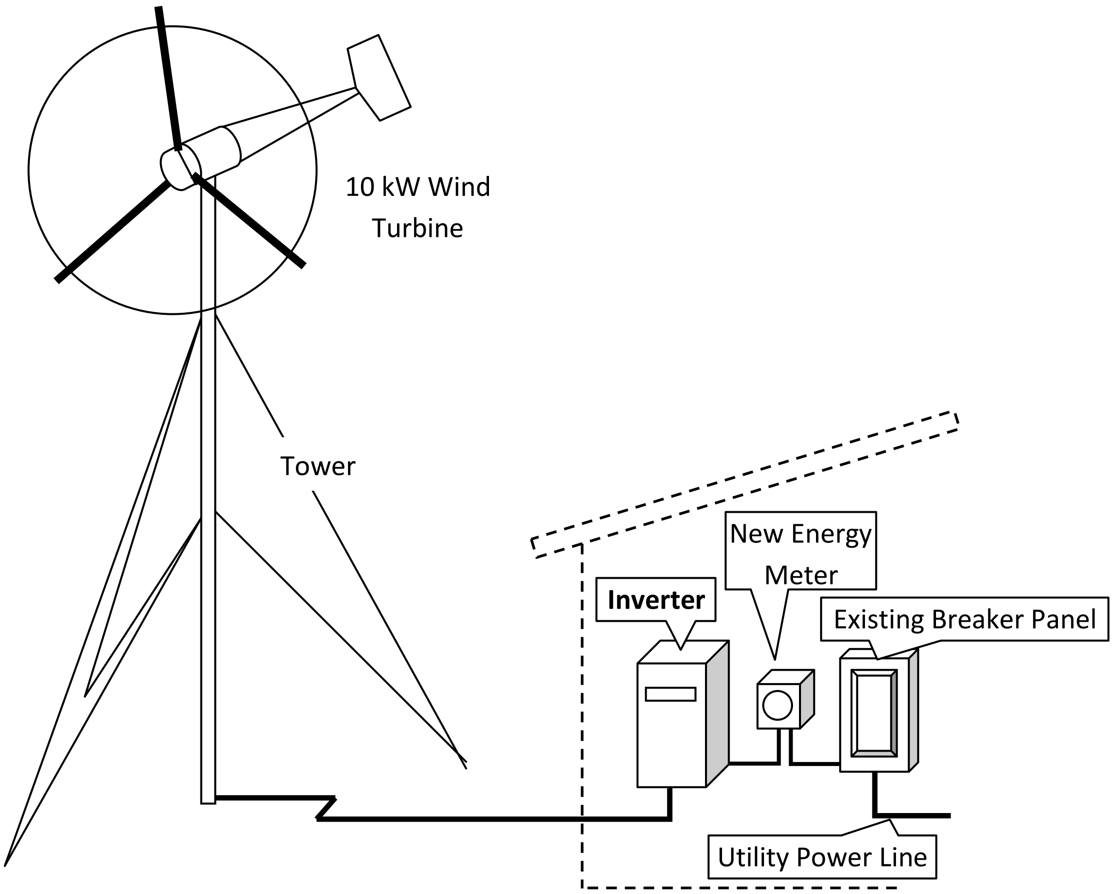
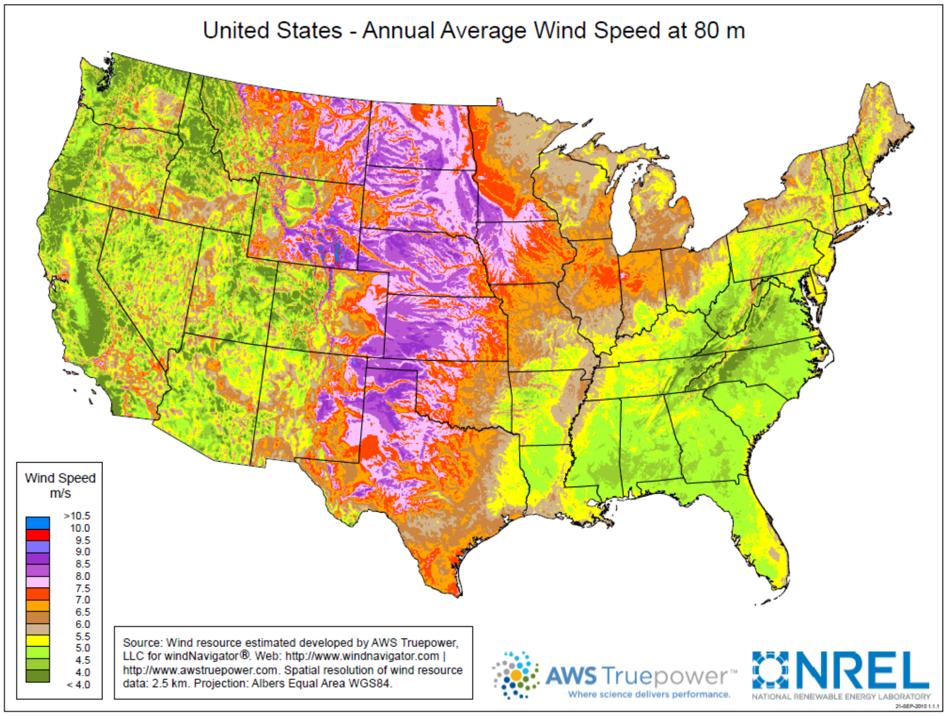


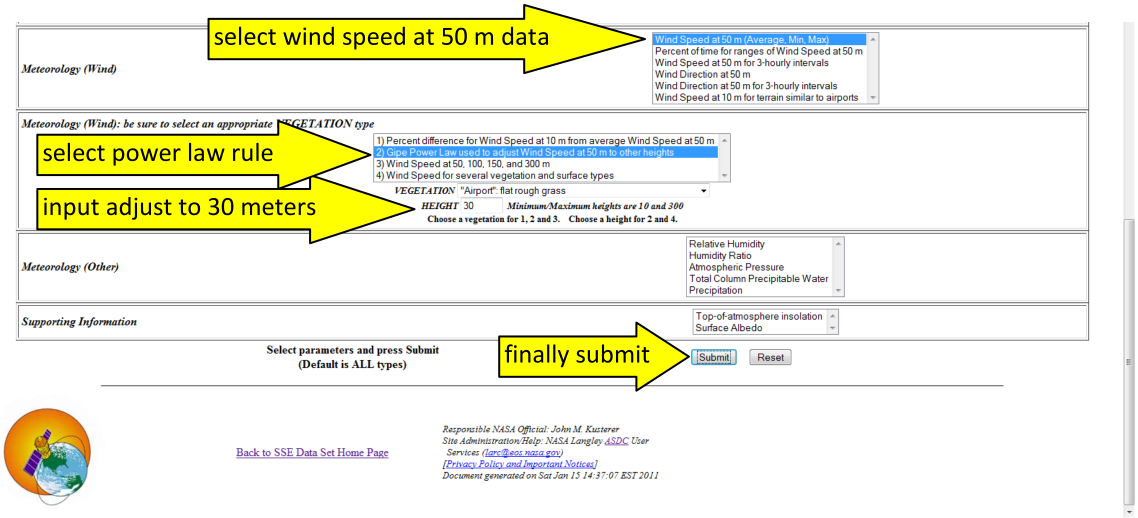
Figure 9. Grid-tied small wind power schematic of components.



Source: Wind resource estimated developed by AWS Truepower, LLC for windNavigator®. Web: http://www.windnavigator.com | http://www.awstruepower.com. Spatial resolution of wind resource data: 2.5 km. Projection: Albers Equal Area WGS84.

http://www.windpoweringamerica.gov/pdfs/wind_maps/us_windmap_80meters.pdf

Figure 10. Annual average wind speed at 80 meters above ground.



Meteorology (Wind)

Wind Speed at 50 m (Average, Min, Max)
Percent of time for ranges of Wind Speed at 50 m
Wind Speed at 50 m for 3-hourly intervals
Wind Direction at 50 m
Wind Direction at 50 m for 3-hourly intervals
Wind Speed at 10 m for terrain similar to airports

Meteorology (Wind): be sure to select an appropriate VEGETATION type

1) Percent difference for Wind Speed at 10 m from average Wind Speed at 50 m
2) Gipe Power Law used to adjust Wind Speed at 50 m to other heights
3) Wind Speed at 50, 100, 150, and 300 m
4) Wind Speed for several vegetation and surface types

VEGETATION "Airport": flat rough grass

HEIGHT 30 *Minimum/Maximum heights are 10 and 300*

Choose a vegetation for 1, 2 and 3. Choose a height for 2 and 4.

Meteorology (Other)

Relative Humidity
Humidity Ratio
Atmospheric Pressure
Total Column Precipitable Water
Precipitation

Supporting Information

Top-of-atmosphere insolation
Surface Albedo

Select parameters and press Submit
(Default is ALL types)

Back to SSE Data Set Home Page

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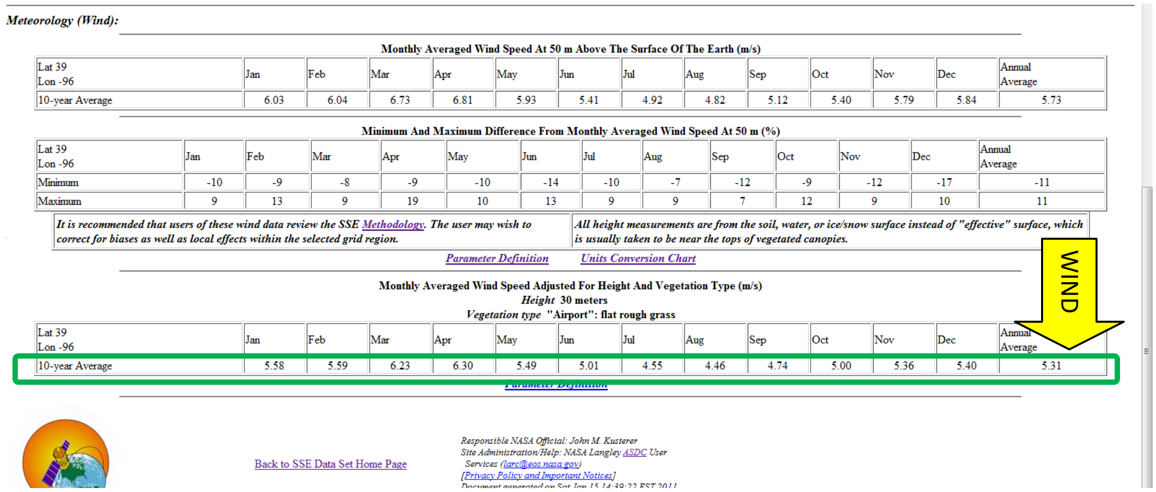
Figure 11 Parameter selection screen for wind data from NASA Surface Meteorology data.

After clicking on "submit" the wind data for the specified latitude and longitude are displayed on the screen as shown in Figure 12. As with the solar radiation outputs, this data may be converted to an Excel worksheet by selecting with a mouse, copy and pasting in to the worksheet as shown in Figure 13. The important wind speed data point is highlighted: annual average of 5.31 m/s. The annual average wind speed is sufficient for the analysis done in this study. It is true that power output from a wind turbine is not linear with wind speed and the average wind speed changes with the seasons, as shown in the data outlined by the green box. However, the difference in the computed energy from the wind turbine used in this study when using the month by month values versus the annual average value was less than 2%.



Meteorology (Wind):

Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)

Lat 39 Lon -96	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	6.03	6.04	6.73	6.81	5.93	5.41	4.92	4.82	5.12	5.40	5.79	5.84	5.73

Minimum And Maximum Difference From Monthly Averaged Wind Speed At 50 m (%)

Lat 39 Lon -96	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Minimum	-10	-9	-8	-9	-10	-14	-10	-7	-12	-9	-12	-17	-11
Maximum	9	13	9	19	10	13	9	9	7	12	9	10	11

It is recommended that users of these wind data review the SSE Methodology. The user may wish to correct for biases as well as local effects within the selected grid region.

All height measurements are from the soil, water, or ice/snow surface instead of "effective" surface, which is usually taken to be near the tops of vegetated canopies.

Parameter Definition *Units Conversion Chart*

Monthly Averaged Wind Speed Adjusted For Height And Vegetation Type (m/s)
***Height* 30 meters**
***Vegetation type* "Airport": flat rough grass**

Lat 39 Lon -96	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	5.58	5.59	6.23	6.30	5.49	5.01	4.55	4.46	4.74	5.00	5.36	5.40	5.31

Parameter Definition

Back to SSE Data Set Home Page

Responsible NASA Official: John M. Kusterer
Site Administration/Help: NASA Langley ASDC User Services (larc@eos.nasa.gov)
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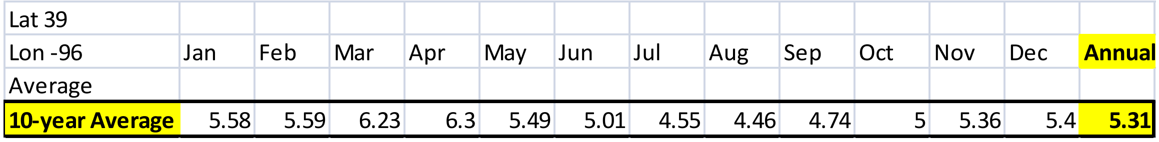
Figure 12 Output from NASA Surface meteorology and Solar Energy - Choices



Lat 39 Lon -96 Average	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual**
10-year Average	5.58	5.59	6.23	6.3	5.49	5.01	4.55	4.46	4.74	5	5.36	5.4	**5.31**

Figure 13 Extracted data from dataset pasted into M/S Excel.

Assumptions for wind data and wind turbine performance

The wind data available at the NASA cite is long term averaged wind speed for the months shown and an annual average. Even though wind speeds do increase in winter months and slow during summer months in many parts of the United States, the average annual speed is sufficient for the analysis being done in this study. Energy computed by factoring monthly changes and summing for the year only differs by less than 2% from the energy computed using the annual average value. It will be shown in the next section that long term average wind speed data is required because of the statistical functions used to compute the wind speed distribution from an average value. Another assumption made when obtaining the data is how wind speed measured at 50 meters is converted to the 30 meters compatible with the tower used in this study. A wind shear power law function is used with a ground roughness of "AIRPORT flat rough grass". The specified ground roughness implies the wind tower in this study is far removed from trees and other structures. The presence of ground level wind turbulence due to trees or structures will significantly lower turbine performance.

In addition, the wind turbine power curve produced by the vendor of the turbine is generated under ideal conditions. Exposure to weather may cause the turbine blades to become soiled or covered with ice, both will lower turbine performance. Finally, because the turbine has moving parts unlike the PV array system, some allowance for nonproductive time should be made for servicing.

Computing energy from wind turbine

The calculation for the energy from a wind turbine is more complicated than that required for the PV array. First, the power curve for a wind turbine is not linearly proportional to wind speed as shown in Figure 14. Second, the total power output by a wind turbine is computed using a statistical model of wind speed distributions. The total power output at an average speed is the sum of the probability of the wind being at a specific speed multiplied by the power that would be generated at that speed. The calculation requires expressing the distribution with a Weibull probability distribution function that uses the mean wind speed as a scaling factor and a shape factor parameter, K equal to 2. Figure 15 illustrates the Weibull wind distribution for a scaling factor of 5 m/s.

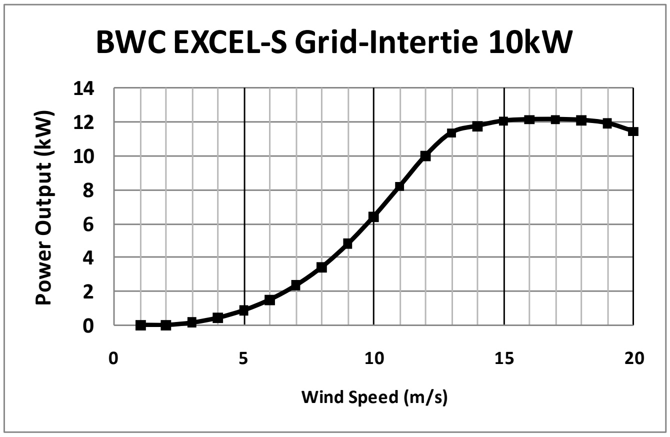


Figure 14 The power curve for the wind turbine used in this study.

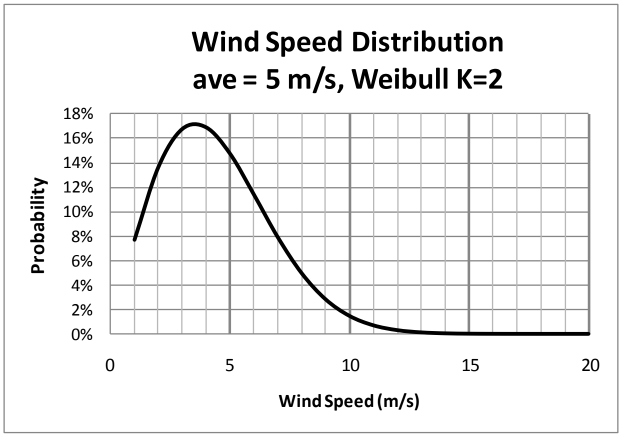


Figure 15 Representative wind speed distribution using long term statistical estimates.

The calculations performed in this study are done in M/S Excel which supports calculation of the Weibull function. The Weibull probability density function, as expressed in M/S Excel is

$$f(x;\kappa,\lambda) = \frac{\kappa}{\lambda^{\kappa}}\ x^{(\kappa-1)}\ e^{-\left(\frac{x}{\lambda}\right)^{\kappa}} \tag{5}$$

where
x = wind speed increment of distribution,
κ = Wiebull K, the shape parameter for the probability distribution, equal to 2,
λ = scale parameter for probability distribution, proportional to the average hub height air speed.

The syntax for the Weibull probability density function used in M/S Excel:

= WIEBULL(x, κ, λ, cumulative)
where, cumulative = logical constant; set to FALSE.
FALSE causes function to return the Weibull probability density function.

The net steady power generated by the wind turbine is the product of the wind speed distribution using the Weibull probability function times the wind turbine power curve. The output is a steady power value because the input velocity is a long term average wind speed and the distribution of speed are also long term average values. An example of this calculation is shown in Figure 16. The energy generated by the turbine is computed by simply multiplying the steady power value by hours of operation.

These calculations do not take into account any losses due to down time, soiling or icing of the air foil, or other power connection losses.

Captured Wind Energy with Wind Turbine NO DERATING ASSUMED IN THIS CALCULATION.

Average wind speed at hub (m/s)	5.0	(from NASA data set)
Weibull K	**2**	(Weibull function shape factor)
Lamda	**5.6**	(Weibull function scale factor)

Wind Speed (m/s)	Wind Probability (%)	Turbine Power Curve (kW)	Net Power Output (kW)
1	6%	0.00	-
2	11%	0.00	-
3	14%	0.14	0.02
4	15%	0.43	0.07
5	14%	0.88	0.13
6	12%	1.51	0.18
7	9%	2.35	0.22
8	7%	3.43	0.23
9	4%	4.80	0.21
10	3%	6.42	0.17
11	2%	8.21	0.12
12	1%	10.02	0.08
13	0%	11.37	0.04
14	0%	11.76	0.02
15	0%	12.06	0.01
16	0%	12.14	0.00
17	0%	12.15	0.00
18	0%	12.10	0.00
19	0%	11.92	0.00
20	0%	11.44	0.00
Total Steady Power Output (kW)			**1.51**
Total Energy Generated per Year (kWhr/yr)			**13,227**

1) Wind Probability from Weibull distribution.
2) Turbine Power Curve from manufacturer specs.
3) Net Power = Wind Probabilty X Turbine Power

= sum of Net Power Output
= 24 x Total Steady Power Output x 365

Figure 16. Representative calculation of energy generation from turbine.

Financial incentives for renewable energy

The most significant incentive for homeowners installing a renewable energy system is the federal Residential Renewable Energy Tax Credit[6] made law by the federal Energy Policy Act of 2005. This bill establishes a federal personal income tax credit of up to 30% of the installed cost for residential solar PV and small wind and is in effect until December 31, 2016. The most comprehensive source for financial incentives involving the installation of renewable systems is the Database for State Initiatives for Renewables and Efficiency at http://www.dsireusa.org/
A single source link for information about federal, state, and utility incentives state by state can be found at: http://www.dsireusa.org/summarytables/finre.cfm

The state-based incentives come in three types: state tax credits, rebates, and utility company rebates. Most incentives are computed based upon dollars per watt installed power. Some incentives are based upon generated power made the first year of service. In one state, a utility company offers a five-year contract to purchase PV generated energy from a customer at significantly higher rates than the standard utility rate. A summary of the state-based incentives used in this case study is presented in Appendix A. Table 1 lists the cash value of the incentives available for each of the seven cities examined in this study and the net cost to install a system. In addition, Table 1 lists the initial electricity rates used for each state. Many of the state-based incentives are available on a first come first served basis with a limited set of funds. Many of the incentives available in recent years have ended to lack of state funds. Thus, they will not be used in this analysis.

FEDERAL & STATE INCENTIVES & NET SYSTEM COST			
		PV	WIND
Electric Rates	Retail Cost	$14,000	$57,000
($/kWhr)	Federal (@30%)	$4,200	$17,100
0.1073	Phoenix AZ	$4,500	$25,000
	NET COST	$5,300	$14,900
0.1238	Lubbock TX	$5,000	$0
	NET COST	$4,800	$39,900
0.1127	Champaign IL	$0	$0
	NET COST	$9,800	$39,900
0.1013	Altlanta GA	$5,800	$10,500
	NET COST	$4,000	$29,400
0.0868	Corvallis OR	$9,000	$6,000
	NET COST	$800	$33,900
0.0953	Manhattan KS	$1,400	$5,700
	NET COST	$8,400	$34,200
0.1474	Riverside CA	$6,240	$0
	NET COST	$3,560	$39,900

PV in Phoenix, AZ

Retail PV	$14,000
Federal credit	$ 4,200
State credit	$ 4,500
Net PV cost	$ 5,300

PV in Champaign, IL

Retail PV	$14,000
Federal credit	$ 4,200
State credit	$ 0
Net PV cost	$ 9,800

WIND in Corvallis, OR

Retail WIND	$57,000
Federal credit	$17,100
State credit	$ 6,000
Net WIND cost	$33,900

Table 1. Federal and State Incentives and Electric Utility Rates

Electricity costs and inflation

The savings in electrical energy cost for the homeowner is used to compute the return on investment of the renewable energy systems. The analysis employs a net-metering model with the assumption that the homeowner receives a credit for generating a kilowatt of energy at the same cost that they would pay for it. The utility electricity rates by state[7] are shown in Table 1. This is a point of policy debate because the price paid for a kilowatt of electric energy[8] has a generation (66%), a transmission (7%), and a distribution (26%) cost component. The generation costs are the cost of fossil fuel and amortizing the generation plant. The transmission and distribution cost accounts for the construction and maintenance of the power transmission system that delivers the energy to the customer. If a homeowner gets credit for generating a kilowatt of energy at the rate they would have paid for it, they are in effect getting paid for supporting the transmission and distribution of this energy when in fact they only generated the energy. The final input for computing revenue is the assumption of a 2% inflation of electricity costs[8] over the period in this study. A steady 2% compounding inflation is assumed when performing a more detailed internal rate of return.

Earnings from energy capture

The objective of the study is to show how the return on investment for two renewable energy systems varies depending upon the local weather patterns and the local cash incentives to install such systems. The cities used in this study were chosen because they offer a variety of climate and varied state cash incentives. The climate data shown in Table 2 is a primary driver for computing the earnings. The same 2 kW PV array and 10 kW wind turbine are assumed to be installed at each of the seven cities used in the study. Further, the installation costs are assumed to be the same in spite of the likely differences in the cost of living. To include site specific cost of labor and zoning permits is beyond the scope of this study.

City, State	Latitude	Longitude	Sun-hr/day	30 meter wind (m/s)
Phoenix, AZ	33	-112	6.03	4.58
Lubbock, TX	33	-102	5.53	6.07
Champaign, IL	40	-88	4.24	5.42
Altlanta, GA	33	-84	4.67	3.52
Corvallis, OR	44	-123	4.24	4.35
Manhattan, KS	39	-96	4.63	5.31
Riverside, CA	34	-117	5.82	4.50

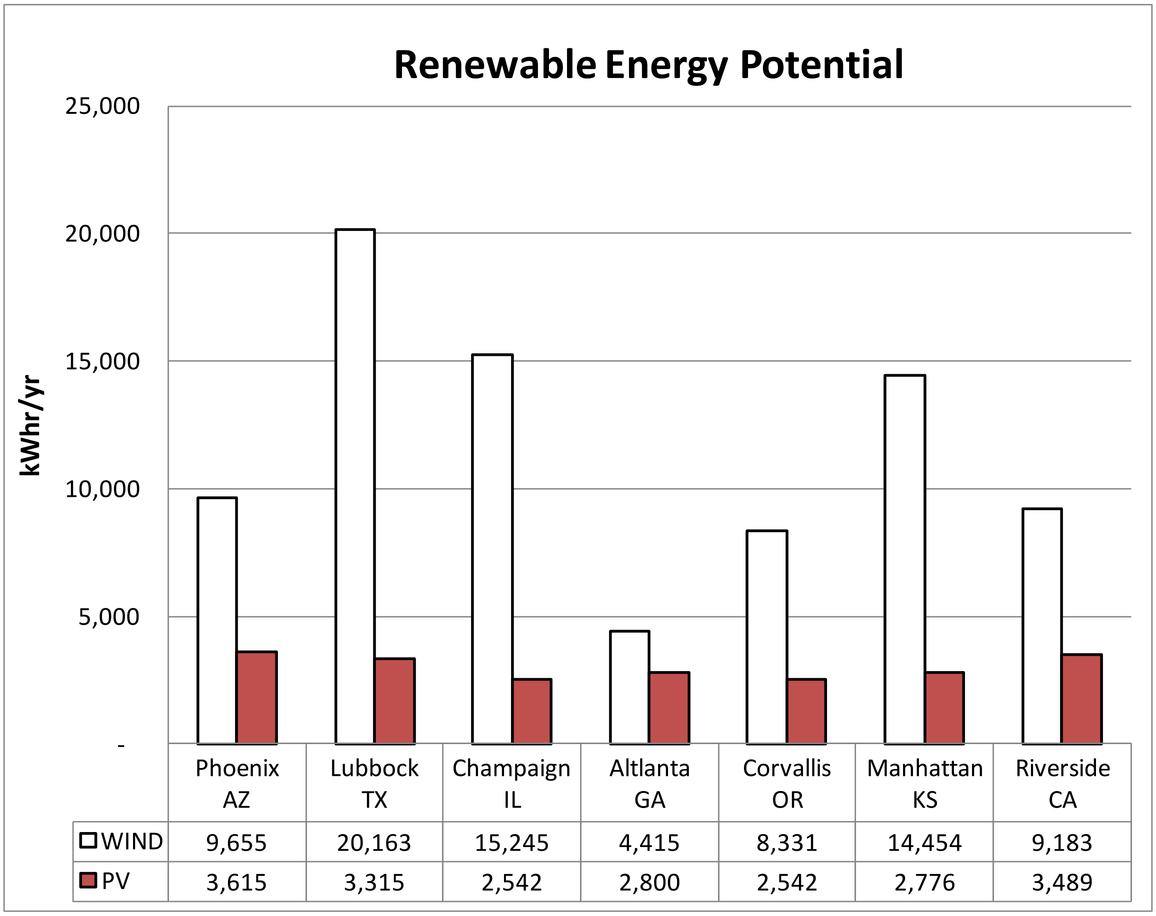
Table 2. Geographic data, solar insolation, and wind speeds for cities in study.

The life expectancy and net derating, or delivery %, used for each system is summarized in Table 3. The Delivery % derating parameter is a multiplier that lowers the computed ideal energy available to a expected actual value given various loss factors in the conversion process from either solar radiation to AC power or wind energy to AC power.

Derating and Life Expectancy of Systems			
PV		**Wind**	
Nameplate	95%	Available	98%
Soiling	0%	Icing & Wiring Losses	5%
Array Wiring Losses	9%	**Delivery %**	**93%**
Inverter Efficiency	95%		
Delivery %	**82%**		
Aging Reductions		**Wind Turbine**	**Years**
Years 2 - 10	92%	Short Life	15
Net Derating 2 - 10 yrs	**76%**	**Expected Life**	**20**
Years 11 - 25	82%	Long Life	25
Net Derating 11 - 25 yrs	**67%**		
PV Array life (yrs)	25		

Table 3. Derating parameters for energy capture.

Before computing the earnings from each system at each location, it is worthwhile to look at the net energy possible from each location. Figure 17 summarizes the renewable energy potential at each site. These figures are computed using either the sun-hrs or wind speed at 30 meters. The delivery % initial deratings are assumed for both solar and wind. Energy from wind is significantly greater than that from solar PV in part because a few of the sites have moderately good wind resources.



	Phoenix AZ	Lubbock TX	Champaign IL	Altlanta GA	Corvallis OR	Manhattan KS	Riverside CA
☐ WIND	9,655	20,163	15,245	4,415	8,331	14,454	9,183
🟥 PV	3,615	3,315	2,542	2,800	2,542	2,776	3,489

Figure17. Energy per year possible with specified PV and wind turbine.

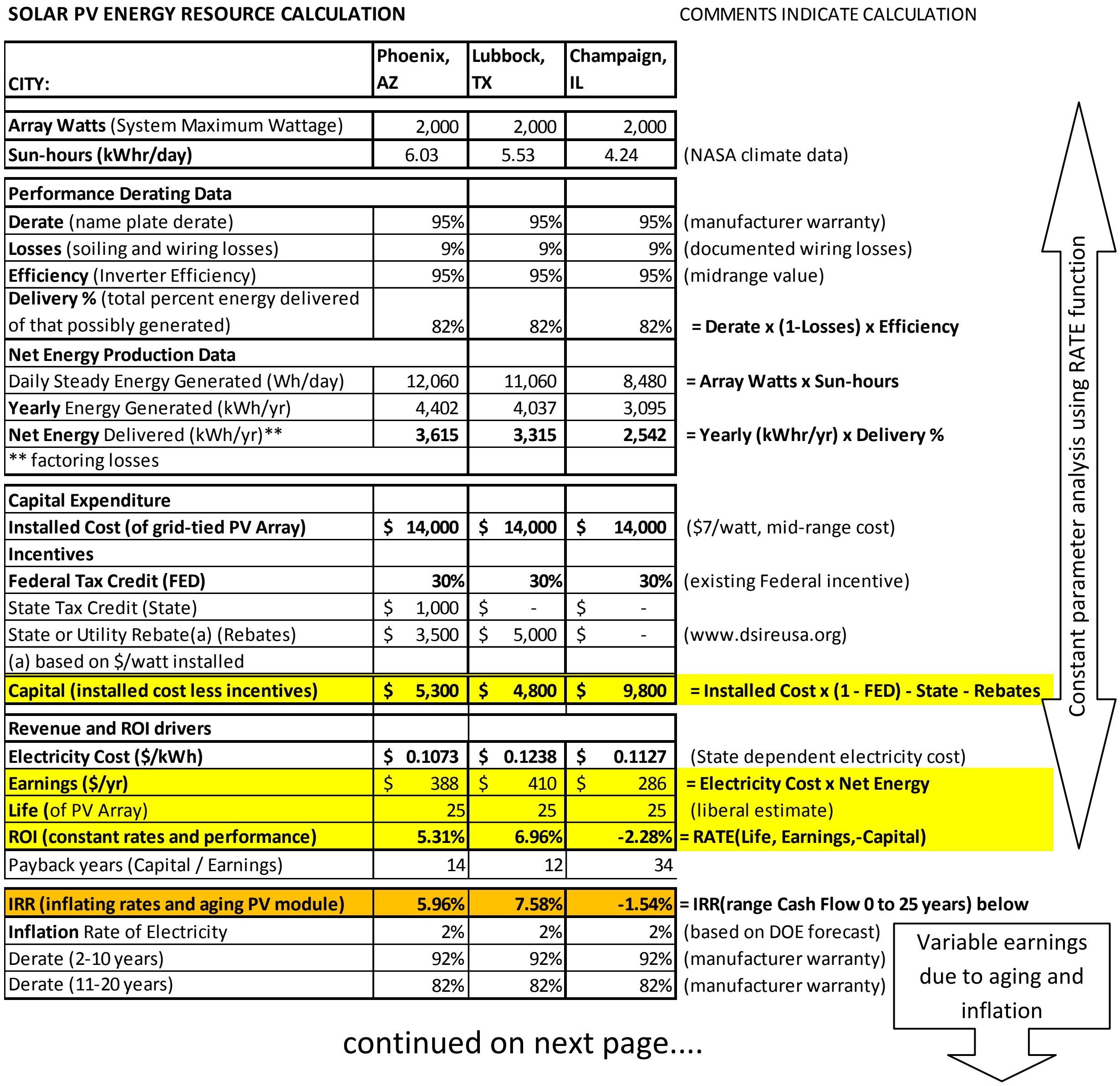
Computing return on investment

The calculations for the return on investment are done using Microsoft Excel. The layout of the worksheet used to compute the return on investment of the solar PV array are shown in Figures 18a and 18b. Comments in the figures clarify what is being computed throughout the worksheet. The data is organized from top to down in this way:

1. Array size (or turbine size for wind)
2. Solar insolation (or average wind speed at 30 meters for wind)
3. Performance derating values
4. Energy production (ideal converted to expected)
5. Capital Expenditures (factoring cost and incentives)
6. Revenue and ROI drivers (earnings, life of system)

7. ROI (constant earnings calculation of return on investment)
8. IRR (variable earnings due to aging PV modules and inflation of electricity cost)

There are two levels of detail used in this case study: a constant parameter, or earnings, analysis and a variable earnings analysis due to aging and inflation. The constant parameter analysis is computed using the Excel financial function RATE. Only the life, the earnings per year, and the capital investment are required. This provides a straight forward approach to someone learning the basic factors presented in this case study. It serves as a starting point for any case study to be presented to students. The IRR calculation for the PV array factors loss in performance due to aging but also the increase in value of the electrical energy due to inflation. Figure 18b shows the trends in earnings per year for three of the cities with comments about how the variable earnings are computed.

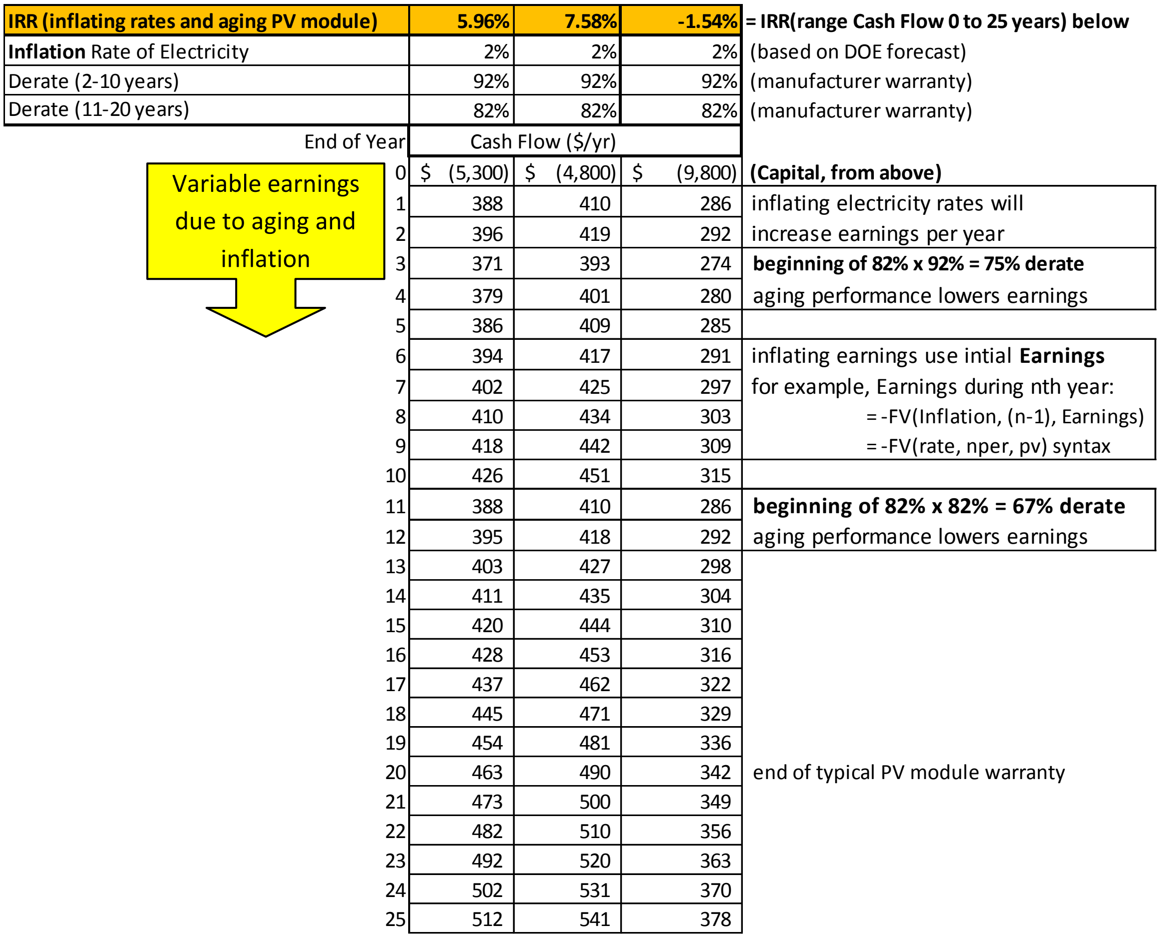


SOLAR PV ENERGY RESOURCE CALCULATION COMMENTS INDICATE CALCULATION

CITY:	**Phoenix, AZ**	**Lubbock, TX**	**Champaign, IL**	
Array Watts (System Maximum Wattage)	2,000	2,000	2,000	
Sun-hours (kWhr/day)	6.03	5.53	4.24	(NASA climate data)
Performance Derating Data				
Derate (name plate derate)	95%	95%	95%	(manufacturer warranty)
Losses (soiling and wiring losses)	9%	9%	9%	(documented wiring losses)
Efficiency (Inverter Efficiency)	95%	95%	95%	(midrange value)
Delivery % (total percent energy delivered of that possibly generated)	82%	82%	82%	**= Derate x (1-Losses) x Efficiency**
Net Energy Production Data				
Daily Steady Energy Generated (Wh/day)	12,060	11,060	8,480	**= Array Watts x Sun-hours**
Yearly Energy Generated (kWh/yr)	4,402	4,037	3,095	
Net Energy Delivered (kWh/yr)**	**3,615**	**3,315**	**2,542**	**= Yearly (kWhr/yr) x Delivery %**
** factoring losses				
Capital Expenditure				
Installed Cost (of grid-tied PV Array)	**$ 14,000**	**$ 14,000**	**$ 14,000**	($7/watt, mid-range cost)
Incentives				
Federal Tax Credit (FED)	**30%**	**30%**	**30%**	(existing Federal incentive)
State Tax Credit (State)	$ 1,000	$ -	$ -	
State or Utility Rebate(a) (Rebates)	$ 3,500	$ 5,000	$ -	(www.dsireusa.org)
(a) based on $/watt installed				
Capital (installed cost less incentives)	**$ 5,300**	**$ 4,800**	**$ 9,800**	**= Installed Cost x (1 - FED) - State - Rebates**
Revenue and ROI drivers				
Electricity Cost ($/kWh)	**$ 0.1073**	**$ 0.1238**	**$ 0.1127**	(State dependent electricity cost)
Earnings ($/yr)	$ 388	$ 410	$ 286	**= Electricity Cost x Net Energy**
Life (of PV Array)	25	25	25	(liberal estimate)
ROI (constant rates and performance)	**5.31%**	**6.96%**	**-2.28%**	**= RATE(Life, Earnings,-Capital)**
Payback years (Capital / Earnings)	14	12	34	
IRR (inflating rates and aging PV module)	**5.96%**	**7.58%**	**-1.54%**	**= IRR(range Cash Flow 0 to 25 years) below**
Inflation Rate of Electricity	2%	2%	2%	(based on DOE forecast)
Derate (2-10 years)	92%	92%	92%	(manufacturer warranty)
Derate (11-20 years)	82%	82%	82%	(manufacturer warranty)

continued on next page....

Figure18a. Spreadsheet format for solar energy calculations: constant parameter analysis.



IRR (inflating rates and aging PV module)	5.96%	7.58%	-1.54%	= IRR(range Cash Flow 0 to 25 years) below
Inflation Rate of Electricity	2%	2%	2%	(based on DOE forecast)
Derate (2-10 years)	92%	92%	92%	(manufacturer warranty)
Derate (11-20 years)	82%	82%	82%	(manufacturer warranty)
End of Year	Cash Flow ($/yr)			
0	$ (5,300)	$ (4,800)	$ (9,800)	**(Capital, from above)**
1	388	410	286	inflating electricity rates will
2	396	419	292	increase earnings per year
3	371	393	274	**beginning of 82% x 92% = 75% derate**
4	379	401	280	aging performance lowers earnings
5	386	409	285	
6	394	417	291	inflating earnings use intial **Earnings**
7	402	425	297	for example, Earnings during nth year:
8	410	434	303	= -FV(Inflation, (n-1), Earnings)
9	418	442	309	= -FV(rate, nper, pv) syntax
10	426	451	315	
11	388	410	286	**beginning of 82% x 82% = 67% derate**
12	395	418	292	aging performance lowers earnings
13	403	427	298	
14	411	435	304	
15	420	444	310	
16	428	453	316	
17	437	462	322	
18	445	471	329	
19	454	481	336	
20	463	490	342	end of typical PV module warranty
21	473	500	349	
22	482	510	356	
23	492	520	363	
24	502	531	370	
25	512	541	378	

Figure18b. Spreadsheet for solar energy calculations: variable earnings and IRR cash flows.

The spreadsheet analysis for the revenue from wind energy has a similar format to that used for the PV array with the addition of the Weibull distribution function to compute the net steady power output from the turbine. Refer to Figures 19a and 19b for the worksheet used to compute the return on investment for wind energy. The ROI calculation, as with the PV array, assumes constant energy production and constant electricity rates. The RATE function in Excel returns the return on investment for a given life of the turbine, the initial earnings, and the initial capital investment. The IRR calculation derives from the cash flow, refer to Figure 19b, resulting from an inflating electricity cost over the life of the turbine. Unlike the PV array, there is no aging related derating assumed and maintenance costs during the life of the turbine are neglected.

WIND ENERGY RESOURCE CALCULATION

CITY: Phoenix, AZ		COMMENTS BELOW INDICATE CALCULATIONS
Wind Distribution Constants		
Wind Speed (Hub Height Ave Wind Speed) (m	4.58	(from NASA data set adjusted for 30 meters)
Weibull K	2	
Shape Factor (Weibull shape factor, lamda)	5.1	= Wind Speed / 0.89 (following Bergey's analysis)
Performance Derating Data		
Availablility (due to down time)	98%	(liberal estimate)
Losses (air foil soiling/icing, & wiring losses)	5%	(liberal estimate)
Delivery % (Total Percent Energy Delivered of that possibly generated)	93%	**= Availability x (1 - Losses)**
Net Energy Production Data		
Daily Energy Generated (kWh/day)	28	**= 24 x Total Steady Power Output (below)**
Yearly Energy Generated (kWh/yr)	10,370	**= Daily Energy x 365**
Net Energy Delivered (kWh/yr)**	**9,655**	**= Yearly Steady Energy x Delivery %**
** factoring losses		
Capital Expenditure		
Installed Cost (grid-tied Wind Turbine)	**$ 57,000**	(manufacturer estimate)
Incentives		
Federal Tax Credit	**30%**	(existing Federal incentive)
State Tax Credit (State)	1,000	
State or Utility Rebate(a) (Rebates)	$ 24,000	(www.dsireusa.org)
(a) based on $/w installed		
Capital (installed costs less incentives)	**$ 14,900**	**= Installed Cost x (1 - FED) - State - Rebates**
Revenue and ROI drivers		
Electricity cost ($/kWh)	0.1073	(State dependent electricity cost)
Earnings ($/year)	$ 1,036	**= Electricity Cost x Net Energy**
Life (of Turbine)	25	(liberal estimate)
ROI (constant electric rates)	4.80%	**= RATE(Life, Earnings, -Capital)**
Payback years (capital / earnings)	14	(a commonly used ratio, but ignores time value of money)
IRR (inflating electricity rates)	**6.7%**	**= IRR(range Cash Flow 0 to 25 years) below**

Constant parameter analysis using RATE function

Captured Wind Energy				
Wind Speed (m/s)	Wind Probability (%)	Turbine Power Curve (kW)	Net Power Output (kW)	**1) Wind Probability from Weibull distribution. 2) Turbine Power Curve from manufacturer specs. 3) Net Power = Wind Probabilty X Turbine Power**

continued on next page ...

Figure19a. Spreadsheet for wind energy calculations: constant parameter analysis.

Captured Wind Energy

Wind Speed (m/s)	Wind Probability (%)	Turbine Power Curve (kW)	Net Power Output (kW)
1	7%	0.00	-
2	13%	0.00	-
3	16%	0.14	0.02
4	17%	0.43	0.07
5	15%	0.88	0.13
6	12%	1.51	0.18
7	8%	2.35	0.20
8	5%	3.43	0.18
9	3%	4.80	0.15
10	2%	6.42	0.11
11	1%	8.21	0.07
12	0%	10.02	0.04
13	0%	11.37	0.02
14	0%	11.76	0.01
15	0%	12.06	0.00
16	0%	12.14	0.00
17	0%	12.15	0.00
18	0%	12.10	0.00
19	0%	11.92	0.00
20	0%	11.44	0.00
Total Steady Power Output (kW)			1.18

1) Wind Probability from Weibull distribution. 2) Turbine Power Curve from manufacturer specs. 3) Net Power = Wind Probabilty X Turbine Power

Wind energy calculation

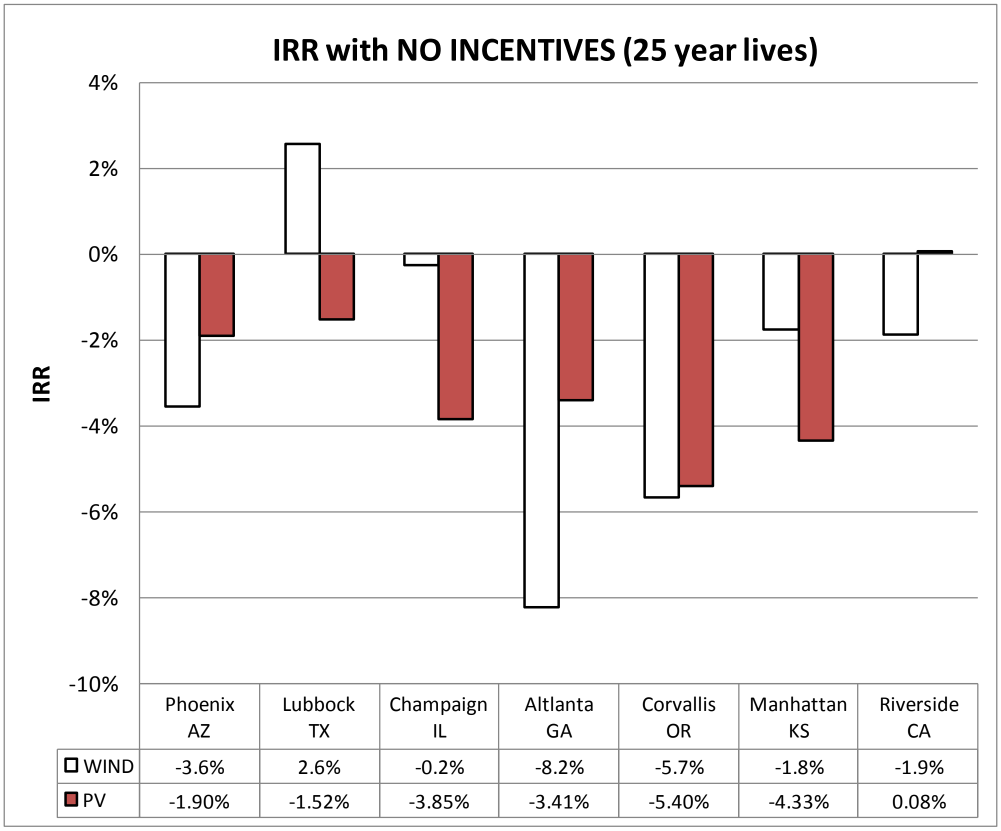
= sum of Net Power Output
(used to compute daily energy)

Variable earnings due to inflation

Inflation	2%	(growth of cost for electricity based upon the DOE forecast)
End of Year	Cash Flow	($/yr)
0	$ (14,900)	**(Capital, from above)**
1	$1,036	(value of **Earnings** during current year based upon inflation)
2	$1,057	Earnings is computed above under Revenue and ROI drivers
3	$1,078	for example, Earnings during 3th year:
4	$1,099	= -FV(Inflation, 2, Earnings)
5	$1,121	
6	$1,144	
7	$1,167	
8	$1,190	for example, Earnings during nth year:
9	$1,214	= -FV(Inflation, (n-1), Earnings)
10	$1,238	
11	$1,263	
12	$1,288	
13	$1,314	
14	$1,340	
15	$1,367	
16	$1,394	
17	$1,422	
18	$1,451	
19	$1,480	
20	$1,509	
21	$1,539	
22	$1,570	
23	$1,602	
24	$1,634	
25	$1,666	

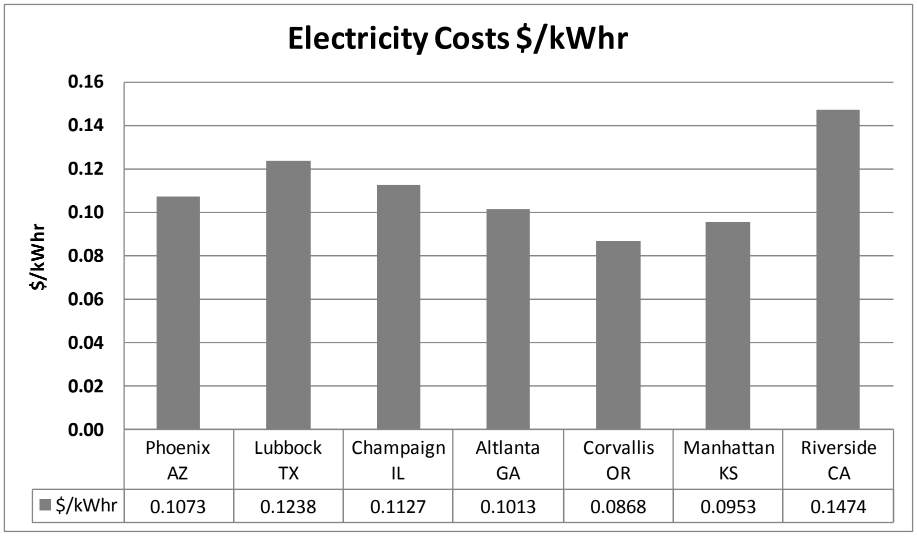
Figure19b. Spreadsheet for wind energy calculations: net power output and IRR cash flows.

The internal rate of return for most of the cities is negative when no incentives of any kind are considered as shown in Figure 20. The exception is Lubbock, TX because this city has moderately good wind resources and the electricity rate is relatively high in the group; refer to Figure 21. Riverside, CA also shows a nonnegative return for PV for similar reasons. Although the energy potential for wind is higher than PV for the cities examined, Figure 17, the return on investment for wind is generally lower than for PV because of the higher initial investment.



	Phoenix AZ	Lubbock TX	Champaign IL	Altlanta GA	Corvallis OR	Manhattan KS	Riverside CA
☐ WIND	-3.6%	2.6%	-0.2%	-8.2%	-5.7%	-1.8%	-1.9%
🟥 PV	-1.90%	-1.52%	-3.85%	-3.41%	-5.40%	-4.33%	0.08%

Figure 20. IRR for PV and wind with NO INCENTIVES.



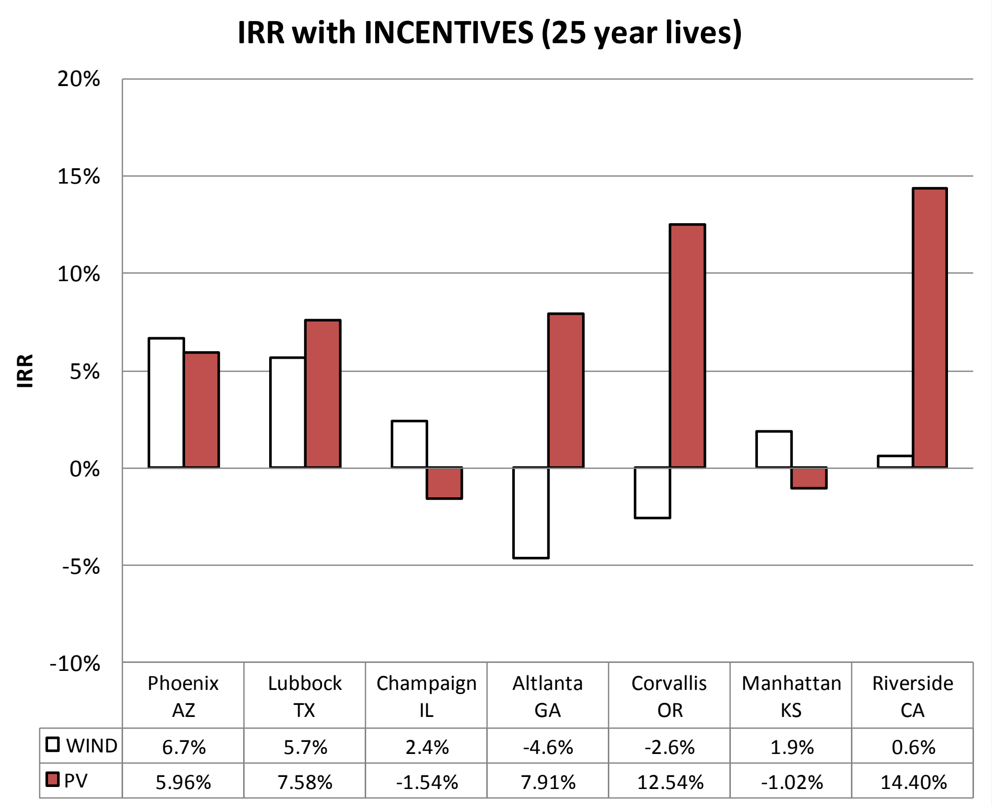
	Phoenix AZ	Lubbock TX	Champaign IL	Altlanta GA	Corvallis OR	Manhattan KS	Riverside CA
■ $/kWhr	0.1073	0.1238	0.1127	0.1013	0.0868	0.0953	0.1474

Figure 21. Electricity costs assumed for earnings calculations.

When the federal and state incentives are factored that lower the capital investment to install the energy systems, most of the cities chosen in this study show a positive rate of return. The values in Figure 22 indicate that subsidized energy systems for home owners may prove profitable. Further, because the savings accrued by the home owner for generating their own energy is not taxable income, a more proper assessment of the return for these systems would be a before tax estimate of the IRR. The before tax IRR would be the IRR shown in Figure 22 adjusted for the personal income tax bracket of the home owner.

$$\text{Before Tax IRR} = \frac{\text{IRR}}{(1-\text{Tax Bracket})} \tag{6}$$

For someone in the 28% tax bracket, this equates to a multiplier of 1.39 for the IRR displayed in Figure 22. Figure 23 displays the IRR for each system adjusted for a 28% tax bracket homeowner. Now some systems exceed 15% before tax return on investment.



	Phoenix AZ	Lubbock TX	Champaign IL	Altlanta GA	Corvallis OR	Manhattan KS	Riverside CA
☐ WIND	6.7%	5.7%	2.4%	-4.6%	-2.6%	1.9%	0.6%
🟥 PV	5.96%	7.58%	-1.54%	7.91%	12.54%	-1.02%	14.40%

Figure 22. IRR for PV and wind with Federal and State INCENTIVES.

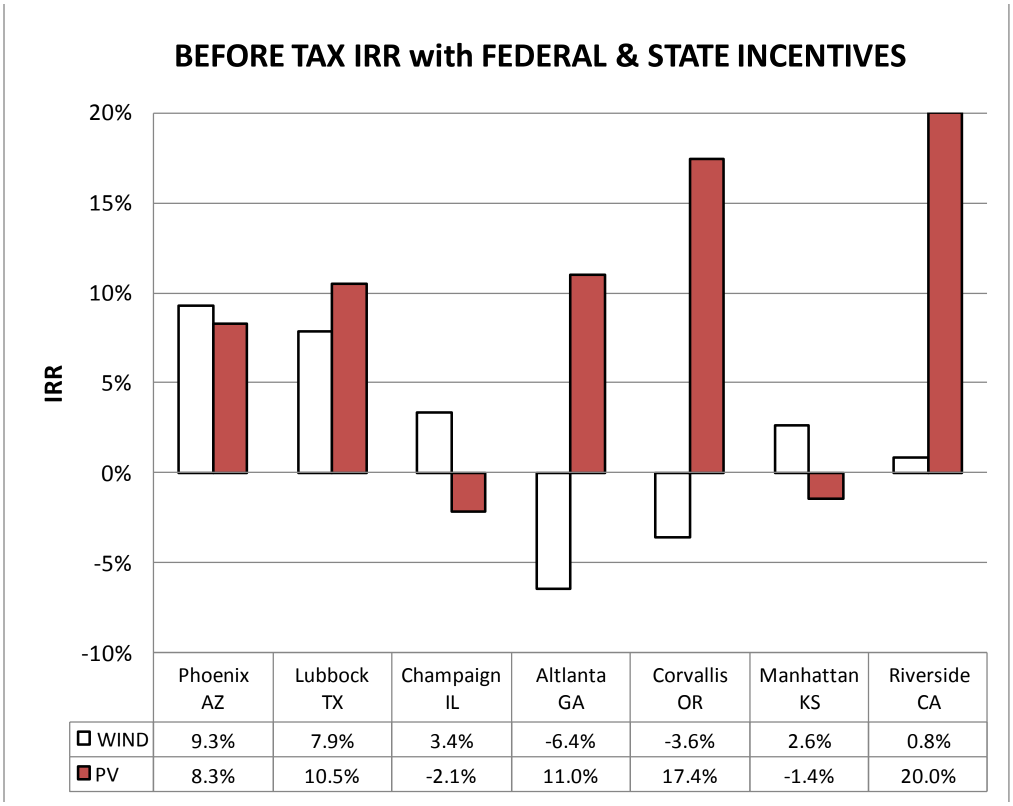


Figure 23. Before tax (28% tax bracket) IRR for PV and wind WITH INCENTIVES.

Effect of variations of uncertain parameters on IRR

Because state-based incentives are often subject to available funding, the effect of such incentives is examined in Figure 24 for Riverside, CA. Riverside is one city whose state-based incentive funding has been exhausted. If the state-based incentive is removed, then the before tax IRR drops from 20% to only 4%. The 4% before tax IRR is the result of the federal tax credit that reduces the cost to install a system by 30%.

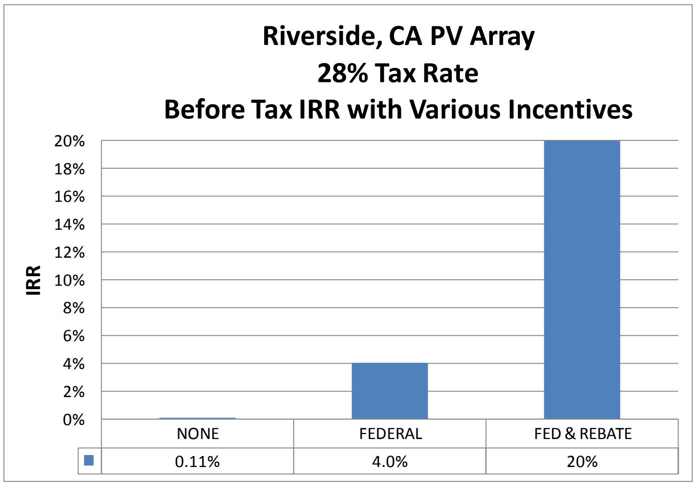


Figure 24. Before tax (28% tax bracket) IRR for PV: effect of incentives.

Another uncertainty is the soiling that may occur to PV arrays. On the other hand, newer PV module technology may prove more efficient at converting solar radiation to electric power. This would be positive change in performance. Both of these adjustments are considered for a nominal situation and summarized in Table 3. The sensitivity of the IRR to a change to the annual revenue will depend upon the nominal IRR of the system. Several nominal IRR values are considered. The values reported under the "loss IRR" and the "gain IRR" columns are the net changes to the nominal IRR for the 10% reduction and 10% improvement of the PV module performance, respectively. For the 25 year life assumed in this study, Table 3 data indicates a 10% reduction in performance will result in about a 1% reduction of the IRR. A 10% gain will result in about a 1% gain in the IRR. One may conclude there is a 10 to 1 sensitivity of PV array performance to computed IRR.

PV Array Performance Change		
10% Loss	Nominal	10% Gain
IRR Change with PV performance		
loss IRR	Nominal IRR	gain IRR
-0.6%	-3.8%	0.6%
-0.7%	-1.5%	0.7%
-0.7%	-0.8%	0.7%
-0.8%	1.1%	0.8%
-1.0%	6.3%	1.0%
-1.2%	9.7%	1.2%

Table 3. PV array soiling and improved technology effect on IRR.

Finally, the effect of life is examined in the data shown in Table 4. A 25 year life was assumed for this study. Some estimators place the life of a small wind turbine at 15 years. The manufacturer of the turbine used in this study, Bergey, implies the turbine may have 30 years of productive life. Again, the sensitivity of the IRR to a change in life will be depend upon the nominal IRR. Lubbock, TX was chosen because this city yielded a positive (after tax) IRR with no federal or state incentive. As the incentives increase, the nominal IRR (at a 25 year life) increases, as expected. The data in Table 4 indicate that a 10 year reduction in life will lower the IRR by about 5%. A 5 year increase in life will raise the IRR by about 1%. Consequently, if the small wind turbine used in Lubbock only lasts 15 years, this system will not prove profitable.

Lubbock, TX Wind Energy			
Wind Turbine Life Effect			
15	**25**	**30**	
IRR with change of Life			
-10 yrs	**Nom: 25**	**+5 yrs**	Incentive
-3.2	2.6	3.8	$0
-2.1	3.3	4.4	$5,000
-1.0	4.2	5.2	$1,000
1.0	5.7	6.6	$17,100
10 yr loss: 5% reduction of IRR	IRR improves with incentive	5 yr gain: 1% increase of IRR	
IRR values NOT adjusted for taxes			

Table 4. Wind turbine life effect on IRR.

In-Class Case Study Using Solar Energy

The author has used the solar photovoltaic data in this paper as an in-class case study activity. After a lesson plan addressing how to compute the return on investment of alternative financial plans students were presented the material in this paper dealing with solar photovoltaic systems. A handout containing an abbreviated version of this paper containing Figures 1 through 8 and Figure 18 was prepared. This handout also had equations 1 through 4 to illustrate the calculations required to compute earnings. Finally, students were given a working version of the spreadsheet shown in Figure 18 which can be used to compute return on investment using both the constant earnings and inflating/aging earnings per year models. With this information as background, students were grouped into small teams and given a set of questions asking them to

- derive how the earnings are computed at different times,
- illustrate representative cash flows for a constant earnings vs. an inflating/aging scenario,
- compute the return on investment for two case study cities not listed in the paper assuming a 30% federal tax credit and assuming both a constant parameter (fixed earnings) and an inflating/aging earnings model. This latter model assumes the cost of electricity inflates and the performance of the PV module degrades with age.
- evaluate what conditions would be necessary to raise the IRR of a PV system to 8% for each case study city when the IRRs were initially much lower than this. They could change tax credits, inflation, and derating parameters with specified limits.

The students were very interested in the presentation of the solar PV technology. There was a lively discussion because of the general interest in renewable energy for this generation. Further, the students were engaged by being tasked to determine what combinations of subsidies, energy costs, and performance factors could increase the return on investment of the system. The author believes that this case study helped students appreciate the value in the software and methods deployed in their engineering economics class to solve real-world problems.

Conclusion

The economic benefit of generating electricity from solar PV and small wind for residential grid-tied systems is found to be highly dependent upon federal, state, and utility company incentives. Only two cities examined in this study were shown to have a positive return on investment for a residential grid-tied renewable energy system without any subsidy or tax credit. The cost factors and performance parameters chosen in this study are based upon information provided by vendors and third party estimators for renewable energy systems. The parameters used to compute the IRR of the systems are considered neutral, neither too liberal nor too conservative. Although the non-subsidized returns are not positive, the subsidized IRR values are positive for the majority of cities examined. The before tax returns on investment for the solar energy systems showed significant promise in some cases.

Reasonable variations in the performance and the productive life of the systems show that the positive IRR outcomes for any of the systems is highly dependent upon the expected range of variations examined. For example, the positive IRR for a small wind system in Lubbock, TX is highly dependent upon the unit operating at the upper limit of its expected life. The trend revealed in this study is that small wind is less likely to be profitable for a residential application.

It should be noted, however, that small wind technology operates at the lower margin of efficiency for given wind resource due to the elevation of the turbine above ground and the size of the swept area.

The information provided in this paper can readily be used for case study problems by students. The means to source the solar and wind data are explained in detail. The explanations of how to compute the revenue that could be generated from these inputs are clearly derived. Finally, example spreadsheet layouts with comments showing how data used in the study was computed are shown. These three inputs provide enough information for an instructor of engineering economy to develop a case study for students to explore the value of such renewable energy systems in their own cities.

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City	Residential Credits or Rebates for either 2 kW PV or 10 kW wind turbine	Value in study ($)
Phoenix, AZ		
Tax Credit	25% of the cost to install, max: $1,000 per residence.	$1,000
Rebate	**Arizona Public Service (APS)**	
Rebate PV	Grid-tied PV: $1.75/watt DC; $1.75 x 2,000 = $3,500	$3,500
Rebate Wind	Grid-tied wind: $2.50/W up to 50% of the system cost or $75,000; LESS State Tax Credit	$24,000
Lubbock, TX		
Tax Credit	no state credits available now	
Rebate PV	**American Electric Power Texas Central Company**	
	Rebates are offered at a flat rate of $2.50 per watt (DC)	*$5,000*
Champaign, IL	No credits or rebates are available. Funds exhausted.	
Altlanta, GA		
Tax Credit	tax credit is equal to 35% of the cost of the system (including installation)	
	maximum of $10,500 per residence for photovoltaics (PV) and wind energy systems.	
	Began in 2008, expiration date: 12/31/2012 PV (2 kW) $14,000 x .35 = $4,900	$4,900
	Wind (10 kW) $57,000 x .35 = $19,950	$10,500
Rebate PV	**Central Georgia Electric Membership Corporation**	
	$450/kW installed capacity with max: $4,500.	$900
Production PV	**Georgia Power**	
	pay $0.17/kWh for PV, sign contract for 5 years	**adjust rate**
Corvallis, OR		
Tax Credit	**Renewable Energy Incentive**	
PV	PV systems eligible $3 per peak watt (W) with a maximum limit of $6,000; one tax year may not exceed $1,500 , carry forward up to 5 years.	$1,500/yr for 4 years.
Wind	Wind turbines credit lesser of $2 per kWh produced during the first year, or $6,000. Estimated kWh generated = 8,800 kWhr. $2 x 8,800 = $17,600	$6,000
Rebate PV	**Energy Trust of Oregon's (Energy Trust) Solar Electric Buy-Down Program**	
	$1.50/watt-DC (W) installed for Pacific Power customers; max: $20,000 per site.	$3,000
	2009 Budget: $1.6 million for projects in Pacific Power's service territory (any $ left?)	
Manhattan, KS		
Tax Credit	10% of the system's cost for the first $50,000,000 invested	
	PV (2 kW) $14,000 x .10 = $1,400	$1,400
	Wind (10 kW) $57,000 x .10 = $5,700	$5,700
Riverside, CA		
State Rebate	**California Solar Initiative Rebates**	
	Expected Performance-Based Buydown funds no longer available	
Rebate PV	**Riverside Public Utilities**	
	$4/watt AC; $4 x 1,560 = $6,240	$6,240
	Program funding for the residential PV rebate program is currently exhausted	

Appendix A Descriptions of State Tax and Rebates for PV and Wind